UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Higher Education Sustainability: Investigating the barriers and opportunities to sustainable infrastructural development in tertiary education institutions

by

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Abstract

The research investigates sustainability initiatives in South African higher education, focusing on the refurbishment of water heating systems at the University of the Witwatersrand, Johannesburg. It examines the economic and environmental impacts of adopting greener technologies, highlighting the importance of stakeholder engagement. Using a mixed methods approach, the study combines qualitative interviews to understand stakeholder perspectives with quantitative analysis of costs and carbon emissions.

The findings reveal that the new water heating system significantly reduces emissions—6.6 times less than the traditional system—resulting in a 9.71 kg monthly carbon footprint versus 64.296 kg with old geysers. Financial analysis shows an 81% cost reduction in water heating expenses due to the switch from grid electricity to natural gas, achieving a 4.16% return on investment.

The research underscores the challenges in securing broad stakeholder support and the importance of a holistic sustainability approach that integrates economic, environmental, and social factors. It highlights the potential of such initiatives to reduce environmental impact, save costs, and drive innovation, providing insights for future sustainability efforts in higher education.

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1.1. Introduction and Background

The University has stood as a bastion of knowledge and understanding since the establishment of the first such institution in the 9th century and continues to remain a space for intellectual development within society (Hoque and Abdullah, 2021). The sustainability of the concept of *higher education* has remained steadfast since this period and has been maintained as the model has been adopted throughout the world. In South Africa, the first higher education institution was opened in 1873, with the establishment of the University of the Cape of Good Hope, which later restructured to become known as the University of South Africa which is still in operation today (Singh, 2011).

As society has developed with time it has become evident that the nature of how institutions engage with the world is pivotal to their ongoing presence, and as such, the university has had to adapt to remain relevant and valuable to the societies in which they exist (Farag and Aktas, 2024). The role of university as thought leaders has been consistent over time, as they are seen to develop and nurture the great thinkers and doers of the world. One of the ways in which society has begun to reshape its values is the emergence of sustainability as a theoretical practice. Whilst *sustainability* has been practiced by multiple societies over time, it only was formally defined in 1987 by G.H. Brundtland as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987; Clarke and Bray, 2024).

Sustainable development, which links the concepts of sustainability and development and has been a key term in a range of disciplines such as geography, economics, governance, engineering, and sociology (Scoones, 2016; Clarke and Bray, 2024). Sustainable development responds to the societal need and desire for change and progress, as well the consumption and extraction required to fulfil these needs into consideration, whilst ensuring that the wellbeing of the environment is not compromised in the pursuit of development. This term has since also been adopted and engaged with by academia and the higher education sector, as universities now must address the possible environmental repercussions of their day-to-day operations (Leal-Filho *et al.*, 2018).

Higher education institutions have thus taken on the challenge of redefining their spaces beyond the sprawling campuses and stately buildings, to being institutions that welcome and embrace sustainability as a core precept of their development and practices (Badat, 2009; Mutinda and Liu, 2021).

In 2012, the United Nations formed the Higher Education Sustainability Initiative, which aimed to develop a set of best practices which can be used as tools for institutions to develop themselves sustainably (Leal-Filho *et al*., 2018). With the announcement of the United Nations' Sustainable Development Goals in 2015, the international higher education sector has been challenged to find ways to operate and develop with sustainability in mind (Mawonde and Togo, 2019). The South African higher education sector has embraced the proliferation of sustainable development, thinking and design, with many local institutions being members of the Higher Education Sustainability Initiative, or creating policies that correspond to the goals outlined by the UN Sustainable Development Goals (Awuzie and Emuze, 2017; Mawonde and Togo, 2019).

The enthusiasm of the higher education sector in South Africa to adopt technologies that increase energy efficiency, reduce waste and pollution or landscaping that is less environmentally taxing is unfortunately often dampened by the ever-looming socioeconomic reality of the developing world – insufficient resources, aging infrastructure, and lack of sociotechnical support (Togo and Lotz-Sisitka, 2013; Kgarose *et al*., 2023). Despite these well-known challenges, institutions within the South African higher education sector are still making strides in the effort to meet and achieve their own sustainable development goals.

The University of the Witwatersrand, Johannesburg is one public institution which has initiate multiple efforts to enhance its overall sustainability, with one of these projects being a solar-gas hybrid thermal water heating system which has been introduced in residences, which boasts a two-kilometre-long solar thermal water heating system - which is the largest in Africa and the Southern hemisphere - and as such, offers a significant amount of insight to what higher education institutions are capable of envisioning, planning, and implementing (Huang, 2018; Ulmer and Wydra, 2018).

To holistically evaluate the identified pilot project – which will be the ongoing refurbishment of residences at the University of the Witwatersrand, where traditional geysers are being replaced with solar-gas hybrid thermal water heating systems – a comparative and multifaceted analysis will be assumed. As sustainable thinking underpins this research, this study will make use of the water heating pilot project as a means of evaluating whether achieving environmental, economic, and social sustainability can be a realistic goal within tertiary education institutions in South Africa, and what barriers and opportunities may be faced when undertaking such an effort (Ulmer and Wydra, 2020).

1.2. Research Problem

The sustainable development paradigm acknowledges the necessity of progress while ensuring environmental preservation and societal well-being. The adoption of sustainable practices has extended to higher education, where institutions are tasked with redefining their roles beyond academic pursuits to incorporate sustainability principles into their operations (Leal-Filho *et al*., 2018). The Higher Education Sustainability Initiative, launched by the United Nations in 2012, and the subsequent Sustainable Development Goals introduced in 2015 have spurred international higher education sectors, including South Africa, to prioritize sustainability (Mawonde & Togo, 2019).

The core problem lies in bridging the gap between the enthusiasm for sustainability and the practical constraints faced by South African higher education institutions. Achieving sustainable development goals requires addressing these challenges comprehensively and strategically, leveraging available resources effectively, and fostering collaborative efforts with stakeholders to overcome barriers to sustainability implementation (Farag and Atkas, 2024).

Despite this momentum, South African higher education institutions face multifaceted challenges in fully embracing sustainable development. Issues such as limited resources, aging infrastructure, and inadequate sociotechnical support pose significant obstacles (Togo & Lotz-Sisitka, 2013; Kgarose *et al*., 2023). However, amidst these challenges, institutions are actively striving to align with sustainable development goals and integrate environmentally friendly technologies and practices. The University of the Witwatersrand, Johannesburg is one such institution hoping to minimise the negative environmental impact of its daily operations. The Wits University Campus Housing and Residence Life programme accommodates 6200 students throughout the academic year, which results in the University having to provide adequate amenities and facilities, which includes the provision of hot water on a continuous basis (Huang, 2018).

The heating of water has been identified as one of the mechanisms in which households and large scale residences can reduce the environmental and financial costs of basic daily operations, which ultimately enhances the scope of their sustainable practices (Chiradeja *et al.*, 2019). This pilot project has been selected as the focus of this research as the project itself addresses the idea of making one of the day-to-day practices within campuses and general society still continue in a manner that is more sustainable, whilst still making a significant contribution to how the University develops and reshapes itself in the 21st century (Mutinda and Liu, 2021).

As sustainable thinking underpins this research, this study will make use of the water heating pilot project as a means of evaluating whether achieving environmental, economic, and social sustainability can be a realistic goal within tertiary education institutions in South Africa, and what barriers and opportunities may be faced when undertaking such an effort (Ulmer and Wydra, 2020). To holistically evaluate the identified pilot project – which will be the ongoing refurbishment of residences at the University of the Witwatersrand, where traditional geysers are being replaced with solar-gas hybrid thermal water heating systems – a comparative and multifaceted analysis between the traditional geysers and new solar-gas hybrid water heaters will be assumed.

The Wits University solar-gas hybrid thermal water heating system which has been introduced boasts a two-kilometre-long solar thermal water heating system which is the largest in Africa and the Southern hemisphere, and as such, offers a significant amount of insight to what higher education institutions are capable of envisioning, planning, and implementing (Huang, 2018; Ulmer and Wydra, 2018). Thus, as a response to this problem, the research explores the gaps in the theoretical understanding of these types of sustainable intervention within the context of South African public universities. As most public South African universities are residential, this research explores a solution which could potentially enhance the scope and feasibility of sustainability practices in the South African higher education sector (Ali and Anufriev, 2020). This research centres sustainability as the epistemological approach to answering the questions that have been identified as being one of the most relevant to the higher education sector (Scheman, 2012; Samian, 2014; Meyer and Peukert, 2020).

1.3. Aims and Objectives

The aim of this research project was to investigate how the South African tertiary education sector is approaching and responding to sustainability, and how this is shaping landscape of public universities in the country. With this aim, the objectives of the study are as follows:

- To evaluate if there is a significant difference in the amount of carbon dioxide emissions during the water heating process when using the new water heating technology
- To identify the fiscal ramifications of the introduction of new sustainable technologies by comparing the capital and operational expenditures associated with each of the water heating systems (traditional geysers and solar-gas hybrid water heaters)
- To investigate and document the perspectives and opinions of relevant stakeholders on the barriers and opportunities faced by tertiary education sector when introducing sustainable infrastructure and technology.

1.4. Research Questions

The aims and objectives that have been outlined form the basis of the questions that this research aims to answer. The direction and outcome of this study aims to evaluate, analyse, and understand the following questions:

a) Is there an opportunity to minimise the costs incurred by the University of the Witwatersrand in heating water when using the solar-gas hybrid thermal water heating system compared to traditional geysers?

b) Does the difference in environmental impact (measured by carbon emissions) of heating water in Wits residences when using traditional geysers or making use of the solar-gas hybrid thermal water heating system actually present an opportunity to become more sustainable?

c) Are the perceptions held about the introduction and adoption of alternative energy and technologies amongst the relevant stakeholders to this project a potential challenge to the success of the pilot project?

2. Literature Review

The integration of alternative energy sources into the energy mix of South Africa has been a gradual process, primarily driven by the global shift away from coal-based electricity due to environmental concerns. The negative impacts associated with coal-fired power generation, such as greenhouse gas emissions, coal ash leaching, and land degradation, have catalysed a transition towards cleaner energy sources (Walwyn, 2020; Marais et al., 2022). While some regions globally have swiftly embraced greener technologies like nuclear, hydropower, and solar energy, South Africa's transition has been hindered by various challenges, leading to a slower adoption rate (Ramluckun et al., 2024; Sarkodie and Strezov, 2019).

Despite these challenges, there have been notable strides in diversifying the energy mix in South Africa, with renewable energy contributing significantly to the grid. For instance, in 2022, renewable energy accounted for 13.7% of the grid energy mix, marking a substantial increase from 2015 when it only contributed 2.4 GW of energy (Essex and de Groot, 2019; Pierce and le Roux, 2023). This shift has been propelled by both public and private institutions aiming to reduce their reliance on unsustainable energy sources and enhance their environmental, social, and economic sustainability (Walwyn, 2020; Swartz, 2023).

The context of South Africa as a developing nation heavily reliant on energy for industrial and economic growth has shaped its energy landscape. Historically, the country's energy grid heavily depended on coal due to its abundance and cost-effectiveness, with Eskom playing a central role in national energy production (Ngam, 2023; Essex and de Groot, 2019). However, post-apartheid efforts focused on expanding electricity access to all households, leading to a gradual increase in electrification rates by 2018 (Department of Mineral Resources and Energy, 2022). The dominance of coal in the energy mix has not come without environmental repercussions, including air and water pollution, land degradation, and greenhouse gas emissions (Marais et al., 2022). Moreover, the energy sector in South Africa has faced significant challenges such as grid instability, frequent load shedding, and organizational issues within Eskom, prompting calls for a transition towards cleaner and more sustainable energy sources (Kgarose et al., 2023; Hlongwane and Daw, 2023).

Amidst these challenges, alternative energy sources like solar photovoltaic, wind, hydropower, biomass, natural gas, and nuclear power have emerged as viable options (Mugambiwa and Rapholo, 2023). Solar energy has gained traction given South Africa's favourable geographic conditions for solar power generation (Dekker et al., 2012). Additionally, natural gas has been considered a transitional energy source due to its lower environmental impact compared to coal (Clark and McGregor, 2023).

Technological transitions in the energy sector, as conceptualized by Geels (2002), are underway, with alternative energy sources gradually gaining acceptance and market share. South Africa's energy landscape is at a crucial juncture where organizational and institutional changes are necessary to facilitate a successful transition to cleaner energy sources (Geels, 2002; Xavier et al., 2017).

This literature review delves into the complexities of South Africa's energy transition, examining the historical context, current challenges, alternative energy options, technological transitions, and the role of organizations and institutions in driving sustainable energy practices. Through an in-depth analysis, this review aims to contribute to a better understanding of the multifaceted dynamics shaping South Africa's energy future**.**

2.1. Sustainability as a Research Approach

This research project is underpinned by the concept of sustainability, and how the higher education institutions are finding ways to increase the long-term feasibility of their infrastructure, operations, and systems (Awuzie and Emuze,2017; Leal Filho *et al.*, 2018). As such, it is important to investigate how the interaction between three fundamental elements of sustainability – environment, economy, and people – apply to the context of selected research project (Meyer and Peukert, 2020; Mutinda and Liu, 2021).

2014).

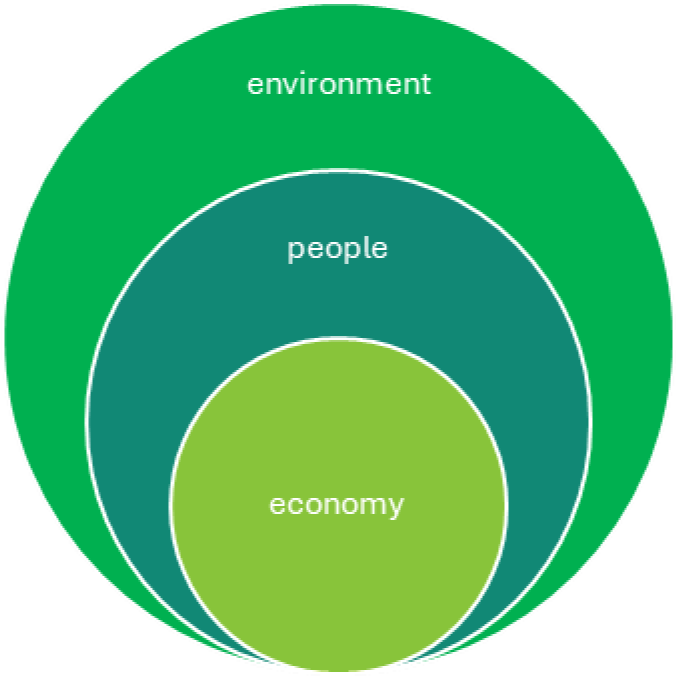

Figure 1: A diagram illustrating the sustainability triad, with environment being the central tenet of sustainable thinking.

The sustainability triad, as illustrated in Figure 1, has been adopted by the environmental science disciplines as the most straightforward means of understanding how human activity, such as the extraction and use of natural resources like coal, can negatively affect the environment, despite improving economies and accelerating sociotechnical development (Scoones, 2016; Phiri and Nyoni, 2023). Therefore, it results in the case against the use of coal as it is less sustainable than the alternative energy sources such as wind, which have a lower environmental impact whilst providing electricity that still positively influences sociotechnical development and being cheaper for consumers to buy (Walwyn, 2020; Ramluckun *et al.*, 2024).

It is also essential to consider whether each individual part of the triad is sustainable in and of itself, for the entire system to be considered truly sustainable (Scheman, 2012; Samian, 2014). However, it must also be noted that within this triad, the environment is the principal basis of sustainability, as societies rely on nature for their basic needs, this also places economy last in the consideration of sustainability, as it is reliant on both anthropogenic activity and the environment – which provides the resources needed for the primary economic sector (Samian, 2014).

2.2. The South African context

South Africa's gradual shift towards alternative energy sources mirrors a global trend away from coal, primarily due to its detrimental environmental impacts, including greenhouse gas emissions, coal ash leaching, and land degradation (Walwyn, 2020; Marais et al., 2022; Akinlabi et al., 2019). The country has made slow but notable progress in transitioning to cleaner energy, with renewable energy contributing 13.7% to the energy mix in 2022, up from 2.4 GW in 2015 (Essex and de Groot, 2019; Pierce and le Roux, 2023). This transition aligns with broader global efforts, where regions with more developed economies have rapidly adopted greener technologies like nuclear, hydropower, and solar energy, despite the high costs involved (Ramluckun et al., 2024; Sarkodie and Strezov, 2019).

South Africa's energy grid has evolved slowly, driven in part by the need to address frequent load shedding and grid instability. These issues have pushed public and private entities to seek partial or complete independence from the national grid, particularly as the country's economic and industrial sectors rely heavily on a stable energy supply (Walwyn, 2020; Swartz, 2023; Akpeji et al., 2020; Phiri and Nyoni, 2023). Historically, the development of the electrical grid was uneven, largely due to apartheid-era policies that restricted electricity access for many citizens. Coal has long dominated the country's power generation, with coal-fired stations being established soon after the coal mining industry emerged in the late 19th century (Munnik et al., 2010; Essex and de Groot, 2019).

Eskom, the national power utility founded in 1923, centralized energy production but excluded large segments of the population, particularly those in homelands and townships, from its services. These areas depended on cheap, polluting fuels like paraffin and gas, which often led to fires and poor indoor air quality (Ngam, 2023; Ntshangase et al., 2023; Madziga et al., 2018; Mujuru et al., 2020). The first non-coal power station, Koeberg Nuclear Power Station, was established in 1984. Post-1994, efforts were made to extend electricity access to all households, achieving significant milestones by 2000, with 86.15% of households having access to electricity by 2018 (Beute, 2012; Meyer and Overen, 2021; Department of Mineral Resources and Energy, 2022).

Coal-fired power stations remain a significant source of greenhouse gas emissions in South Africa, contributing to air pollution and the release of harmful gases like CO_2, SO_2, and NO_x, which degrade air quality and harm human health (Munnik et al., 2010; Denoon-Stevens et al., 2021; Pretorius et al., 2015; Sproul et al., 2019; Millar et al., 2022). Additionally, these stations contribute to water pollution through acid mine drainage, where coal ash leaches toxic chemicals into water systems, affecting both aquatic life and human health (Millar et al., 2022; Langerman et al., 2023). The Highveld region in Mpumalanga province, a key area for coal mining and power generation, was designated a Highveld Air Pollution Priority Area in 2007 due to pollutant levels exceeding both global and national air quality standards (Millar et al., 2022).

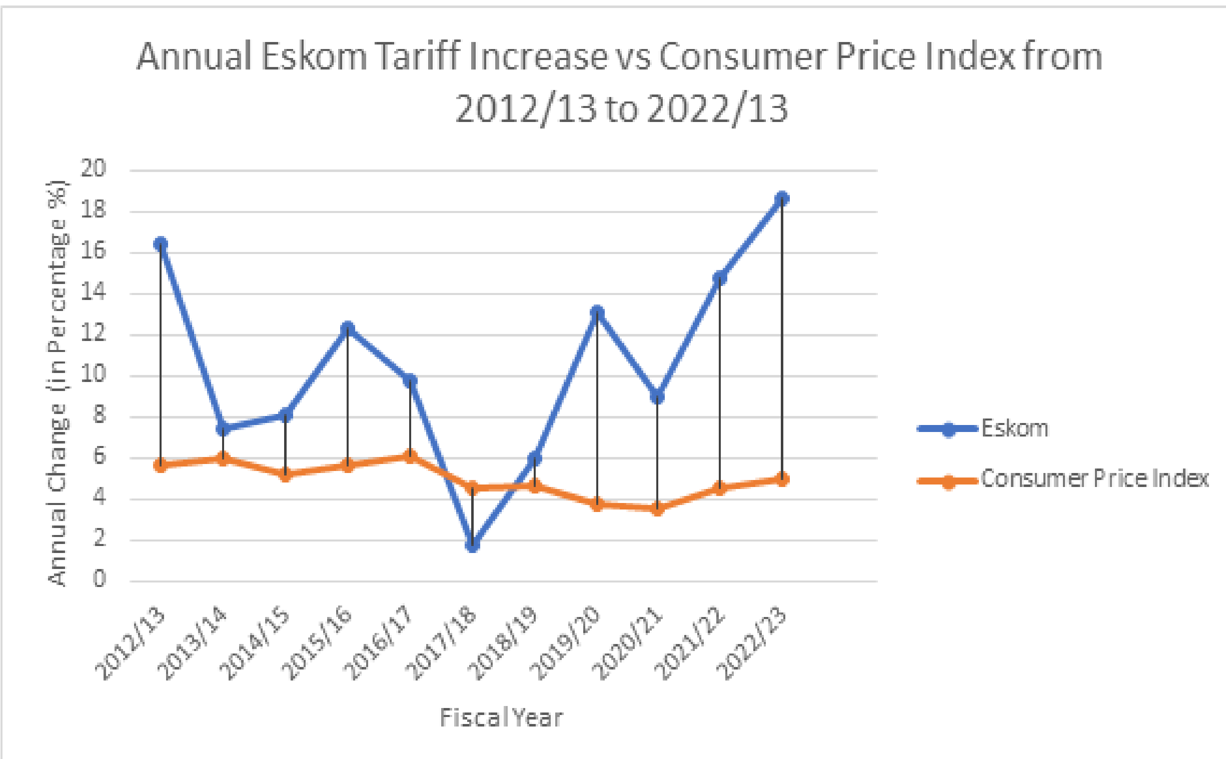

Figure 2: Chart indicating the annual difference between Eskom's electricity tariff and the South African Consumer Price Index.

The energy crisis in South Africa, marked by Eskom's struggles with power supply and tariff hikes since 2008, as illustrated in Figure 2, underscores the urgent need to transition to more sustainable energy sources (Essex and de Groot, 2019; Ngam, 2023; Ntshangase et al., 2023). Load shedding has become a common response to grid instability, which stems from factors like inadequate generation capacity, aging infrastructure, and sudden losses in generation (Walsh et al., 2021; Swartz, 2023). The severity of load shedding increased notably in 2022, with more severe stages becoming prevalent and unscheduled outages occurring without prior announcement (Kgarose et al., 2023; Wright et al., 2023).

Eskom's challenges also include budgetary crises, staffing shortages, and the inability to rapidly transition to renewable energy, highlighting the need for introducing new energy sources to stabilize and sustain South Africa's electricity supply (Hlongwane and Daw, 2023; Muller, 2023). Despite these difficulties, South Africa, in line with global commitments, is focused on reducing carbon emissions by shifting towards sustainable and renewable energy sources, which is reshaping electricity generation not only by Eskom but also by independent power producers (Department of Mineral Resources and Energy, 2022; Clark and McGregor, 2023). This transition, though slow, is crucial for addressing both the environmental impact of coal and the instability of the national grid, paving the way for a more sustainable energy future in South Africa.

2.3. *Alternative Energies in South Africa*

The transition from coal to alternative energy sources in South Africa is challenging due to the country's abundant coal resources and the economic dependency of mining towns on coal-related employment. In 2022, coal still accounted for 80% of the national energy mix, employing over 92,000 people directly and approximately 170,000 indirectly, making a swift, just, and equitable transition difficult (Marais et al., 2022; Department of Mineral Resources and Energy, 2022). South Africa is exploring various renewable energy sources such as solar, wind, hydropower, biomass, natural gas, and nuclear power, which are less environmentally damaging than coal (Mugambiwa and Rapholo, 2023; Pierce and le Roux, 2023). However, Eskom's focus on coal has limited the development of these alternatives within the public sector. Consequently, private sector players have taken the lead in providing alternative energy, offering consumers cheaper, more reliable, and environmentally friendly options (Hlongwane and Daw, 2023; Swartz, 2023).

Solar energy, in particular, has gained traction due to South Africa's high levels of solar radiation. Johannesburg, for instance, receives about 6.85 hours of viable solar energy per day, encouraging the adoption of solar power in households and businesses (Pierce and le Roux, 2023; Dekker *et al*., 2012). However, the variability in climate conditions due to climate change could affect the long-term feasibility of solar energy in different regions (Fant *et al.*, 2016). The cost of solar photovoltaic systems, while initially high, is becoming more affordable in the long term compared to electricity from Eskom. However, increased regulation in the independent power production sector by Eskom and the National Energy Regulator of South Africa (NERSA) has introduced challenges for further solar energy expansion (Walsh *et al*., 2021; Phiri and Nyoni, 2023; Murray and de Kock, 2018; Joubert and Raji, 2023).

Natural gas, another alternative energy source, has also seen significant market penetration. While not renewable, natural gas is less environmentally harmful than coal and has been a parallel fossil fuel in South Africa for heating and cooking. It is considered a transitional energy source, particularly in Europe, where it is widely used for electricity generation. The environmental impact of natural gas, though lower than coal, still includes significant carbon dioxide emissions (Clark *et al*., 2022; Clark and McGregor, 2023; Orthofer *et al*., 2019). Balancing the costs of transitioning to alternative energy sources versus maintaining the status quo is complex, especially for public institutions like the University of the Witwatersrand. These institutions often rely on large generators during load shedding, which can be costly. The university's hybrid system, integrating solar energy with natural gas, offers a solution by providing a backup energy source during cloudy days or at night, reducing the need for expensive diesel generators (Kgarose *et al.*, 2019; Huang, 2022; Babaei *et al*., 2023; Amusan *et al.*, 2024).

Despite the environmental benefits of alternatives like solar and natural gas, they are not without negative impacts. Natural gas extraction, transportation, and combustion still result in significant carbon dioxide emissions, although these are up to 60% lower than those from coal-fired power stations (Clark and McGregor, 2023). Additionally, the long-term environmental impacts of such energy transitions are difficult to assess, particularly on a local scale, and have not been extensively studied (Mulrow *et al.*, 2019; Ali and Anufriev, 2020). While South Africa is making strides towards diversifying its energy mix, the transition from coal remains complex due to economic dependencies and infrastructural challenges. The adoption of alternative energy sources like solar and natural gas offers environmental and economic benefits but also presents new challenges that need careful consideration and long-term planning.

2.4. *Technological Transitions*

Geels (2002) considered the factors and forcing agents that contribute to the ideation, manifestation, and successful adoption of technological transitions as "evolutionary reconfiguration processes", such as the one that is explored in this research report. Geels defines evolution as a combination of processes where (i) changes come about through differentiation from the norm, which eventually becomes the preferred option and a mainstay or (ii) changes occur because of reconstitution and redesign of existing technologies over time.

In the case of the transition of technology away from electricity derived from coal to sustainable energy sources, both processes have informed the desire to move away from the status quo (Akpeji *et al.*, 2020; Hölscher *et al*., 2023). There have been multiple 'new' sources of energy introduced since the early days of electricity, which have become preferred in some contexts (such as nuclear power and gas in Russia) as well as reconfigurations to coal-fired power stations which have optimised and reduced the overall emissions of greenhouse gases at power stations (such as carbon capture and storage) (Fouché and Brent, 2019).

Within this theory of technological transitions, it is also posited that there are three phases or mechanisms of technological transitions, namely the micro-level where there is *niche-cumulation*, which is the design and creation of new technological solutions that respond to a niche within society (Geels, 2002; Hölscher *et al*., 2023). This phase is soon followed by the meso-level of *technological add-on and hybridisation*, where these innovative solutions are introduced into the market and accepted by early adopters, which may refashion existing sociotechnical regimes (Geels, 2002; Geels, 2005). The phases conclude with the macro-level where the technology is *riding along with market growth*, where the success or failure of this innovative technology is evaluated by the rate of adoption and market share in comparison to the older technology, transforming the sociotechnical regime and landscape (Geels, 2002; Genus and Coles, 2008).

In the South African context, the introduction of renewable energy sources as a technological transition can be considered to be in the meso-level of sociotechnical regime change, as the production and supply of alternative energy has been introduced and adopted in society but is still a niche market that has yet to become a valid competitor to the dominance and monopolisation of power generation that is Eskom (Isa *et al*., 2018; Walwyn, 2020). There is currently still a "window of opportunity" within the energy production sector, where alternative sources and producers of energy can become integrated into the national grid or choose to create a network 'off the grid' which can completely alter the landscape of energy within South Africa (Isa *et al*., 2018; Fouché and Brent, 2019).

2.5. *Organisational and Institutional Change*

One of the main elements that contribute to the success of a technological transition is whether societies – individuals and institutions – are stable and capable enough to withstand and adopt to change (Xavier *et al*., 2017). The role of institutional structure in any transition is paramount, as the individuals within the structure determine whether new alternative solutions are rejected or accepted (Bush, 2019). There also needs to be clearly defined organisational willingness to accept change and transition (Isa *et al*., 2018).

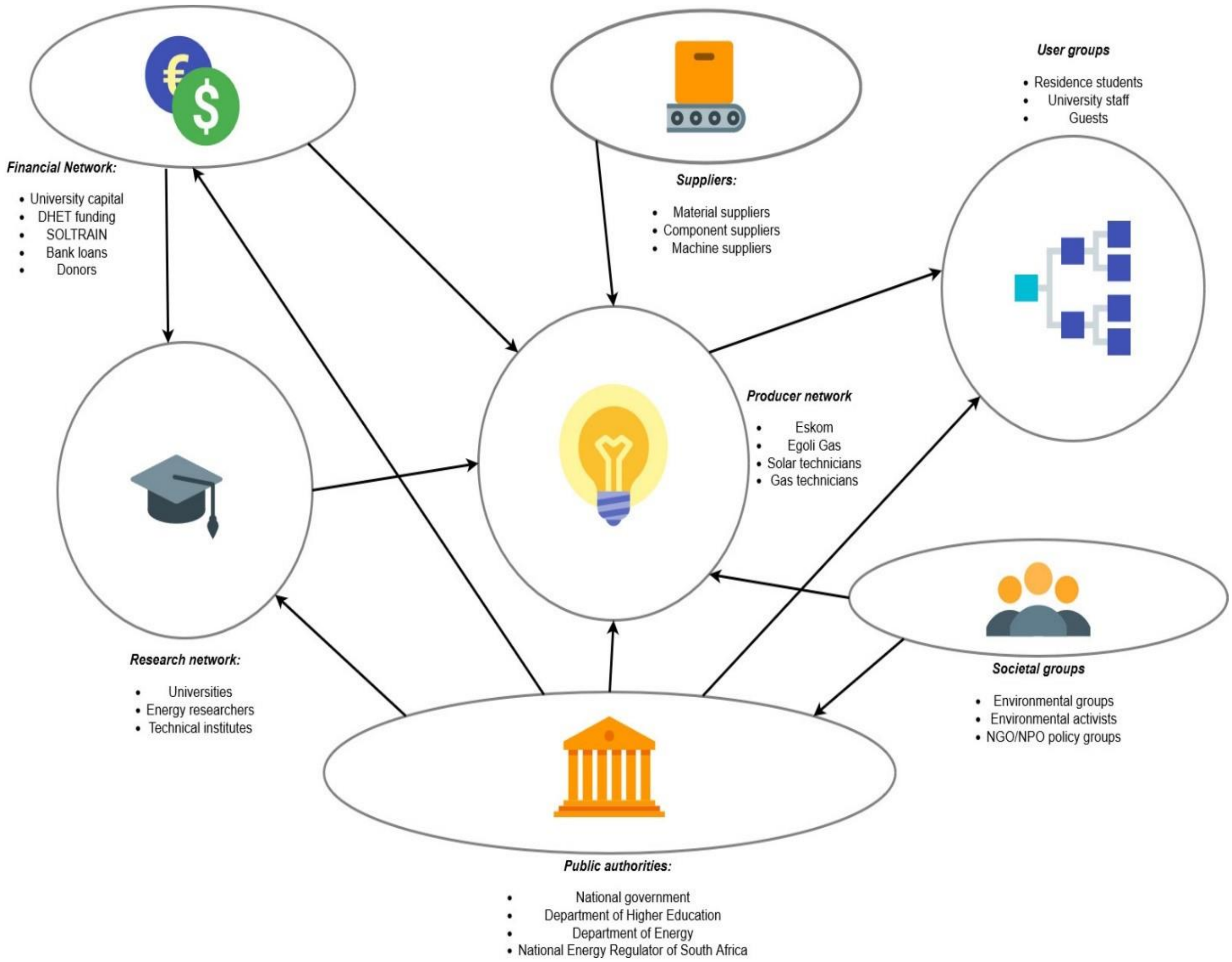

Figure 3: Network map of the stakeholders involved in the Wits solar-gas hybrid thermal water heating technological transition.

Within the context of a university, there are multiple departments, units and faculties which all play a role in the adoption of changes, which is demonstrated in a network map in Figure 3 (Badat, 2009: Awuzie and Emuze, 2017). However, the organisational structure of the higher education sector is often fragmented and disjointed with a preponderance towards 'silo thinking' where individual departments function independently while aiming to achieve one overarching goal (Ulmer and Wydra, 2020). The goals and vision of each institution often proposed and initiated by the university's senior executive and management teams (Pillay and Pillay, 2012; Togo and Lotz-Sisitka, 2013). The steps that are necessary to achieve these goals are then dictated by the departments focused on developing and designing the infrastructure of the campus (Ndelu and Utete, 2023). After extensive research and feasibility analyses, these plans are then implemented throughout the institution with or without the consultation of all the relevant and necessary stakeholders (Leal Filho *et al*. 2018; Ulmer and Wydra, 2020).

The need to create sustainable universities has become a point of discussion – and a goal – throughout the world, as the academic sphere is often considered to consist of thought leaders and innovators who reshape and redefine societies (Awuzie and Emuze, 2017; Leal Filho *et al.*, 2018). This perception and expectation about the higher education sector has placed new demands on universities as organisations – a need for niche culmination (as discussed by Geels) that coincides with the current window of opportunity in the alternative energy sector (Geels, 2002; Hölscher *et al*., 2023). This convergence of ideas suggests that the organisational culture and structure of universities must also be reframed to respond to and adopt changing sociotechnical regimes (Mutinda and Liu. 2021). The top-down silo approach must be reevaluated if sustainability is truly to be achieved as a daily practice rather than as a theoretical concept (Pillay and Pillay, 2012; Mzangwa, 2019).

2.6. ***Contextualising the South African Higher Education Sector***

South Africa's tertiary education sector includes 26 public universities and universities of technology, alongside public technical and vocational colleges and private institutions, serving over one million students as of 2023 (McLaren and Struwig, 2019; Mbatha, 2023; Leal Filho *et al.*, 2018). As most universities are residential, there is a significant need for sustainable development and technology.

The higher education sector has grown rapidly, reflecting the increasing complexity of the economy and the need for skilled professionals (Hoque and Abdullah, 2021). However, this sector faces a fiscal crisis, with institutions struggling with debts from unpaid student fees and operational costs (McLaren and Struwig, 2019). Financial constraints often overshadow environmental sustainability in decision-making, as societal issues like access to education and decolonisation take precedence (Leal Filho *et al*., 2018). Universities are operating at a financial deficit, making it difficult to fund sustainable projects or refurbish buildings (McLaren and Struwig, 2019). Research on sustainability in South African public institutions is limited, though some initiatives exist. For example, the education sector leads in solar water system installations, accounting for 18% of South Africa's total solar boiler capacity (Joubert *et al.,* 2016). The University of Johannesburg has launched a solar panel project generating 4343.5 gigawatt-hours annually, while Rhodes University has established a "Green Fund" to finance sustainability projects initiated by staff and students (University of Johannesburg, 2021; Togo and Lotz-Sisitka, 2013).

2.7. *Contextualising the University of the Witwatersrand*

Wits University has taken multiple steps to further the cause of sustainability, with multiple projects being undertaken to improve the overall efficiency and effectiveness of their operations (University of the Witwatersrand, 2023). Additionally, the financial instability in the cost and supply of electricity from Eskom has placed the public institution into a crisis when planning for future fiscal terms (McLaren and Struwig, 2019). The revised hot water system, which was initiated in 2018, is powered by a hybrid of solar energy and piped natural gas, both alternative energy sources which have been identified as suitable transition energy sources, as they minimise the amount of carbon dioxide which is emitted during the heating of water in residences (Huang, 2018; Clark *et al*.,2022).

The Wits Junction complex was completed in 2012, and initially relied on 146 individual Solahart branded geysers for water heating which were planned to be evenly dependent on both electricity and solar power as power sources. Ultimately, those Solahart geysers only used fossil-fuel electricity rather than the designed hybrid system due to poor planning (Huang, 2018; Huang, 2022). The David Webster Hall used 50 traditional domestic-use geysers for water heating (Huang, 2018). A solar-gas hybrid thermal water heating system illustrated in Figure 3 combines solar energy and natural gas to efficiently provide hot water. The system begins with solar thermal panels installed on the roof to capture solar energy, which is then converted into electrical and thermal energy (Amusan *et al*., 2024). This electrical and thermal energy heats the water directly, which is then piped to water storage tanks (Rozon *et al.*, 2023).

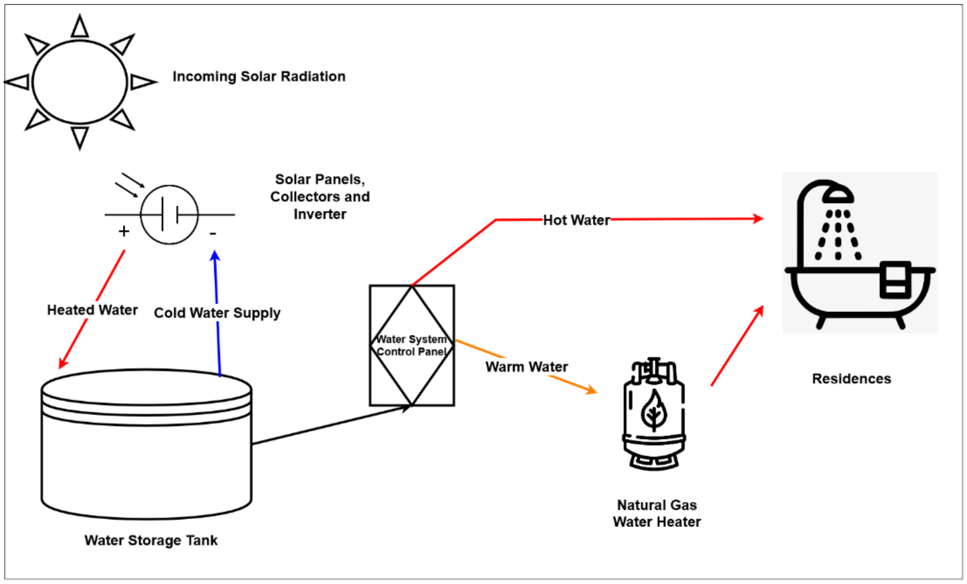

Figure 4: Simple diagram of the solar-gas thermal water heating system used at residences at Wits University (After Huang, 2018)

Alongside the solar components, there is a gas water heater fuelled by natural gas, serving as a backup or supplementary heat source when solar energy is insufficient (Babaei *et al*., 2023; Amusan *et al*., 2024). Hot water generated by the system is stored in an insulated water storage tank, and a water circulation pump circulates it to various points of use (Chiradeja *et al*., 2019). The system also includes a heat exchanger for more efficient heat transfer between the solar and gas component (Chiradeja *et al*., 2019). The system also includes a control panel for monitoring and adjusting operations, and a connection to the natural gas supply for the backup gas heater. Hot water distribution lines deliver the heated water to taps, showers, and appliances throughout the building (Amusan *et al*. 2024).

The first phase of the new residential hot water system proved to be financially more effective in the first few months of operation, with an optimisation of water heating costs from the older system which cost R1,88 per kWh, while the hybrid water heating system costing R0,80 per kWh in 2018 (Huang, 2018). The new system has also been noted to be more efficient in the service of delivering hot water using less energy, as there is more water available per person (80*l*) than in the older system (50*l*), as well as having the capacity to store more heated water (Huang, 2018). The new adopted solar-gas thermal system also minimises some of the added operational costs of hot water provision by not being reliant on costly diesel generators (approximately R25.53 on the 1st of August 2022) during power outages or planned load shedding events.

2.8. Literature Review Summary

South Africa's energy transition reflects an attempt to shift from a coal-dependent system to a more sustainable and environmentally friendly model. Historically reliant on coal due to its abundance and cost-effectiveness, the country has faced considerable challenges related to the environmental impacts of coal, including greenhouse gas emissions, air and water pollution, and land degradation. By 2022, renewable energy sources contributed 13.7% to the national grid, up from just 2.4% in 2015, illustrating a slow but steady transition towards cleaner energy. This shift is driven by the need to address environmental concerns and align with broader sustainability goals that emphasize the interconnectedness of environmental health, economic stability, and social well-being.

The transition is also influenced by South Africa's energy context, where coal has historically dominated due to its cost-effectiveness and the central role of Eskom, the national utility. However, the sector has faced challenges such as instability and frequent load shedding. To address these issues, the country is exploring various alternative energy sources including solar, wind, hydropower, biomass, natural gas, and nuclear power. Solar energy, in particular, has gained traction due to favourable geographic conditions, while natural gas is seen as a transitional fuel with lower environmental impact compared to coal. Hybrid systems that combine solar with natural gas are also being implemented to tackle energy shortages and reduce costs.

Technological transitions in South Africa follow a framework that involves niche accumulation and gradual market integration. While renewable technologies are progressively being adopted, they are still in the meso-level phase, indicating incremental growth rather than a full-scale shift from coal. The current energy crisis presents a critical opportunity for integrating alternative energy sources and reshaping the energy landscape.

Institutional and organizational changes play a crucial role in this transition. For instance, South African universities are increasingly exploring hybrid energy solutions and striving to align their operations with sustainability goals. Effective change requires overcoming traditional silos and fostering collaboration across departments. Institutions must adapt to support the transition towards a more sustainable energy system, emphasizing the need for comprehensive and integrated approaches to sustainability.

3. Methodology

3.1. Study Site

The University of the Witwatersrand is one of the oldest higher education institutions in South Africa, having been formally established in 1922. The infrastructure of the University's campuses was mostly constructed in the 20th century, having seen significant expansion from one campus to five teaching campuses and two research campuses.

Wits University is an urban campus located within central Johannesburg, which is one of the most built-up areas within South Africa. This significantly influences the type of physical infrastructural change and development that can take place, as the University and the area surrounding the campus cannot be altered drastically.

Additionally, the need for sustainability in infrastructure was not an initial consideration in the development and design of the University, with durability and aesthetic value being paramount at the time of their construction (Togo and Lotz-Sisitka, 2013; Ulmer and Wydra, 2020).

The residences which have been selected for the hybrid water heating systems are the Wits Junction which accommodates 1100 students which located in Parktown and was first occupied in 2012 and David Webster Hall of Residence, which houses 330 students, which part of the West Campus Cluster which opened in 1992 (Huang, 2018).

3.2. Methodological Approach

The study adopts a mixed-methods research design to explore the environmental, economic, and social impacts of introducing solar-gas hybrid thermal water heating systems at Wits University. This design integrates qualitative and quantitative approaches to provide a comprehensive understanding of stakeholder perspectives and project feasibility. Quantitative data on emissions and costs are analysed using standardized formulas and economic feasibility metrics to provide a comprehensive assessment of the project's environmental and economic impacts. Stakeholder perceptions and attitudes toward the solar-gas hybrid thermal water heating system are gathered through semi-structured interviews. This qualitative method allows for in-depth exploration of stakeholder views and experiences. Participants include staff from the Campus Planning and

Development department, representatives from the Campus Housing and Residence Life Office, and students. Interview questions are designed to address key themes such as costs, environmental impact, sustainability efforts, and behavioural adjustments. These interviews provide insights into stakeholder acceptance and adaptability to the new system.

3.3. Sampling Procedure

For the semi-structured interviews, it was important to identify stakeholders who represented the stakeholders within the University. As the project centred around on-campus residences, the interviewees had to be directly attached to the project or the Campus Housing and Residence Life Office. The Campus Planning and Development department was approached for an interview, as that department oversees and manages all infrastructural changes within the University space. As the department is relatively small, one interview was conducted with the departmental director. Within the Campus Housing and Residence Life Office there are multiple sub-departments which handle different components of the University's residential programme. The Operations Manager oversees all of these components as well as the future planning and strategy for the department. As such, for the research interview, this portfolio was selected.

For the student stakeholders, invitations for interviews were sent to students in the Wits Junction residence as well as those residing in David Webster Hall of Residence. Nine students were interviewed individually who were all undergraduate students in various stages of completing Bachelors or Bachelor Honours degrees. The sample of interviewees all possessed at minimum a high school education, with many also having graduated with at least one post-secondary qualification, which suggests a level of access or awareness of information and concepts about sustainability, as it has been integrated into multiple subjects within the basic education syllabus in South Africa (Singh-Pillay, 2023). Furthermore, for the two staff member interviewed, sustainability and sustainable development make up a significant portion of their portfolio mandates.

A total of eleven stakeholders were interviewed, which meets the criteria delineated in Subedi (2021), as the depth of information which was gleaned from the interviews did not necessitate the need for additional interviews to be conducted.

3.4. Data Collection

In response to the social element of sustainability, the quantitative instrument that was determined to be most suitable was the semi-structured interview, as it allowed for a level of consistency among the data collection process, and the gathering of long-form answers (compared to brevity of a questionnaire or survey) would be most effective in gaining the actual perceptions and attitudes that stakeholders held (Valentine, 2013; Roulston and Choi, 2018). As this project can also be understood as a technological transition, it is imperative that both the social nature of the landscape should be understood to effect any meaningful change through the introduction of new technological solutions to old problems (Geels, 2002; Geels, 2005; Hölscher *et al*., 2023). The interviews were conducted from October 2023 to February 2024, with all the interview sessions ranging from 35 minutes to an hour in length, with all sessions being conducted in-person at the University of the Witwatersrand.

For the environmental element of the research, electricity consumption data and figures for both the old and new water heating systems were sourced from the Campus Planning and Development department prior to the interview with the representative, as well as the overall capacity of both systems, which were useful in developing extrapolated and calculated data.

When collecting data for the economic component for the research, the cost and operational expenditure figures for the project were also sourced from the Campus Planning and Development department after the interviews were conducted, in addition to information about the capital expenditure for the refurbishment. Data about the change in electricity and gas tariffs were sourced from the service providers and industry regulators, namely Eskom, Nersa, and Egoli Gas.

3.5. Data Analysis

The aforementioned information would then bring the introduction of solar-gas hybrid thermal water heating systems into question: is it environmentally less harmful than coal-based traditional water heating systems? Is the cost of this type of refurbishment financially sound? Is society able to accept and adapt to such development?

3.5.1. Measuring Environmental Impact

Despite the assumed reduction of emissions, an accurate measurement of the impact of a transitioning to a hybrid solar power-gas system can be difficult to assess, as the amount of emissions and other indicators of environmental and climate change on a small scale (such as a university campus) is not measured directly with air quality assessments, but is often calculated, extrapolated, or inferred (Leal Filho *et al.*, 2018; Ali and Anufriev, 2020). The possible changes to local and regional environmental processes and systems because of an energy transition have also not been well defined or studied over a longer duration of time (Langerman *et al.*, 2023; Joubert and Raji, 2023)

As such, it is essential to make use of a standard method of deciding the emissions from a point source, such as a power station or generator system. The International Panel of Climate Change has devised a guide for the conversion of energy consumed (in megawatts per hour) into carbon dioxide emitted (in kilograms), which incorporates the emission factor of each energy source, which can be described as the amount of greenhouse gases (in kilograms) emitted per megawatt/hour (IPCC, 2006; Seymore *et al.*, 2014; Department of Forestry, Fisheries, and the Environment, 2024).

The formula for standard carbon dioxide equivalent conversion calculations is as follows in Equation 1:

$$(Energy\ Consumption\ in\ MWh)\ (emission\ factor) = xCO_2e\ kg/MWh$$

With *x* being the output value derived from the input variables.

The general formula of the emissions calculator uses emission factor which were developed as a tool to simply and streamline the carbon accounting process. The emission factor values were derived as a relative measure of the amount of greenhouse gases (carbon dioxide equivalent emissions) that are polluted into the atmosphere from during the operation and generation process (IPCC, 2006; Department of Environmental Affairs, 2016). The emission factors for the energy sources used in this research project are tabulated below:

Table 1: Emission factors of energy sources (IPCC, 2006; IPCC, 2019)

Energy Source	Emission Factor
National Grid	1.013
Natural Gas	0.213
Solar Energy	0.012

It is also possible to calculate the individual greenhouse gases emitted during the energy generation process, such as nitrous oxide and sulphur dioxide, but the lack of exact measurements of energy consumption by electrical source in a hybrid system needs extrapolation and inference (Seymore *et al*., 2014; Mulrow *et al*, 2019). As such, in the research the determination of the respective carbon dioxide equivalent (CO_2e), which can be useful in producing one cohesive aggregate of all possible greenhouse gases that can be emitted (Department of Environmental Affairs, 2016; Noludwe and Folly, 2023).

Solar energy has the lowest emission factor, which is due to the lower overall amount of particulate matter that is released during energy generation process, as no substances are burnt to convert physical energy into electrical energy (Sproul *et al*., 2019; Phiri and Nyoni, 2023). Coal and diesel have the highest emission factors of the four fuels or electrical sources which are used at the University of the Witwatersrand, which is because of the substantial number of particulates emitted during the burning and firing processes that are used to convert chemical, mechanical, and physical energy into electrical energy (Waters, 2023; Wright *et al*., 2023). The carbon dioxide equivalent values of energy type will then be compared to evaluate the environmental impact of each fuel or alternative energy type which is being explored at Wits University residences (Michael *et al*., 2019; Department of Forestry, Fisheries, and the Environment, 2024).

3.5.2. Measuring economic considerations

Undertaking an economic feasibility analysis for a substantial infrastructural endeavour, such as the installation of hybrid energy systems, demands a meticulous evaluation that encompasses a multitude of critical variables (McClaren and Struwig, 2019). This analysis delves into the financial sustainability of the project and involves a detailed assessment of various aspects. Firstly, the assessment involves a comprehensive examination of both the first capital outlay and the ongoing operational expenses associated with deploying and supporting these hybrid energy systems throughout their lifecycle (Madziga *et al*., 2018; Mujuru *et al*., 2020). This includes costs related to equipment procurement, installation, integration with existing infrastructure, maintenance, repairs, and potential upgrades or replacements over time (Mujuru *et al*., 2020). By quantifying these costs, stakeholders can gauge the financial commitments needed at various stages of the project.

Furthermore, the economic feasibility analysis entails a thorough investigation of trends in electricity and natural gas prices (Clark *et al.*, 2022). This examination extends across short- and medium-term horizons to find the viability of the project under varying market conditions (McClaren and Struwig, 2019). Factors such as historical price fluctuations, projected price trajectories, and market dynamics are considered to assess the potential financial risks and rewards associated with the investment. The monthly operating costs of each system will be evaluated and compared, making use of the data reported from the Campus Planning and Development department, as calculating what a possible continuation of the traditional water system would cost in 2024 using the following formula used in Equation 2:

$$\begin{aligned} &Monthly\ Operating\ Expenditure \\ &\qquad = Average\ monthly\ energy\ consumed\ by\ geyser \\ &\qquad \times Price\ of\ electricity\ per\ kilowatt - hour \end{aligned}$$

In addition to cost considerations, the analysis also evaluates the cost-effectiveness of the hybrid energy systems. This involves comparing the expected benefits, such as energy savings, reduced operational costs, and potential revenue generation from surplus energy production or sale, against the total investment and operating expenses (Mutinda and Liu, 2021; Rozon *et al*., 2023). As such, the return on investment will be calculated for the solar-gas hybrid water heating system using the following formula in Equation 3:

$$Return\ on\ Investment = \frac{(Financial\ value\ - Project\ Costs)}{Project\ Costs} \times 100$$

Moreover, the overarching fiscal impact on the institution is a crucial aspect of the analysis. This includes assessing the budgetary implications, potential funding sources, financing options and overall alignment with the institution's financial goals and sustainability aims (Sarkodie and Strezov, 2019). By delving into these intricacies and conducting an economic analysis, stakeholders can gain a comprehensive understanding of the economic viability and potential outcomes of implementing hybrid energy systems (Mujuru *et al*., 2020; Amusan *et al.*, 2024. This informed decision-making process ensures that investments in sustainable energy solutions are not only environmentally beneficial but also financially sound and aligned with long-term strategic goals (Mutinda and Liu, 2021).

3.5.3. Evaluating people's perceptions and attitudes towards the project

Often when research is conducted about infrastructural development on university campuses, the students' - client's perspective is often neglected, or seen to be a mandatory exercise the public participation process (Togo and Lotz-Sisitka, 2013; Xavier *et al*., 2017). The population and demographic of residences is not constant, with continuous change due to the transitional nature of the campus space (Michael *et al.*, 2019). However, this is not sufficient cause to negate the opinions of students, as true and holistic sustainable development is contingent on giving equal levels of consideration to the three pillars of sustainability (Scoones, 2016).

The interview questions that were asked were designed to align and respond with the aims, objectives and research questions that were developed for this research project. The questions, which can be found listed in the addendum touched on the following thematic categories which were derived and expanded from the research questions:

a) What is the cost incurred during the process of heating water in residences at the University of the Witwatersrand, and how does it compare to the costs incur heating water using the solar gas hybrid thermal water heating system?

b) What is the environmental impact (measured by carbon emissions) of heating water in Wits residences using traditional geysers or making use of the solar-gas hybrid thermal water heating system?

c) What is the University of the Witwatersrand's approach on sustainability and how does the University assesses, monitor, and evaluate the effectiveness of its sustainability efforts?

d) What are the perceptions held about the introduction and adoption of alternative energy and technologies amongst the relevant stakeholders to this project?

e) How are students adjusting their behaviour to accommodate the solar-gas hybrid thermal water heating system?

f) How are other tertiary education institutions in the developing Global South approaching and engaging with sustainable thinking and development?

3.5.4. Research Assumptions

As discussed within the literature review, the solar thermal panel network installed on the rooftops of the Wits Junction complex is two-kilometres-long (Huang, 2018). Due to Johannesburg receiving 6,8 hours of viable solar energy per day, the average solar radiation received is 4,7 kilowatt-hours per square metre of surface within the span of a day (Joubert *et al.*, 2016). With this being considered, it can be inferred that the solar panels at the Wits Junction generate 9400 kWh of energy in a day, using the following formula used in Equation 4:

$$\sum Daily\ solar\ energy\ generated \equiv Average\ solar\ radiation\ per\ m^2 \times Solar\ thermal\ panel\ surface\ area$$

To evaluate the average amount of energy consumed by a traditional geyser, it has been assumed that the geysers followed the normal heating cycle where the heating element for a 150-litre geyser is on for six hours and fourteen minutes in day (Catherine *et al.*, 2012). The amount of energy that is required daily to heat the water in a geyser to 70°C is 11.67 kWh, in addition to the 2.531 kWh that are lost as the thermal energy within the system throughout the day (Catherine *et al.*, 2012).

As the Wits Junction residence previously had 149 geysers distributed, it can be determined that 2115.72 kWh are used daily by the traditional geysers that were replaced by using the following formula in Equation 5:

$$\sum Daily\ energy\ consumed\ by\ traditional\ geyser \equiv \sum Average\ daily\ energy\ consumed\ + Average\ daily\ energy\ lost \times Number\ of\ geysers$$

Gas heaters, which are used to supplement the solar water heating process, require approximately 990 kWh of energy per day to mitigate the standing losses of a solar heating system that works at 85% efficiency. This assumes that for the gas boiler to produce 450 kilowatts of thermal heat (kW_t), 990 kW of energy is consumed daily (Department of Business, Energy, and Industrial Strategy, 2021).

3.6. Data Limitations

This study encountered several significant challenges that affected the depth and breadth of its findings. Foremost among these challenges was the difficulty in obtaining comprehensive data from the University of the Witwatersrand. Despite diligent efforts to procure information regarding energy consumption rates within residences from key administrative departments such as Campus Planning and Development and the Property and Infrastructure Management Divisions, substantial data remained elusive. Consequently, this study had to rely extensively on publicly available data related to the refurbishment project, supplemented by insights gleaned from lectures and presentations dedicated to this initiative.

Another notable challenge arose from the reluctance of student leadership groups to actively take part in the research process. Despite outreach attempts directed at bodies like the Student Representative Council and the All-Residences Sub-Council, both of which serve as representatives of the student body, their non-involvement needed alternative recruitment strategies. Ultimately, students were recruited via notices posted at the Wits Junction residence, highlighting the impact of these organizational dynamics on the study's participant selection and representation.

The reliance on extrapolated, interpolated, and inferred data posed substantial methodological challenges, particularly concerning the exploration of causal relationships and variables' interconnections. This limitation constrained the ability to make accurate predictions and estimations and hindered the comprehensive statistical analysis that could have enriched the study's findings. However, the trustworthiness of the collection of qualitative data was more certain, as ethical clearance was provided prior to conducting the interview, and all interview participants signing a consent form free of duress.

Furthermore, the adoption of a mixed methods approach, while valuable in capturing diverse perspectives, added layers of complexity to drawing definitive conclusions. The integration of quantitative and qualitative data presented challenges in synthesizing findings and establishing robust links between environmental impacts, fiscal trends, and social realities.

Despite these obstacles, it is noteworthy that this research framework is still replicable and adaptable for similar studies in the future. However, addressing the identified data limitations, methodological constraints, and participant engagement issues will be critical to enhancing the overall rigor, reliability, and validity of subsequent research endeavours in this field.

3.7. Ethical Considerations

The reliance on extrapolated, interpolated, and inferred data posed substantial methodological challenges, particularly concerning the exploration of causal relationships and variables' interconnections. This limitation constrained the ability to make accurate predictions and estimations and hindered the comprehensive statistical analysis that could have enriched the study's findings. However, the trustworthiness of the collection of qualitative data was more certain, as ethical clearance was provided prior to conducting the interview, and all interview participants signing a consent form free of duress.

Furthermore, the adoption of a mixed methods approach, while valuable in capturing diverse perspectives, added layers of complexity to drawing definitive conclusions. The integration of quantitative and qualitative data presented challenges in synthesizing findings and establishing robust links between environmental impacts, fiscal trends, and social realities. The research was thus conducted with the approval of the Wits University Non-Medical Ethics Committee, as well as the directors of the Campus Housing and Residence Life Office and Campus Planning and Development department. All research participants also signed consent forms that acknowledged that they were being interviewed without any compulsion, coercion or obligation.

4. Results and Discussion

4.1. Results

4.1.1. *Environmental Component*

At the Wits Junction, within in the first three months of commissioning the solar-gas water heating system – August to October 2018 – the residence's energy consumption was 840 000 kilowatts hour (kWh), compared to 1 540 000 kWh in the same three-month period in 2017. This reduction of energy consumption was also observed at the two residences in West Campus, where the solar-gas thermal water heating system was introduced in 2018. In the same August to October period, in 2018 the residences both recorded 190 000 kWh of energy consumed, in comparison to the 345 000-kilowatt hours logged in 2017. Both sites of the project saw a 55% reduction in overall residence energy consumption during the August to October 2018 period, in comparison to the previous year, which coincides with the commissioning of the new water heating systems, as the number of residents and hot water demand remained consistent during this period.

By examining carbon dioxide emissions per megawatt of energy consumed, a clear distinction appears between electricity sourced from the national grid, primarily powered by coal, and alternative energy options such as gas and solar energy. The results of the comparative analysis of emissions between the traditional coal-fired electrical geysers and the new solar-gas hybrid thermal water heating system have been calculated using the formulae delineated in the methodology chapter.

Table 2: Carbon dioxide emissions (CO_2e) from the different electrical sources used at the Wits Junction Residence.

Electrical Source used at Wits Junction	Average daily energy consumption by water heating system (MWh)	Average monthly energy consumption in megawatt hours (MWh)	Monthly carbon dioxide equivalent emissions (CO_2e) in kilograms per megawatt hour (kg/MWh)
National grid	2.115	63.471	64.296
Solar thermal panels	9.4	282	3.384
Piped natural gas	0.99	29.7	6.326

Table 2 outlines the calculated carbon dioxide equivalent values (CO_2e) derived from Equation 1 that are emitted from the traditional geysers, which make use of electricity sourced from the national grid, as well as the emission of the new solar gas hybrid thermal water heating system (IPCC, 2006; IPCC, 2019). This has also been calculated based on generation capacities of the solar panel rings installed at the Wits Junction, as well as the average monthly amount of piped natural gas bought from Egoli Gas and the emission factors of these energy sources.

4.1.2. *Economic Component*

When the University of the Witwatersrand (Wits) started a project to upgrade the water heating systems at the Wits Junction residence and the West Campus Cluster residences the process involved transitioning from the existing setup of 149 distributed geysers to a centralized system housed in a single facility. The aim was to improve efficiency and reduce operational costs over time.

Initially, the project was budgeted at around R3 500 000 for capital expenditure. However, unforeseen expenses arose during the implementation phase, particularly related to achieving high-efficiency infrastructure. As a result, the final capital expenditure for the first phase of the project amounted to R 12 600 000, which was more than three times the first estimate. However, the value of the hybrid water heating system has appreciated over time, as it has had a 4.16%

return on investment over time, as it is now valued at R17 846 837 making use of the formula delineated in Equation 3.

The projected operating expenditure – which includes the purchase of piped natural gas and the routine maintenance of the water heating system - for the project was estimated at R 300 000 per month in 2018. This estimation proved to be correct, as the monthly costs have remained consistent over time, as the Campus Planning and Development department noting that any increases mainly attributable to inflation in 2024, the annual operating cost of the hybrid water heating system is now R 384 854.71 (which is equal to R32 071.23 each month). Using the formula listed in Equation 2, it can be determined that the projected monthly costs for 149 traditional geysers in 2024 would be R250 710.45 per month. The projected operational cost of the traditional geyser is 7.8 times more than that of the new solar-gas water heating system, which suggests that the transition to a new water heating system reduces the amount of money needed to provide the same service to residence students.

Table 3: Average annual change in the price of piped natural gas for consumers from 2018 to 2022 Source: Egoli Gas.

	2018	2020	2022	2024
R/GJ	222.23	147.23	112.16	134.59
Percentage change (%)	-	- 33.75%	- 23.83%	+ 19.99%

The University sources piped natural gas, specifically piped natural gas from an external private sector provider called Egoli Gas. Piped natural gas is used as an energy source for water heating systems alongside solar thermal panels, which incur regular maintenance fees but are mostly cost-free in terms of energy consumption, as it is a natural and renewable resource. The price of piped natural gas is an important economic consideration for the university's operations. Table 3 provides an overview of the average annual change in piped natural gas prices for medium-scale consumers from 2018 to 2022. This data shows a significant reduction in piped natural gas prices over the specified period.

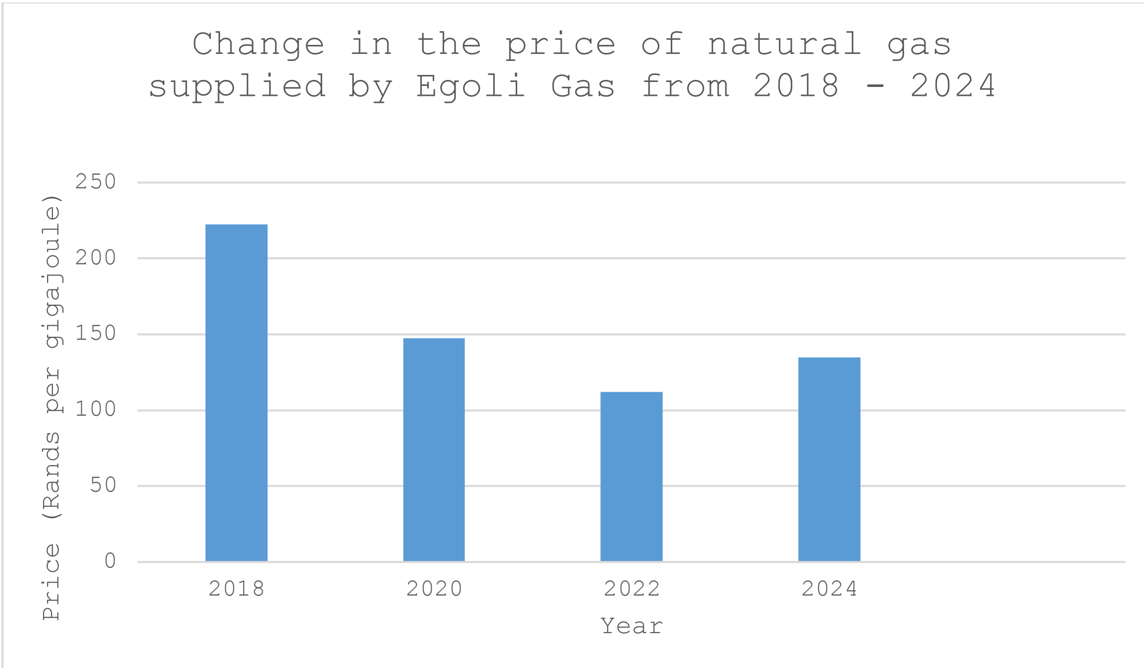

Figure 5: Chart displaying the change in the price of piped natural gas, which is bought from Egoli Gas from 2018 to 2024. Source: Egoli Gas.

In 2018, the cost of piped natural per gigajoule (GJ) was R 222.23. However, by 2022, this price had decreased to R 112.16 per GJ, marking a significant reduction of 57.58% over the four-year period, which is displayed in Figure 5, however this is not a consistent trend or pattern for pricing, as the change has been non-linear and multidirectional as the price per kilojoule has had reductions and increments over the 2018 to 2024 period.

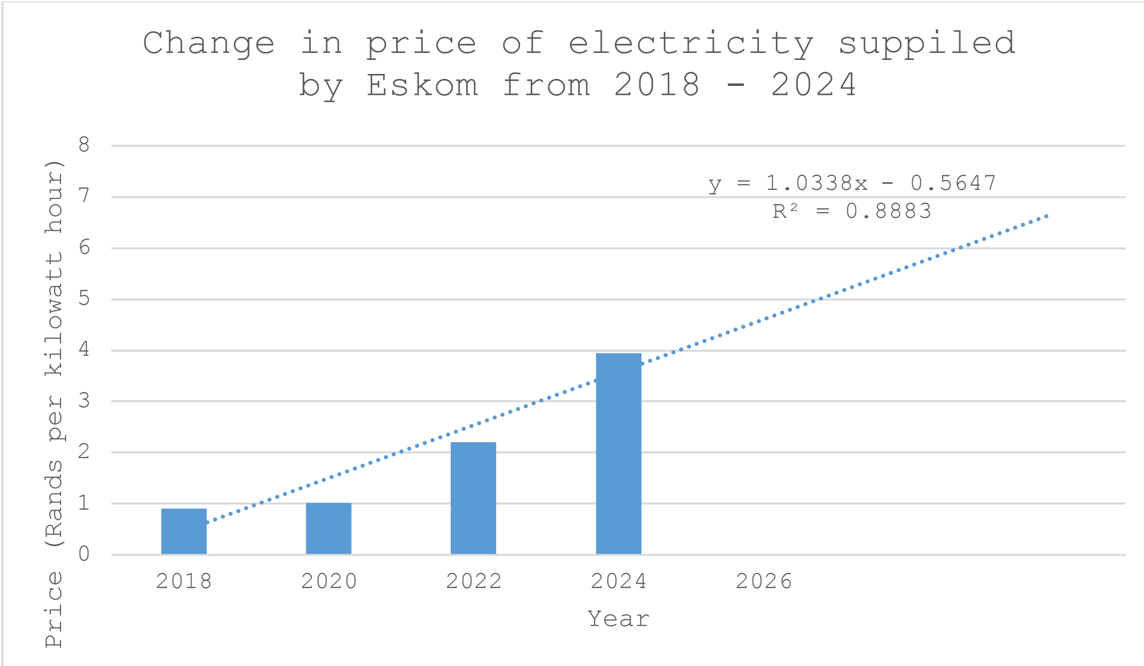

Figure 6: Chart displaying the change in electricity prices, which is bought from Eskom, from 2018 to 2024. Source: Eskom.

In contrast to piped natural prices, the cost of electricity supplied by Eskom, the national electricity provider, experienced substantial gradual increments as evidenced in Figure 6. From 2018 to 2022, there was a cumulative 55.3% increase in electricity prices. This variance in energy costs between piped natural gas and electricity suppliers contributes to the overall financial dynamics and budget considerations for the university's infrastructure projects, including the water heating system upgrades.

4.1.3. Social component

The content analysis of stakeholder perspectives on water heating and sustainability at Wits University reveals significant insights into awareness, costs, environmental impact, attitudes, and the broader context of sustainability efforts. Staff and students outside the Campus Planning and Development department are generally unaware of the cost of water heating, with even this campus unit lacking exact figures. This information gap frustrates stakeholders like the Campus Housing and Residence Life Office, which feels cut off from crucial technical data. Despite this, all interviewees acknowledged the need for increased government support and subsidies for infrastructure improvements, particularly noting that costs decreased with the installation of a new solar thermal system.

Environmental awareness among stakeholders varies. While there is widespread recognition of the link between electricity generation and climate change, detailed understanding is inconsistent. The new solar-gas hybrid water heating system is expected to significantly reduce carbon dioxide emissions, which is widely supported by evidence which has been stressed by the Campus Planning and Development department representative, "***I think if we can call any project successful, the numbers have to back it up – and unlike many projects on campus the change and impact has been east to track and compare – that's what we need to focus on***". However, estimates of the university's energy consumption for residences vary widely, and safety concerns about using piped natural gas in older buildings were raised. These discrepancies highlight the need for better communication and education on energy consumption and environmental impacts.

Attitudes towards sustainability are generally positive across all stakeholder groups. Departments like Campus Planning and Development and Campus Housing and Residence Life Office prioritize sustainability, though to varying degrees, and students often prioritize academic concerns over sustainability due to decision-making processes being handled by student leaders and staff, with one student stating, "***I am not in the House Comm. Nobody really asks us anything about stuff like that, and besides, I am not really involved in the stuff that happens at res***" [sic]. There is consensus that each department's vision aligns with the university's sustainability policies. However, the level of personal buy-in varies, indicating a need for greater inclusion of students in decision-making processes to foster deeper engagement.

Students are passionate about sustainability but feel constrained by the institutional framework. While they believe in the importance of sustainability, they often feel their choices are limited and that they lack power to effect meaningful change. One student remarked that “***it feels like it doesn’t matter whatever we suggest, even if they are really good ideas***”. Staff perceive students as aware but not always acting in accordance with their knowledge, suggesting a gap between awareness and action. Institutional initiatives like appointing a Pro-Vice Chancellor for Climate, Sustainability, and Inequality demonstrate commitment, but practical engagement and educational campaigns could bridge this gap.

In the context of the Global South, universities face unique challenges related to resource constraints and socioeconomic issues. Despite these challenges, Wits University is seen as well-resourced and capable of attracting foreign investment, positioning it as a potential leader in sustainability. “***Wits is advanced compared to other universities***”, stated the representative from Campus Housing and Residence Life Office, “***they want to remain a leader in the South African landscape***”. The emphasis on collaboration and shared resources reflects a recognition that sustainable development requires collective effort and shared solutions, both within the university and with external partners. This analysis underscores the complex landscape of sustainability at Wits University, highlighting areas for improvement in information dissemination, engagement, and collaborative efforts to enhance sustainability in a challenging context.

a. Costing and Funding

The approximate cost of water heating was not well known to staff and students outside of the Campus Planning and Development department, with the exact figure also not being readily known by this stakeholder who said, “***despite not having the precise numbers, I can tell you that a lot of the cost is increased due to inefficiency and wasteful usage”.*** The lack of dissemination of information was bemoaned by the representative from the Campus Housing and Residence Life Office who also noted that their office is cut-off from technical data as it seems “***a lot of information was given to the previous Operations manager, but I have not really been brought into this conversation***”. Similarly, interviewees could not estimate how much money is spent in the water heating process at residences. The interviewee from the Campus Planning and

Development department was quick to indicate that the cost of water heating was significantly reduced upon installation of the new solar thermal water heating system.

The need for increased government support was shared by all interviewees, with the representative from Campus Housing and Residence Life Office mentioning a need for more governmental subsidies for the improvement and upgrading of higher education sector's infrastructure. Furthermore, this interviewee was supportive of the need for collaboration and resource sharing within the higher education sector. The Campus Planning and Development department representative delved further into this subject, discussing how the Department of Higher Education and Training does provide some level of support, which is meaningful, but not sufficient to cover the capital and operating expenditure of the project. Further funding – "***somewhere between three-and-a-half and ten million rands***" – was provided by the Southern African Solar Thermal Demonstration & Training Initiative (SOLTRAIN) which itself is funded by the Austrian Development Agency and implemented by the Austrian Institute for Sustainable Technologies.

Regarding how this project should be financed, the student interviewees strongly opposed the notion that the cost and burden of financing the refurbishment should fall upon students. This sentiment was shared by all interviewees, with the representative from Campus Planning and Development department highlighting the existing student and tertiary institution fiscal crisis in South Africa emphasising that "***the current Wits accommodation model is barely breaking even, there is a lot of student debt – current and historical – and any added fees on students would be almost impossible to recoup despite the students still living in the building***". Additionally, the representative touched upon how the residence model at the University if the Witwatersrand is not breaking even financially despite annual accommodation rate hikes, and as such, it would not be possible to introduce new costs to students.

b. Environmental impact of water heating systems

All the interviewed groups shown that they were familiar with the relationship between electricity generation and climate change/global warming. However, the self-reported level of awareness varied between the interview groups. The interviewee from the Campus Housing and Residence Life Offive who described himself as "***entry level***" and Campus Housing and

Residence Life Office interviewee was in agreement and said she "***knew most of the general things most people know***" both readily admitted to being less knowledgeable about the causes and effects of greenhouse gas emissions and global warming.

Students were more confident in their understanding of climate change, greenhouse gas emissions and global warming, with one student saying that "***these days young people are more informed about things like climate change because we are even taught about it from primary school***". although a few also reported that they felt they did not have technical expertise in these fields. The interviewees were all in agreement that the installation of the solar-gas hybrid thermal water heating system would result in a reduction of carbon dioxide emissions, when compared to traditional water heating systems.

Students gave a variety of estimations about what amount of the University's total energy consumption was used in residences, with some estimating as little as 5% while others guessed as much as 35%. Staff members gave more conservative estimations, with a range from 10 to 20%. These variations align with how the respondents felt unsure about the exact details of the hot water project.

The interviewee from the Campus Planning and Development department estimated that the new water heating system could result in less emissions as it was more energy efficient (85% efficiency) than the traditional water heating systems, which are only 30-35% efficient. As such, the new system would need less resources to run, and reduce the carbon dioxide emitted while burning gas. The respondent from the Campus Housing and Residence Office was in support of the project, but also questioned the safety of making use of piped natural gas in older buildings, as well as the safety of the piped gas infrastructure provided by Egoli Gas, which is also aging, and juxtaposed the campus to other parts of Johannesburg which were fitted with gas by positing that "***coal is safer than gas. If the gas is in the air and fire breaks out there will be more damage than when it is coal".***

Most of the participants supported the need for a transition, despite the relatively prohibitive cost, as the reduction of greenhouse emissions was a necessary change. Some students interviewed stated that the University should divert their attention to other causes, as they found the issues facing students (insufficient accommodation, rising tuition costs, reduction in funding from the National Student Financial Aid Scheme) to be more relevant to them presently.

c. *Wits University's sustainable goals and vision*

Staff members were more familiar with the policies and goals that the University has set in aims of increasing and reaching sustainability on campus, and discussed Vision2033, which was sets medium-term goals for the University. Another policy that was brought up was by the Campus Planning and Development department representative was the then upcoming strategic policy which will ***"hopefully be approved by the Wits Council in November (2023), the Council and Senate really want to push for investment and progress and this approval will be a big push".*** The exact content of this policy was not disclosed by the representative.

Student interviewees had less familiarity with the University's policies and could not name any specific aims and goals that have been outlined by Wits Senate, Council or Campus Planning and Development department as one student lamented that, "***they don't really make this information available, and when it is available, it is hard to read and follow because it's not written in a way that everyone can understand***". As such, students had less knowledge about the measurement of sustainability on campus and could not give possible measures of efficiency or effectiveness. The representative from the Campus Housing and Residence Life Office also could not give a clear measurement or assessment tool for measuring the value of sustainable efforts on campus, beyond estimating a campus carbon footprint.

The interviewee from the Campus Planning and Development department mentioned that the use of the Before – After – Control – Impact approach, wherein the values for energy consumption are contrasted from before and after the installation, as well as the use of control (residences where the new system has not been installed) and impact (Wits Junction and David Webster Hall) site to identify if change is happening, clarifying that "***for now, as the project is still relatively new, we don't really have many ways to monitor or measure things in depth, maybe in the medium-term when there is more data we can spot trends***".

Most respondents were aware of the United Nations' Sustainable Development Goals as a concept, but many could not name any specifically. Furthermore, the interviewees felt that the University did not specifically align with the goals outlined by the UN, but one issue that was brought up was the inapplicability of some of the goals within the parameter of a university. When the interviewees were made aware of one of the UN Sustainable Development Goals they had prioritised (SDG 11: Sustainable Cities and Communities), they felt that this goal could be achieved as one student stated "***Wits has access to things and if it is for UN type of goals, I think people with resources would be willing to help***", emphasising the vast network financial, intellectual, and social capital with current students and alumni, as well as the willingness of all stakeholders.

d. Attitudes and Perceptions of Stakeholders

The staff respondents noted that within their own departments, there does seem to be some level of importance given to environmental sustainability, as it is one of the mandates given by the University. Personal and individual buy-in within the Campus Housing and Residence Life Office was reported to be variable, with it being noted that although there was an elevated level of awareness, there was a lack in education, detailed information and follow-through amongst the staff with the representative saying that "***we know the basics, closing taps and switching off lights when we leave the office, but so often you will be the last person to leave and half of the lights are still on***".

The staff member interviewed from the Campus Planning and Development department remarked that there was elevated level of buy-in and awareness amongst the department, as their focus was planning and developing a more sustainable campus. Student respondents felt that their fellow residents did not always display awareness or interest about issues surrounding sustainability, as many seem to prioritise academic wellbeing over other considerations. Furthermore, they indicated that buy-in was not encouraged or needed, often because of the decision-making process often being taken by residence student leaders (house committees) or the Campus Housing and Residence Life Office itself.

e. Impact and Influence of Student Behaviours

The students who were interviewed were passionate when responding to the that interrogated the role of student behaviour on the success of the solar-gas hybrid thermal water heating system, as well as other efforts to increase sustainability on campus. One respondent said that "***the burden of reaching sustainability on campus lies with the campus management exclusively, as students are only able to consume what the University provides to us"***. Another student respondent felt that students were aware of the impact of their behaviour and choices, but often felt that those choices were limited, as personal hygiene could not be compromised for sustainability as ***"people have to be clean, and if that sometimes means longer or multiple showers in a day then so be it***". A further interviewee believed the sustainability of the University was a responsibility shared by all who occupy it, but due to the leadership style and segregation between students, student leaders and staff, it often felt as though an average student did not have much power to effect meaningful change.

The staff respondents both felt that students were mostly aware about climate change and sustainability but did not act in a manner that reflected such knowledge. The representative from the Campus Planning and Development department intimated that student often displayed "***carelessness and disregard"*** about the impact of their behaviour. Furthermore, this interviewee considered some students to be demanding of services to be rendered (such as hot water supply), but displayed a level of impatience about these services, which suggested that they were active consumers, but not cautious ones. The staff member from the Campus Housing and Residence Life Office believed students to be aware of their impact in residences, and pointed to a considerable number of projects and initiatives led by students which focus on sustainability on campus by stating that "***we are trying, and these kids are trying, I am amazed by some of the projects and initiatives they have started by themselves***". This was an upward indicator and was understood to symbolise that students could change their behaviour (such as consumption of hot water) if it resulted in the collective good of the University and society at large.

Most interviewees mentioned that they were aware of the University's efforts to increase awareness about environment sustainability, but many felt that they were not reaching the target audience. The representative from the Campus Planning and Development department felt that the efforts were not designed in such a way that they could be engaging to students. The respondent from Campus Housing and Residence Life Office pointed to the instalment of a Pro-Vice Chancellor for Climate, Sustainability, and Inequality at Wits, as well as the initiation of projects such as the 'Save Our Resources Campaign' and the Campus Housing and Residence Life Office Green Campus Initiative Living and Learning Community were indicative of a ramping up of sustainability awareness and education by the University. Student respondents described the University's sustainability efforts as lacklustre and prescriptive, with one interviewee calling the University's approach "***boring and basic***" and as such, it would be difficult for students to feel a need to increase their awareness of sustainability, as the University has developed policies and practices for them.

f. Improving sustainability as a higher education institution in the Global South context

The interviewees felt that Universities in the Global South were limited in their immediate responsiveness about sustainability due to insufficient or unequal resources, compared to those in developed countries. The students interviewed suggested that for higher education institutions in the Global South, the issues related to socioeconomic realities of developing countries outweighed the need to become *greener* or more environmentally sustainable, with one student saying that "***a lot of institutions and qualifications from Africa aren't taken seriously***" citing Harvard and Oxford as universities that are respected worldwide, " ***we need to focus on being taken seriously in the academic space, then we can start to think about climate and environment***".

The economic and political instability of some universities in South Africa was also mentioned by the respondents from the Campus Housing and Residence Life and Campus Planning and Development departments, but both interviewees said that this was a window of opportunity for universities in the developing world to reposition themselves and redefine their role as global thought leaders. The University of Fort Hare was brought up as an example of an institution that still valued environmental sustainability despite facing challenges with their political and economic sustainability.

The two staff member interviewed spoke positively about the University of the Witwatersrand's position in the Global South, as it relates to efforts to become more environmentally sustainable institution. The representative of the Campus Housing and Residence Life Office felt that the University was making strides but was also slowing itself down by focusing on large-scale projects rather than grassroots initiatives. "***We like new buildings and big renovations, but we don't put enough attention on things like the community gardens in some residences, or even one residence that had a seedling growing contest. These things are also good, but it seems like nobody recognises them***".

The representative of the Campus Housing and Residence Office echoed similar sentiments to those from the representative of the Campus Planning and Development department and felt that Wits and other higher education institutions could receive help from more collaboration, as the premise of sustainable thinking and development is that the Earth and environment are shared resources. As such, it would also improve how universities are able to attract financial investment and support from the private sector and foreign entities.

4.1.4. Results Summary

Between August and October 2018, the University of the Witwatersrand (Wits) saw a significant reduction in energy consumption following the installation of solar-gas water heating systems. The Wits Junction residence cut its usage from 1,540,000 kWh in 2017 to 840,000 kWh in 2018. Similarly, West Campus residences reduced their energy use from 345,000 kWh to 190,000 kWh, reflecting a 55% decrease across both sites (University of Johannesburg, 2021).

Economically, the project to upgrade water heating systems involved transitioning from 149 geysers to a centralized solar-gas system. Initially budgeted at R3.5 million, the cost soared to R12.6 million due to unforeseen expenses. Despite the high initial cost, the new system has provided a 4.16% return on investment, now valued at R17.85 million. Operating costs have remained stable at R32,071 per month, compared to R250,710 for traditional geysers, indicating substantial savings (Joubert et al., 2016). Natural gas prices decreased significantly from R222.23/GJ in 2018 to R112.16/GJ in 2022, contrasting with a 55.3% increase in electricity prices over the same period (Egoli Gas; Eskom). This shift highlights the cost benefits of transitioning to hybrid systems. Socially, stakeholder awareness of the system's cost and environmental impact varies. While staff and students generally support sustainability efforts, there is a need for better communication and involvement in decision-making processes. Students often feel their influence is limited, despite their enthusiasm for sustainability (Togo and Lotz-Sisitka, 2013).

In summary, the Wits project demonstrates the potential financial and environmental benefits of modernizing water heating systems, though challenges in stakeholder engagement and funding persist (McLaren and Struwig, 2019; Ulmer and Wydra, 2020).

4.2. Discussion

4.2.1. Environmental Component

The analysis of the environmental component within Wits University's water heating system refurbishment offers valuable insights into the carbon footprint associated with various energy sources. The results of the comparative analysis between the traditional coal-fired electrical geysers and the new solar-gas hybrid thermal water heating system suggest that there is a significantly lower amount of carbon dioxide which is being emitted during the water heating process.

Solar energy is still the least environmentally taxing source of energy of the three, having only emitted 3.384 kilograms of carbon dioxide emission per megawatt hour of energy consumed. The use of co-generative energy is still necessary due to a combination of factors which have been outlined, and as such, the new system for water heating cannot be considered absolutely carbon neutral. This is shown in the overall emissions that are produced when heating and burning gas – 64.296 kilograms of carbon dioxide emissions per megawatt hour consumed. The monthly amount of carbon dioxide equivalent emissions from using natural gas to heat water is 1.9 times higher than that emitted by solar thermal panels but is also ten times less than that emitted by traditional geysers.

The overall carbon dioxide emissions released during water heating from traditional geysers is 6.6 times more than the combined carbon dioxide emissions released from the cogenerated solar-gas hybrid system. Research studies conducted by Mujuru *et al.* (2020) and Thobejane *et al.* (2019) align with this observation, highlighting the significantly higher emissions linked to electricity generated from the national grid, particularly from coal-based sources. Conversely, investigations by Fant *et al.* (2016) and Mujuru *et al.* (2020) indicate that solar photovoltaic energy exhibits the lowest emissions, with Mujuru *et al.* (2020) noting the significantly lower amount of greenhouse gas emissions when making use of solar energy.

Of note is the transitional role of natural gas as an energy source, due to the substantially lower emissions compared to other fossil fuels which have been used previously in residences at the University of the Witwatersrand. This assertion finds support in the analysis by Clark and

McGregor (2023), which emphasizes the enhanced efficiency and reduced transmission losses associated with natural gas, thereby leading to minimized on-site and life cycle emissions from gas boilers. The observed decrease in energy consumption within Wits residences following the implementation of the solar-gas water heating system, as documented by Michael *et al*. (2019), further bolsters the environmental effectiveness of this initiative. It can be inferred that current and projected energy consumption levels have markedly declined post-installation, contributing significantly to reduced carbon dioxide emissions and overall electricity consumption within the residences.

These findings substantiate the rationale behind adopting the solar-gas hybrid thermal water heating system, highlighting its pivotal role in augmenting the environmental sustainability of Wits University residences. The integration of solar and gas technologies not only reduces carbon dioxide emissions during water heating but also fosters a culture of energy conservation within the residences, aligning with sustainable energy practices and highlighting a positive stride towards greener energy infrastructure.

4.2.2. ***Financial Component***

The significance of financial backing from investors and development agencies like SOLTRAIN becomes evident when examining the capital expenditure required for projects like the water heating system refurbishment. Unexpected costs, as noted by Rozon *et al*. (2023), can easily impede progress if not adequately supported. This aligns with the discussions by Sarkodie and Strezov (2019) and Walwyn (2020), stressing the pivotal role of securing financial support, especially from foreign investors, to expedite sustainable development in developing nations.

The 4.16% return on investment also supports the transition away from traditional geysers, as the value of the new water heating system has appreciated in value over a short period of time. Analysing operational costs reveals the effectiveness of transitioning away from sole reliance on Eskom for electricity. The projected increase in Eskom's tariffs, estimated at R1.033 per kilowatt-hour every two years based on current trends, underscores the financial burden it poses.

The difference in the current monthly operating costs of the new water heating system (R32 071.23 per month) in contrast to the projected cost of retaining the traditional geyser systems (R250 710.45

a month) shows that the new system is more likely to be financially sustainable in the long term. Ngam (2023) and Essex and de Groot (2019) further elaborate on Eskom's fluctuating tariff increases, highlighting their impact on operational costs. Comparing the purchasing cost of these fossil fuels underscores the financial prudence of transitioning to alternative suppliers of fuels. Natural gas emerges as a cheaper choice in this research project, especially in the short term, as highlighted by Clark *et al*. (2022). This financial analysis supports the decision to move away from reliance on the national grid.

Overall, a financial evaluation emphasizes the importance of securing financial backing, transitioning from Eskom to alternative suppliers like Egoli Gas, and considering the long-term cost benefits of solar energy in sustaining efficient and economically viable water heating systems. However, new instabilities in the natural gas provision sector suggest that the viability of gas may not be certain in the medium or long term, as SASOL struggles to stabilise its supply of natural gas to private vendors

4.2.3. Social component

The interviews conducted shed light on several critical aspects about the long-term viability and success of the new water heating system at Wits University. One notable observation is the overall positive response from all interviewee categories toward the project's premise, showing a collective optimism about its potential environmental benefits, and the reduction of the environmental impact of water heating. The content analysis of stakeholder perspectives on water heating and sustainability at Wits University reveals significant insights into awareness, costs, environmental impact, attitudes, and the broader context of sustainability efforts. Staff and students outside the Campus Planning and Development department are generally unaware of the cost of water heating. This information gap frustrates stakeholders like the Campus Housing and Residence Life Office which feels cut off from crucial technical data. Despite this, all interviewees acknowledged the need for increased government support and subsidies for infrastructure improvements, particularly noting that costs decreased with the installation of a new solar thermal system.

Environmental awareness among stakeholders varies. While there is widespread recognition of the link between electricity generation and climate change, detailed understanding is inconsistent. The new solar-gas hybrid water heating system is expected to significantly reduce carbon dioxide emissions, which is widely supported. However, estimates of the university's energy consumption for residences vary widely, and safety concerns about using piped natural gas in older buildings were raised. These discrepancies highlight the need for better communication and education on energy consumption and environmental impacts. Regarding sustainability goals, staff members are more familiar with the university's policies, such as Wits Vision2033, than students, who struggle to identify specific aims. The university uses the Before – After – Control – Impact approach to measure sustainability impacts, yet there is limited awareness of the UN Sustainable Development Goals among stakeholders. This suggests a need for improved communication and education to engage the student body in sustainability initiatives and align the university's efforts with global goals.

Attitudes towards sustainability are generally positive across all stakeholder groups. The departments approached for interviews prioritize sustainability, though to varying degrees, and students often prioritize academic concerns over sustainability due to decision-making processes being handled by leaders and offices. There is consensus that each department's vision aligns with the university's sustainability policies. However, the level of personal buy-in varies, indicating a need for greater inclusion of students in decision-making processes to foster deeper engagement. This optimism is crucial for navigating the technological transitions outlined by Geels (2002) effectively. Similar positive attitudes have been observed in other contexts, such as Ekurhuleni (Mujuru *et al*., 2019) and Hessequa Municipality (Fouche and Brent, 2019), where sustainable technologies were introduced and adopted successfully.

However, despite the positive outlook, there are notable challenges highlighted through the interviews. One such challenge is the discrepancy between the University's top-down approach to decision-making and the limited buy-in from end users, including students and staff outside infrastructure-focused departments. This is problematic when the research project is evaluated using a sustainability approach, as it suggests that economic value or environmental impacts are more important facets of development in universities, as this approach emphasis the need for public participation and involvement in decision-making. This aligns with findings from studies at other South African universities like the University of Kwa-Zulu Natal (Pillay and Pillay, 2012) and Rhodes University (Togo and Lotz-Sisitka, 2013), indicating a prevalent leadership style within the higher education sector that may not effectively engage stakeholders in sustainability initiatives.

Students are passionate about sustainability but feel constrained by the institutional framework. While they believe in the importance of sustainability, they often feel their choices are limited and that they lack power to effect meaningful change. Staff perceive students as aware but not always acting in accordance with their knowledge, suggesting a gap between awareness and action. Institutional initiatives like appointing a Pro-Vice Chancellor for Climate, Sustainability, and Inequality demonstrate commitment, but practical engagement and educational campaigns could bridge this gap. Furthermore, while there is a general awareness of sustainable thinking and development among participants, there is a notable gap in technical understanding between staff at the Campus Planning and Development department, and respondents affiliated to residences regarding specific projects and interventions started by the University. This disconnect between awareness and technical knowledge is a common challenge in sustainable technology implementations, as noted by Xavier *et al*. (2017) and Meyer and Overen (2021).

In the context of the Global South, universities face unique challenges related to resource constraints and socioeconomic issues. Despite these challenges, Wits University is seen as well-resourced and capable of attracting foreign investment, positioning it as a potential leader in sustainability. The emphasis on collaboration and shared resources reflects a recognition that sustainable development requires collective effort and shared solutions, both within the university and with external partners. This analysis underscores the complex landscape of sustainability at Wits University, highlighting areas for improvement in information dissemination, engagement, and collaborative efforts to enhance sustainability in a challenging context.

The interviews also revealed a communication gap regarding the solar-gas thermal water heating system installation, with many student respondents unaware of its details and benefits. This lack of engagement limits the potential for behaviour adjustments that could enhance project outcomes, as highlighted by Xavier *et al*. (2017). A more holistic and inclusive approach to stakeholder engagement, as emphasized by Xavier *et al*. (2017), is crucial for successful energy transitions and sustainable project outcomes. A lack of understanding of sustainable technology can act as a barrier in the rate of adoption of ‘green’ solutions within the campus space, as the perceived value this and similar projects may not be shared amongst stakeholders.

Moreover, the prevailing techno-economic approach within the higher education sector, coupled with communication silos, as discussed by Mbatha (2023) and Ndelu and Utete (2023), indicates the need for a paradigm and organisational behaviour and management shift. This then suggests that if the University of the Witwatersrand and other higher education institutions in South Africa are to become competitive players in the global context, it would be essential to reconsider how they govern themselves, and how they engage with the stakeholders: there need to be a pronounced shift from making solutions ***for*** the campus, but rather solutions ***with*** the campus.

4.2.4. Discussion Summary

The environmental analysis of Wits University’s water heating system refurbishment underscores a significant reduction in carbon emissions through the adoption of a solar-gas hybrid system compared to traditional coal-powered geysers. The study reveals that the solar thermal panels emit the least carbon dioxide (3.384 kg CO_2e/MWh), followed by natural gas (6.326 kg CO_2e/MWh), with electricity from the national grid generating the highest emissions (64.296 kg CO_2e/MWh). The hybrid system’s overall carbon emissions are 6.6 times lower than those from traditional geysers, reflecting a substantial environmental benefit.

Supporting research by Mujuru *et al.* (2020) and Thobejane *et al.* (2019) confirms the higher emissions from coal-based electricity, while studies by Fant *et al.* (2016) and Mujuru *et al.* (2020) validate the lower emissions associated with solar energy. The transitional role of natural gas is noteworthy, given its relatively lower emissions compared to other fossil fuels. This aligns with findings by Clark and McGregor (2023), which highlight the efficiency and reduced emissions of natural gas systems.

Moreover, the decrease in energy consumption post-installation, as documented by Michael et al. (2019), further emphasizes the system's effectiveness in reducing carbon emissions and electricity usage. These findings justify the adoption of the solar-gas hybrid system, underscoring its pivotal role in enhancing the environmental sustainability of Wits University residences. The integration of solar and gas technologies not only mitigates carbon emissions but also fosters energy conservation, aligning with sustainable energy practices and promoting a shift towards greener infrastructure.

5. Conclusion and Recommendation

5.1. Conclusion

The pursuit of sustainability within South African higher education institutions faces a myriad of challenges, yet these obstacles also present opportunities for proactive development. Adopting a multifaceted sustainability strategy, which encompasses environmental, economic, and social dimensions, has proven significant potential in reducing both operational costs and environmental impacts.

Through the implementation of greener technologies, such as the solar-gas hybrid thermal water heating system at the University of the Witwatersrand, substantial progress has been made in curbing carbon dioxide emissions during water heating processes. The new water heating system does not completely mitigate greenhouse gas emissions from residences but does manage to reduce the monthly carbon dioxide equivalent emissions by 54.6 kilograms in comparison to the old traditional geyser system. This technological advancement has not only reduced energy consumption within residences but has also displayed the institution's commitment to sustainable practices.

Financially, the monthly cost of operation for water heating at the Wits Junction has been reduced by R218 633.22, which is a significant amount of money saved by the university. Furthermore, the new water heating system has also had a positive amount of return on investment (4.16%), which is a stride in achieving economic sustainability, as the project is appreciating in value. However, despite these strides in environmental and economic sustainability, social integration is still a critical area for improvement. The lack of meaningful engagement with students and housing staff highlights the need for comprehensive stakeholder involvement throughout sustainability initiatives. Enhancing communication and collaboration channels can bridge this gap and foster a more inclusive approach to sustainable development.

A holistic perspective on policymaking and decision-making is imperative for successful sustainability endeavours. This entails not only considering environmental and economic factors but also prioritizing social equity and engagement. By embedding sustainability principles into the fabric of governance and operations, higher education institutions can emerge as leaders in sustainable development, driving positive change within their communities and beyond. The success of the Wits hot water project underscores the potential of technological innovations to align with sustainability objectives. Moving forward, a continued focus on holistic sustainability, coupled with robust stakeholder engagement and effective governance structures, will be pivotal in advancing the sustainability agenda within the South African higher education landscape.

5.2. Recommendations

Having made use of sustainability as a research framework, and the research methods selected, the following recommendations have been made to increase the success of the South African higher education sector's efforts to increase its sustainability:

a. *Enhance Stakeholder Engagement*

Develop and implement a comprehensive stakeholder engagement strategy that encompasses students, staff, and relevant departments within the university infrastructure. This strategy should prioritize effective communication channels to bridge existing gaps and foster a deeper understanding and appreciation of sustainable initiatives. Regularly scheduled updates, interactive workshops, and targeted educational sessions can serve as effective platforms to engage stakeholders and garner support for sustainability projects.

b. *Invest in Communication Channels*

Allocate resources towards establishing clear and accessible communication channels to disseminate information about the solar-gas hybrid thermal water heating system and other sustainable initiatives. Utilize a diverse range of platforms, including newsletters, social media platforms, campus-wide events, and educational campaigns, to reach a broader audience and encourage active participation and feedback from stakeholders.

c. *Foster a Culture of Sustainability*

Cultivate a robust culture of sustainability within the university community by integrating sustainability principles into academic curricula, training programs, and campus activities. Offer specialized courses, workshops, and awareness programs that focus on sustainable practices, energy conservation strategies, and environmental stewardship. Empower students and staff to initiate and lead sustainability projects, thereby fostering a sense of ownership and responsibility towards sustainable behaviours and practices.

d. *Collaborate with External Partners*

Strengthen collaborative partnerships with external stakeholders, including investors, development agencies, industry experts, and local communities. Leverage these partnerships to access financial resources, technical expertise, and additional resources necessary to accelerate the implementation of sustainable development initiatives. Engage with governmental bodies, non-governmental organizations (NGOs), and sustainability networks to facilitate knowledge-sharing, exchange best practices, and leverage collective efforts towards sustainability goals.

e. *Implement Continuous Monitoring and Evaluation*

Establish a robust monitoring and evaluation framework to systematically assess the environmental, economic, and social impacts of sustainability projects over time. Collect and analyse data related to energy consumption, carbon emissions reduction, cost savings, stakeholder engagement levels, and overall project performance. Utilize this data-driven approach to evaluate progress, identify areas for improvement, and make informed decisions for future sustainability initiatives, thereby ensuring continuous learning and enhancement of sustainability practices within the university setting. By adopting and implementing these recommendations with an emphasis on academic rigor and scholarly discourse, the University of the Witwatersrand, as well as other South African higher education institutions can further advance their sustainability agenda and contribute significantly to fostering a more resilient, efficient, and environmentally conscious campus community and civic society.

5.3. Suggestions for further research

a) *Long-Term Environmental Impact Studies:*

Future research could focus on the long-term environmental impacts of the solar-gas hybrid thermal water heating system compared to traditional methods. This would involve tracking emissions over a more extended period to validate the system's effectiveness in reducing carbon dioxide and other pollutants.

b) *Cost-Benefit Analysis Over a Longer Range of Time:*

A detailed cost-benefit analysis of the hybrid system could be conducted to better understand its financial implications over a longer duration. This research should include not only capital and operating costs but also potential savings in maintenance and energy efficiency improvements.

c) *Comparative Analysis with Other Green Technologies:*

Exploring the performance of the solar-gas hybrid system relative to other green technologies, such as heat pumps or advanced geothermal systems, could provide valuable insights into its relative effectiveness and sustainability.

d) Stakeholder Awareness and Engagement:

Research could investigate methods to enhance stakeholder awareness and engagement regarding sustainability initiatives. This could include assessing the effectiveness of communication strategies and educational programs in improving understanding and involvement in sustainability efforts.

e) Safety and Risk Assessment:

A thorough safety and risk assessment of using piped natural gas in older (or heritage) buildings should be undertaken. This research would address concerns about infrastructure safety, such as those mentioned by the Campus Housing and Residence Life Office representative and provide guidelines for mitigating potential risks.

f) Economic Impact of Energy Price Fluctuations:

Analysing how fluctuations in energy prices, such as those of piped natural gas and electricity, impact the cost-effectiveness of hybrid water heating systems could offer insights for future investments and financial planning in higher education institutions.

g) Student and Staff Sustainability Behaviour:

Investigating the behaviour and attitudes of students and staff towards sustainability initiatives, including the impact of the hybrid system, could help tailor programs and policies to foster greater engagement and commitment.

h) Integration of Global Sustainability Goals:

Research could examine how the university's sustainability efforts align with global sustainability goals, such as those outlined by the United Nations. This could help identify gaps and opportunities for better integration and alignment with international standards.

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Addendum

Research Title: Higher Education Sustainability: Investigating the barriers and opportunities to sustainable infrastructural development in tertiary education institutions

Research Instruments

In order to evaluate the perceptions and attitudes of stakeholders in residences, a series of interviews will be conducted where the research questions will be posed with the management staff of the Campus Housing and Residence Life office and a representative from the Systems and Operations department at the University in order to engage with management.

To gauge student opinions on environmental sustainability on the University campus, interview sessions will be hosted with 5 undergraduate students who live in the University's residences as participants where the research questions will also be posed to the students for open discussion, and the responses will be recorded as a means of determining the student's opinions and perceptions towards campus sustainability

The use of interviews is to promote full engagement with the stakeholders on campus by the emphasising the utilisation of narrative analysis as a means of exploring sustainable development qualitatively - which will respond to the research questions in conjunction with the quantitative cost analysis - rather than the use of a fixed content analysis-focused research methodology such as a questionnaire or survey with a set scale or range for answers.

A. **Interview and Focus Group Questions**

i. Costing and Funding

- What is the cost of the electricity is used for heating water in residences (what do you estimate the cost of water heating to be?)
- How does it compare to the potential cost the University would incur heating water using solar thermal water heating?
- How do you think the University should be financing this transition?
- If residence fees were to be increased by 10% in order to fund solar thermal water heating, would that be problematic?

ii. *Environmental Impact of a new water heating system*

- Are you aware of the environmental impact of energy production on climate change and global warming?
- How would you rate your level of awareness and understanding about the causes and effects of greenhouse gas emissions and global warming?
- Do you think that a transition from traditional electrical water heating systems to solar thermal water heating would reduce or increase carbon dioxide emissions?
- What percentage change would a shift to a solar thermal water heating system make regarding carbon dioxide emissions?
- Do you think that the existing environmental impact of the University residence's electrical systems and infrastructure for water heating is acceptable relative to the cost of a transition?
- What percentage of the University's energy consumption (and subsequent greenhouse gas emissions) comes from residences?

iii. *The University's sustainable goals and vision*

- Does the University have a policy on sustainability and energy efficiency?
- How does the University assess, monitor, and evaluate the effectiveness of its sustainability efforts?
- Do you know about the United Nations Sustainable Development Goals?
- Do you think that the University is giving a suitable amount of emphasis to adhering to UN sustainable development goals?
- Do you think University's sustainability goals (Sustainable cities and communities – SDG11) and ambitions are attainable?

iv. *Attitudes and Perceptions of Stakeholders*

- What are the perceptions towards changing to solar thermal water heating in residences and other University infrastructure in your department/residence?
- Is environmental sustainability an important element in your department's/ residence's planning?
- Do you think there is a cohesiveness between your department's/residence's vision and that of the University?
- Is there a high level of buy-in about environmental issues and sustainability, amongst the people in your department/residence?

v. *Impact and Influence of Student Behaviours*

- Do you think students living in residences are conscious of their individual and collective environmental impacts?
- Do you think that students are willing to adapt and adjust their behaviour to make the adoption of solar thermal water heating systems successful?
- What can the University do to enhance environmental awareness amongst students?

vi. *Improving sustainability as a higher education institution in the Global South context*

- Are tertiary education institutions in the developing Global South doing enough in addressing their greenhouse gas emissions?
- How do you think that the University of the Witwatersrand is performing in its greenhouse gas emission reduction efforts compared to other institutions in South Africa?