

**DEVELOPMENT OF A MODEL TOWARDS THE  
IMPROVEMENT OF BUILDING ENERGY PERFORMANCE IN  
SOUTH AFRICAN PUBLIC UNIVERSITIES USING SOLAR  
PHOTOVOLTAICS**

**NUTIFAFA GEH**

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Promoter: Prof. Fidelis A. Emuze  
Co-Promoter: Prof. Dillip K. Das

Bloemfontein  
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## DECLARATION OF ORIGINAL AUTHORSHIP

I, Nutifafa GEH, student number \_\_\_\_\_, do hereby declare that this research project submitted to the Central University of Technology, Free State, for the degree of Doctor of Engineering, is my independent work and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State, and has not been submitted before to any institution by myself or any other person in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification.



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Signature of Student

24 January 2023

Date

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the favour and mercy that is mine in the future. Without you LORD, I would not have been and, likewise, this milestone would not have been achieved. Papa God, I am most grateful for your providence.



## **DEDICATION**

I dedicate this work to Jehovah, the Creator of the heavens and the earth (Gen. 1:1), and to all who have shown me love by blessing me in various ways.

## LIST OF PUBLICATIONS

The following is the list of publications that the author of this thesis published during the research project.

### A. Refereed journal papers that have been published

**Geh, N., Emuze, F. and Das, D.K. (2022), "Barriers to the deployment of solar photovoltaic in public universities in South Africa: a Delphi study", *International Journal of Building Pathology and Adaptation*, Vol. ahead-of-print No. ahead-of-print. DOI: <https://doi.org/10.1108/IJBPA-11-2021-0147>.**

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### B. Refereed book chapters that have been published

**Geh N., Emuze F.A., Das D.K. (2022), "Key factors influencing deployment of photovoltaic systems: A case study of a public university in South Africa", In: Gorse C., Scott L., Booth C., Dastbaz M. (Eds.), *Climate Emergency – Managing, Building and Delivering the Sustainable Development Goals*. Springer, Switzerland, pp. 105–118, DOI: [https://doi.org/10.1007/978-3-030-79450-7\\_10](https://doi.org/10.1007/978-3-030-79450-7_10).**

### C. Journal papers under review

**Geh, N., Emuze, F. and Das, D.K., "Solar photovoltaics deployment acceleration model to advance the sustainability of buildings in public universities in South Africa."**

## ABSTRACT

Buildings perform various important functions in society and their construction and maintenance have evolved over the years. The call to construct sustainable buildings has made individuals and organisations more aware that they cannot continue on the old trajectory and expect better results. Globally, universities have several buildings which need energy to operate and because the consumption of energy from non-renewable sources contributes significantly to carbon emissions, there is presently the need to construct and retrofit buildings to consume less energy and generate renewable energy on-site to reduce carbon emission. In South Africa, solar photovoltaics (PVs) are the most deployed renewable energy technology. Therefore, to partly advance the sustainability of buildings in South African public universities in terms of renewable energy development, the deployment of PV is the ideal choice. However, deployment is not yet at the desired level at public universities in South Africa to contribute significantly to the change that is needed. From empirical evidence, little is known about the progress that universities have made in installing PVs, and the factors that engender and hinder deployment. Therefore, this study was undertaken to investigate the phenomenon and develop a model to advance the sustainability of buildings through the deployment of PVs in public universities in South Africa. Accordingly, the specific research objectives were to: (1) ascertain the progress made in installing PVs on public campuses, (2) identify and evaluate the drivers for deployment, (3) identify and evaluate the barriers to deployment, (4) evaluate the influence of the drivers and barriers on deployment, and (5) develop a model to advance building sustainability. A sequential exploratory mixed methods research design was adopted for the study.

Firstly, regarding the progress in deployment, it was observed that the minimum total capacity of installed solar electricity generation was 6 MW, and the systems were either

purchased outright or procured through power purchase agreements. It was also found that most universities were engaging third-parties to design, install and service the systems. The systems were mounted on rooftops, on the ground (in open spaces), and on high poles with tracking devices. Secondly, the results highlighted that a total of 18 drivers engender the deployment of PVs in the sector. The top five drivers identified were: the reduction of the energy costs of the university, reduction of energy-related greenhouse gases, enhancement of university sustainability performance, contribution to the attainment of the sustainable development goals, and potential use for research opportunities for students and staff. Thirdly, based on the results, the conclusion was that a total of 12 barriers hamper deployment. Some of the barriers included the lack of financial resources, lack of green building targets, lack of clear policy direction, lack of government incentives, and lack of demand from government project financiers. Fourthly, the results of the partial least squares structural equation modeling analysis established that ‘direct benefits’ have a statistically significant positive influence on deployment, and ‘government-related barriers’ have a statistically significant negative influence on deployment. Lastly, based on all the findings, a Photovoltaics Deployment Acceleration Model was proposed, which provided insight into actions that should be taken to reinforce the drivers and eliminate the barriers to the use of PV energy in public universities.

The study contributed to theory by bridging the literature gap by providing empirical evidence on campus sustainability from an African perspective. The findings have practical implications as they offer insight into how university stakeholders can boost deployment. At the policy level, the study provided information on the contribution that public universities in South Africa have made to Sustainable Development Goal 7, and evidence that can help policy-makers to develop relevant policies and renewable energy-related development targets for the sector.

**Keywords:** Campus sustainability, Higher education institutions, Public universities, Solar photovoltaics, South Africa

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## ABBREVIATIONS

AfDB	African Development Bank
CS	Campus sustainability
CUT	Central University of Technology, Free State
DEA	Department of Environmental Affairs
DHET	Department of Higher Education and Training
DMRE	Department of Mineral Resources and Energy
GB	Green building
GBCSA	Green Building Council South Africa
GHG	Greenhouse gases
GCI	Green Campus Initiative
HESI	Higher Education Sustainability Initiative
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LEED	Leadership in Energy and Environmental Design
PV	Photovoltaic
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
RSA	The Republic of South Africa
SAPUs	South Africa Public Universities
SB	Sustainable building
SD	Sustainable development
SAG	South African Government
SSA	Statistics South Africa
UN	United Nations
UNEP	United Nations Environment Programme
USAF	Universities South Africa
ZCB	Zero Carbon Building
ZEB	Zero energy building

## DEFINITION OF TERMS

**Solar photovoltaics** is a system of converting solar radiation into electricity using photovoltaic effect (Sampaio and González, 2017, p. 591).

**Net zero carbon** refers to an energy-efficient building that produces on-site, or procures, enough carbon-free renewable energy to meet the energy consumption of building operations annually (Becqué *et al.*, 2019, p. 74).

**Net zero energy** refers to an energy efficient building that produces enough on-site or nearby renewable energy to meet the energy consumption of building operations annually on a net basis (meaning the building delivers at least the same amount of renewable energy to the grid as the grid uses over the course of a year) (Becqué *et al.*, 2019, p. 74).

**Renewable energy** is defined as energy generated from a source that is not depleted when used (Becqué *et al.*, 2019, p. 73).

**Sustainable building** is a healthy facility designed and built in a cradle-to-grave resource-efficient manner, using ecological principles, social equity, and life-cycle quality value, and which promotes a sense of sustainable community (Berardi, 2013, p. 53).

## CHAPTER 1: ORIENTATION OF RESEARCH

### 1.1. Introduction

Buildings are constructed to serve several important needs and over the years, their design and construction have been altered considerably for several reasons. For instance, the intended use of the buildings, availability of materials, land prices/conditions, and aesthetics have determined to a large extent how buildings are designed and constructed. More recently, the trend has been informed largely by the need to integrate the tenets espoused by ‘sustainable development’. Sustainable development (SD), according to *Our Common Future* is defined as the ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (World Commission on Environment and Development [WCED], 1987, p. 41). In line with this thinking, the construction of green buildings (GBs), sustainable buildings (SBs), zero carbon buildings (ZCBs), zero energy buildings (ZEBs), and many others, has become appealing, and their adoption is the current approach to advance the sustainability of buildings (Becqué *et al.*, 2019; Brandon *et al.*, 2011; Jungclaus *et al.*, 2018; NBI, 2018; Sow and Reap *et al.*, 2020).

Buildings cannot function effectively without energy, and a significant share of energy is consumed in buildings for cooling or heating space, ventilation, running equipment, lighting, and many more reasons (Beggs, 2009). It is estimated that, in 2010, buildings (i.e. the building operation and construction industry) accounted for 32% of global final energy consumption (including electricity-related), approximately 51% of global electricity consumption, and 19% (9.18 GtCO<sub>2</sub>eq) of all energy-related CO<sub>2</sub> emissions globally (Lucon *et al.*, 2014, p. 677). In 2019, it was estimated that 30% of global final energy consumption was used in building operations, representing 28% of global energy-related CO<sub>2</sub> emissions (10 GtCO<sub>2</sub>eq), and the building construction industry consumption was 5%

of global final energy consumption, representing 10% of global energy-related CO<sub>2</sub> emissions. In the same report, it was also presented that the electricity used in operating buildings constituted almost 55 per cent of global electricity consumption (United Nations Environment Programme [UNEP], 2020, p. 4). The activities that contribute to the above statistics if left unchecked, will only increase naturally. Therefore, it is necessary to reduce the use of energy in buildings as much as possible through effective building design and the use of energy-efficient systems and equipment, as well as generating renewable energy (RE) for use in buildings (Lucon *et al.*, 2014; Sow and Reap *et al.*, 2020; UNEP, 2020). As promoted in the Sustainable Development Goals (SDGs), efforts must be harnessed to advance access to energy globally (SDG 7) and to also specifically increase substantially the share of RE in the global energy mix by 2030 (SDG target 7.2) (United Nations [UN], 2014).

Therefore, the transition to renewable energies is a matter of necessity as one of the means to position the building sector on a path to sustainability. Among the RE technologies available, solar energy is the most diffused source and ‘solar photovoltaics’ (PVs) are the most widely used solutions for generating renewable electricity globally (Belussi *et al.*, 2019). Whilst PV deployment is engendered by several drivers, the non-adoption of the technology is caused by various barriers. For example, the quest for monetary gain, the need to reduce exposure to power cuts or rising electricity cost, concern for the environment, lack of connection to the national grid, incentives, reduction of CO<sub>2</sub> emission, image/reputation, and government policy and regulations can drive the diffusion of the technology (Awuzie and Emuze, 2017; Balcombe *et al.*, 2014; Bergek and Mignon, 2017; Briguglio and Formosa, 2017; Kurata *et al.*, 2018; Lee and Shepley, 2020; Walters, *et al.*, 2018b; Wong and Cronin, 2019). In contrast, some factors that inhibit deployment are high investment costs, long pay-back period, lack of support from top

management/stakeholders, lack of financial resources, lack of promotion, and unavailability of space (Ansari *et al.*, 2013; Ávila *et al.*, 2019; Garlet *et al.*, 2019; Mah *et al.*, 2018; Nandal *et al.*, 2019; Rosales-Asensio *et al.*, 2019; Shah *et al.*, 2019; Zhang *et al.*, 2012).

## **1.2. Research Background**

### **1.2.1. Campus Sustainability**

Globally, universities are on a quest to attain campus sustainability (CS) or sustainable university (SU) status by implementing numerous sustainable initiatives. The CS movement emerged in the early 1990s (Sharp, 2009) and it brought about a paradigm that required that, while seeking and exploring economically viable opportunities, universities should also ensure that their activities are culturally and socially just, and ecologically sound (Orr, 2002). It is widely acknowledged that universities have the ideal socio-cultural setting in which to be key change-drivers in leading society toward a sustainable future by establishing themselves as models and nurseries for SD (Alshuwaikhat *et al.*, 2016; Bekessy and Burgman, 2003; Colding and Barthel, 2017; Cortese, 2003; Dagiliūtė *et al.*, 2018; Leal Filho, Vargas, *et al.*, 2019; Lozano *et al.*, 2013). Similarly, Sharp (2009), a campus sustainability expert, suggested that the success of universities in reforming their practices is an important indicator of humankind's ability also to succeed in building a sustainable future across all sectors of society. Sharp (2009) added further that 'if universities would not change, then who can and who will . . .?' (p. 1). Therefore, it is evident that universities ought to be the forerunners in leading the way to a sustainable future.

Sustainable practices by universities, according to Cortese (2003), can be delineated into four major categories: teaching and learning, campus operations, research, and community

outreach. It is shown in the literature that several scholars have attempted to uncover how these practices unfold in higher education institutions (HEIs) in Africa. For instance, the study by Ulmer and Wydra (2019) involving 29 universities in 16 African countries confirmed that there appears to be an ongoing implementation of all four aspects of sustainability in the universities. A study about the perceptions of facility directors of the challenges to sustainable procurement (SP) in higher education institutions (HEIs) in Nigeria and South Africa (SA) showed that poor awareness of SP, absence of requisite skills for SP implementation, lack of commitment and support from organisational leadership, lack of funding, non-specification of requirements of SD based in contract documents, and lack of commitment from management were hampering progress (Awuzie and Emuze, 2016). Regarding the drivers of the implementation of SD in a university context, using a single case study approach, Awuzie and Emuze (2017) found nine drivers which were specific to the Central University of Technology, Free State (CUT). These drivers were related to cost, competitive advantage, regulation, and community engagement. In another study, the organisational factors that influence SD implementation in a South African university were highlighted by Awuzie and Abuzeinab (2019), and they emphasised the relevance of improving communication to gain optimal results. Concerning initiatives at the University of South Africa (UNISA), Mawonde and Togo (2019) reported that the university was undertaking several projects, including the installation of solar panels on Maluleka Building, which made the building fully reliant on solar electricity. However, the university is said to be challenged by financial limitations, and to be having difficulty involving students in sustainability projects because of the open distance education and learning status of the institution. Rhodes University, South Africa, was included in the CS discourse. According to Bulunga and Thondhlana (2018), their investigation of energy use behaviour among students in halls of residence led them to the

conclusion that energy use in student accommodation can be reduced when students are incentivised and are provided with energy-saving tips together with regular feedback.

Green movements, in the form of student-led organisations, are also emerging on various campuses. In SA, Green Campus Initiative (GCI) is a popular, student-led, action organisation launched in 2012, and it has been established in several universities in the country (DUT, 2020; SANews, 2012; UCT, 2020a).

### ***1.2.2. Deployment of Renewable Energy***

It is reported that solar energy is currently the fastest-growing RE in Africa and that SA and Egypt were the largest solar energy producers. The two countries collectively accounted for over three-quarters of installed solar capacity on the continent in 2020 (International Renewable Energy Agency [IRENA] and African Development Bank [AfDB], 2022, p. 41). The growth in the deployment of PVs in SA can be attributed to government policies and initiatives. The 2003 White Paper on Renewable Energy was a key policy document that laid the foundation for promoting RE technologies in SA (the Republic of South Africa [RSA], 2003). Furthermore, the Integrated Resource Plan (IRP), which was initially promulgated in 2010, and revised recently in 2019, is guiding energy infrastructure investments by setting a target of 31.2 GW of installed RE capacity by 2030 (Department of Mineral Resources and Energy [DMRE], 2019). The carbon tax, introduced in 2019, which is levied on the sum of the greenhouse gas (GHG) emitted, also accounts for the transition (SAG, 2019). Another important driver is the large-scale, grid-connected RE development programme called Renewable Energy Independent Power Producers Procurement Programme (REIPPPP), which was launched in 2011 to source electricity from renewable sources from the private sector (Statistics South Africa [SSA], 2019). Briefly, REIPPPP enables Independent Power Producers (IPPs) to submit bids during a

series of energy auctions to supply power through long-term power purchase agreements (PPAs). By March 2021, 5 078 MW of electricity generation capacity from hydro-power, biomass, landfill gas, concentrated solar power, photovoltaic, and wind have been contracted from 79 REIPPPP projects and connected to the grid (DMRE, 2021). By 2030, the Government of South Africa also hopes to de-commission 11 GW of coal-fired power stations (SSA, 2019, p. 155).

Apart from the South African Government's (SAG's) RE projects, organisations and individuals are also deploying various types of RE, especially PVs and wind power based on the maturity of the technology and the perception of financiers (Naicker and Thopil, 2019). PVs appear to be the dominant RE being deployed within the public university sector in SA, which comprises 26 universities. For instance, 153 kWp and 1 700 kWp PV systems have been installed by CUT and the University of Johannesburg (UJ), respectively (Geh *et al.*, 2022a; UJ, 2021). It was also reported that 1 280 rooftop PVs had been installed at the University of Free State (UFS), and approximately R 7 100 000 was invested in a PV project at the University of Witwatersrand (WITS) (UFS, 2018; WITS, 2017). At the University of Cape Town (UCT), the institution is using the Hasso Plattner School of Design Thinking to initiate the installation of PVs on all campuses (UCT, 2020b). It is also evident that Stellenbosch University (SU), Nelson Mandela University (NMU), and the University of South Africa (UNISA) have adopted the technology (Mawonde and Togo, 2019; NMU, 2018; SU, 2018; UNISA, 2018).

With particular reference to buildings, scholars have emphasised the importance of sourcing electricity from RE sources to enhance the sustainability of university buildings. For example, it was demonstrated generally that universities could improve their buildings' performance by supplying a substantial share of the energy that is required through the

installation of PVs (Fonseca *et al.*, 2018; Genta *et al.*, 2019; Kapseu *et al.*, 2012; Zhu *et al.*, 2018). Primarily, HEIs should be concerned about the use of PVs for two key reasons, as revealed in the literature. Firstly, the non-existence of sustainable buildings on campuses accounts for the low performance of HEIs on the sustainability scale (Ávila *et al.*, 2019), but the adoption of PVs can add value to the built assets and enhance sustainability. Secondly, given the effort by governments to promote the use of PVs in society and the ideal socio-cultural setting which is regarded as key change drivers (Colding and Barthel, 2017; Cortese, 2003), HEIs have a moral responsibility to establish themselves as exemplars for society to emulate for information and good practice. Therefore, by installing PVs, institutions will supplement the government's efforts for countries to reach acceptable RE deployment targets, and will further cement their role as true progenitors of knowledge and models that the public can observe to learn sustainable living practices.

### **1.3. Problem Formulation and Statement**

The installation of PVs in HEIs is a sure means of generating electricity sustainably. PVs are green building technologies (GBTs) and their deployment in the built environment is critical to advancing the sustainability of buildings, both existing and new constructions (Darko *et al.*, 2018a). However, deployment is not at the desired level yet at public universities in SA to contribute significantly to the transition to sustainable living. Although greenness can vary across universities (Zhao and Zou, 2017), generally, the uptake of PVs in South African Public Universities (SAPUs) appears to remain somewhat marginal and far below expectation. The low patronage is evident on the campuses considering: (1) there are still a substantial number of old buildings with roof spaces and façades that could be retro-fitted and integrated with PVs, (2) the non-installation of PVs in buildings that were constructed recently, and (3) open spaces that could be explored for the installation of PVs have not been utilised. Therefore, these occurrences suggest that,

albeit the motivation for implementing existing projects, universities might be encountering difficulties in installing PV systems. Therefore, the question arises that: if universities attest through research that PVs are beneficial, why are they not filling their campuses with solar panels? Or why are they not practising what they preach? Thus, there is a dichotomy which calls for an investigation.

Even though a significant number of scholars have explored PV deployment and investigated the drivers of, and barriers to, PV adoption, it is evident from the literature that the studies were targeted mostly at examining adoption at an individual, household and community/national levels. There seem to be few studies in which the phenomenon was explored from organisational perspectives (Kurata *et al.*, 2018; Mah *et al.*, 2018). More precisely, in SA, Awuzie and Emuze (2017) suggested that PVs were installed at CUT because they are a cheaper, alternative source of energy, and Mawonde and Togo (2019) showed that the installation of PVs at UNISA was a means of attaining the SDG targets. Other scholars have mentioned other sustainability subjects (Awuzie and Emuze, 2016; Awuzie and Abuzeinab, 2019; Bulunga and Thondhlana, 2018; Eromobor, 2017) but it appears that no study has provided information on PV deployment holistically in the South African public university sector. For instance, questions regarding the total installed PV capacity in the sector, the types of PVs being installed, the dominant mode of acquisition (i.e., outright purchase, power purchase agreement, lease etc.), whether universities design, install and service the PV systems themselves or contract third-parties to provide the services have not been answered. Therefore, little is known from empirical evidence about the progress that has been made in terms of deployment in SAPUs, the factors that engender/hinder deployment, and how deployment can be advanced. For these and other reasons, a comprehensive and in-depth analysis of PV deployment in SAPUs was worthwhile and a recognisable necessity. This concurs, in part, with the recommendation

by Raimi (2020) to investigate the issues that affect sustainability practices in HEIs in future studies.

Therefore, the problem statement of this study was that there are driving forces for the installation of PVs in SAPUs but deployment is progressing at a slow pace because of several challenges faced by institutions. The problem is exacerbated further by the lack of systematic investigation of the situation and the absence of a context-specific model that can address the peculiar barriers and strengthens the drivers to advance the sustainability of the buildings.

#### **1.4. Research Questions**

Ensuing from the background information and the research problem identified above, the primary research question was: how could the deployment of PVs be enhanced within SAPUs to advance the sustainability of buildings on campuses, through the elimination of barriers and strengthening of the drivers of deployment?

Accordingly, this study was guided by the following secondary research questions, within the context of PV deployment in public universities in South Africa:

1. What progress has been made by universities concerning the deployment of PVs on campuses?
2. What are the factors (i.e. drivers) that engender the deployment of PVs?
3. What are the factors (i.e. barriers) that hinder the deployment of PVs?
4. How significantly do the drivers and barriers influence the deployment of PVs?
5. What model can advance building sustainability through the strengthening of the drivers and ameliorating the barriers to solar electricity generation?

### **1.5. Research Aim and Objectives**

The study aimed to develop a model to advance the sustainability of buildings through the deployment of PVs at public universities in South Africa.

Thus, to answer the research questions and realise the aim of the study, the research objectives were:

1. To ascertain the progress made in installing PVs at universities;
2. To identify and evaluate the drivers for the deployment of PVs at universities;
3. To identify and evaluate the barriers to the deployment of PVs at universities;
4. To evaluate the influence of the drivers and barriers on the deployment of PVs;
5. To develop a model to advance building sustainability, through the reinforcement of the drivers and the elimination of the barriers to solar electricity generation.

### **1.6. Research Scope**

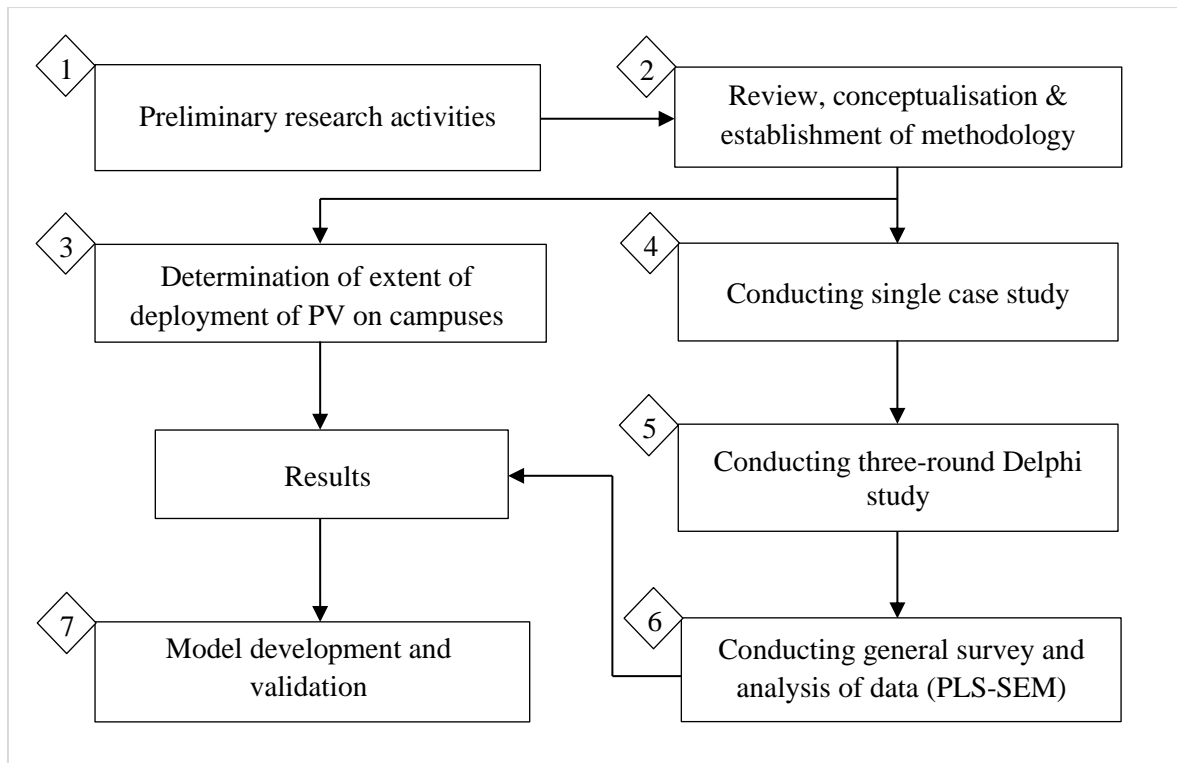
The deployment of PVs within the public university sector in South Africa was explored in the study. The sector has 26 public universities, which are located across all the nine provinces in the country (DHET, 2020). The focus of the study was on PVs installed on-site only, that is, on university properties/facilities, and directly used by the universities for operational activities on campus. Both non-adopters and adopters of PVs were included in the study i.e. universities that have installed PV systems and those that are yet to install them. This approach was similar to previous studies in which adopters and non-adopters were investigated to obtain a holistic perspective on the determinants for adoption/non-adoption (Kurata *et al.*, 2018; Sigrin *et al.*, 2015; Vasseur and Kemp, 2015). The government of South Africa has been proactive in expanding RE deployment in the country, especially through the REIPPPP. Therefore, the public university in South Africa was deemed worthy of the investigation so that measures can be identified and

implemented to advance the deployment of PV in the sector to augment the government's effort of increasing the share of RE in the energy mix.

### **1.7. Overview of Research Processes**

Research is a way of answering questions objectively, and the legitimacy of research findings depends highly upon the soundness of the research procedures adopted by a researcher. As such, research processes attested to in the literature were followed (Adabre, 2021; Anderhofstadt and Spinler, 2019; Chun and Nam, 2019; Darko et al., 2018b; Osei-Kyei, 2017). The research onion espoused by Saunders et al. (2019) was used to define the philosophical stance, methodological choice, and research strategies of the study. The study was guided by a pragmatist philosophical stance in addressing the various facets of the research. To determine the methodological choice, a sequential, exploratory, mixed-methods research design was adopted, and the chosen research strategies were case study and survey (Saunders *et al.*, 2019). Since this was a doctoral research project, which was limited by time, the research was cross-sectional, and only provided a view of the public university sector at a particular time.

Overall, a seven-step approach was adopted to carry out the research as illustrated in Figure 1.1. The study commenced with an initial literature review to establish the study background, identify the research problem, and define the aim and objectives. This phase also assisted in defining the scope of the study and identifying a possible research design and strategies which could be adopted. During phase two, a comprehensive review of the literature was carried out to analyse and synthesise the literature on PV deployment, campus sustainability, and green/sustainable buildings. Reference was made to journal articles, books, reports, websites, master's dissertations, and doctoral theses.



**Figure 1.1: Overview of the research process**

*Source: Researcher's construct*

In phase three, a survey was conducted to identify the adopters and non-adopters of PVs, as well as the progress institutions have made in deploying the technology on campuses. Phase three was executed concurrently with the subsequent phases. During phase four, a case study was conducted at CUT. By interviewing seven key experts at the selected institution, including site observations, the challenges that were believed to be hindering the upscaling of technology at the institution were identified, and the current installed PV capacity was also determined. Thereafter, during phase five, a three-round Delphi survey was conducted. There were 18 panellists from 11 public universities who participated in this study. The Delphi study was useful in identifying the drivers and barriers that were relevant to the public university sector in SA. The results from the Delphi study were used to design the questionnaire for the general survey in phase six, and this generated a larger dataset which was used to carry out partial least squares structural equation modeling

(PLS-SEM). In the final phase, the model, which can advance the sustainability of buildings through the use of PV systems, was developed and validated.

### **1.8. Contributions of the Study**

Higher education institutions have evolved significantly over the past decades, and a growing number of institutions have made considerable progress in pursuing sustainability through teaching/learning, research, campus operations, and community outreach. Unfortunately, it has been argued that research on sustainability in HEIs has been focused largely on universities that are located outside Africa (Ulmer and Wydra, 2019). Thus, in a bid to contribute to theory by bridging the gap in the literature, by focusing on public universities in SA, this study contributes to research on CS and provides insight into how campus sustainability can be achieved partly by developing a PV Deployment Acceleration Model to advance the sustainability of buildings.

A deeper understanding of the drivers and barriers influencing the sector can lead to radical progress in the uptake and upscaling of PVs in SAPUs. Therefore, the findings of this study have practical implications. Specifically, the factors that drive and hinder PV deployment have been identified in the study and guidelines have been provided to university stakeholders on how to reinforce the drivers to deliver more results and eliminate the barriers to accelerating solar electricity generation. Through the application of the recommended actions, institutions will increase their RE portfolio and, considering the number of buildings on university campuses, deployment will contribute significantly to improving the sustainability of the buildings in the area of green electricity generation.

As part of the SDGs, the purpose of Goal 7 is to advance access to energy globally, and the aim of Target 7.2 is to increase substantially the share of RE in the global energy mix by 2030 (United Nations [UN], 2014). Thus, at the policy level, the study provides insight into

the contribution that SAPUs have made to SDG 7, and the path that should be taken to ensure that universities improve on their present achievements. Since buildings and construction-related activities have heavyweight implications for climate action (GABC, 2021), the findings of the study also provide important empirical evidence that can help policy-makers in developing relevant policies and RE-related development targets for the public university sector.

### 1.9. Structure of the Thesis

The detailed report of the research project presented in this thesis has been organised into seven chapters as follows:

- **Chapter 1 (Orientation of the Research):** The study is introduced by presenting the background to the study, as well as stating the research problem, research questions, and the aim and objectives of the study. The scope of the study and the structure of the thesis is also presented.
- **Chapter 2 (Literature Review):** A comprehensive literature review is presented in this chapter. The topics covered include CS, GB, PV technology, drivers of, and barriers to, the deployment of PV technology.
- **Chapter 3 (Theoretical and Conceptual Model):** A key element of doctoral research is to establish a solid theoretical grounding, and questions about this subject matter are answered in this chapter. In addition, the conceptual framework that was used to guide the study is discussed.
- **Chapter 4 (Research Methodology):** In this chapter, an overview of the research processes is provided by expounding on how the data were collected and analysed.
- **Chapter 5 (Data Analysis and Results):** Part 1 of 2 of the data analysis and results is presented in this chapter. Specifically, information on the progress that

universities have made in terms of deploying PVs is given. Also, the factors that influence deployment (i.e. drivers and barriers), specifically within the public university sector, are presented.

- **Chapter 6 (Model Development and Validation):** Part 2 of the data analysis and results is presented in this chapter. Information about the modelling of the influence of the drivers and barriers affecting PV deployment are outlined in this chapter, including the development and validation of the PV Deployment Acceleration Model.
- **Chapter 7 (Conclusions and Recommendations):** In the concluding chapter, the findings of the research and the contributions to the field of study are summarised. Furthermore, the limitations of the study are highlighted, and considerations for future research are given.

### **1.10. Chapter Summary**

This chapter was the introductory segment of the report and provided an overview of the research. The chapter commenced by providing the background to the research. Broadly, the research was about building sustainability but was focused specifically on investigating the deployment of PVs in public universities in SA. The research problem and the five research questions that were answered during the study were outlined in the chapter. The aim and objectives of the study, an outline of the research processes, and the scope were covered in this chapter. Finally, the significance of the study and an overview of the overall structure of the thesis (consisting of seven chapters) was presented.

## CHAPTER 2: LITERATURE REVIEW

### 2.1. Introduction

In the previous chapter, an overview of the research was provided, and this chapter contains a literature review. Specifically, campus sustainability, sustainability in the built environment, renewable energy, and the factors (i.e. drivers and barriers) that influence the adoption of PVs are discussed in this chapter. An overview of the public university sector in South Africa is also provided in this chapter.

### 2.2. Literature Review Background

Research requires engagement with existing literature at every stage of the process. The engagement with the literature is termed a ‘literature review’, which is a critical analysis of past research presented as a specific piece of argumentative writing that acts to create space for research (O’leary, 2010). A literature review is what provides the context and theoretical framework for research, and enables research findings to be placed within the wider body of knowledge (Saunders *et al.*, 2019). Thus, the review of the literature in this study helped to become acquainted with the available body of knowledge, establish the theoretical roots of the study, develop the research methodology, identify the variables, and ultimately consolidate the research findings with the existing body of knowledge.

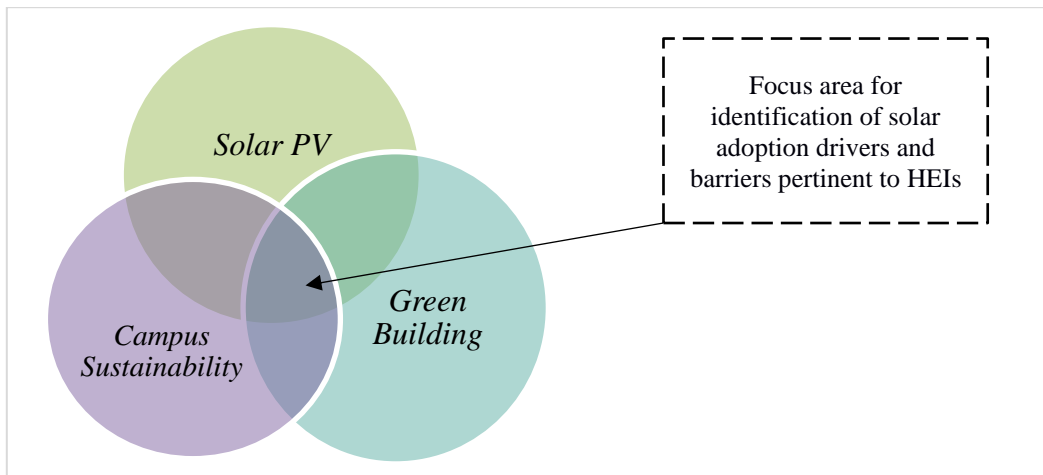
To generate an initial list of drivers and barriers, an extensive review of the literature was carried out. Popular search engines/databases, such as ScienceDirect, Emerald, Taylor and Francis, and Google Scholar were used to retrieve appropriate literature. While the major databases were used to identify published journal papers, ProQuest was used to help to find relevant theses/dissertations. The keywords used for the search were: solar photovoltaic, renewable energy, adoption, deployment, drivers, enablers, barriers, challenges, hindrances, benefits, campus sustainability, green campus, sustainable development, green

building, and sustainable building. In addition to running searches in the databases, the reference sections of the articles retrieved initially were used to identify additional articles for inclusion in the review. This was done because it helped to identify additional articles that might not have been retrieved using the search engines/databases.

Insight from the literature revealed a scarcity of research undertaken to examine specifically the drivers and barriers to the deployment of PVs in universities. However, there were studies conducted with different research objectives, which implied possible factors which could be driving or inhibiting the adoption of the technology in universities. Firstly, the factors that influence PV adoption in households or communities have been examined in some studies, in which important generic factors were highlighted which are common to all groups of adopters (Schelly and Letzelter, 2020; Walters *et al.*, 2018a). Secondly, literature about the operationalisation of SD or CS in universities also offers insights into the subject matter (Awuzie and Emuze, 2017). Thirdly, since PV is a green building technology (GBT) which is applied to achieve energy-related sustainability targets in GBs, the drivers and barriers related to PV adoption are also identified in the literature (Darko *et al.*, 2017a). For the above reasons, the approach to reviewing the literature for this study was to collate the information about the factors from all three of the perspectives above to produce a sufficient list of possible drivers and barriers which could then be verified through expert review in a Delphi survey. The justification for taking this stance was based on literature about the adoption of PVs within the HEI sector being scarce, and this approach was essential to elicit enough information for further investigation in the study.

The review of the literature elicited a total of 55 drivers and 67 barriers, which are presented in Tables 2.2 and 2.3, respectively. Through the application of the conceptual framework

that is presented in Figure 3.7, 22 drivers and 23 barriers were selected as being relevant factors for examination within the university sector. The drivers are shown in Figure 3.8, and the barriers are in Figure 3.9. These drivers and barriers were re-worded to make them applicable in the university context, and they were used to design the questionnaire for the Delphi surveys.



**Figure 2.1: Intersecting areas of literature**

*Source: Researcher's construct*

The breakdown of the sub-sections in relation to the research objectives is presented in Table 2.1. Sections 2.3, 2.4, and 2.6 contain information on the factors which were identified from the literature and used to design the questionnaires for the various phases of the research. This breakdown also helped in discussing the findings of the study. Sections 2.5 and 2.7 contain the information needed to conduct the survey in Phase Three to achieve Objective 1.

**Table 2.1: Literature review breakdown relative to objectives**

Section	Research Objectives				
	1	2	3	4	5
2.3 <sup>a</sup>		●	●	●	●
2.4 <sup>a</sup>		●	●	●	●
2.5 <sup>b</sup>	●				
2.6 <sup>a</sup>	●	●	●	●	●
2.7 <sup>b</sup>	●				

<sup>a</sup> The drivers and barriers identified for the design of the questionnaire in Phase 5, and the discussion of the findings

<sup>b</sup> Information provided which will be included in the survey in Phase 3

### **2.3. Campus Sustainability in Higher Education Institutions**

#### **2.3.1. Overview of Campus Sustainability Operationalisation**

The operationalisation of campus sustainability, through teaching and learning, research, campus operations and community outreach, is evident in both developed and developing countries (Alshuwaikhat *et al.*, 2016; Leal Filho, Vargas, *et al.*, 2019; Ulmer and Wydra, 2019). The success in expanding CS coverage can be attributed partly to its promotion at international and national levels. For instance, international university associations/networks and student-driven movements have contributed greatly to championing the global CS agenda. The Higher Education Sustainability Initiative (HESI), which is headed by the UN, has over 300 university signatories around the globe (HESI, 2014; Moon *et al.*, 2018). Green movements, in the form of student-led organisations, are also emerging on various campuses. In SA, Green Campus Initiative (GCI) is a popular student-led action organisation launched in 2012, and it has been established in several SAUs (DUT, 2020; SANews, 2012; UCT, 2020a). Additionally, many universities around the globe have gone a step further by utilising tools for campus sustainability assessments (CSAs) as a means of gauging and communicating their sustainability performance (Alshuwaikhat *et al.*, 2016; Sassen and Azizi, 2018; Sonetti *et al.*, 2016).

Different issues concerning CS have also been addressed by scholars. To cite a few examples, the views of stakeholders have been sought on CS matters, including students (Conner *et al.*, 2018; Dagiliūtė *et al.*, 2018; Ifegbesan *et al.*, 2017) and staff/facility managers (Awuzie and Emuze, 2016). The relevance of ecological fairs has been noted (Brandli *et al.*, 2019), the carbon footprint of a university was calculated (Syafudin *et al.*, 2020), and student-led actions on campuses have also been highlighted (Murray, 2018). The importance of green/sustainability offices and research centres has also been emphasised in the literature (Adom̂ent *et al.*, 2019; Burger and Sherry, 2017; Leal Filho, Will, *et al.*, 2019; Soini *et al.*, 2018). Leal Filho *et al.* (2019) provided an exposé on community projects, which are led by universities, in both developed and developing countries. In SA, Eromobor (2017) evaluated the performance of three South African universities (i.e. indoor environmental quality, energy efficiency, and water use efficiency), and the findings led to the recommendation that universities should adopt PVs as a means of reducing reliance on electricity supplied from municipalities (Eromobor, 2017; Eromobor *et al.*, 2021).

Furthermore, Alshuwaikhat *et al.* (2016) highlighted sustainability practices in Saudi Arabian public universities. In Romania, an overview of campus greening initiatives at universities was provided by Sima *et al.* (2019), and Lee *et al.* (2016) provided information on how SD was integrated into school curricula in Hong Kong. It has been shown that, in addition to taking sustainability courses, students are involved in sustainability research projects on and off campus (Ceulemans and Severijns, 2019). Other case studies have been presented from universities in Belgium and Chile (Bruckner *et al.*, 2014), China (Zhao and Zou, 2015), Italy (Paletta and Bonoli, 2019), Jordan (Qdais *et al.*, 2019), Brazil, Portugal, Spain (Bizerril *et al.*, 2018; Frandoloso and Rebelatto, 2019), and Australia (Khoshbakht *et al.*, 2018).

Recently, tools to enhance the implementation of the SDGs in universities (Leal Filho *et al.*, 2021), and to assess sustainability-related issues at institutions have been developed (Adenle *et al.*, 2021; Hernandez-Diaz *et al.*, 2021). Research has also been focused on landscapes (Gomez and Derr, 2021), university ranking (Atici *et al.*, 2021), and lessons in sustainable campus operations (Amaral *et al.*, 2021). How to eliminate the carbon footprint of HEIs has also been included in the discourse (Kourgiouzou *et al.*, 2021; Li *et al.*, 2021; Rodgers, 2021). Rodgers (2021) particularly recommended investing in energy efficiency to reduce energy demand and using the savings from energy efficiency to invest in RE. Others have also provided information that can help to report practices better (Aras *et al.*, 2022), and how the implementation of smart practice at universities contributes to the SDGs (Dalla Gasperina *et al.*, 2022). Evidence of the integration of sustainability at universities in Colombia has also been given (Hernández-Diaz *et al.*, 2021).

There are many other publications in international journals, so the list of CS studies continues. Therefore, it is evident that interest in CS is increasing, resulting in much research being carried out on the subject. As such, it is equally important for scholars in Africa to give attention to the subject and produce high-quality research that can inform and enhance implementation on the continent.

With respect to campus operations, sustainable initiatives are reported to include GB construction and operations, RE development, energy conservation programmes, recycling, waste reduction, double-sided copying, green cleaning, alternative fuels, green office/laboratory practices, environmental purchasing, organic landscaping, public bus transit systems, bicycle/pedestrian-friendly systems on campus, and many more (Alshuwaikhat *et al.*, 2016; Bulunga and Thondhlana, 2018; Cheung *et al.*, 2018; Kahler, 2003; Sima *et al.*, 2019). With particular reference to the built environment, according to

Ávila *et al.* (2017), the limited availability of sustainable buildings, where the principles of sustainability are demonstrated, is a significant barrier to SD implementation and innovation at universities. Hopkins (2016), for instance, suggested that institutions should adopt GBs. It has been said that universities are like small towns (Dave *et al.*, 2014), having several buildings which need electricity to operate (Bekker *et al.*, 2010). Therefore, the construction, refurbishment, and operation of buildings in a sustainable manner is a clear necessity that will not only transform the vast portfolio of university buildings but will also provide the needed environment in which CS practices can be demonstrated, as observed by Ávila *et al.* (2017). In addition, because buildings and energy-use-related activities in buildings are responsible for a substantial proportion of GHG emissions (Lucon *et al.*, 2014; UNEP, 2020), measures must be implemented to curb emissions on campuses. One way in which this can be done is to have on-site PV systems that generate electricity to supply power to the buildings on campus. This is not new because it has been demonstrated generally that universities could improve the sustainability of their buildings by supplying a substantial share of the energy that is required by installing PV systems (Fonseca *et al.*, 2018; Genta *et al.*, 2019; Kapseu *et al.*, 2012; Zhu *et al.*, 2018). According to the definition provided by Ávila *et al.* (2017, p. 1269), PV adoption is part of operational innovation, which ‘refers to the introduction of tools which might enhance and maximize the operations of the institution’.

### ***2.3.2. Drivers of Campus Sustainability: Insight into PV Adoption***

Sustainable development is, and will continue to be, a matter of substantial international interest and concern (Leal Filho *et al.*, 2015). Even more so, the operationalisation of SD within HEIs will become even more important because of the unique ability that HEIs have to be models of sustainable living (Shriberg, 2003). To express it more strongly, a CS expert submitted that ‘higher education institutions bear a profound, moral responsibility

to increase the awareness, knowledge, skills, and values needed to create a just and sustainable future' (Cortese, 2003, p. 17). Therefore, it is not surprising that this subject has drawn the attention of scholars. For instance, the impact of HEIs on sustainable development, and how to establish sustainable campuses has been well documented, and there have also been attempts to acknowledge what stakeholders in HEIs are initiating (Adom̂ent *et al.*, 2019; Findler *et al.*, 2019; Murray, 2018).

In SA, the drivers of implementing SD in a university have been explored by Awuzie and Emuze (2017) who found nine drivers which were specific to CUT, by adopting a qualitative case-study approach. Primarily, it was found that the institution was driven to make a financial gain, comply with policies and declarations, enhance community engagement, and gain a competitive advantage. One of the drivers identified as a motive in the category of financially-related drivers was the 'quest for cheaper, alternative sources of energy (renewable)' (Awuzie and Emuze, 2017, p. 1183).

The constraints that influence the uptake of GBs at the University of Waterloo (UW) were explored by Richardson and Lynes (2007). This was achieved by analysing the building process at the university. Among other things, Richardson and Lynes (2007) found a lack of green building construction at UW. However, it was acknowledged by the informants that the construction of GB at the university would garner benefits. For example, it would provide an opportunity for the purposes of demonstration and education, elevate the value of buildings, reduce operation and maintenance costs over the life-cycle of the buildings, enhance the university's image, and support publicity to attract staff and students. The existence of several groups advocating GB on campus was also reported in the study, including the Greening Waterloo (WATgreen) Advisory Committee, which comprises staff, students and faculty responsible for greening on campus, and four student groups.

A study by Li *et al.* (2013) contained an extensive list of drivers and barriers influencing the uptake of GB in Australian HEIs. A total of 14 drivers appear to address the solar PV adoption discourse and are therefore incorporated in this study. Some of these drivers are: fulfilment of the aim and core values of institutions, enhancing reputation and publicity, impact on the local community, providing technical study opportunities for students and researchers, reducing running costs, and attracting government funding.

Insight from HEIs in the USA was provided by Shriberg (2003), who was able to demonstrate that institutions striving to improve their external and internal image are likely to be open to sustainability initiatives. Furthermore, the model that was developed predicts that HEI leadership in sustainability is most likely to come from collaborative, ethical institutions with transformational leaders and commitment to social responsibility. Also, the importance of students, staff, and even alumni in promoting a drive for sustainability within HEIs through activism was acknowledged. It was noted further that initiatives are most successful when driven by diverse stakeholders and supported by top management.

### ***2.3.3. Barriers to Campus Sustainability: Insight into PV Adoption***

Universities on a quest to pursue a sustainable path are certain to encounter both internal and external hurdles (Brandli *et al.*, 2015). A review of the literature shows that scholars, such as Ávila *et al.* (2017, 2019), Emuze and Awuzie (2016), Kasai and Jabbour (2014), Richardson and Lynes (2007), and Shriberg (2003), have undertaken studies related to SD, CS, innovation, and green building that are indicative and give insight into HEI related barriers. Thus, these studies were reviewed to provide insight into possible factors that could be examined and identified as barriers that impede the diffusion of PV technology among SAPUs.

It has been submitted that universities in developed countries are leading in promoting sustainability, while those in developing countries are laggards (Ávila *et al.*, 2019). Ávila *et al.* (2017) explored the barriers to adopting initiatives in innovation and sustainability at 172 universities. Lack of adequate support from the administrative personnel was found to be the main barrier according to the findings. Other factors identified were lack of green building policies, lack of interest/motivation, lack or inefficiency of local champions (e.g. sustainability offices, and specific working groups), lack or inadequate planning and focus, and resistance to change. The barriers identified by Ávila *et al.* (2017) were corroborated further by Ávila *et al.* (2019) when a comparative analysis was undertaken from a continental perspective, which included North and South America, Africa, Asia, Europe, and Oceania.

The exposé by Richardson and Lynes (2007) also provided insight into factors that inhibit the implementation of GB practices on university campuses. The barriers to, and motivations for, the construction of green buildings at the University of Waterloo (UW) specifically were explored in the study. Richardson and Lynes (2007) identified the key barriers to be the lack of incentives which results in low motivation, lack of support and commitment from stakeholders with decision-making power, lack of quantifiable green building targets, and lack of commitment towards sustainability reporting. Similarly, through an investigation of the main barriers to the adoption of green buildings at two traditional Colleges of Engineering in the State of Sao Paulo, Kasai and Jabbour (2014) found that high capital cost, lack of financial incentive, resistance to change, and lack of dialogue and collaboration were negatively correlated to the adoption of green buildings by the universities.

In a study by Shriberg (2003), the organisational factors were identified that determine why and how some HEIs are emerging as sustainability leaders while most campuses lag in the United States of America (USA). Colleges and universities which have signed the Talloires Declaration on Sustainability were surveyed in the study, the environmental efforts at two public Mid-Western universities were compared, and an assessment of sustainability initiatives at the University of Michigan was made. The findings of the study indicated that, among other factors, lack of financial resources, resistance to change, lack of support from top management, inter-personal conflicts, political battles and lack of co-ordination were key prevailing factors in universities that were lagging. Commenting on the lack of commitment, Shriberg (2003, p. 232) stated that ‘environmental issues are not on the “radar screen” of most decision-makers’.

Regarding sustainable procurement (SP) and delivery of built assets within public and private HEIs in Nigeria and SA, Emuze and Awuzie (2016) have observed that there was a lack of SP practices. A qualitative research design and interviews with staff from estate/maintenance departments in the institutions were adopted in the study to arrive at the conclusions. It was found that the lack of SP practices could be attributed to a low level of awareness and understanding, lack of commitment from organisational leadership, lack of experts to champion SP, and lack of funding. It was also found that ‘there was no incentive for bringing in sustainability-related innovation into the delivery process but rather there was an incentive for reduced delivery cost’ (Awuzie and Emuze, 2016, p. 1556). Similarly, other scholars have found that the long-term economic benefits of green buildings, as opposed to short-term benefits, were not appreciated by end-users (Wu *et al.*, 2019; Yas and Jaafer, 2020).

Recently, insight was provided from Chile. It was found that, although public universities in Chile are constructing GBs and certifying them using Leadership in Energy and Environmental Design (LEED) certification, a major hindrance to progress was the unavailability of budget to do more (Mac-lean *et al.*, 2022).

## **2.4. Sustainability in the Built Environment**

### **2.4.1. Green Buildings**

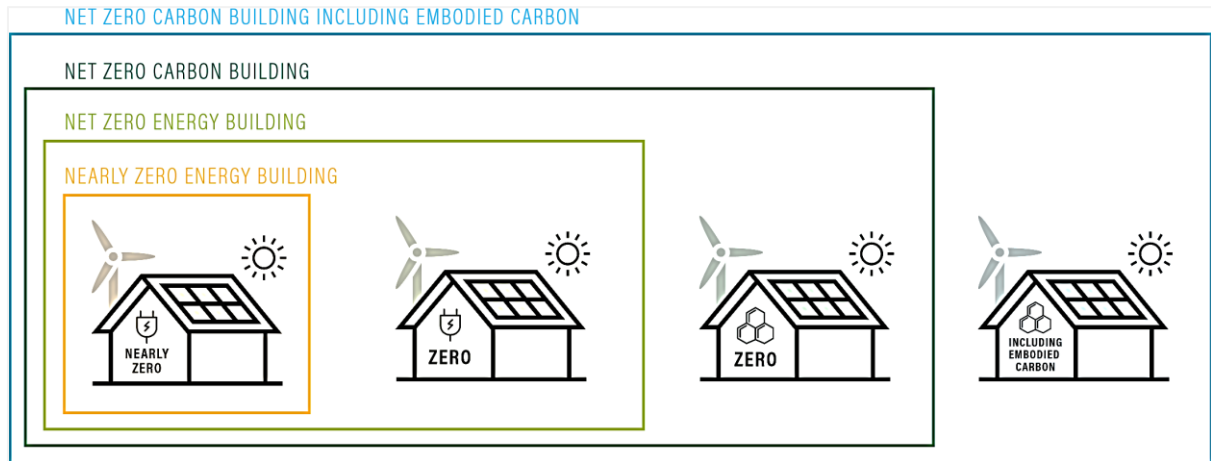
The inter-play between the environment and buildings has become clearer with time, and the standards for sustainability operationalisation in the built environment continue to evolve for the better. Institutions/organisations and scholars continue to investigate and suggest ways to improve practices, and examples have also been shared so that others can glean lessons from them (Akadiri *et al.*, 2012; Jungclaus *et al.*, 2018; Krstić-Furundžić *et al.*, 2020; Mushi *et al.*, 2022; Oyetunji *et al.*, 2022; Scofield, 2002; UNEP, 2020, 2021). It can be argued that because of the significant amount of resources consumed in the construction and operation of buildings, the building sector holds enormous potential to make the transition to the future of low-carbon energy possible or derail it (GABC, 2021; Lucon *et al.*, 2014; UNEP, 2021). With the above understanding of the drivers and others, GBs, which are also referred to as SBs, have emerged to bring about the needed harmony between people and the natural and built environment (Allen and Iano, 2014). Green building is defined by the World Green Building Council (WorldGBC) as ‘a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment’ (WorldGBC, n.d.). Other definitions include:

Sustainable buildings – in both their operation and construction – must use less energy, consume fewer resources, cause less pollution of the air, water, and soil, reduce waste, discourage wasteful land development practices, contribute to the protection of the

natural environment and ecosystem, provide healthier interiors for building occupants, and minimize adverse social impacts. (Allen and Iano, 2014, p. 5).

Green buildings have many benefits. They are known to have huge environmental benefits, as well as economic, and social benefits (Dwaikat and Ali, 2018; He, 2022; Zhao *et al.*, 2022). Green building standards are achieved through the incorporation of GBTs. GBTs are diverse and they chiefly address sustainability in areas of energy, water, use of building materials, occupational health/well-being, bio-diversity, and many more (Masia *et al.*, 2020). These sustainability goals can be achieved through measures such as the application of energy-efficient lighting systems, utilising natural ventilation and lighting, choosing appropriate air-conditioning systems, optimising building orientation and configuration, installation of water-efficient appliances and fixtures, using environmentally friendly and recycled materials, reducing waste, water harvesting, using RE, and many more (Darko *et al.*, 2018a; Koebel *et al.*, 2015; Masia *et al.*, 2020; Patil *et al.*, 2022; Yas and Jaafer, 2020).

In pursuit of the tenets espoused in GB, new concepts have emerged, with the objective of further enhancing the sustainability performance of buildings. To accelerate the decarbonisation of the built environment, the construction of zero energy buildings (ZEBs) and zero carbon buildings (ZCBs) has been suggested as the best way to proceed (Ahmed *et al.*, 2022; Becqué *et al.*, 2019; Belussi *et al.*, 2019; Wilberforce *et al.*, 2021). As shown in Figure 2.2, the different concepts all refer to buildings that achieve, or nearly achieve, a balance between energy demand and RE supply or the carbon emissions associated with energy demand and provision. The RE can be on- or off-site and, under circumstances where it is impossible or impractical to have 100% RE supply, carbon offset options can be employed as the last option partly to achieve net zero emission targets for the buildings (e.g. invest in energy efficiency or carbon-free RE elsewhere) (Becqué *et al.*, 2019).



**Figure 2.2: Zero energy/carbon building concepts**

*Source:* (Becqué *et al.*, 2019, p. 10)

Scholars are increasingly investigating and producing findings that will enhance the adoption of ZEBs/ZCBs. Insight has been provided from Ghana (Ohene *et al.*, 2022), Germany (Galvin, 2022), Sweden (Niskanen and Rohrer, 2022), and other European countries (Attia *et al.*, 2022; D’Agostino *et al.*, 2021). Others have developed frameworks or case studies which can be used to assist implementation (Lin and Chen, 2022; Wang, Han, *et al.*, 2021; Wang, Liu, *et al.*, 2021). The certification of the above types of buildings have also been included in the literature (Afroz *et al.*, 2020; Alhamlawi *et al.*, 2021; Cheng and Venkataraman, 2016; Zhang *et al.*, 2019).

Briefly, the primary objective of GBs/SBs/ZEBs/ZCBs is for new buildings to be constructed and old buildings to be retro-fitted to function better and provide the unique potential for occupants to be exposed to building features that use resources responsibly. Whether GBs/SBs/ZEBs/ZCBs are obligatory or schemes that individuals or organisations signed up for voluntarily, it cannot be ruled out that they produce a positive drive for innovation in the built environment which accelerates decarbonisation of the building stock.

It is a positive step to construct GBs and even better to acquire GB certifications, especially when public buildings are involved as they will provide examples for society to observe. Insight based on the current investigation indicated that only a few SAPUs have certified their buildings. For example, the Nelson Mandela Metropolitan University has GB certification for the Business School building from the Green Building Council of South Africa (GBCSA) (i.e. Green Star SA – Public and Education Building As-Built v1 (GBCSA, 2017a; NMMU, 2014)). It was also found that UCT had acquired Green StarSA – Public and Education Building v1 Design certification for a proposed lecture hall in 2015 (GBCSA, 2017b). Recently, it was reported that the lecture hall was completed in 2017, and three other buildings of the university have been certified in a similar manner. What is not clear, at the moment, is whether the buildings that were completed now have ‘As-Built’ certifications or only the ‘Design’ certifications (Krige, 2021).

#### ***2.4.2. Drivers of Green Building Adoption: Insight into PV Adoption***

In line with the developments in construction, scholarly discussions on the subject of GBs are increasing and publications on the subject have increased recently. In a sciento-metric review of global research about green building, it was found that aspects of the environmental sustainability of GB have been the central focus, while social and economic dimensions were investigated and reported less (Darko *et al.*, 2019).

Insights from the literature suggest that numerous factors have been identified and deemed to be relevant to policy and practice, both in developed and developing countries. In a review undertaken by Darko *et al.* (2017c), 64 drivers were identified (categorised as project-level drivers, external drivers, property-level drivers, corporate-level drivers, and individual-level drivers). Out of the 64 drivers, 21 drivers were examined through a survey involving 104 international experts, and it was found that energy-efficiency, water

efficiency, occupants' comfort and satisfaction, reduced environmental impact, and company image/reputation were the top-five drivers (Darko *et al.*, 2017b). In Ghana, it was found that the top-five factors driving GB adoption were: setting a standard for future design and construction, improving occupants' health and well-being, greater energy efficiency, reducing whole life-cycle costs, and conservation of non-renewable resources (Darko *et al.*, 2017a). The significant drivers from the above studies that have a bearing on PV adoption include: reduced environmental impact, good image/marketing strategy, addition of value to the property, commitment to social responsibility, set standards for future design and construction, job creation, and preservation of natural resources.

Windapo (2014) also examined drivers of GB in the Western Cape Province, South Africa, using a multi-case-study strategy. Windapo (2014) found that the key drivers engendering GB in the study area could be attributed to the industry's Green Star rating system, legislation, rising energy costs, and competitive advantages. The findings led to the conclusion that 'the increase in green building has little to do with ecological factors and more to do with economic factors – operational costs and stakeholder demands' (Windapo, 2014, p. 6088).

In assessing the driving and impeding factors for green practices in the Chinese Construction/Building Industry, Liu *et al.* (2012) conducted an industry-wide survey, involving 65 participants. It was found that the key motivations were to gain incentives and recognition from the government, upgrade project influence, generate lucrative income, and earn social reputation (Liu *et al.*, 2012).

Durdyev *et al.* (2018b) investigated GB adoption in Cambodia, and the drivers were examined under economic, environmental, and social categories. Under the environmental category, the three topmost drivers identified were: greater energy efficiency, resource

conservation, and reduction of the negative environmental impact of buildings. Factors in the economic category included the retention of skilled manpower, value for money, and reduction of life-cycle cost. Lastly, health and safety, well-being, culture, and job creation were key drivers in the social category.

Other studies in GB have also provided insight into other motivating factors, and/or corroborated the findings of the previous studies discussed earlier. For instance, the monetary gain through lower utility or life-cycle cost, image/reputation-related drivers, environmental protection, value addition to property, government fiscal incentives, mandatory requirements or standards, and job creation drivers were also identified by scholars such as Andelin *et al.* (2015), Hoxha and Shala (2019) and Potbhare *et al.* (2009). Recently, Yas and Jaafer (2020) explored the adoption of green buildings in the United Arab Emirates (UAE), and it was found that decreased energy and water consumption was the most significant driving factor, and governmental financial incentive was suggested as the best promotion strategy that could increase the adoption of GBs in UAE.

#### ***2.4.3. Barriers to Green Building Adoption: Insight into PV Adoption***

With regard to barriers hindering the adoption of GBTs, a comparative examination highlighted that the key barriers to GBT adoption varied between developed and developing countries, although there were slight commonalities. Specifically, it was found that between Ghana, USA, Canada, and Australia, the key barriers in Ghana generally varied from those in the developed countries of the US, Canada, and Australia. However, the high cost of GBTs was a barrier that was ranked high and was common to all countries (Chan *et al.*, 2018). Other barriers identified in the Ghanaian context were the lack of financing schemes, lack of government incentives, lack of research and development

institutes, and the unavailability of GBT suppliers (Chan *et al.*, 2018). The high cost of projects was also identified as a key challenge in China (Liu *et al.*, 2012).

Not very long ago, Durdyev *et al.* (2018b) conducted a survey involving local construction professionals with the aim of identifying the barriers that hinder the adoption of sustainable construction in Cambodia. Having examined 104 valid responses, Durdyev *et al.* (2018b) found the barriers, in descending order, to be: high cost, lack of incentives from the government, economic needs of higher priority, absence of requisite statutory requirements, non-existence of skilled professionals, lack of client demand, lack of education and training, long pay-back of investment, tendency to maintain current practices, and lack of environmental concern.

A qualitative research design was adopted by Wimala *et al.* (2016) to obtain information from building occupants in Indonesia. Among other things, Wimala *et al.* (2016) found barriers such as low availability of green products, burdensome implementation, negligence, resistance to change, inadequate knowledge/information, absence of supportive/enabling environment, insufficient supervision, high cost of construction, lack of awareness, and lack building management role.

Overall, there has been considerable concurrence in the literature regarding key barriers that suppress the uptake of green buildings. Firstly, the high capital cost of inculcating GBTs in construction has been noted by scholars in several countries (Abidin *et al.*, 2013; Azeem *et al.*, 2017; Chan *et al.*, 2018; Mesthrige and Kwong, 2018; Nguyen *et al.*, 2017; Potbhare *et al.*, 2009; Wang *et al.*, 2019; Wu *et al.*, 2019; Yas and Jafer, 2020). The long pay-back period required to recoup investment is also not attractive to property investors and can have a negative influence on the adoption rate (Azeem *et al.*, 2017; Nguyen *et al.*, 2017). Obviously, the lack of financial resources will not encourage GB development and,

similarly, the difficulty of accessing credit (Azeem *et al.*, 2017; Chan *et al.*, 2018; Nguyen *et al.*, 2017; Potbhare *et al.*, 2009). It was also noted that lack of awareness, lack of trustworthy sources from which to acquire information, lack of successful projects that people can observe, lack of skilled personnel and lack of promotion of GB can be counted as barriers (Mesthrige and Kwong, 2018; Potbhare *et al.*, 2009; Yas and Jaafer, 2020). Besides the above factors, lack or inadequate fiscal support and non-fiscal policies, lack of building codes as well as green building rating systems, and the lack of interest from clients have been reported as barriers to the adoption of GBs (Chan *et al.*, 2018; Nguyen *et al.*, 2017; Wu *et al.*, 2019).

Insight from UAE suggested that the high cost of GBs and the delayed time expected to develop GBs were not barriers in UAE. However, it was found that the shortage of experienced professionals and the lack of awareness and demand from property developers and end-users were the key barriers (Yas and Jaafer, 2020).

## **2.5. Energy Transition for a Sustainable Future**

### ***2.5.1. Global Trends in Renewable Energy Development***

It is a main theme in development that energy enables the world to thrive. As the beneficiary, humankind has made significant use of energy for development, and no generation has ever been more reliant on energy than today's society (Beggs, 2009). Both at home and work, energy is being used to power various, everyday equipment, tools and appliances and, without energy, our high-tech, computer-reliant society could cease to function (Beggs, 2009). As important as energy is, it also fosters negative impacts on the environment. The energy supply sector is noted as being the largest contributor to global GHG emissions and it was estimated that the energy supply sector was responsible for approximately 35% of total anthropogenic GHG emissions in 2010 (Bruckner *et al.*, 2014).

Because energy is crucial to almost every major challenge and opportunity that the world faces today (UN, 2014), decarbonising the electricity generation sector is a key component of cost-effective mitigation strategies to achieve low-stabilisation levels (Bruckner *et al.*, 2014). The UN stated that almost one billion people live without electricity, and approximately 50 per cent of them are found in Sub-Saharan Africa alone. Although efforts have been made to increase the deployment of RE technologies, the ratio of energy used per unit of Gross Domestic Product (GDP) is declining. Hence, the challenge is far from being resolved completely. Therefore, the UN has called for innovative models to transform the world's energy systems and for accelerated progress regarding the deployment of RE to provide energy/electricity for use in the transport, manufacturing and building sector (UN, 2014). In 2016, UN-Energy, the principal collaborative mechanism of the UN's work on energy, reported the progress of UN-Energy member organisations in: *Activities of Member Organizations and Partners of UN-Energy in support of 2014-2024 Decade of Sustainable Energy for All* (UN-Energy, 2016).

RE is defined as energy generated from a source that is not depleted when used, and the most common forms of RE are photovoltaic systems, solar thermal systems, wind turbines, hydro-electric plants, geo-thermal power plants, and geo-thermal heat pumps (Becqué *et al.*, 2019; REN21, 2019). In the last few years, RE deployment has been increasing; it has been said that the share of RE in final energy consumption reached 17.5% in 2015 (UN, 2014) and 26.2% by the end of 2018 (REN21, 2019, p. 41). Also, the competitively priced electricity from RE sources, such as PVs, wind and hydro-power relative to electricity generated from fossil-fuel in many markets, is helping to convince investors to increase their allocations to RE (SEforAll, 2015).

Globally, by the end of 2018, the added modern RE capacity (hydro-power, solar, wind, geo-thermal, ocean power, and modern bio-fuel production) was approximately 181 GW, and installed power capacity totalled 2 378 GW (REN21, 2019, p. 18). In 2019 and 2020, 210 GW and 251 GW were added, respectively, raising the global total RE capacity to 2 839 GW by the end of 2020 (REN21, 2020, p. 46, 2021, p. 52). In 2021, it was reported that the total installed renewable power capacity grew by 11 per cent to reach approximately 3,146 GW, and renewables generated 28.3 per cent of global electricity (REN21, 2022, p. 22). Despite the growth in the deployment of RE globally, it was observed that the rate of growth is still not sufficient to guarantee a net zero carbon future (IRENA, 2022a).

In Africa, efforts are being made to accelerate the energy transition. For instance, Sustainable Energy for All (SEforAll) has focused on policy reform, investment promotion and private-sector engagement as the three key areas in improving electricity access across Africa, where an estimated 600 million people do not have access to electricity (SEforAll, 2019). Investment banks, such as Africa Development Bank, are also supporting energy developments across Africa to achieve universal electricity access, especially investments in clean and RE solutions. The bank pledges to invest USD 12 billion in the energy sector (AfDB, 2019). It is reported that the total RE generation reached 55 705 MW in Africa (IRENA, 2022a).

It is reported that cities account for approximately 65 per cent of global energy demand and are home to more than half of the world's people. As such, cities are taking a leading role in advancing RE development (IRENA, 2019; REN21, 2019). Reducing energy-related CO<sub>2</sub> emissions is essential to energy transformation. Nonetheless, other drivers such as the

decline in RE costs, demand for air quality improvements, improvement of energy security, and the potential to create jobs are also advancing the transition (REN21, 2012-20).

### ***2.5.2. Renewable Energy Development in South Africa***

South Africa ranks amongst the top-ten coal-producing countries in the world and, while little of what is produced is exported, most of the coal contributes to the country's total primary energy requirements (DMRE, 2016). Eskom, the state-owned electricity utility, is predominantly responsible for the generation and distribution of power (Eskom, 2019). As a result, it is no surprise that SA's contribution to global GHG emissions is one of the highest on the African continent (UNDP, 2016). To deal with the problems associated with the use of coal, and the need to increase the accessibility of electricity, as well as meet demand (avoid power cuts), the SAG has made considerable improvements over the years in developing policies that assist the diversification of the energy mix through the incorporation of renewables. Recent policies include the White Paper on Renewable Energy 2003, the Integrated Energy Plan 2003, National Energy Act 2008, and the REIPPPP (DMRE, 2003a, 2003b, 2012; SAG, 2008). So far, the REIPPPP projects have contributed a total capacity of 5 078 MW of electricity generation nationwide, and the contribution from PV alone was 2 292 MW (DMRE, 2021). The total installed PV capacity in South Africa was estimated at 5 721 MW as of 2021 (IRENA, 2022a). According to Naicker and Thopil (2019), PVs and wind power were the most favourable RE choices in SA because of the maturity of technology and the perceptions of financiers. Other policies, such as the National Climate Change Response White Paper and the Carbon Tax Bill are further demonstrations of SAG's commitment to making the transition to a climate-resilient and lower-carbon economy (Department of Forestry, Fisheries and the Environment [DFFE], 2015; SAG, 2019).

In 2009, the SAG introduced FIT as a government support mechanism for accelerating private investment in RE, but it was later discontinued in 2011 in favour of the large-scale grid-connected RE developments of the REIPPPP, which were available at a more competitive price (Baker, 2015; Eberhard *et al.*, 2014).

In a report by the Southern African Development Community (SADC), it was stated that SA is leading the African continent in the deployment of new RE projects. The country was lauded as a leader in the development of auction systems through the notable REIPPPP which commenced in August 2011 (SACREEE and REN21, 2018). In reporting progress on RE development in SA's SDG 2019 Country Report, it was documented that the annual amount of electricity produced from renewable sources reached 8 731 GWh in 2018 (SSA, 2019, p. 183). According to the latest report in 2021 by IRENA, SA's total installed RE generating capacity reached 10 193 MW, and the RE share of electricity capacity was at 17.6 per cent (IRENA, 2022a).

An ambitious, yet achievable goal was stated in the Integrated Energy Plan Report as 'solar should play a much more significant role in the electricity generation mix than it has done historically, and constitutes the greatest share of primary energy (in terms of total installed capacity) by 2050 (DMRE, 2016, p. 165). Since universal electrification has not been achieved yet in SA (SSA, 2019), diversification of the energy portfolio through the addition of RE will enhance environmental sustainability while reducing vulnerability to price volatility (Sarkodie and Adams, 2018).

## **2.6. Solar Photovoltaics**

### **2.6.1. Introduction**

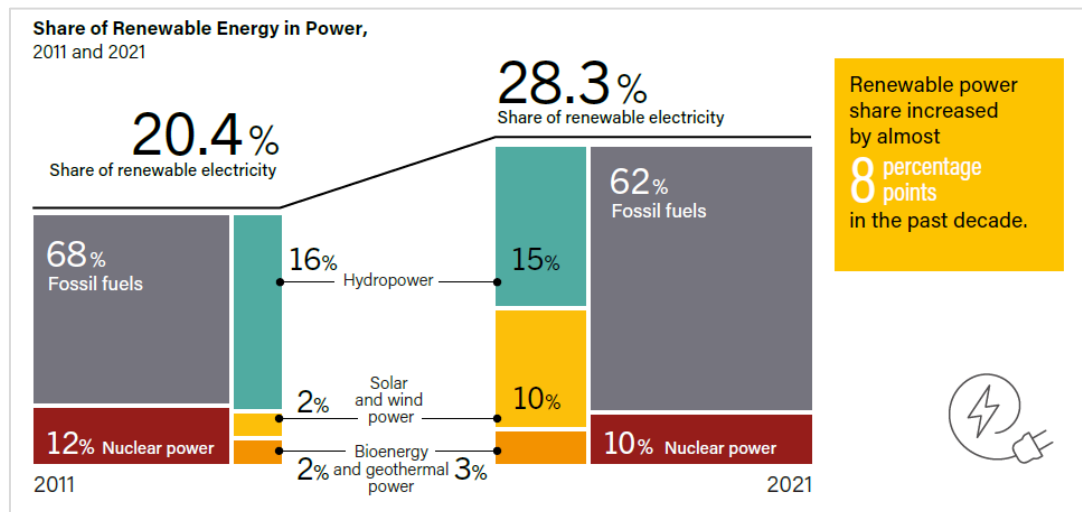
There has been explosive growth in photovoltaics worldwide over the past decade (Baghzouz, 2015; Hersch and Zweibel, 1982). PV energy conversion occurs in solar cells

by the absorption of light which generates an electron-hole pair. The electrons are separated by the structure of the device to the negative terminal and the holes to the positive terminal, thereby generating electrical power (Markvart and Castañer, 2018, p. 3). PV cells are constructed from semi-conducting materials that use sunlight to separate electrons from atoms to create an electric current. Mono-crystalline modules are more efficient but relatively more expensive than poly-crystalline silicon modules (Sampaio and González, 2017). Mono-crystalline silicon cells are mostly square with rounded corners (semi-square), and poly-crystalline cells can be identified by the shimmering shades of blue in their crystal structure (Haselhuhn, 2017, p. 31). Among all low-carbon technology options, it has been estimated that the accelerated deployment of PVs, when coupled with deep electrification, would contribute to almost one-fifth of the total reduction of emissions needed (nearly 4.9 Gt CO<sub>2</sub>) by 2050 (IRENA, 2019). Projections show that, by 2050, PVs could be among the cheapest sources of power available, particularly in areas with excellent solar irradiation, with costs in the range of USD 0.014 - 0.05/kWh in 2050 (IRENA, 2019). With regard to on-site applications of RE energy, PV technologies are currently the most widely used in the building sector (Belussi *et al.*, 2019).

A typical PV system consists of PV module(s), a charge controller, an inverter and a battery when it is necessary to store the electricity that is generated (Kalogirou, 2014; Sampaio and González, 2017). The main types of batteries available today include lead-acid, nickel cadmium, nickel hydride, and lithium. The most commonly used type of batteries are the deep-cycle, lead-acid batteries. The inverter is the equipment used to convert the direct current into alternating current electricity, and the output of an inverter can be single- or three-phase. Controllers regulate the power from PV modules to prevent the batteries from overcharging. The controller can be a shunt type or series type, and also functions as a low-battery voltage disconnect to prevent a battery from over-discharge (Kalogirou, 2014). The

costs of fitting PV systems to new buildings are significantly lower than for a retrofit (Cross, 2018).

According to 2018 records, the contribution of PVs to global electricity production was approximately 2.4% (505.5 GW) (REN21, 2019, p. 41). In 2021, PVs were the most deployed RE technology in the world and it was estimated that the capacity of new PV installations was approximately 175 GW, and the cumulative global capacity reached approximately 942 GW. This accounted for approximately 30 per cent of the global capacity for RE generation since the total global capacity was 3 146 GW (REN21, 2022, p. 126). Although the deployment of PVs has increased rapidly over the years, its composition relative to total global electricity production is minimal. It was reported that PVs and wind energy provided approximately 10 per cent of the world’s electricity for the first time ever, as shown in Figure 2.3 (REN21, 2022, p. 44).



**Figure 2.3: Share of renewable energy in the global energy mix**  
(REN21, 2022, p. 44)

The results above suggest that, although progress has been made in increasing the share of RE in the global energy mix, it is still not sufficient and more needs to be done to reach satisfactory levels. As suggested by IRENA, off-grid PVs are the key technology for

achieving full energy access and achieving the SDGs (IRENA, 2019, p. 8). Therefore, understanding the factors that determine the adoption and non-adoption of the technology in all quarters of society must be paramount.

### **2.6.2. Installation of PV Systems**

As shown in Figures 2.4 - 2.9, PV panels can be mounted on the ground, on the rooftop of a building, or on the vertical surfaces of buildings (i.e. not part of the building) (Cross, 2018; IRENA, 2019; Pedersen *et al.*, 2015). Recently, PV panels can also be installed to float on water, as shown in Figure 2.8 (Dai *et al.*, 2020; Nunes, 2022). Furthermore, because of advancements, it is now possible also to install systems which are an integral part of the building; these applications are called ‘building integrated photovoltaics’ (BIPV) (Kalogirou, 2014; Yang, 2015). All PV installations that are not BIPV can be categorised as building-attached PV (BAPV) (Savvides, 2018). BIPV systems are architecturally integrated into the building design to form a functional part of the building structure – the building envelope material – and as a power generator at the same time (Sampaio and González, 2017). The advantages of BIPV solutions include their adaptability to a variety of surfaces, cost efficiency from savings on roofing/building material costs, and design flexibility in size, shape and colour (IRENA, 2019, p. 8). However, the application of BIPV has unique technical barriers and risks compared with the typical PV panels, hence its limited application. Yang (2015), for instance, has attempted to provide possible solutions to overcome the barriers to BIPV application. Similarly, Ciriminna *et al.* (2015) provided guidelines for integrating solar energy into buildings in Sicily. A case study was also provided to assist the adoption of BIPV in a university (Kumar *et al.*, 2021). For now, based on various built examples highlighted by Krippner (2017), it appears that momentum is building and BIPVs are being adopted increasingly, especially in developed countries.

For PV systems that act as roofs on their own, these can be categorised as inter-locking panel systems or as standard, sloping, face-sealed, glazing systems (Cross, 2018). The inter-locking panel systems either consist of panels that mimic roofing tiles with the PV element embedded in the surface or have a frame bonded to the PV panel which provides the sealing inter-lock. The standard, sloping, face-sealed, glazing systems are built into a double-glazed sealed unit. This type of system is most suitable for buildings where the PV is visible from the inside, and it is necessary to provide natural lighting to the internal space (Cross, 2018).



**Figure 2.4: PVs installed as façade: BIPV type**  
(Metsolar, 2022)



**Figure 2.5: PVs installed as roof: BIPV type**

(Wikimedia Commons, 2009)



**Figure 2.6: PVs installed on pitched roof: BAPV type**

(Wikimedia Commons, 2007)



**Figure 2.7: PVs installed on flat roof: BAPV type**

(World Bank, 2014)



**Figure 2.8: Floating PVs**

(Nunes, 2022)



**Figure 2.9: Ground-mounted PVs**

(IRENA, 2022b)

With reference to the grid, PV installations can also be divided into grid-connected and stand-alone installations (Haselhuhn, 2017, p. 28). A stand-alone system is independent of

the electricity grid, with the energy produced normally being stored in batteries. This is very useful in areas that are not easily accessible or have no access to electricity grids. A typical stand-alone system would consist of PV module(s), batteries, and a charge controller. An inverter might also be added to the system to convert the direct current (DC) generated by the modules into the alternating current (AC) form required by normal appliances (Kalogirou, 2014, p. 24). In grid-connected installations, the PV system is connected to the grid network via the mains service panel of the building. For PV installations with their own electricity supply, a bi-directional meter is installed in the main service panel that records both incoming and outgoing energy amounts (Haselhuhn, 2017, p. 45). The electricity generated by the PV system, in a grid-connected installation, can be used immediately, stored in batteries, or fed into the electricity grid for a fee. In the evening, when the PV system is unable to provide the electricity required and batteries are not installed, power can be bought back from the grid network (Kalogirou, 2014, p. 24).

### ***2.6.3. Methods for Acquisition of PV Systems***

The popular options for procuring PV systems are outright purchase, leasing, and power purchase agreement (PPA) (Rai *et al.*, 2016; Rai and Sigrin, 2013; Sigrin *et al.*, 2015). In the case of outright purchase, adopters pay the total cost for the installed system up front, but in the case of third-party ownership options, such as lease and PPA, the acquisition of the system is arranged differently. In a PPA, a solar finance company designs, purchases, installs, and typically operates and maintains the system, and the consumer buys 100% of the energy produced at a cost that is typically competitive with the local electric utility rate. Under certain contracts, the consumer might be required to make a down payment and, if this is the case, the price per kilowatt-hour will be lower for the contract period. The solar lease model is very similar to the third-party PPA, but the primary difference is in how the

payment is structured. With a lease, the home-owner makes monthly lease payments and there is no sale of electricity (Speer, 2014).

Rai and Sigrin (2013) investigated buy versus lease differences in 365 PV owners in Texas and found that leasing is financially more attractive and has opened up the residential PV market to a new, and potentially very large, consumer segment of those in a tight cash-flow situation. Further, it was noted that the leasing option was not available for 73 per cent of adopters when they were making their decision and, for PV adopters who had the option either to buy or lease a PV system, they chose to buy because they were concerned about potential difficulties with the leasing contract. Sigrin *et al.* (2015) found that most new installations in many markets were leased, and Rai *et al.* (2016) found acquisition options for buy, lease, and PPA among 378 respondents to be 43 per cent, 20 per cent, and 37 per cent, respectively. In India, Dutta and Das (2020) found that PPA, cash and a combination of both were the best financial arrangements. Corporate PPAs are also reported to have become popular in mid-2000 and have since emerged as an attractive option for companies to source renewable electricity. The cumulative global capacity for renewable PPA is said to have reached an estimated 19 GW in 2017 (REN21, 2019, p. 175).

#### ***2.6.4. Drivers for PV Adoption: PV-Specific Literature***

##### *2.6.4.1. Overview of Review*

To optimise the deployment of PVs, it is necessary to understand the underlying issues that influence the diffusion/adoption of the technology (Bach *et al.*, 2020). Therefore, it is not surprising that a significant share of empirical literature has provided insight into factors that drive the diffusion of PVs. In the literature, scholars have approached the topic from different viewpoints. Discussions have ranged from adoption in developed countries (Bach *et al.*, 2020) or developing countries (Qureshi *et al.*, 2017), from a household perspective

(Briguglio and Formosa, 2017), to comparative studies between households and micro-enterprises (e.g. Kurata *et al.*, 2018) or between adopters and non-adopters (Bach *et al.*, 2020; Mundaca and Samahita, 2020; Sigrin *et al.*, 2015; Vasseur and Kemp, 2015). Furthermore, different theories have been used to understand these phenomena, for example, TAM (Pathania *et al.*, 2017), Roger's DOI theory (Qureshi *et al.*, 2017), and UTAUT (Vasseur and Kemp, 2015). Social acceptance has also been very important in driving the adoption of PVs (Ervural *et al.*, 2018). Societal factors that affect adoption also vary between countries. Unequivocally, the drivers engendering the uptake and upscaling of PVs are plentiful, as presented in Table 2.2, and these all act as mechanisms with which to disentangle the barriers to deployment. Furthermore, the findings of the review of the empirical evidence indicated that some of the drivers examined by scholars are inter-related. For instance, fiscal subsidies and a shorter pay-back period can drive PV adoption, and the latter can be affected by the former.

'Drivers' have been referred to in the literature as factors that positively promote the uptake of PVs. Richardson and Lynes (2007), for instance, considered drivers from two perspectives: (1) catalysts or motivators that help to push an agenda forward, and (2) motivations in terms of benefits. In this review, a total of 55 drivers were identified and collated from both perspectives (i.e. catalysts and benefits), as shown in Table 2.2 below.

#### 2.6.4.2. *Discussion of Adoption Drivers*

Economic benefits are expected to increase the willingness of adopters to use PV systems, and it has been observed generally in the literature that economic cluster is the most influential factor which engenders diffusion. Specifically, one of the most recognised motives from an economic perspective is monetary gains made through lower electricity bills or money earned from selling PV electricity to the power grid. Some adopters perceive

their decision as ‘buying tomorrow’s energy with today’s dollars’ (Schelly, 2014, p. 187). In a rich body of literature, importance is given to monetary gain as a driver of PV adoption, both in developed and developing countries. For example, this finding has been reported in the United Kingdom (UK) (Balcombe *et al.*, 2014), Nigeria (Eronini, 2014; Ugulu and Aigbayboa, 2019), New Zealand (King *et al.*, 2014), USA, Bangladesh (Kurata *et al.*, 2018), Malaysia (Ahmad *et al.*, 2017), Germany (Karakaya *et al.*, 2015), Korea (Lee and Shepley, 2020).

Beyond saving or earning money in the short-term, a different set of motives for investment in PVs originates from the opportunity it offers in hedging against possible future increases in electricity bills (Balcombe *et al.*, 2014; Karakaya *et al.*, 2015; King *et al.*, 2014; Korcaj *et al.*, 2015; Pickerill, 2018; Sigrin *et al.*, 2015).

Also, people with low incomes are less likely to use PV systems but high-income earners have greater purchasing power. Thus, the lower the cost of the system, the higher the chances of uptake for some people. Schelly and Letzelter (2020) found low or no upfront cost to be a driver in New York. In public rental apartments in metropolitan Seoul, Korea, it was reported that the government provided PV systems for low-income households and this was the major catalyst for PV usage in those locations (Lee and Shepley, 2020).

In contrast to a high upfront cost being a barrier, the availability of alternative options to own a PV system, such as a lease contract or power purchase agreement, breaks a significant barrier to the uptake of PVs (Rai *et al.*, 2016; Rai and Sigrin, 2013; Sigrin *et al.*, 2015).

**Table 2.2: Factors engendering deployment of photovoltaics**

Code	Description	Key References
D1	Monetary gains through lower bills (i.e. present time)	<sup>a</sup> [1–19,47,54]; <sup>b</sup> [36–39,50]; <sup>c</sup> [40–42]
D2	Monetary gains through indemnity from higher future electricity bills	<sup>a</sup> [2,3,8,14,17,47]; <sup>b</sup> [38]
D3	Low cost of system	<sup>a</sup> [12,34]
D4	Government funding cost of system	<sup>a</sup> [16]
D5	Availability of lease acquisition options	<sup>a</sup> [51,52]
D6	Availability of PPA acquisition options	<sup>a</sup> [53]
D7	Availability of finance to fund project	<sup>a</sup> [14,18,21,44,47]
D8	Generate own electricity and be self-sufficient	<sup>a</sup> [2,3,5,7,8,12,14,15,18,19,20, 21,35,47,48,54,55]
D9	Protects against power cuts from utility companies	<sup>a</sup> [2,18,20,21,34,44,47,55]
D10	Interest in using a new technology/innovation	<sup>a</sup> [2,5,22,44]
D11	Positive image and reputation enhancement	<sup>a</sup> [2,5,14,44]; <sup>b</sup> [37–39,43,49]; <sup>c</sup> [40,42,45]
D12	Enhance environmental quality and reduction of greenhouse gases	<sup>a</sup> [2,3,5–9,11,12,14–17,20–22, 28,34,35, 44,47,48,54,55]; <sup>b</sup> [37–39,50]; <sup>c</sup> [42]
D13	Good solar irradiation in locality	<sup>a</sup> [3,44]
D14	Value addition to property	<sup>a</sup> [3,6,17]; <sup>b</sup> [36–38,43,49]
D15	Lack of connection to the national grid	<sup>a</sup> [4,11,34]
D16	Mitigate indoor air pollution (off-grid rural areas)	<sup>a</sup> [4]
D17	Acquaintances (non-neighbours) own a PV system	<sup>a</sup> [14,15,48]
D18	Positive discussion and expectancy from acquaintances	<sup>a</sup> [11,12,14,15,17,24,44,48]
D19	People in my community own a PV system	<sup>a</sup> [1,6,13–15,17–19,22,23,24]
D20	Demonstrate commitment to social responsibility	<sup>a</sup> [11,14–16,20,23,24]; <sup>b</sup> [36,37,39]; <sup>c</sup> [45]
D21	Set example and standard for others	<sup>a</sup> [5,6,11,12,22,35,47]; <sup>b</sup> [37]; <sup>c</sup> [41,42]
D22	Protest against big energy companies	<sup>a</sup> [5,6,35]
D23	Best alternative source for electricity	<sup>a</sup> [20]; <sup>c</sup> [40]
D24	Awareness and understanding of technology	<sup>a</sup> [1,8,11–13,17,18,44]
D25	Ease of installation	<sup>a</sup> [7,19,47]
D26	Ease of maintenance and operation	<sup>a</sup> [33,44,47,48]
D27	Less maintenance requirement or cost	<sup>a</sup> [44,47,48]
D28	Quiet operation	<sup>a</sup> [18]
D29	Perceived over-billing of grid power	<sup>a</sup> [18]
D30	Availability of FIT, net-metering, fiscal incentives	<sup>a</sup> [5,6,7,9,11–13, 21,22,25– 30,47,48]; <sup>b</sup> [49]
D31	Mandatory government regulations/requirements	<sup>a</sup> [11]; <sup>b</sup> [36]
D32	Shorter pay-back period	<sup>a</sup> [7,22,31]
D33	Availability of space for installation	<sup>a</sup> [10,14,32,44,47]
D34	To improve economy by creating jobs	<sup>a</sup> [11,14,28,47]; <sup>b</sup> [37,39]
D35	Poor reputation of energy producers/companies	<sup>a</sup> [55]
D36	Impress regulators	<sup>b</sup> [36,49]
D37	To demonstrate sustainability practices	<sup>b</sup> [36,37]; <sup>c</sup> [42]
D38	Enhance publicity	<sup>b</sup> [36,37]; <sup>c</sup> [42]
D39	Vision and policy requirements	<sup>b</sup> [36,43]; <sup>c</sup> [42,46]
D40	Availability of industry for green building rating	<sup>b</sup> [38]

Code	Description	Key References
D41	Client demand	<sup>b</sup> [36,38]
D42	Competitive advantage	<sup>b</sup> [36,38]; <sup>c</sup> [40]
D43	Building code requirements	<sup>b</sup> [38,39]
D44	To practice resource conservation	<sup>b</sup> [39]; <sup>c</sup> [42]
D45	Sustainability performance reporting requirements	<sup>b</sup> [43]; <sup>c</sup> [41]
D46	Boost organisation's financial sustainability	<sup>c</sup> [40,42,45]
D47	Comply with sustainable development-related legislation and declarations	<sup>c</sup> [40]
D48	Create awareness among staff and students	<sup>c</sup> [40]
D49	Create awareness within community/society	<sup>c</sup> [40,42]
D50	Create platform for collaboration	<sup>c</sup> [40,42]
D51	Enhance donor support/government funding	<sup>c</sup> [41,42,45]
D52	Top leadership commitment and support	<sup>c</sup> [41,45]
D53	Stakeholder influence – students/activist groups	<sup>c</sup> [41,45]
D54	Stakeholder influence – staff	<sup>c</sup> [41,45]
D55	Provide technical study opportunity for students and research opportunity for staff	<sup>c</sup> [42]

Notes: <sup>a</sup> PV-specific literature; <sup>b</sup> Green building literature; <sup>c</sup> Campus sustainability literature

References are as follows:

- |                                       |   |
|---------------------------------------|---|
| 1 = Rai <i>et al.</i> (2016);         | 28 = Dutta and Das (2020);              |
| 2 = Balcombe <i>et al.</i> (2014);    | 29 = Macintosh and Wilkinson (2011);    |
| 3 = King <i>et al.</i> (2014);        | 30 = Elnokaly and Martin (2014);        |
| 4 = Kurata <i>et al.</i> (2018);      | 31 = Bruderermann <i>et al.</i> (2013); |
| 5 = Mundaca and Samahita (2020);      | 32 = Briguglio and Formosa (2017);      |
| 6 = Palm (2018);                      | 33 = Aggarwal <i>et al.</i> (2019);     |
| 7 = Vasseur and Kemp (2015);          | 34 = Kiprof <i>et al.</i> (2019);       |
| 8 = Karakaya <i>et al.</i> (2015);    | 35 = Palm and Tengvard (2011);          |
| 9 = Sommerfeld <i>et al.</i> (2017);  | 36 = Potbhare <i>et al.</i> (2009);     |
| 10 = Ahmad <i>et al.</i> (2017);      | 37 = Darko <i>et al.</i> , (2017b);     |
| 11 = Wong and Cronin (2019);          | 38 = Windapo (2014);                    |
| 12 = Schelly and Letzelter (2020);    | 39 = Durdyev <i>et al.</i> (2018b);     |
| 13 = Islam (2014);                    | 40 = Awuzie and Emuze (2017);           |
| 14 = Korcaj <i>et al.</i> (2015);     | 41 = Richardson and Lynes (2007);       |
| 15 = Kastner and Wittenberg (2019);   | 42 = Li <i>et al.</i> (2013);           |
| 16 = Lee and Shepley (2020);          | 43 = Andelin <i>et al.</i> (2015);      |
| 17 = Sigrin <i>et al.</i> (2015);     | 44 = Eronini (2014);                    |
| 18 = Ugulu and Aigbayboa (2019);      | 45 = Shriberg (2003);                   |
| 19 = Gastaldo <i>et al.</i> (2019);   | 46 = Raimi (2020);                      |
| 20 = Qureshi <i>et al.</i> (2017);    | 47 = Pickerill (2018);                  |
| 21 = Walters <i>et al.</i> , (2018a); | 48 = Aggarwal <i>et al.</i> (2019);     |
| 22 = Schelly (2014);                  | 49 = Liu <i>et al.</i> (2012);          |
| 23 = Palm (2017);                     | 50 = Hoxha and Shala (2019);            |
| 24 = Curtius <i>et al.</i> (2018);    | 51 = Rai and Sigrin (2013);             |
| 25 = Castaneda <i>et al.</i> (2018);  | 52 = Sigrin <i>et al.</i> (2015);       |
| 26 = Lan <i>et al.</i> (2020);        | 53 = Rai <i>et al.</i> (2016);          |
| 27 = Zhang <i>et al.</i> (2011);      | 54 = Arroyo and Carrete (2019);         |
|                                       | 55 = Leenheer <i>et al.</i> (2011).     |

The built environment is responsible for a significant share of environmental pollution.

Thus, in the bid to avert the negative environmental impacts, PVs are adopted because of their environmental benefits. Notably, scholars varied greatly in their choice of words used

when referring to environmentally-related drivers. A key benefit of solar electricity is its lower GHG emissions relative to electricity produced from fossil fuels. So, for instance, Islam (2014) and Lee and Shepley (2020) used ‘carbon emission’ in the environmental category of drivers. Generally, however, popular words used to refer to drivers in surveys or those that appear in interviews include: help improve/protect the environment, environmental concern, environmental impact, good for the environment, environmentally friendly, positive impact on the environment, improve the natural environment, and many more (Balcombe *et al.*, 2014; King *et al.*, 2014; Palm, 2018; Schelly and Letzelter, 2020; Sommerfeld *et al.*, 2017; Vasseur and Kemp, 2015). Kastner and Wittenberg (2019) used ‘contribute to climate protection’ and ‘for ecological reasons’, while (Kiprop *et al.*, 2019) used ‘air pollution’ and ‘environmental conservation’. Wong and Cronin (2019) also used ‘reduction of climate change effects’ and ‘knowledge that current resource usage is not maintainable’.

Generally, regardless of the word or phrase that is used, there is consensus that environmentally-related factors do drive the adoption of PVs. Mundaca and Samahita (2020) remarked that, in Sweden, those who adopted the technology early did so because of the environmental benefits, while the late adopters did not pay much attention to the environmental benefits. However, Schelly (2014) cautioned that ‘given the political polarization of environmental issues in the United States, those who are not environmentally concerned may be turned away from solar technology adoption because it is framed as a “green” choice’ (p. 189).

Power cuts occur because of technical problems with power plants/transmission lines, or because of planned maintenance to allow time for routine services to infrastructure. Similarly, a natural crisis such as an earthquake or flood can damage power plants or

transmission lines and this can cause power outages. Therefore, protection from potential power cuts motivates the use of PVs (Balcombe *et al.*, 2014; King *et al.*, 2014; Kiprop *et al.*, 2019; Qureshi *et al.*, 2017; Ugulu and Aigbayboa, 2019; Walters *et al.*, 2018a). Other motivations might not be about power cuts, but rather the desire to produce their own electricity and be self-sufficient. Several scholars have identified this as a driver (Gastaldo *et al.*, 2019; Korcaj *et al.*, 2015; Palm and Tengvard, 2011; Pickerill, 2018; Schelly and Letzelter, 2020). Some adopters can be motivated to be self-sufficient because of their lifestyle and their desire for low-impact living (King *et al.*, 2014), or the sheer joy of producing their own electricity (Palm, 2018).

While others have options and seek independence from the grid, the population in rural off-grid areas is motivated differently to use PVs. For example, Kurata *et al.* (2018) found that, in Bangladesh, households and micro-enterprises in rural off-grid areas adopted solar home systems as a way of accessing electricity for daily use such as charging mobile phones and lighting. It also enables ordinary people and micro-enterprises to work at night and helps students to study at night. In addition, the adopters were motivated to use PVs to reduce indoor air pollution (Kurata *et al.*, 2018).

It is noted in the literature that technology diffusion in society can be motivated by peer effect. According to Karakaya *et al.* (2015, p.1096), ‘peer effects in neighbourhoods decrease the perceived complexity for potential adopters and increase the perceived compatibility with the social norms’. Similarly, Palm (2017, p. 10) remarked that ‘the main function of peer contacts in terms of stimulating PV adoption seems to have been a confirmation from a trustworthy source (i.e. a person that the participants knew and that was in a similar situation as themselves) that the technology worked as intended and without hassle’. In a study by Dutta and Das (2020), it was found that 77% of people agreed

that observability leads to adoption or at least potential adoption. Thus, the importance of peer effect cannot be over-emphasised. In previous studies, it has been documented that, knowing an acquaintance who owns a PV system, or the availability of PV systems in a community increases the chances of PV adoption by end-users (Islam, 2014; Kastner and Wittenberg, 2019; Korcaj *et al.*, 2015; Palm, 2018; Rai *et al.*, 2016). Positive discussion or expectancy from acquaintances, and societal demand or the desire to demonstrate commitment to social responsibility can drive uptake of the technology (Curtius *et al.*, 2018; Palm, 2017; Qureshi *et al.*, 2017; Rode and Weber, 2016; Sigrin *et al.*, 2015; Wong and Cronin, 2019). Peer effect can also have a negative impact on adoption. According to Eronini (2014), acquaintances can relay negative experiences and this can stimulate disinterest in adoption.

Social learning systems are also noted to be key factors that engender the adoption of PVs. Parallel to how peer effect activates adoption, one of the reasons for the uptake of PVs is that people want to set a good example for others (Palm and Tengvard, 2011; Pickerill, 2018; Schelly, 2014; Schelly and Letzelter, 2020). It could also be because adopters seek to build a favourable image/reputation (Korcaj *et al.*, 2015; Mundaca and Samahita, 2020), or would like to demonstrate their environmental commitment to others (Balcombe *et al.*, 2014). In a study by Mundaca and Samahita (2020), it was found that the people who adopted the technology early were highly motivated by environmental reasons, while those who adopted the system later wanted to enhance their image in society.

The findings of the literature review suggested further that people adopt PVs because they are interested in using the ‘new’ technology (Balcombe *et al.*, 2014; Schelly, 2014). There has to be solar radiation before PV systems can work, and this factor has also been cited

explicitly as a driver in some literature (Eronini, 2014; King *et al.*, 2014). There are also times when PVs are installed to add value to the property (Palm, 2018; Sigrin *et al.*, 2015).

As confirmed by previous studies, an advantage of a shorter pay-back period is that it stimulates more investment in PVs. For instance, Brudermann *et al.* (2013) found that, when the pay-back investment in PV systems is shorter, small-scale farmers are more likely to invest in the technology, and Vasseur and Kemp (2015) found that people showed interest in PVs when they could recoup their investment within a maximum of five years. Nonetheless, this would not always be the case because Schelly (2014) found that a shorter pay-back period was not an important reason for most adopters in the state of Wisconsin.

It has been suggested that policies and regulations are the top priority in RE investment decision-making (Ozorhon *et al.*, 2018). The deployment of PV systems has improved considerably in recent years partly because of supporting policies, such as fiscal incentives, subsidies, rebates, FIT, net metering and tax credits. For instance, in Sweden, Mundaca and Samahita (2020) confirmed the significance of subsidies in engendering the adoption of PVs. Also, according to Schelly (2014), the availability of tax credits and rebates, which significantly reduced the pay-back period by absolving part of the investment cost, was highly useful in increasing the uptake of PVs in Wisconsin. In a similar manner, Macintosh and Wilkinson (2011) found that the PV residential rebate programme of the central government in Australia gave a major boost to PV adoption and, as result, deployment since 2000 increased approximately six times. Pickerill (2018) also reported that, since 2018, residents of rural Midwest USA have enjoyed a 30% solar tax deduction from the federal government. Also, businesses made savings on future electricity bills by investing their profits in PV systems (Pickerill, 2018). Insight from Briguglio and Formosa (2017) suggested that ‘front-end loaded’ schemes are more effective than ‘back-end loaded’

schemes; the front-end loaded schemes enable consumers to pay for the net rather than the gross value of PV systems. For instance, for the back-end loaded system, governments reimburse people after they have paid for the installation or pre-funded the whole project. Tax breaks were also mentioned as a form of fiscal incentive that promotes PV uptake (Schelly and Letzelter, 2020). In India, exemption from court fees for the registration of documents was noted as an incentive by the government (Dutta and Das, 2020).

Feed-in-tariff (FIT), a system that guarantees a minimum price paid to the supplier per kWh produced and fed into the grid, is applauded as an effective policy in addressing on-site RE generation mismatch with the grid. Thus, the availability of FIT can trigger adoption by removing the additional cost of energy storage systems (ESS), which are known to form a substantial cost component of PV systems (Elzarka *et al.*, 2017). FIT schemes are available in the form of passing all or excess solar electricity to the national grid (Islam, 2014). In Australia, Lan *et al.* (2020) found that FIT policies were inspiring households to adopt the technology in Southeast Queensland. In Germany, a country-wide FIT fostered the adoption of PV systems until grid parity was reached in 2012. In a study by Karakaya *et al.* (2015), it was revealed that the reduction in FIT demotivated people from installing the system because the rate was less than the average electricity retail price. Similarly, Castaneda *et al.* (2020) found that the diffusion of PVs was slowing down in the UK owing to FIT reductions.

Insights from the literature suggested further that pricing in FIT is very important in Australia. As noted by Sommerfeld *et al.* (2017), in Australia, different FIT rates (\$0.44 and \$0.06) were paid for solar electricity fed into the grid, whereas consumers were charged \$0.28 for energy consumed from the grid. This resulted in a behavioural change, where adopters earning \$0.44 reduced self-consumption during solar generation hours to increase

supply to the grid to earn more money. Conversely, adopters who had a lower FIT (\$0.06) rather optimised the self-consumption of solar electricity and decreased the use of electricity purchased from the energy supplier. Net metering, a method of billing that credits customers for the excess electricity they produce and supply to the grid is also considered to be a significant driver engendering the deployment of PVs in many countries (Pickerill, 2018). In Columbia, Castaneda et al. (2018) investigated how incentive policies affected residential PV deployment, and the findings led to the recommendation of net-metering and feed-in tariffs as being the two best alternatives to encourage PV investments rather than capital subsidy.

Beyond fiscal incentives, non-fiscal aspects, in the form of policies and regulatory frameworks, which are effected by government intervention in energy sectors can be diverse and very impactful. For instance, Wong and Cronin (2019) identified mandatory RE targets as a significant factor.

Other drivers identified in the literature are: protest against big energy companies (Mundaca and Samahita, 2020; Palm, 2018; Palm and Tengvard, 2011); best alternative source for electricity (Qureshi *et al.*, 2017); awareness and understanding of technology (Karakaya *et al.*, 2015; Rai *et al.*, 2016; Ugulu and Aigbayboa, 2019); ease of installation/operation and less maintenance requirement (Pickerill, 2018); quiet operation, generator fuel theft/fraud, and perceived over-billing of grid power (Ugulu and Aigbayboa, 2019); availability of space for installation (Ahmad *et al.*, 2017; Briguglio and Formosa, 2017; Korcaj *et al.*, 2015); and improvement of the economy through job creation (Wong and Cronin, 2019).

## **2.6.5. Barriers to PV Adoption: PV-Specific Literature**

### *2.6.5.1. Overview of Review*

In contrast to drivers, which are catalysts for adoption, barriers cause the non-adoption of PVs in society. While there is some commonality in some of the barriers (e.g. high upfront cost) among many countries, some of the barriers are unique to individual countries. Overall, it appears from the literature that the barriers hampering the deployment of PVs exist in every country. A total of 67 barriers were identified from the literature, as presented in Table 2.3 below.

Generally, barriers to the diffusion of PVs have been considered in terms of purchasing the system on an outright basis, and only a few scholars have examined other acquisition methods, such as leasing and power purchase agreements, which are also termed ‘third-party ownership’ (TPO) (Rai *et al.*, 2016; Rai and Sigrin, 2013; Rosales-Asensio *et al.*, 2019). For example, high upfront cost as a barrier is exclusive to outright purchase but, when TPOs are introduced, this barrier can be eliminated.

### *2.6.5.2. Discussion of Barrier Factors*

PVs are currently the second most deployed RE technology in the world in terms of installed capacity, after wind. This success is greatly attributed to the technology’s falling costs (IRENA, 2019). However, deployment would have been much more successful, especially in developing countries, had it not been for the high cost of initial investment that is required. In addition to the cost of PV modules and balance of system (BOS) components, additional costs can be attributed to equipment importation and transport cost, especially because, in some countries, equipment is subjected to high value-added tax and import duties (Nygaard *et al.*, 2017). In a significant body of literature, high initial cost is confirmed as being a primary barrier to the adoption of PVs (Garlet *et al.*, 2019; Mah *et*

*al.*, 2018; Palm, 2018; Palm and Tengvard, 2011; Qureshi *et al.*, 2017; Shah *et al.*, 2019; Sindhu *et al.*, 2016a; Vasseur and Kemp, 2015; Walters *et al.*, 2018b). PV systems are also perceived to be too expensive in general (Balcombe *et al.*, 2014; Garlet *et al.*, 2019; Kurata *et al.*, 2018; Pode, 2010).

Owing to the efficiency of PV modules and the high initial capital cost, the estimated pay-back period is normally long and, because it takes very long to recoup the capital investment, this can foster non-adoption (Ansari *et al.*, 2013; Garlet *et al.*, 2019; Mah *et al.*, 2018; Nandal *et al.*, 2019; Palm, 2018; Palm and Tengvard, 2011; Qureshi *et al.*, 2017; Roberts and Sims, 2008; Sindhu *et al.*, 2016b, 2016a; Zhang *et al.*, 2012).

A previous study found that consumers showed interest only if the pay-back was a maximum of five years (Vasseur and Kemp, 2015). The energy produced by PV systems is intermittent depending on weather conditions and, in the absence of solar radiation, no electricity can be generated. Thus, energy storage systems (ESS) offer the solution to overcome the challenges of intermittency to increase the share of self-consumption of the electricity produced (Belussi *et al.*, 2019; Cucchiella *et al.*, 2018). Nonetheless, ESS is known to increase installation costs substantially (King *et al.*, 2014), hence it has been identified to be a barrier to adoption (Ansari *et al.*, 2013).

**Table 2.3: Factors hindering the deployment of photovoltaics**

Code	Description of barriers	Key References
B1	High cost of solar photovoltaic (i.e., expensive)	<sup>a</sup> [1–3,9]; <sup>b</sup> [31,33–40]; <sup>c</sup> [26]
B2	High upfront cost (i.e. outright purchase option)	<sup>a</sup> [3,4,13–17,5–12,21,30,42]
B3	Long pay-back period of investment	<sup>a</sup> [5,6,19,7-10,13-15,18]; <sup>b</sup> [34-36]; <sup>c</sup> [27]
B4	Lack of financial resources	<sup>a</sup> [1,3,4,7,18,43]; <sup>b</sup> [34]; <sup>c</sup> [28,41]
B5	Satisfaction with current electricity source/supplier	<sup>a</sup> [1,11,13,14,22,23]
B6	Cheaper electricity from grid	<sup>a</sup> [6]
B7	Scarcity of favourable PPA options for adoption	<sup>a</sup> [20]
B8	Lack of access to credit or financing facilities	<sup>a</sup> [3–5,8,9,18–20,21]; <sup>b</sup> [33,35,36]

<b>Code</b>	<b>Description of barriers</b>	<b>Key References</b>
B9	Perceived high operation and maintenance costs	<sup>a</sup> [1,6,10,18]
B10	Uncertainty of recouping investment cost	<sup>a</sup> [12,14,20,22]
B11	Aesthetic challenges with rooftop systems	<sup>a</sup> [1,6,10,12,14,16,23]
B12	Variability in system performance or low yield	<sup>a</sup> [1,5,6,8,12,13,15,16,19]
B13	Distrust about system's lifespan or durability	<sup>a</sup> [6,7,9,12,14,16]
B14	Inadequate or lack of suitable installation space	<sup>a</sup> [1,4,6,9,10–12,16,22,30,43]
B15	Challenges of energy storage system requirements	<sup>a</sup> [5,8,18]
B16	Scarcity of solar radiation data/measuring centres	<sup>a</sup> [5,8,18,19]
B17	Neighbour impact considerations (e.g., reflections)	<sup>a</sup> [1,6]
B18	Lack of sufficient local manufacturing	<sup>a</sup> [4,5,9,18,19]
B19	Environmental benefits insufficient to justify investment	<sup>a</sup> [1,22]
B20	Perceived hurdles relating to installation and maintenance	<sup>a</sup> [1,6,13,16,42]
B21	Perception of early damage or breakdown of PV	<sup>a</sup> [2]
B22	Lack of information or well-known sources to acquire PVs	<sup>a</sup> [1,12,14]; <sup>b</sup> [33,35,36]
B23	Lack or limited knowledge regarding benefits	<sup>a</sup> [2,12,30]; <sup>b</sup> [34,35]
B24	Lack or low level of knowledge about existence of PV	<sup>a</sup> [12,18,21]; <sup>b</sup> [38]
B25	Lack of successful projects that people can observe	<sup>a</sup> [2,11,12,22]; <sup>b</sup> [33–37]
B26	Limited access to trustworthy dealers/skilled-manpower	<sup>a</sup> [3,5,6,8,10,12–14,18,19,21,42]; <sup>b</sup> [31,40]
B27	Scarcity of attractive offers to potential buyers	<sup>a</sup> [12]; <sup>b</sup> [35]
B28	Non-existence of aftersales service from installers	<sup>a</sup> [9,12]
B29	Liability insurance requirements	<sup>a</sup> [6,30]
B30	Structural issues in existing buildings	<sup>a</sup> [6,10,12]
B31	Lack of in-house capacity for solar initiatives	<sup>a</sup> [6]
B32	Challenges between tenants and home-owners (e.g. property succession hurdles)	<sup>a</sup> [1,6,16]
B33	Perception of non-value adding to property	<sup>a</sup> [10]
B34	Uncertainty about the future developments of technology	<sup>a</sup> [11,14]
B35	Lack of well-defined rules for handling administrative requirements	<sup>a</sup> [9,14]
B36	Lack of competition in photovoltaic market	<sup>a</sup> [18]
B37	Lack of sufficient market base	<sup>a</sup> [5,18]
B38	Grid access cost	<sup>a</sup> [20]
B39	Fear of theft or vandalism of system	<sup>a</sup> [29]
B40	Narration of negative experience from adopter	<sup>a</sup> [29]
B41	Lack of interest or demand from end users	<sup>a</sup> [16,22]; <sup>b</sup> [33,35–37,39]; <sup>a</sup> [43]
B42	Lack of clear policy direction	<sup>a</sup> [6]; <sup>c</sup> [24,25]
B43	Resistance to change or new technology	<sup>a</sup> [8,18]; <sup>b</sup> [31,34–36,38]; <sup>c</sup> [24–26,28]
B44	Lack of/inadequate financial incentives from government	<sup>a</sup> [4–6,9,10,11,13,18,19,21,42]; <sup>b</sup> [33–39]
B45	Lack of/inadequate regulatory framework from government	<sup>a</sup> [3–6,8,10,11,18–21,30]; <sup>b</sup> [32,34,38,39]
B46	Lack of strong political will and leadership	<sup>a</sup> [5,18,19]
B47	Political instability	<sup>a</sup> [9,18]

Code	Description of barriers	Key References
B48	Inconsistent or changing fiscal incentives	<sup>a</sup> [16,30]
B49	Limited commitment to operationalising university policies	<sup>a</sup> [43]
B50	Limited appreciation of the benefits gained from PV use	<sup>a</sup> [43]
B51	Inadequate funding for infrastructure development	<sup>a</sup> [43]
B52	Lack of demand from government project financiers	<sup>a</sup> [43]
B53	Disbelief regarding the benefits of green building technologies	<sup>b</sup> [34,35]
B54	Lack of green building codes and regulations	<sup>b</sup> [32,33,35,36]
B55	Lack of green building rating systems	<sup>b</sup> [35]
B56	High risks and uncertainties associated with investment	<sup>b</sup> [34–36]
B57	Low public awareness/acceptance of environmental issues	<sup>b</sup> [38,39]
B58	Perceived limited benefit to enterprise reputation	<sup>b</sup> [39]
B59	Lack of appreciation of long-term economic benefits	<sup>b</sup> [39,40]; <sup>c</sup> [41]
B60	Lack of support from management	<sup>b</sup> [38]; <sup>c</sup> [27,28,41]
B61	Lack of green building targets	<sup>c</sup> [27]
B62	Lack of commitment towards sustainability	<sup>c</sup> [24,25,28,41]
B63	Lack of planning and focus on the topic	<sup>c</sup> [24,25]
B64	Lack of specific sustainability working groups/office	<sup>c</sup> [24,25]; <sup>a</sup> [43]
B65	Lack of sustainability reporting and accountability	<sup>c</sup> [27]
B66	Lack of incentive for reducing building operational cost	<sup>c</sup> [26,27]
B67	Lack of sustainability advisor/champion	<sup>c</sup> [41]

Notes: <sup>a</sup> PV-specific literature; <sup>b</sup> Green building literature; <sup>c</sup> Campus sustainability literature

References are as follows:

1 = Balcombe *et al.* (2014);

2 = Kurata *et al.* (2018);

3 = Pode (2010) ;

4 = Shah *et al.* (2019);

5 = Ansari *et al.* (2013);

6 = Mah *et al.* (2018);

7 = Roberts and Sims (2008);

8 = Sindhu *et al.* (2016b);

9 = Garlet *et al.* (2019);

10 = Zhang *et al.*, (2012);

11 = King *et al.* (2014);

12 = Walters *et al.* (2018a);

13 = Qureshi *et al.* (2017);

14 = Palm (2018);

15 = Palm and Tengvard (2011);

16 = Vasseur and Kemp (2015);

17 = Zhang *et al.* (2011) ;

18 = Sindhu *et al.* (2016a);

19 = Nandal *et al.* (2019);

20 = Rosales-Asensio *et al.* (2019);

21 = Seetharaman *et al.* (2019);

22 = Mundaca and Samahita (2020);

23 = Bach *et al.* (2020);

24 = Ávila *et al.* (2017);

25 = Ávila *et al.* (2019);

26 = Kasai and Jabbour (2014);

27 = Richardson and Lynes (2007);

28 = Shriberg, (2003);

29 = Eronini (2014);

30 = Pickerill (2018);

31 = Abidin *et al.* (2013);

32 = Hoxha and Shala (2019);

33 = Potbhare *et al.* (2009);

34 = Azeem *et al.* (2017);

35 = Chan *et al.* (2018);

36 = Nguyen *et al.* (2017);

37 = Mesthrige and Kwong (2018);

38 = Wang *et al.* (2018);

39 = Wu *et al.* (2019);

40 = Yas and Jaafer (2020);

41 = Awuzie and Emuze (2016);

42 = Arroyo and Carrete (2019);

43 = Geh *et al.* (2022a)

Lack of financial resources is an obvious reason for non-adoption and has been identified by several scholars as a major challenge to the deployment of PVs, the construction of GBs, and the implementation of CS initiatives within several HEIs (Ávila et al., 2019; Azeem et al., 2017; Balcombe et al., 2014). Equally, the lack of access to loans/credit facilities can result in non-adoption (Pode, 2010; Rosales-Asensio *et al.*, 2019). With scarce resources, there is pressure to allocate resources to needs with higher priority goals, and this makes it even more difficult to fund PV projects even if there is interest. Sometimes, the reason is that end-users do not have any interest and scholars, such as Mundaca and Samahita (2020), and Vasseur and Kemp (2015), have documented this as a barrier. Furthermore, some potential end-users are satisfied with the current electricity supplier (i.e. from the grid) (Bach *et al.*, 2020; King *et al.*, 2014), or they consider electricity supplied by the grid to be much cheaper (Mah *et al.*, 2018). Uncertainty about recouping investment costs, grid access costs, and liability of insurance has also been cited as barriers (Mah *et al.*, 2018; Pickerill, 2018; Rosales-Asensio *et al.*, 2019). Indirectly, unemployment, which signals the unavailability of finance, has also been mentioned in the literature as an important barrier to the uptake of PVs (Briguglio and Formosa, 2017).

Insight from the literature also indicated that, apart from outright purchase, the availability of other acquisition methods, such as leasing and PPA, encourages adopting the technology, especially by end-users who do not have the capital for upfront payment (Rai and Sigrin, 2013). Thus, the unavailability or complexity of lease or power purchase agreement (PPA) contracts in some markets can hinder adoption (Rai *et al.*, 2016; Rosales-Asensio *et al.*, 2019). Besides the absence of alternative acquisition options, uncertainty about the performance of PV systems (i.e. gaining the promised efficiency) or general mistrust of PVs (Vasseur and Kemp, 2015), fear that the system might break down easily (Kurata *et al.*, 2018), and distrust of system durability/lifespan (Palm, 2018; Roberts and

Sims, 2008; Walters *et al.*, 2018a) are also factors that must be addressed to increase the diffusion of PV technology. Similarly, overcoming barriers such as a lack of sufficient local manufacturing of PVs (Garlet *et al.*, 2019; Shah *et al.*, 2019), scarcity of solar radiation data or radiation measuring centres (Ansari *et al.*, 2013; Nandal *et al.*, 2019; Sindhu *et al.*, 2016a, 2016b), clearing the uncertainty of end-users about future developments of the technology (Palm, 2018) is necessary, and the belief that PVs do not add value to the property (Zhang *et al.*, 2012) is an evident need that must be championed by relevant stakeholders to increase adoption of the technology in society.

Roofs and façades might be altered substantially when PVs are attached to them and this can affect building aesthetics. For this reason, home-owners tend to raise aesthetic challenges, especially with respect to rooftop-mounted PVs. It was suggested in the literature that people will not adopt PV systems because they believe the systems are not visually appealing or not congruent with local housing styles and traditions (Bach *et al.*, 2020; Balcombe *et al.*, 2014; Mah *et al.*, 2018; Palm, 2018; Vasseur and Kemp, 2015).

Photovoltaic systems take up space, either on the ground or on a building/rooftop. Whereas the availability of space facilitates the installation of PV systems (Briguglio and Formosa, 2017), the unavailability or inadequacy/unsuitability of space to install PVs could also hinder adoption. In some cases cited, existing regulations require high-rise, public housing blocks to reserve rooftop areas as a refuge for occupants in case of fire and this could limit the space that is available for PV installation (Mah *et al.*, 2018). Non-adoption could also be the result of poor solar orientation of homes and roof architecture (Garlet *et al.*, 2019) or the need for a large space to produce a sizeable quantity of electricity to satisfy demand, referred to as ‘too much space’ by Balcombe *et al.* (2014, p. 409). At other times, non-adoption could result from structural challenges, fear of damage to the roof causing leaks,

or shade from tall adjacent buildings (Walters *et al.*, 2018a). In Hong Kong, Zhang *et al.* (2012) found that the lack of space in individual buildings for installing solar energy was a significant barrier. Therefore, Zhang *et al.* (2012, p. 246) proposed that, for solar energy systems to be maximised, ‘BIPV can be considered as an alternative approach to solving Hong Kong’s “limited roof area” problem.

For PV systems to function efficiently, it is necessary to establish a systematic maintenance culture. This added responsibility and cost (or hurdle) can also result in non-adoption (Balcombe *et al.*, 2014; Mah *et al.*, 2018; Sindhu *et al.*, 2016a; Zhang *et al.*, 2012). Inadequate local manufacturers (Ansari *et al.*, 2013; Shah *et al.*, 2019), and the perception that environmental benefits are too small (Balcombe *et al.*, 2014; Mundaca and Samahita, 2020) have all been cited in the literature as barriers to adoption.

For end-users who do not have the technical expertise to install and maintain PV systems, the availability of established and trustworthy dealers or installers is important for adopting the technology. Therefore, it is not surprising that the lack of, or confirmed access to, trustworthy dealers or skilled personnel is cited as a barrier by scholars (Mah *et al.*, 2018; Pode, 2010; Qureshi *et al.*, 2017). In addition, although there might be service providers, if aftersales service (maintenance services) is non-existent or service delivery is poor, it could deter people from adopting the technology because of concerns about inability to service the product when the need arises in the future.

Findings from further review of research suggested that property ownership plays a key part in the adoption/non-adoption of PVs. For example, people perceive that they will lose money if they move homes (Balcombe *et al.*, 2014), or the fact that they are not homeowners deters them from investing in the installation of PVs (Vasseur and Kemp, 2015). Also, the hurdles involved when installing PVs can generate a negative feeling about using

PV systems (Mah *et al.*, 2018). To encourage investment in rental dwellings, it was suggested that there should be arrangements that can facilitate PV investments between tenants and home-owners. For instance, there could be schemes such as investment agreements to which both parties can commit and sign (Briguglio and Formosa, 2017).

Further barriers mentioned by scholars are: lack of, or limited, knowledge regarding benefits; lack of, or low level of, knowledge about the existence of PVs; scarcity of attractive offers and promotions; resistance to change (Walters *et al.*, 2018a); lack of well-known sources from which to acquire information; concern for neighbours regarding annoyance or reflections/radiation (Balcombe *et al.*, 2014; Mah *et al.*, 2018); a lack of or the low number of successful projects that people can observe (Kurata *et al.*, 2018; Mundaca and Samahita, 2020; Walters *et al.*, 2018a); lack of competition in the PV market and sufficient market base (Sindhu *et al.*, 2016a).

Mah *et al.* (2018) were some of the few scholars who investigated PV adoption in institutions and identified the lack of in-house capacity for solar initiatives, and lack of clear policy direction as important barriers. Similarly, Eronini (2014) mentioned fear of theft or vandalism as a barrier. According to Mundaca and Samahita (2020), peer effects can encourage adoption but, conversely, it was shown that narration of negative experiences by peers discourages adoption (Eronini, 2014).

In terms of financial barriers, for example, high upfront cost was identified as a factor in both developed and developing countries, and the power that government wields in either promoting or hampering adoption was also conclusive in all contexts. The positive influence that government exerts on nations in propelling the development of RE has been discussed extensively under Section 2.6.4.: Drivers of PV Adoption. In terms of barriers, it has been noted in the literature that lack of, or inadequate, fiscal incentives from

governments (FIT, rebates, tax credits) and non-fiscal incentives (mandatory RE target, regulatory policies) is negatively correlated to the diffusion of PV technology in several countries, including Tanzania and Zimbabwe (Pode, 2010), Pakistan (Qureshi *et al.*, 2017; Shah *et al.*, 2019), India (Ansari *et al.*, 2013; Nandal *et al.*, 2019; Sindhu *et al.*, 2016a, 2016b), Brazil (Garlet *et al.*, 2019), China and Hong Kong (Zhang *et al.*, 2012), and USA (King *et al.*, 2014; Pickerill, 2018). Additionally, the lack of strong political will and leadership or political instability (Sindhu *et al.*, 2016a), as well as inconsistent or changing fiscal incentives can make adoption less attractive (Pickerill, 2018).

## **2.7. Public Universities in South Africa**

There are 26 public universities located across all nine provinces of SA, as listed in Table 2.4, and each province has at least one university (Universities South Africa (USAF), n.d.). The 26 public universities are segmented into 11 general academic universities, 9 comprehensive universities and 6 universities of technology. The report released in March 2020 by the Department of Higher Education and Training (DHET) contained comprehensive information about post-school education and training institutions (PSET). It was reported that, in 2019, student enrolment in all 26 public universities was 1 074 912. Females constituted the highest proportion of students (59.6%) enrolled in 2019, while 40.4% were males. The student population in the institutions increased by 28.3% (237 136) between 2009 and 2019. In 2019, the permanent staff at public HEIs consisted of 64 124 of which 31 952 were administrative staff, 19 901 were instruction and research staff, and 12 271 were services staff. In the same year, public universities received R 42.3 billion and, collectively, between 2010 to 2019, the funding to HEIs stood at R 294.3 billion (DHET, 2020). Student enrolment was reported to have increased to 1 094 808 in 2020 (DHET, 2021).

**Table 2.4: Public universities in South Africa**

No.	University	Website	2019 Student Enrolment*	2020 Student Enrolment**
1	Cape Peninsula University of Technology	www.cput.ac.za	33 941	32 383
2	Central University of Technology	www.cut.ac.za	21 225	21 103
3	Durban University of Technology	www.dut.ac.za	35 442	33 933
4	Mangosuthu University of Technology	www.mut.ac.za	14 328	14 652
5	Nelson Mandela University	www.mandela.ac.za	29 490	29 286
6	North West University	www.nwu.ac.za	63 671	56 425
7	Rhodes University	www.ru.ac.za	8 247	8 596
8	Sefako Makgatho Health Sciences University	www.smu.ac.za	6 456	6 256
9	Sol Plaatje University	www.spu.ac.za	1 994	2 386
10	Tshwane University of Technology	www.tut.ac.za	67 673	62 482
11	University of Western Cape	www.uwc.ac.za	23 784	23 730
12	University of Cape Town	www.uct.ac.za	28 641	28 447
13	University of Fort Hare	www.ufh.ac.za	16 982	15 880
14	University of Free State	www.ufs.ac.za	41 505	41 602
15	University of Johannesburg	www.uj.ac.za	50 590	48 563
16	University of KwaZulu-Natal	www.ukzn.ac.za	50 158	46 924
17	University of Limpopo	www.ul.ac.za	21 490	21 617
18	University of Mpumalanga	www.ump.ac.za	3 471	4 364
19	University of Pretoria	www.up.ac.za	50 594	50 955
20	University of South Africa	www.unisa.ac.za	342 797	392 050
21	University of Stellenbosch	www.sun.ac.za	31 523	30 995
22	University of Venda	www.univen.ac.za	16 783	15 166
23	University of Witwatersrand	www.wits.ac.za	40 890	40 667
24	University of Zululand	www.unizulu.ac.za	17 738	17 082
25	Vaal University of Technology	www.vut.ac.za	21 927	20 293
26	Walter Sisulu University	www.wsu.ac.za	33 572	28 971
Total			1 074 912	1 094 808

Notes: \* Source: DHET (2020, p.97)

\*\* Source: DHET (2021)

## **2.8. Overview of Literature and the Gap in Knowledge**

Evidently, literature on the diffusion of PVs has shown that the factors (i.e. drivers and barriers) that influence the adoption of PVs are numerous and they exist in both developed (Mundaca and Samahita, 2020) and developing countries (Shah *et al.*, 2019). Scholars have adopted qualitative, quantitative, and mixed-method approaches in their studies. The findings of the literature search showed further that, while there were many studies examining PV adoption/non-adoption at the individual/household level (Qureshi *et al.*, 2017) and the national/country level (Tidwell *et al.*, 2018), there were only a few published studies that were focused on PV adoption/non-adoption within organisations (Kurata *et al.*, 2018; Mah *et al.*, 2018). More specifically, it appeared that, currently, there has been no study in which PV adoption within SAPUs has been examined exclusively, and this examination would be worthwhile and fill the knowledge gap which currently exists.

## **2.9. Chapter Summary**

In this chapter, the literature on CS, GB/ZEB/ZCB, PV, and the factors that influence the diffusion of PVs were discussed. Generally, there was congruity in the findings of scholars and, in a few cases, there were divergent discoveries regarding the drivers and barriers. Overall, 55 drivers and 67 barriers were identified in the literature and presented in Tables 2.2 and 2.3, respectively. The next chapter contains an analysis of the different theories/models that explain the adoption of innovations and the conceptual framework of this study.

## CHAPTER 3: THEORETICAL AND CONCEPTUAL MODELS

### 3.1. Introduction

This chapter contains an overview of the theories that underpin the knowledge base of the phenomenon that was investigated and the conceptual framework for the study. Firstly, five theories/models are discussed: (1) Diffusion of Innovation (DOI) Theory, (2) Technology Acceptance Model (TAM), (3) Unified Theory of Acceptance and Use of Technology (UTAUT/UTAUT2), (4) Technology Organisation Environment Framework (TOE), and (5) Electronic Data Interchange Model (EDI). Secondly, the conceptual framework called the ‘PV Deployment Conceptual Framework’ (PVDCF) is presented, outlining the factors (barriers and drivers) that influence the uptake and upscaling of PV systems in a university context.

### 3.2. Overview of Theoretical Models and Conceptualisation

Theoretical and conceptual frameworks provide direction to research inquiries and make findings more meaningful and acceptable to the theoretical constructs in a research field (Adom *et al.*, 2018). According to Grant and Osanloo (2014), certain theories are popular and there is no perfect theory for research. However, with regard to research inquiries that relate to the adoption of innovations by individuals or organisations, theories such as DOI, TAM, UTAUT, the TOE framework and EDI model are commonly used by scholars (Hameed *et al.*, 2012; Kee, 2017; Lundblad, 2003). For this reason, these theories were also considered in developing the conceptual framework for this study.

Adopting innovation in an organisation is a complex process and researchers tend to give attention predominantly to the issues that affect the rate of adoption, with the aim of fast-tracking the uptake of beneficial innovations (Lundblad, 2003). A similar approach was taken in this study to identify the possible factors that influence the adoption processes so

that strategies could be devised to engender the uptake and upscaling of PVs for the advancement of building sustainability in universities.

The breakdown of the chapter in relation to the study objectives is provided in Table 3.1. Section 3.2 contains a review of the models/theories that helped to develop the conceptual framework. The conceptual framework is presented in Section 3.3 and this contributed significantly to addressing Objectives 2, 3, 4 and 5.

**Table 3.1: Breakdown of sections in relation to objectives**

Sections	Research Objectives				
	1	2	3	4	5
3.2 <sup>a</sup>				●	
3.3 <sup>b</sup>		●	●	●	●

<sup>a</sup> Provided the theoretical background for the development of the conceptual framework

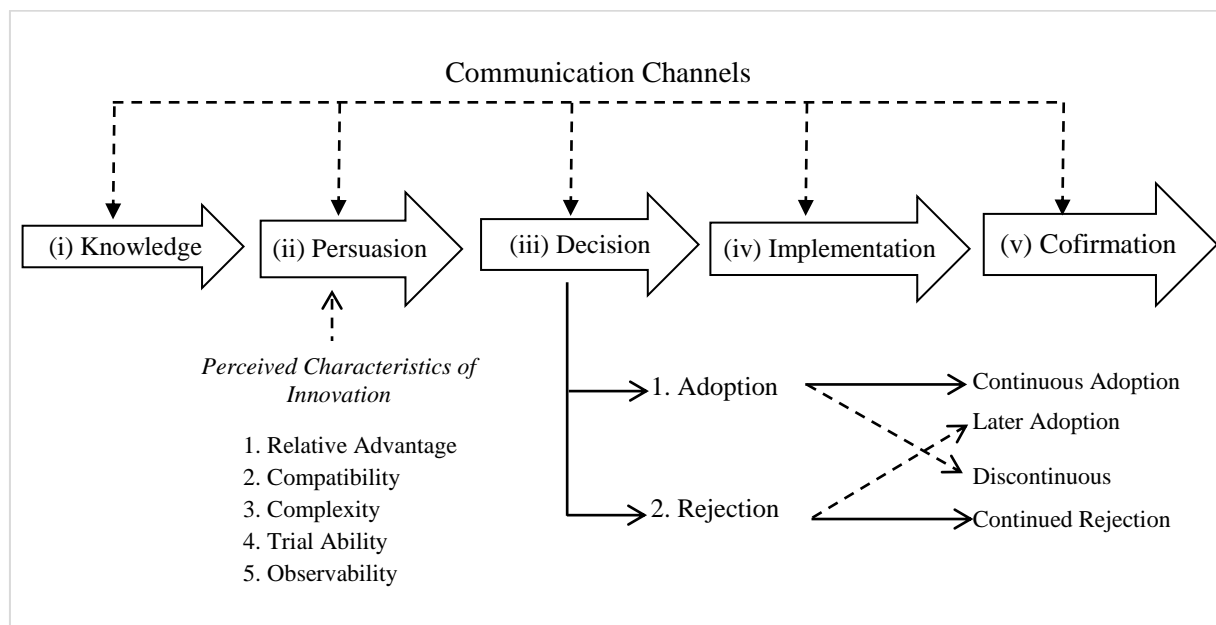
<sup>b</sup> Presented the conceptual framework which was used in Phases 5 and 6 to address Objectives 2, 3, 4, and 5

### **3.2.1. Diffusion of Innovation Theory**

The Diffusion of Innovation (DOI) theory, postulated by Rogers (1995), is often used to investigate how the diffusion of innovations develops. Rogers defined innovation as an object, technology, behaviour, practice or idea that is perceived to be new to potential adopters. In the theory, it is suggested that an adopter passes through the stages of awareness or knowledge formation, persuasion, decision to adopt or reject the innovation, followed by implementation and, finally, the confirmation of the decision, as illustrated in Figure 3.1. Knowledge, which is the foremost means of persuading decision-makers to reject or adopt an innovation, is influenced by: (1) previous practice, (2) felt needs/problems, (3) innovativeness, and (4) the norms of social systems. Next, at the persuasion stage, before deciding to reject or adopt an innovation, the influence on a potential adopter is based on five major characteristics of the innovation: (1) relative

advantage, (2) compatibility, (3) complexity, (4) trial ability, and (5) observability. Characteristics 1, 2, 4 and 5 are positively associated with the rate of adoption, whereas complexity has a negative correlation. Rogers (2003) defined the above attributes as:

- Relative advantage: the degree to which an innovation is considered better than its contemporaries;
- Compatibility: the degree of consistency of the innovation with existing values, past experiences and current needs of potential adopters;
- Complexity: the degree to which an innovation is perceived as relatively difficult to understand and use;
- Trial ability: the degree of experiencing the innovation on a trial basis, which reduces uncertainty and risks; and
- Observability: the visibility of innovation to others in order to see the results of innovation adopted in the social system.



**Figure 3.1: Rogers' Diffusion of Innovation Model**

*Source:* (Rogers, 2003, p. 209)

### 3.2.1.1. *DOI: Specific Attributes of Organisational Innovation Adoption*

In DOI theory, two phases for the decision process of organisational innovation were identified. First is the initiation phase when information is gathered and planning occurs: agenda-setting and matching. Thereafter, if an innovation is accepted for adoption, the implementation phase is initiated, which comprises three phases: restructuring/redefining, clarifying, and routinising. In reality, these stages are non-linear (Kee, 2017). Organisational structure and characteristics were also identified by Rogers (2003) to be influential in adopting innovation in organisations. These structures include centralisation, organisational complexity, formality, inter-connectivity, organisational slack (availability of resources), size, leadership, and system openness.

In DOI theory, three layers of decisions about innovation in an organisational setting were also introduced: optional, collective, and authoritative. These are defined as:

- Optional innovation decision: is when an individual within an organisation has the freedom of choice to decide whether to adopt an innovation or not;
- Collective innovation decision: is when members of an organisation (i.e. team, department, or the entire organisation) make a joint decision to adopt or reject an innovation; and
- Authoritative innovation decision: is when a few individuals decide on behalf of an organisation to adopt or reject an innovation, usually based on positional, expertise or status authority.

However, Rogers' model has been critiqued for its limited explanation of the variables that extend the innovation theory to organisations. In a review paper, Lundblad (2003) identified that, while the interaction of all the variables that influence the diffusion of innovation among individuals was well defined, the discussion of the variables pertinent to

organisations was superficial. That is, it was unclear how the variables interact to influence adoption in organisations, and whether organisational type, size, or industry affects adoption. Therefore, the points raised by Lundblad (2003) can be cited as the limitations of the model proposed by Rogers (2003). In summary, it is suggested in the theory that the adoption of innovation within organisations is highly influenced by the characteristics of organisations and the innovations.

#### *3.2.1.2. Applications of Diffusion of Innovation Theory*

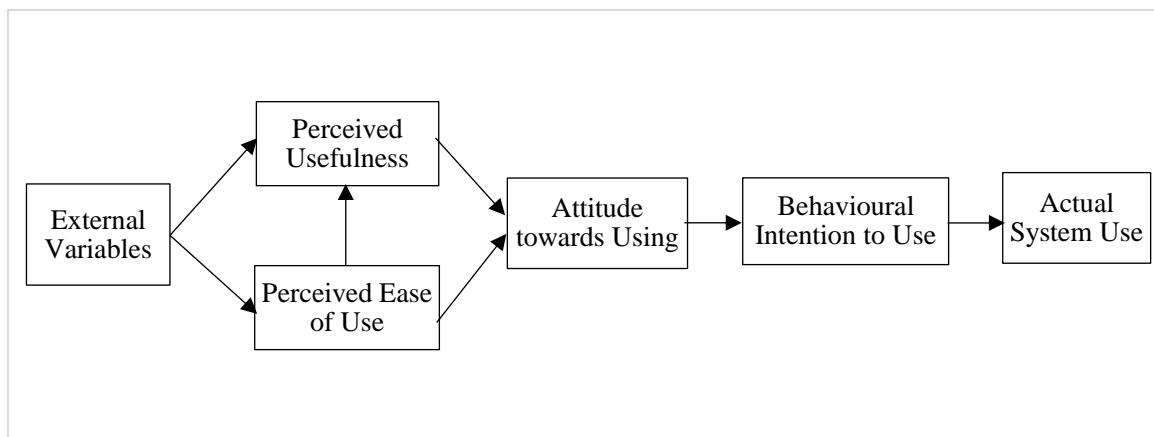
Although DOI was developed originally in the context of diffusing innovation in information technology (IT), empirical literature shows that the theory and, particularly the five attributes, have been employed mostly in investigating the diffusion of RE. For instance, some early research on the adoption of solar energy technology, such as the work of Labay and Kinnear (1981) and Kaplan (1999), used Rogers' popular innovation diffusion model as the theoretical foundation for their studies. Recently, Qureshi *et al.* (2017) used the attributes to identify the determinants that influence the decisions of households to adopt PVs in Lahore, Pakistan. Qureshi *et al.* (2017) found that high initial cost was the topmost barrier. Kapoor and Dwivedi (2020) also adopted DOI theory and, based on their study, they suggested that relative advantage and compatibility strongly influenced consumer intentions, and that such behavioural intentions had a significantly positive effect on the adoption of solar equipment. Other studies of innovation diffusion that included DOI theory in the research framework include research by Franceschinis *et al.* (2017) and Wang *et al.* (2019).

#### *3.2.2. Technology Acceptance Model*

The Technology Acceptance Model (TAM), shown in Figure 3.2, was developed and validated by Davis (1989). Similar to the Theory of Planned Behaviour (Ajzen, 1991),

TAM was also adapted from the Theory of Reasoned Action (Fishbein and Ajzen, 1975). Briefly, according to TAM, an adopter's behavioural intention to use an innovation can be predicted by examining the perceived usefulness and perceived ease of use of the innovation. It is suggested further that perceived usefulness and ease of use are also influenced by external variables. Davis (1989, p. 320) defined the major constructs of TAM as:

- Perceived usefulness: the degree to which a person believes that using a particular system would enhance his or her job performance; and
- Perceived ease of use: the degree to which a person believes that using a particular system would be free of effort.



**Figure 3.2: Technology Acceptance Model**

*Source: (Davis et al., 1989, p. 985)*

The two case studies that were conducted to test the validity of the model showed that “usefulness was significantly more strongly linked to usage than was the ease of use” (Davis, 1989, p. 333).

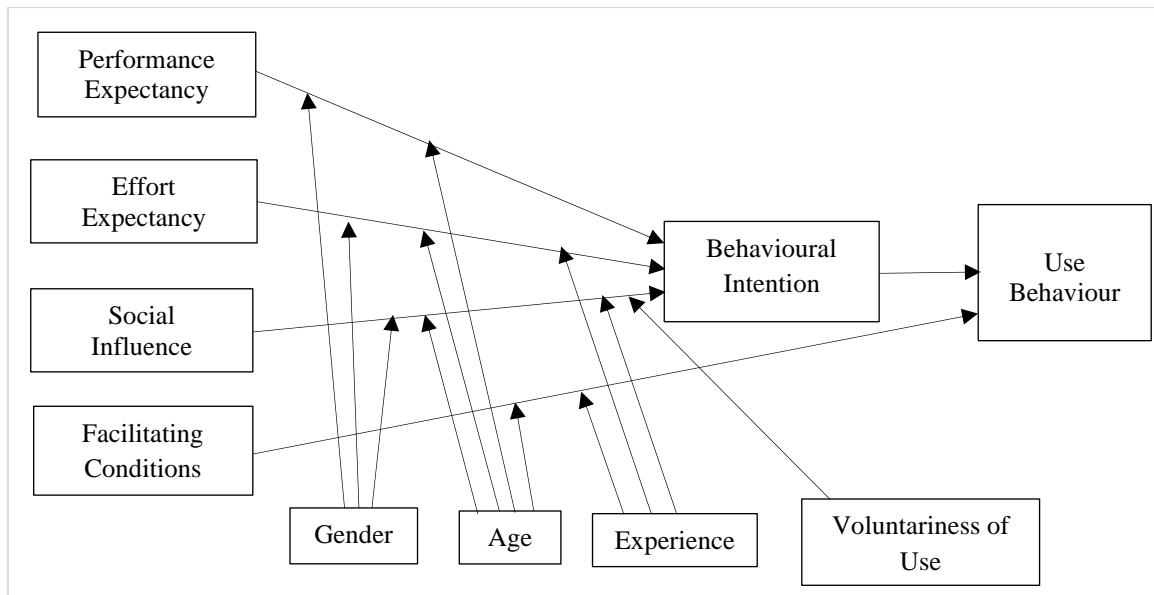
### 3.2.2.1. *Applications of Technology Acceptance Model*

In the empirical literature, evidence is provided that TAM can be relevant to research about the diffusion of RE (Akroush *et al.*, 2019; Kim *et al.*, 2014). The model can also be adapted to study the diffusion of innovation in areas of research mainstream about construction. For example, Wang *et al.* (2019) used TAM in combination with DOI theory to study the spread of GBTs in China. The model has also been used widely in the IT sector to study the diffusion of various innovations (Hameed *et al.*, 2012)

### 3.2.3. *Unified Theory of Acceptance and Use of Technology*

In the Unified Theory of Acceptance and Use of Technology (UTAUT), eight previously established models were adapted and synthesised (Venkatesh *et al.*, 2003). The UTAUT model, as shown in Figure 3.3, has four core determinants of behavioural intention and usage: (1) performance expectancy, (2) effort expectancy, (3) social influence, and (4) facilitating conditions. The model also includes four moderators of key relationships: (1) gender, (2) age, (3) experience, and (4) voluntariness of use. The four core determinants of behavioural intention and usage are defined by Venkatesh *et al.* (2003) as:

- Performance expectancy: the degree to which an individual believes that using the system will help to attain gains in his or her job;
- Effort expectancy: the degree of ease associated with the use of the system;
- Social influence: the degree to which an individual perceives how others believe that it is important that he or she should use the new system; and
- Facilitating conditions: the degree to which an individual believes that an organisational and technical infrastructure exists to support the use of the system.

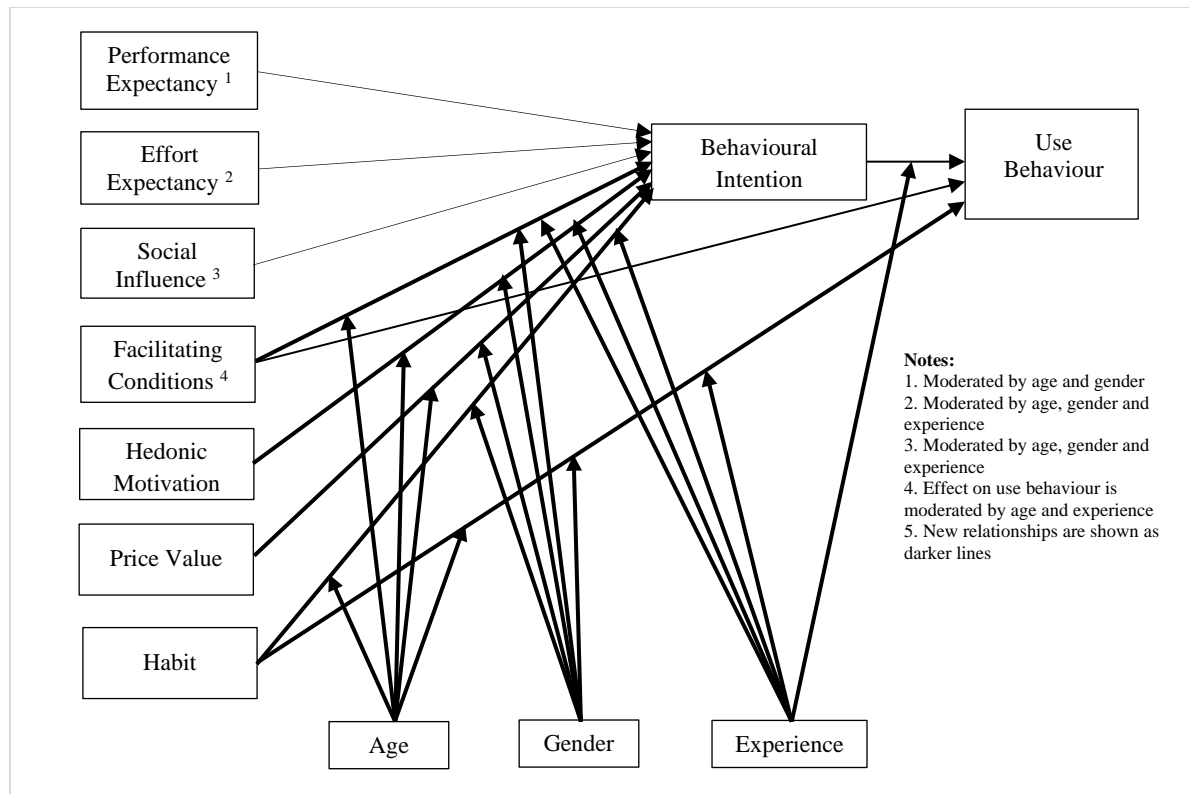


**Figure 3.3: UTAUT model**

*Source: (Venkatesh et al., 2003, p. 447)*

Almost a decade after introducing UTAUT, Venkatesh et al. (2012) modified the model by adding hedonic motivation, price value, and habit as additional determinants of behavioural intention and usage, and removing voluntariness of use as moderator, and called the revised model UTAUT2 (Figure 3.4). The additional constructs were defined as:

- Hedonic motivation: the fun or pleasure derived from using technology;
- Price value: the consumers' cognitive trade-off between the perceived benefits of the applications and the monetary cost of using technology; and
- Habit: the extent to which people tend to perform behaviours automatically because of learning.



**Figure 3.4: UTAUT2 model**

Source: (Venkatesh *et al.*, 2012, p. 160)

### 3.2.3.1. Applications of UTAUT and UTAUT2

UTAUT and UTAUT2 have been used by scholars to examine the decision-making process of adoption used by individuals. For instance, Mulugo *et al.* (2019) adopted UTAUT and used the structural equation modelling (SEM) technique to examine farming practices in central Uganda. Mulugo *et al.* (2019) identified social influence and farmer innovativeness as significant predictors of farmers' intention to use tissue culture planting materials. In a different study, using UTAUT, Muriithi *et al.* (2016) found that performance expectancy and facilitating conditions were the most frequent influencers in the adoption of information communication technology for collaborative research. Furthermore, UTAUT has been adapted to develop the Integrated Acceptance and Sustainability Assessment Model (Aizstrauta *et al.*, 2015), which was used to study factors behind the adoption and non-adoption of PVs in the Netherlands (Vasseur and Kemp, 2015). UTAUT2 has also

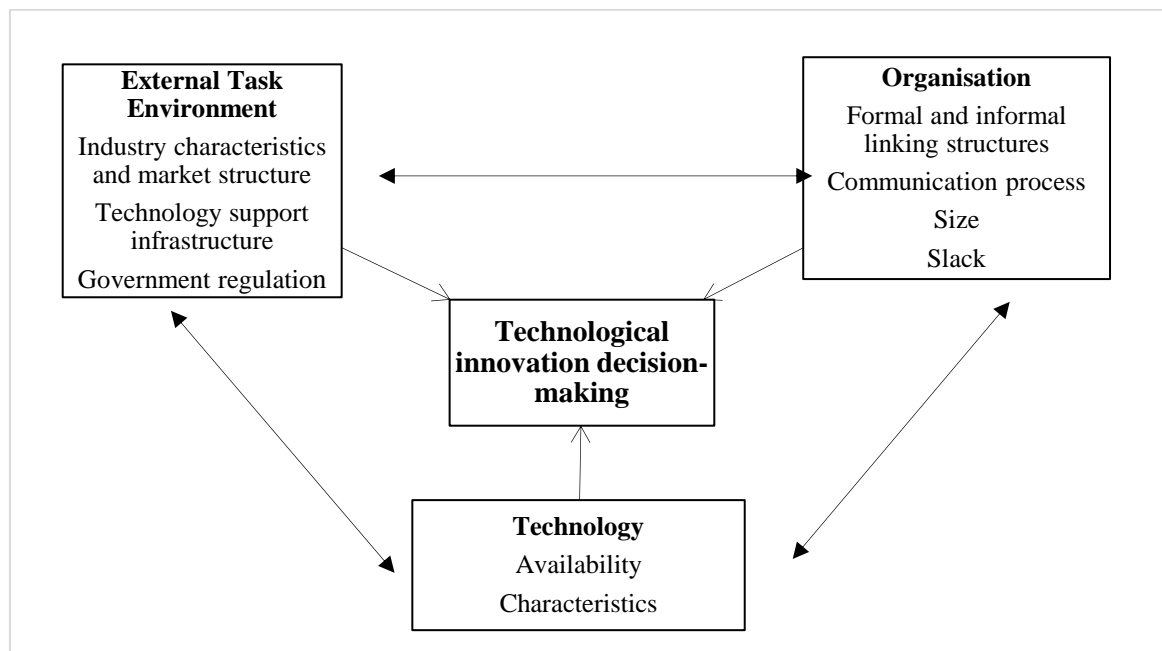
been used by Gimpel *et al.* (2020) to study the determinants of the adoption of smart energy technology in Europe, Asia, and North America. Other scholars who have also used UTAUT2 were reported by Tamilmani *et al.* (2019).

### ***3.2.4. Technology, Organisation and Environment Framework***

Using the Technology, Organisation and Environment (TOE) framework, which is shown in Figure 3.5, Tornatzky and Fleischer (1990) provided the basis for understanding the process of adoption of innovations at an organisational level. In the TOE framework, it is postulated that diffusion is determined by technological, organisational, and environmental elements. Firstly, the technological construct is used to examine the availability and characteristics of the technology. Secondly, the various aspects of an organisation are explored in the organisational context, for example, the size and structure, degree of centralisation, human resources, and the availability of internal resources. Thirdly, factors such as the characteristics of the industry (e.g. size and structure), the availability of technology service providers, and the economic and regulatory environment in which the organisation operates are considered in the environmental context.

#### ***3.2.4.1. Applications of TOE Framework***

The TOE framework was used by Awa *et al.* (2016) to show that the adoption of enterprise resource planning (ERP) software by Nigerian small and medium enterprises was driven primarily by technological factors as opposed to organisational and environmental factors.



**Figure 3.5: TOE framework**

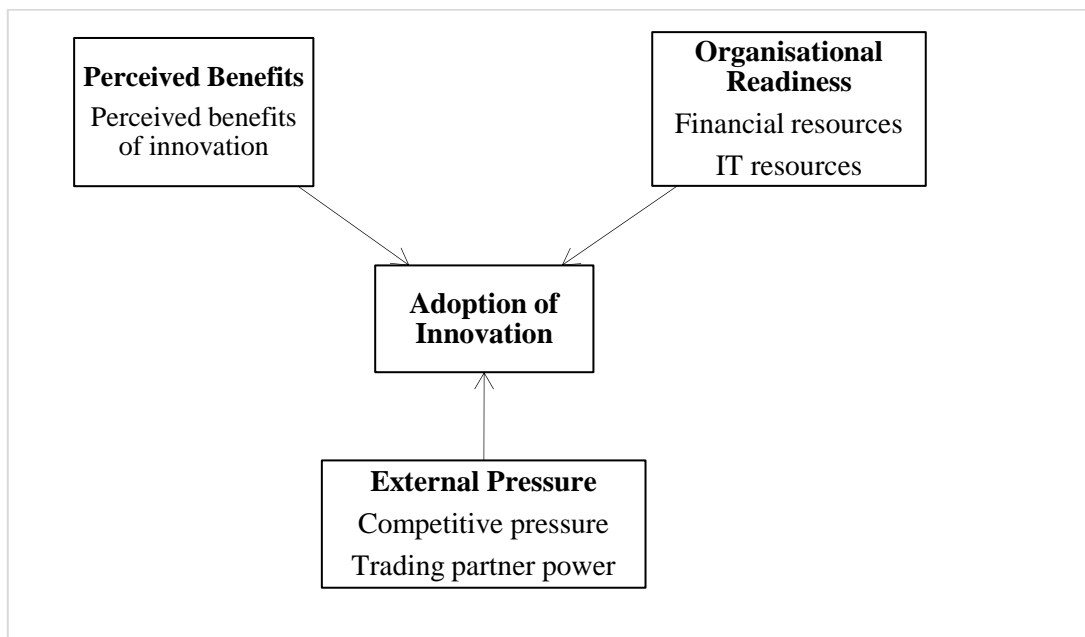
*Source:* (Tornatzky and Fleischer, 1990, p. 71)

In a different study by bin Ibrahim and binti Jaafar (2016), TOE was used with the Theory of Planned Behaviour, to introduce behaviour, attitude, and awareness mediators that were lacking in TOE. The findings from this study suggested that the environmental factor was the most influential factor affecting the adoption of environmental management practices among the Federation of Malaysian Freight Forwarders, followed by organisational and technological factors (bin Ibrahim and binti Jaafar, 2016). Furthermore, Arpaci *et al.* (2012), Baker (2012), and Oliveira and Martins (2014) cited several authors who adopted the TOE framework to research the diffusion of IT innovation.

### **3.2.5. Electronic Data Interchange Model**

With a view to facilitating high penetration of Electronic Data Interchange (EDI) in small firms, Iacovou *et al.* (1995) found that perceived benefits, organisational readiness, and external pressure were the three core factors that influenced adoption (Figure 3.6).

Perceived benefits are potential advantages that the technology has to offer (both directly and indirectly); organisational readiness is related to the level of technological (e.g. hardware, expertise, and a competent project lead) and financial resources available in the firm; and external pressure is the influences from the organisational environment: competitive pressure, and imposition by trading partners (Iacovou *et al.*, 1995). The major distinction between the EDI model and the TOE framework is that a new category of factors, called perceived benefits, was introduced in the EDI model, and the technological and organisational context of the TOE framework was combined under one category, called organisational readiness.



**Figure 3.6: EDI Adoption Model**

Source: (Iacovou *et al.*, 1995, p. 480)

#### 3.2.5.1. Applications of EDI Theory

Chwelos et al. (2001) used the EDI model to examine the diffusion of EDI. Chwelos et al. (2001) found that, although perceived benefits, organisational readiness, and external pressure were significant in predicting the intention to adopt EDI, the last two factors were considered more important than perceived benefits. In a different study, it was found that

small businesses were more concerned about immediate and direct benefits as opposed to long-term indirect benefits of adopting electronic data interchange (Chau and Hui, 2001).

### **3.3. Conceptual Model**

#### **3.3.1. General Overview**

The factors driving or inhibiting the diffusion of innovations have been widely researched in many countries and different sectors. As shown in the previous sections, in most studies, popular theories, such as DOI, TAM, UTAUT/UTAUT2, TOE and EDI models, were used to guide the development of conceptual frameworks. As suggested by Simon and Goes (2011), a research framework could be based on either a theory or logic. Thus, by examining the theories discussed above and synthesising prior empirical studies, the conceptual framework, referred to as the ‘PV Deployment Conceptual Model (PVDCM)’ was proposed in this study, as shown in Figure 3.7. In other words, theories and past empirical studies were used to assist in selecting the variables that covariate with the adoption of PV technology in a university context.

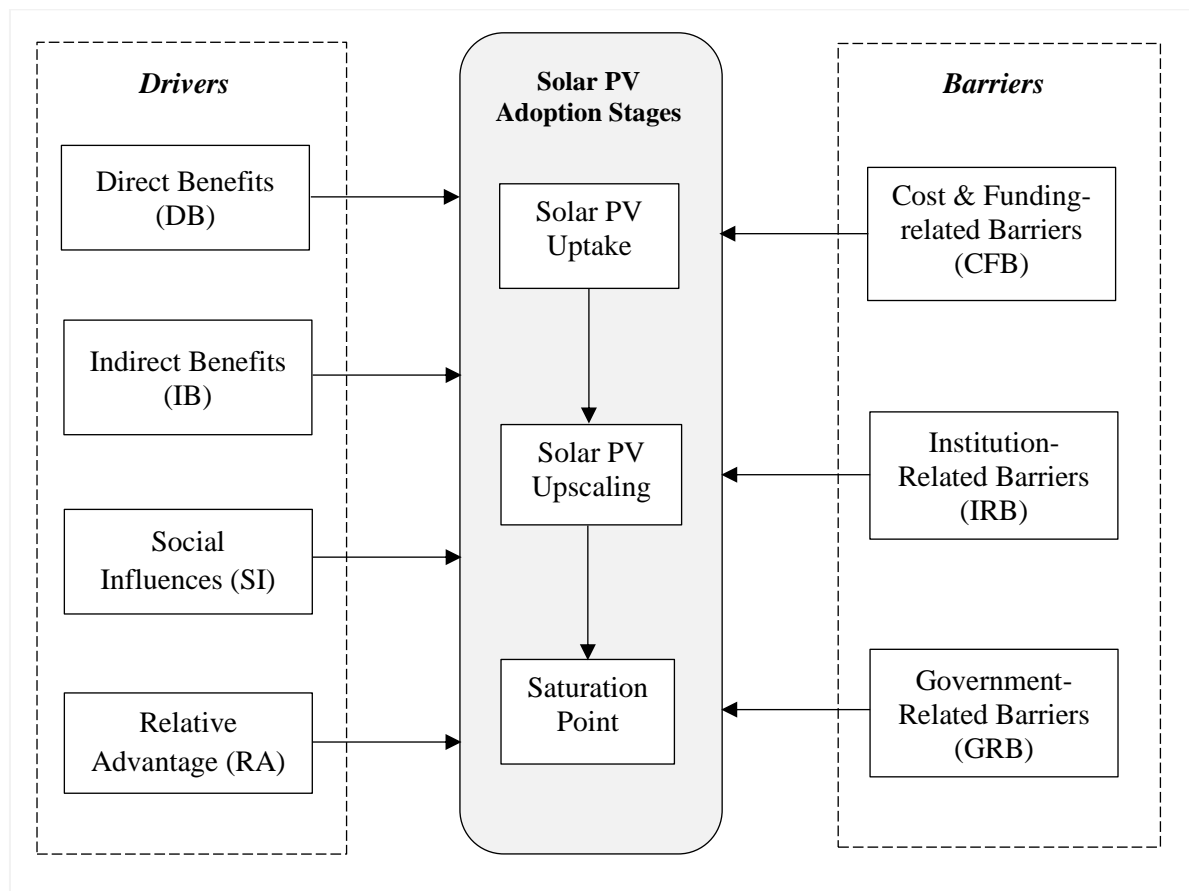
A total of seven main categories of factors (four categories of drivers and three categories of barriers) were identified as the potential cluster of determinants of PV uptake and upscaling in universities. The CP was developed by setting all seven constructs as latent exogenous variables, and PV uptake, PV upscaling, and saturation point as the endogenous variables. Each of the seven constructs was measured by three or more indicators.

The development of the conceptual model was premised on one main assumption. Knowledge has been identified as a key predictor of the adoption of innovation (Davis, 1989; Rogers, 1995; Venkatesh *et al.*, 2003, 2012). However, knowledge was not included in the conceptual model based on the assumption that the knowledgeableability of universities is not disputed. This is because, as progenitors of knowledge generation, universities are

very knowledgeable about the innovation of PVs and institutions are aware that the installation of PVs is beneficial (Richardson and Lynes, 2007; Shriberg, 2003).

### 3.3.2. *Dependent Variables: PV Adoption Stages*

Universities are large entities and are even considered to be small towns (Dave *et al.*, 2014). Unlike individuals or households, who can deploy PV systems in one instalment to meet all their energy demands, this is not the case for universities. Therefore, the viewpoint taken in this study was that the diffusion of PVs in a university is a progressive process instead of a once-off event. As an incremental development, adoption begins when an organisation installs the first PV system to meet the energy demand partly in a university facility. This is labelled ‘Solar PV Uptake’ in Figure 3.7.



**Figure 3.7: PV Development Conceptual Model (PVDCM)**

*Source: Researcher's construct*

The ‘Solar PV Uptake’ phase can be referred to as the ‘trialability’ of the technology in a university, which parallels the ‘trialability’ constituent in the DOI model of Rogers (2003). Acceptance in this phase is necessary to move to the next phase which is the continuous adoption of the technology. Continuous adoption mode is activated when a university develops additional PV systems to augment the first installation, to increase generation capacity and this is referred to as ‘Solar PV Upscaling’. This phase does not entail the addition of only one system, but it can comprise the installation of several systems over a period. The primary objective at this stage is for an institution to reach a saturation point where all opportunities for investment in PV are exhausted. This phase is labelled ‘Saturation Point’ in the model. The saturation point can be reached when all available spaces and options (e.g. building façade, roof spaces, open spaces, etc.) have been reasonably utilised for solar electricity generation.

### ***3.3.3. Independent Variables: Drivers***

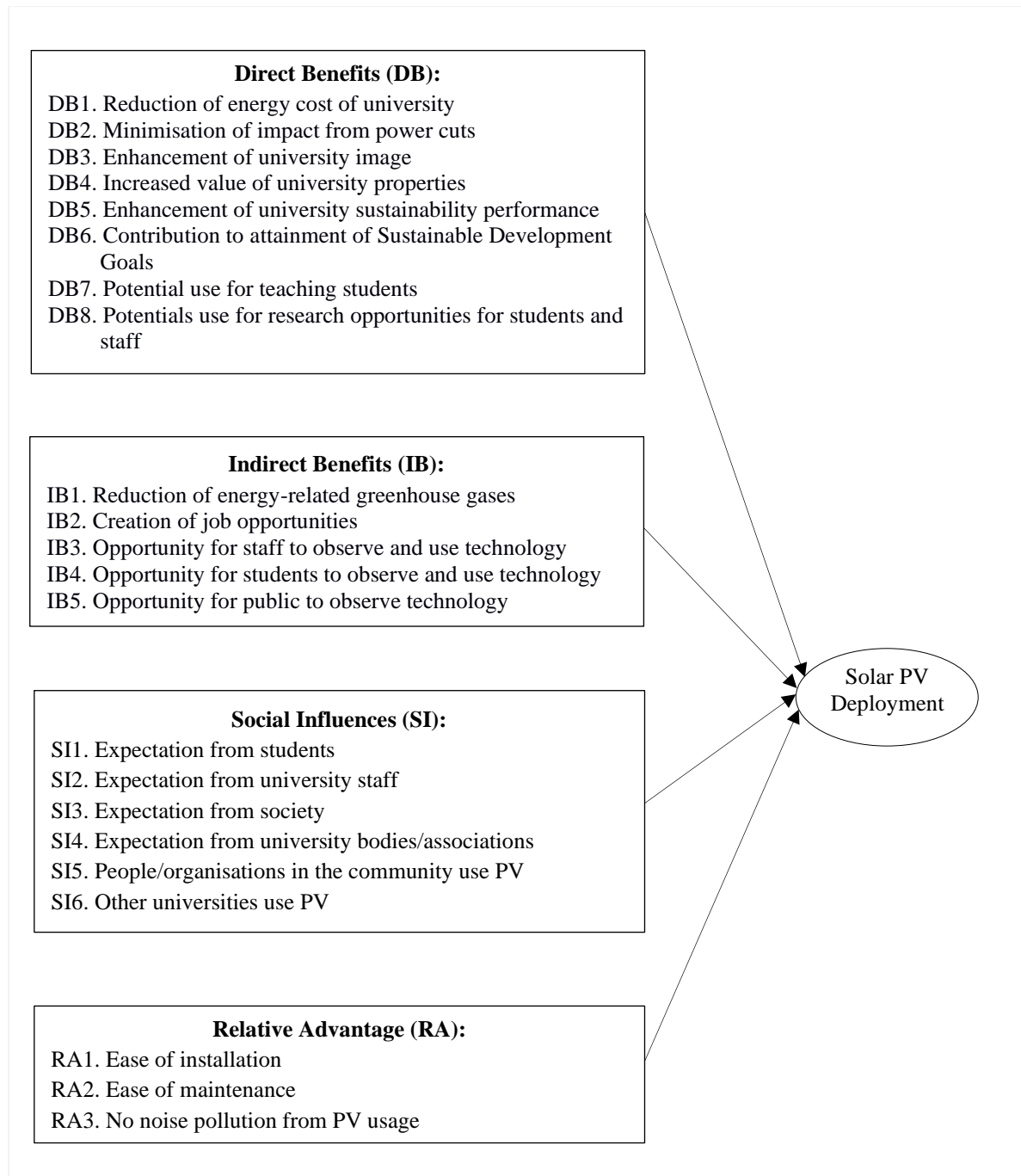
Drivers are positive influencers of the diffusion of innovations, and researchers have approached the study of drivers from different perspectives, depending on their objectives. The study had an objective to identify the drivers which are relevant for promoting the deployment of PV systems in universities. Hence, four core areas which were validated empirically to be relevant were selected to form the constructs: (1) direct benefits, (2) indirect benefits, (3) social influences, and (4) relative advantage.

Firstly, adopters use PVs because of the expected benefits or usefulness. Perceived benefits are potential advantages that innovation can offer (i.e. both direct and indirect benefits) and are positively related to the adoption of innovation (Davis, 1989; Iacovou *et al.*, 1995). Specifically, Iacovou *et al.* (1995) used the words ‘perceived benefits’, while Davis (1989) used ‘perceived usefulness’.

Secondly, it has been validated empirically that the relative advantage of technology has a positive impact on the rate of diffusion (Rogers, 1995), and it has been confirmed to apply to the diffusion of RE (Kapoor and Dwivedi, 2020). Relative advantage has equivalent constructs in other models such as ‘perceived ease of use’, which was applied in TAM by Davis (1989), and ‘effort expectancy’, which was applied in UTAUT by Venkatesh et al. (2003). Lastly, the effect of social influences on the diffusion of innovations was proposed by Rogers (1995) and Venkatesh *et al.* (2003).

**Table 3.2: Conceptual model constructs: Drivers**

No.	Code	Constructs	Related references
1	DB	Direct Benefits	<i>Theoretical references:</i> Perceived benefits (Iacovou <i>et al.</i> , 1995); Relative advantage (Rogers, 1995); Perceived usefulness (Davis, 1989); Performance expectancy (Venkatesh <i>et al.</i> , 2003)
2	IB	Indirect Benefits  Definition: potential advantages that the technology has to offer.	<i>Empirical references:</i> Perceived benefits (Kim <i>et al.</i> , 2014); Benefits (Vasseur and Kemp, 2015); Benefits (Bergek and Mignon, 2017); Benefits expected of technology (Peek <i>et al.</i> , 2014); Value (Aggarwal <i>et al.</i> , 2019)
3	SI	Social Influences  Definition: the degree to which an organisation perceives how others (persons/organisations) believe it is important that they should use PV	<i>Theoretical references:</i> Norms of the social systems (Rogers, 1995); Social influence (Venkatesh <i>et al.</i> , 2003, 2012); External pressure (Iacovou <i>et al.</i> , 1995)  <i>Empirical literature references:</i> Social influence (Vasseur and Kemp, 2015); Social influence (Peek <i>et al.</i> , 2014); Social barriers (Mah et al., (2018)
4	RA	Relative Advantage  Definition: the degree to which a university believes that using PV technology would be free of effort.	<i>Theoretical references:</i> Perceived ease of use (Davis, 1989); Complexity (Rogers, 1995); Effort expectancy (Venkatesh <i>et al.</i> , 2003)  <i>Empirical literature references:</i> Perceived maintenance requirements (Zhai and Williams, 2012); Ease of installation (Vasseur and Kemp, 2015); Maintenance (Eronini, 2014)



**Figure 3.8: Model of drivers pertinent to the education sector**

Venkatesh *et al.* (2003) defined social influence as the degree to which an individual (in this case, a university) perceives how others believe that it is important that they should use new technology. It has been suggested also that organisations adopt innovations based on current trends and practices of other organisations in the same industry (Kee, 2017). Therefore, although the adoption of PVs by public universities might be driven by the

expected benefits or relative advantage, it could also be determined significantly by the need to meet stakeholders' expectations as well as to remain competitive in the market. Thus, by drawing upon the theories and empirical evidence discussed previously, expected benefits (distinguished as direct and indirect benefits), social influences, and relative advantage were deemed to be relevant in explaining the process of deciding to adopt PVs in SAPUs. Therefore, these were defined as the independent variables in the proposed CF, shown in Figure 3.7. A similar approach has been adopted by other scholars in investigating the diffusion of PVs (Aggarwal *et al.*, 2019; Kaplan, 1999; Kim *et al.*, 2014; Korcaj *et al.*, 2015), and GB (Wang *et al.*, 2019).

A total of 55 drivers was identified after a review of the literature (Table 2.2) and, after screening these using the conceptual model, eight, five, six, and three drivers were selected as indicators to measure direct benefits, indirect benefits, social influences, and relative advantage, respectively. The 22 drivers that were selected are presented in Figure 3.8.

#### **3.3.4. Independent Variables: Barriers**

Barriers have been validated empirically to impact the rate of adoption of innovations negatively. As suggested by Lundblad (2003), 'the diffusion of innovation within and across organisations is a unique context for the diffusion of innovation and brings with it some distinctive elements and relationships' (p. 51). It has been suggested also that the adoption of innovation in organisations is much more complex than among individuals (Lundblad, 2003; Oliveira and Martins, 2014). This complexity is made easier to understand by the TOE framework (Tornatzky and Fleischer, 1990) and the EDI adoption model (Iacovou *et al.*, 1995) which, therefore, were used as the basis for developing the relevant barrier constructs for this study. With reference to Figure 3.7, three constructs were proposed to explain the factors that predict the deployment of PVs: (1) cost and

funding-related barriers (CFB), (2) institution-related barriers (IRB), and (3) government-related barriers (GRB).

Previous studies have strongly affirmed that factors linked to cost and funding greatly influence the non-adoption of PVs in several countries (e.g. Ansari *et al.*, 2013; Balcombe *et al.*, 2014; Garlet *et al.*, 2019; Shah *et al.*, 2019).

**Table 3.3: Conceptual model constructs: Barriers**

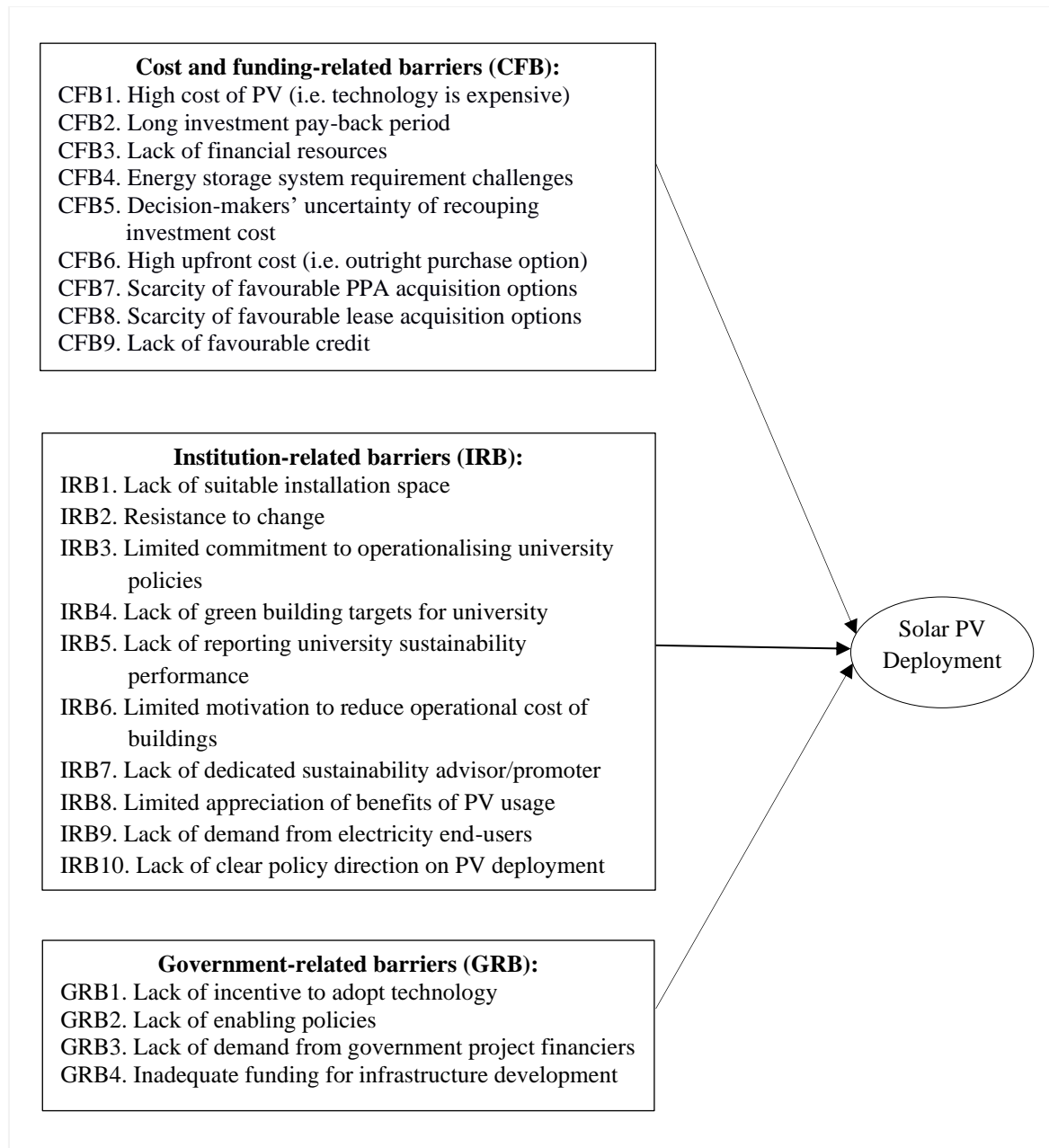
No.	Code	Constructs	Related references
1	CFB	<p>Cost and funding-related barriers</p> <p>Definition: the financial and technical factors that influence the adoption process</p>	<p><i>Theoretical reference:</i> Perceived characteristics of innovation (Rogers, 1995); Technology characteristics (Tornatzky and Fleischer, 1990; Iacovou <i>et al.</i> (1995)</p> <p><i>Related empirical literature:</i> Economic barriers (Seetharaman <i>et al.</i>, 2019); Market competitiveness (Shah <i>et al.</i>, 2019); Economic and financial barriers (Pode, 2010); Economic and financial barriers (Mah <i>et al.</i>, 2018)</p>
2	IRB	<p>Institution-related barriers</p> <p>Definition: refers to the characteristics and prevailing conditions at institutions</p>	<p><i>Theoretical reference:</i> Organisational context (Tornatzky and Fleischer, 1990); Organisational readiness (Iacovou <i>et al.</i>, 1995)</p> <p><i>Related empirical literature:</i> Institutional barriers (Shah <i>et al.</i>, 2019; Ávila <i>et al.</i>, 2019); Organisational barriers (Richardson and Lynes, 2007); Institutional/Technical barriers (Mah <i>et al.</i>, 2018)</p>
3	GRB	<p>Government-related barriers</p> <p>Definition: the external influences that government exert on the adoption process</p>	<p><i>Theoretical reference:</i> External task environment (Tornatzky and Fleischer, 1990); External pressure (Iacovou <i>et al.</i>, 1995)</p> <p><i>Related empirical literature:</i> Political and regulatory barriers (Shah <i>et al.</i>, 2019); Regulatory barriers Seetharaman <i>et al.</i> (2019)</p>

For this reason, the construct called ‘cost and funding-related barriers’ (CFB) was introduced to investigate all the economic issues and technology-related factors that impact the decision-making process. A total of nine indicators were identified from the literature to be related to this construct (Figure 3.9).

According to Iacovou *et al.* (1995), organisational readiness, which is the measure of the technology and resources available in the firm, can foster innovation adoption. Conversely, the unpreparedness of an organisation can become a barrier and hinder adoption. The purpose of this study was to understand adoption in a university context, hence it was appropriate to investigate matters relating to the universities. This need gave rise to the introduction of the ‘institution-related barriers’ (IRB) construct to examine all matters that are associated with universities. A total of 10 indicators were identified in the literature that related to this construct.

Lastly, public universities are state institutions and are susceptible to government influences in several ways, such as funding and regulations. Therefore, the third construct, called ‘government-related barriers’ was included, and this construct was identified with four indicators, as shown in Figure 3.9.

The measurement items identified in the literature as independent variables in the barriers cluster, based on the conceptual model, were 23 in total (Figure 3.9). An exhaustive list of all the barriers (67 in number) is presented in Table 2.3, and a comprehensive review of the literature about the barriers to the diffusion of PVs is presented in the literature review chapter.



**Figure 3.9: Model of barriers pertinent to the education sector**

### 3.4. Chapter Summary

In this chapter, five innovation diffusion theories/models were discussed – DOI theory, TAM, UTAUT/UTAUT2, TOE, and EDI – to provide the grounding to contextualise the conceptual model. In the conceptual model, presented in Figure 3.7, the drivers and the barriers that influence the uptake and upscaling of PVs were outlined. The drivers include: ‘direct benefits’, ‘indirect benefits’, ‘social influences’, and ‘relative advantage’; and the

barriers include: ‘cost and funding-related barriers’, ‘institution-related barriers’, and ‘government-related barriers’. The research methodology used for the study is explained in the next chapter.

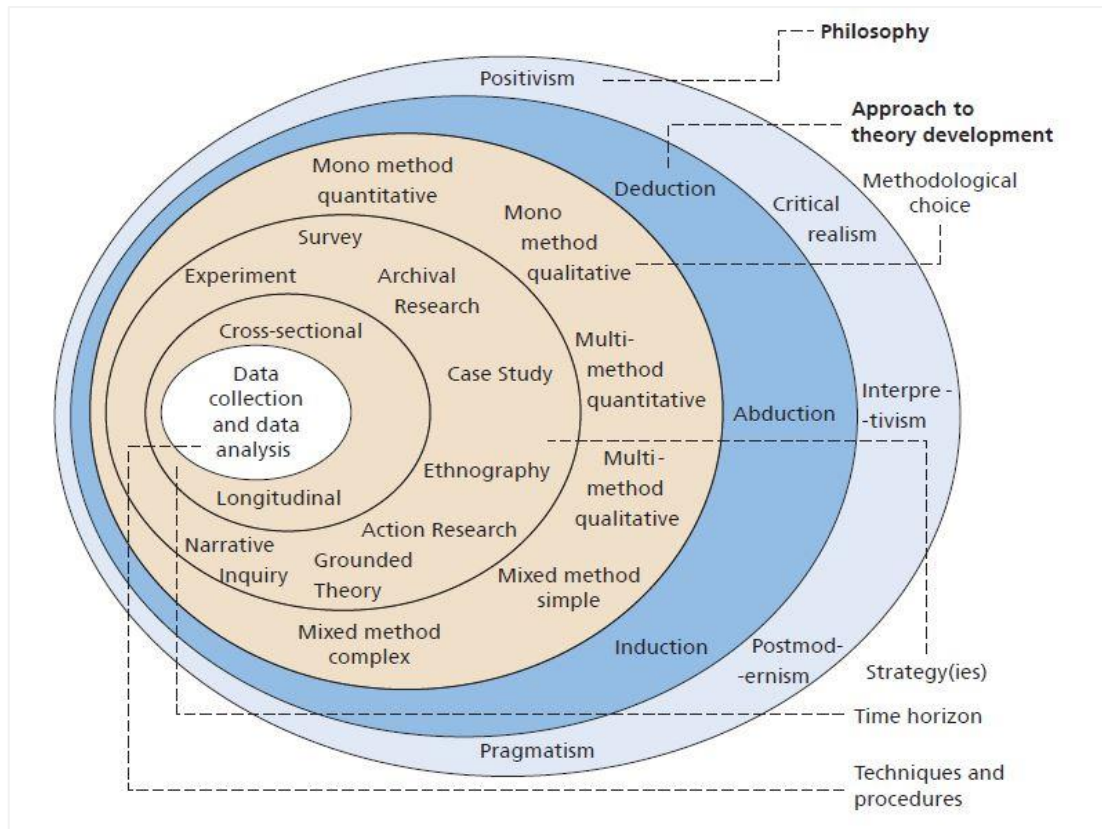
## CHAPTER 4: RESEARCH METHODOLOGY

### 4.1. Introduction

The methodology adopted to achieve the research aim and objectives is explained in this chapter. The philosophical stance of the study is established and an overview of the research design, strategies, and procedures used for the collection and analysis of the data is provided. The study was segmented into seven phases, and the data collection and analysis are discussed in relation to these phases.

### 4.2. Background Information

The terminology used by scholars, especially when discussing the processes for conducting research, sometimes does not convey the same idea but rather describes different aspects of the research process. For instance, dos Santos *et al.* (2021) described ‘research design’ as being cross-sectional, experimental, case study, longitudinal, or comparative. However, Saunders *et al.* (2019) considered ‘research design’ as being either qualitative, quantitative or mixed-method research design. Saunders *et al.* (2019) described the term ‘research strategy’ as being experiment, case study, archival research, action research, ethnography, grounded theory, narrative enquiry, or survey. Whereas, for dos Santos *et al.* (2021), research strategy involved quantitative, qualitative or mixed-methods research strategies. Regardless of the classification (or the terminology) used by scholars, what is clear is that all scholars attempted to cover all the important elements and phases of the research process. The researcher acknowledges these differences in categorisation, and to ensure clear communication of the details of the various aspects of this study, the classifications/terminologies espoused by Saunders *et al.* (2019), as shown in the research onion in Figure 4.1, were adopted.



**Figure 4.1: The research onion**

Source: (Saunders *et al.*, 2019, p. 130)

**Table 4.1: Research structural layers adopted**

Reference to section	Research layer	Adopted layer
4.3	Research philosophy	Pragmatism
4.4	Approach to theory development	Abductive approach
4.5	Methodological choice	Mixed-methods research design (Sequential exploratory)
4.6	Research strategy	Case study and survey
4.7	Time horizon	Cross-sectional based
4.8	Techniques and procedures	Semi-structured interviews, and questionnaire survey

A pragmatist philosophical stance was adopted for the study in order to contribute practical solutions that would inform future CS practices in SA. Premised on the chosen philosophy and the need to carry out the research in phases, where the data obtained from the

qualitative study were used for the quantitative study, a sequential, exploratory, mixed-methods research design was adopted. Case study and survey were the chosen research strategies, and the study was cross-sectional to provide a profile of the public university sector at a particular time. The data were collected using semi-structured interviews and questionnaire surveys.

### **4.3. Research Philosophy**

Research philosophy refers to a system of beliefs and assumptions about the development of knowledge (Saunders *et al.*, 2019). The beliefs and assumptions contribute significantly to determining the choice of research methods and how the findings of a research study are interpreted. In other words, understanding the philosophy of social science is key to every research study because it helps to conduct research effectively (dos Santos *et al.*, 2021). Thus, this study was guided by a philosophical stance that was arrived at after giving consideration to closely associated alternatives. The four research philosophies discussed in this section are: positivism, realism, interpretivism, and pragmatism.

#### **4.3.1. Positivism**

Positivism is a philosophical stance associated mainly with the natural sciences and it involves working with an observable social reality to generate law-like generalisations (Saunders *et al.*, 2019). Positivists view reality as existing objectively and separately from human behaviour and, as such, data can be gathered objectively by observing phenomena directly or ‘measuring’ them using appropriate instruments (Saunders *et al.*, 2019). Positivism incorporates elements of both an inductive approach and a deductive strategy into research (dos Santos *et al.*, 2021). By adopting a deductive approach, positivist researchers can use existing theory to develop and test hypotheses (Saunders *et al.*, 2019).

#### **4.3.2. Realism**

From the philosophical stance of realism, a reality that is independent of the senses is acknowledged, which is accessible to the researcher's tools and theoretical speculations (dos Santos *et al.*, 2021). A realist stance can be classified as direct realism or critical realism. Direct realism specifies that what one sees is what exists, and what a person experiences through the senses is an accurate representation of the world. In contrast, critical realists perceive reality as being independent and external, and what is experienced is only empirical or a manifestation of the things in the real world, rather than the actual things (Saunders *et al.*, 2019). The key difference between realists and positivists is that positivists accept that how they conceptualise a situation directly reflects reality, whereas empirical realists recognise that many practical situations can be understood but cannot be observed directly (dos Santos *et al.*, 2021).

#### **4.3.3. Interpretivism**

Interpretivism is a philosophical stance that enables social scientists to study and create new, richer understandings of social actions and contexts (Saunders *et al.*, 2019). Interpretivists view social actions as being inseparable from the context and time in which they occur and also highlight the need to understand the world as people perceive it, based on their own subjective views of social reality (dos Santos *et al.*, 2021). For instance, people of different cultural backgrounds under different circumstances and at different times, create and experience different social realities. Within such contexts, interpretivists assert that such complexity should not be reduced entirely to a series of law-like generalisations but rather be seen as an opportunity to create new, richer understandings and interpretations of social worlds and contexts (Saunders *et al.*, 2019). According to Saunders *et al.* (2019), the different strands of interpretivism include symbolic interactions, phenomenology, and hermeneutics.

#### **4.3.4. Pragmatism**

Pragmatists assert that concepts are only relevant as long as they support action, and there are multiple realities, hence no single point of view can provide a holistic perspective of the realities (Saunders *et al.*, 2019). Therefore, pragmatists always utilise the application of more than one approach in research to produce knowledge and practical solutions to problems (Creswell, 2014; Saunders *et al.*, 2019). According to Saunders *et al.* (2019), for pragmatists, the key important determinant of the research design and strategy is the research problem/question. It is specified that pragmatists do not see the world as an absolute unity, and pragmatism is not committed to any one system of philosophy and reality. Also, pragmatic researchers consider what and how to research based on the intended consequences (Creswell, 2014).

#### **4.3.5. Philosophical Stance Adopted for this Study**

The purpose of this study was to create new knowledge by identifying and examining the factors that hamper and hinder the deployment of PVs in the public university sector. This phenomenon required objective assessment and measurement using appropriate instruments to identify causal relationships in the data, to create law-like generalisations or predict social actions. It was also necessary for the researcher to remain neutral and detached from the research and data to avoid influencing the findings, and to have a highly structured methodology which could facilitate the replication of the research (Saunders *et al.*, 2019). Furthermore, it was necessary to carry out an in-depth investigation in the beginning phase of the research to generate data that could be used during the later phases of the study.

Given the above requirements, a pragmatist philosophical stance was adopted to enable the researcher to apply multiple methods to answer all the research questions and to provide a

holistic viewpoint on the phenomenon, including the derivation of practical solutions that could inform future CS practices in South Africa.

#### **4.4. Inter-Relationship between Theory and the Research**

Scholars have identified three approaches that researchers can use to express the relationship between theory and their research. These are deductive, inductive and abductive approaches (Creswell, 2014; dos Santos *et al.*, 2021; Saunders *et al.*, 2019). Using the deduction approach, research commences with the identification of relevant theory/theories from the literature, which are then used to determine the research questions and the research process for theory testing/verification. In contrast, using the inductive approach, research starts with research questions, the aim of which is to develop explanations and theories as the outcomes of the research process. The third approach, abductive reasoning, has been developed to make logical inferences, build theories and fill some of the gaps between the deductive and inductive approaches by combining the two techniques (dos Santos *et al.*, 2021; Saunders *et al.*, 2019).

In this study, an abductive approach was adopted, thus utilising elements of the deductive and inductive approaches to complement each other to achieve the respective objectives leading to the achievement of the overall research aim of developing a practical model. Saunders *et al.* (2019, p. 157) commented that ‘a topic about which there is a wealth of information in one context but far less in the context in which you are researching may lend itself to an abductive approach’. The situation cited by Saunders *et al.* (2019) described exactly the current research project in which there was vast information regarding the factors that generally drive PV adoption in households or communities, but little was known from empirical evidence in the university context. Therefore, an abductive approach was chosen as the ideal approach for this research.

#### 4.5. Choice of Methodology

According to Saunders *et al.* (2019), the methodologies that are available to researchers can be classified as quantitative, qualitative or mixed-methods research design, and their choice is influenced by philosophical assumptions. The purpose of quantitative research is to examine the relationships between variables through numerical measurement and statistical analysis. The aim of qualitative research is to explore and achieve an in-depth understanding of situations, values, beliefs or social or human problems (Creswell, 2014; Zikmund *et al.*, 2019). In mixed-methods research, the use of qualitative and quantitative data collection techniques and analytical procedures is combined in the same research project. Some of the types of mixed-methods are: concurrent, sequential exploratory, sequential explanatory, and sequential multi-phase, mixed-methods research designs (Saunders *et al.*, 2019).

In this study, a sequential, exploratory mixed-methods research design was adopted, where qualitative methods were followed by quantitative methods (see Figure 4.2). The selection of a mixed-methods research design was premised on the pragmatist philosophical stance of the study, which enabled the use of different tools and techniques to provide a comprehensive view of social actions. More specifically, there was limited literature on the deployment of PVs in HEIs, which required an in-depth investigation, and a qualitative method was the most suitable technique to use to produce the required results. Also, there it was necessary to identify relationships among the variables to make predictions and this could be achieved using a quantitative research design approach. Qualitative research is appropriate for exploring the variation in any aspect of social life, whereas quantitative research design can be applied to determine the extent of the variation. Therefore, adopting a sequential, exploratory mixed-methods research design for this study helped to answer

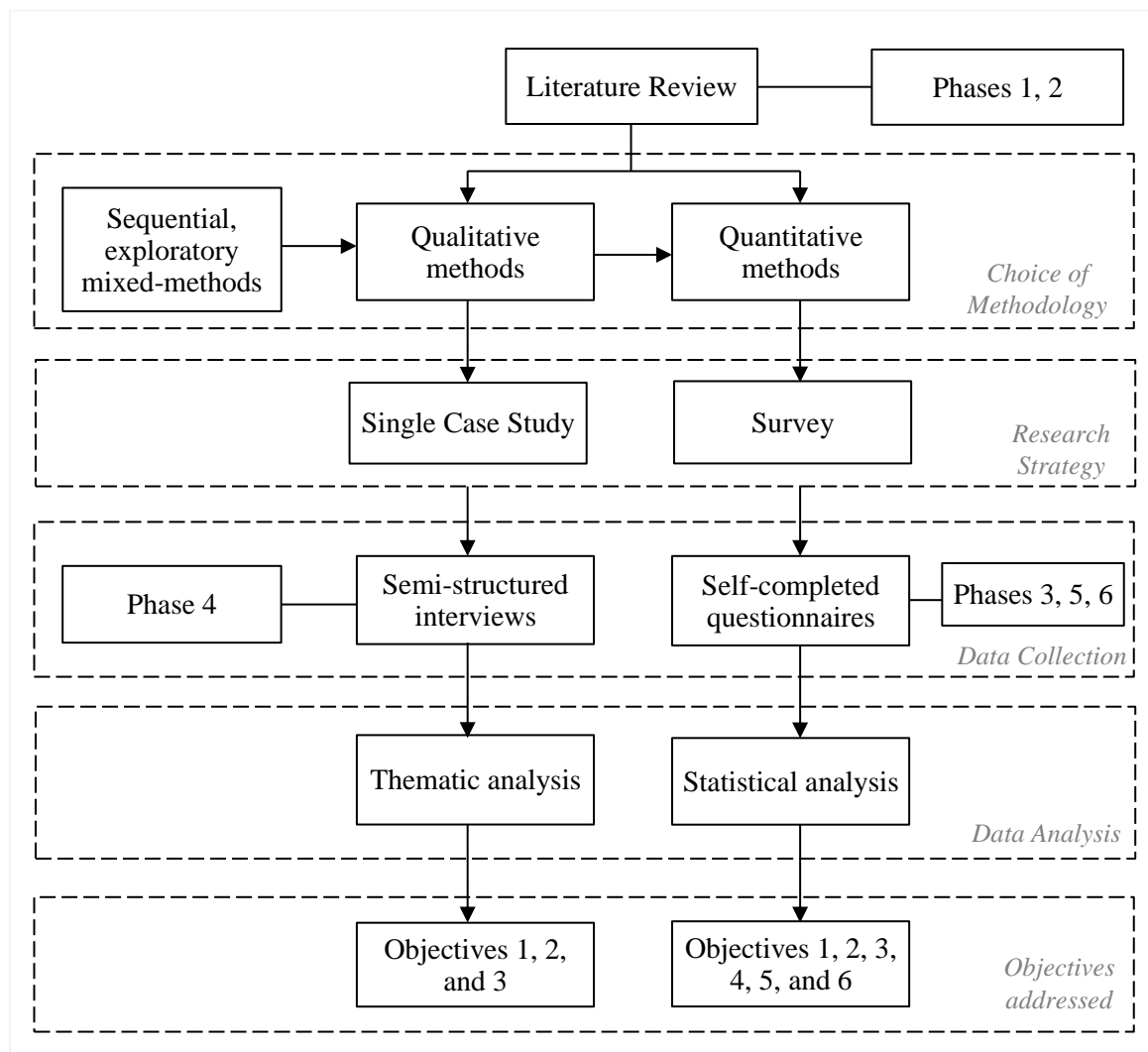
all the research questions adequately, thereby providing a more comprehensive understanding of the phenomenon.

#### **4.6. Research Strategy**

Research strategy can be viewed as a plan of the way in which the research question(s) will be answered by a researcher. The strategy that is selected for any research is significantly determined by the research question(s), the philosophical assumptions, the research purpose, the availability of resources and time, including access to data (Saunders *et al.*, 2019, p. 190). Some of the strategies, according to Saunders et al. (2019), are: (1) survey, (2) experiment, (3) case study, (4) narrative inquiry, (5) action research, (6) archival and documentary research, (7) grounded theory, and (8) ethnography, as shown in Figure 4.1. It is noted that some of the research strategies are not mutually exclusive. For instance, it is possible to use a survey strategy within a case study or combine several different strategies within mixed methods (Saunders *et al.*, 2019, p. 190).

In this study, the chosen research strategies were case study and survey, as shown in Figure 4.2. Case study is defined as an in-depth inquiry into a topic or phenomenon within its real-life setting (Yin, 2018). The focus of an investigation, which is referred to as the ‘case’ in case study research, might be a person, a group, an organisation/association, a change process, an event, etc. (Saunders *et al.*, 2019). Case study strategy is a suitable choice when exploring an area where little is known or where a researcher requires a holistic understanding of a situation, phenomenon, site, group or community, rather than confirming or quantifying data. In a case study, a single method or multiple methods can be used to collect the data necessary to understand the dynamics of a case fully, and a single case or multiple cases can be observed collectively (dos Santos *et al.*, 2021; Saunders *et al.*, 2019; Zikmund *et al.*, 2019). In this study, semi-structured interviews were conducted

to collect data from the selected single case, which was CUT (i.e. in Phase 4). The research objectives would have been achieved without carrying out the single case study (i.e., conducting interviews at CUT) but it was included nonetheless because it provided additional in-depth information which enriched the data. Due to time constraints, a multi-case study was avoided. The second strategy, survey, that was chosen in this study was the most dominant strategy used during the research project; it was used during Phases 3, 5 and 6 (see Figure 4.3).



**Figure 4.2: Overview of choice of methodology, research design and strategies**

Survey strategy is the process of collecting data by asking a range of individuals the same questions at a single point in time to collect a body of quantitative or quantifiable data in

connection with two or more variables, which are examined to detect patterns of association (Saunders *et al.*, 2019).

The selection of the two research strategies above was justifiable based on the nature of the research. Firstly, although the case study option did not allow for generalisation, it produced context-specific understanding and data that were useful for the development of the instrument for the surveys in the subsequent stages of the research. Also, the selection of the case study minimised travel time, enhanced access and reduced research costs. Regarding the second choice, the survey strategy supplemented the case study by producing findings which applied to the public university sector as a whole (i.e. allowing for generalisation) which, in the end, provided valuable information to support future planning and development of the sector.

In Section 4.8, the operationalisation of the mixed-methods strategy (i.e. case study and survey) is discussed extensively and in relation to Phases 3, 4, 5, and 6

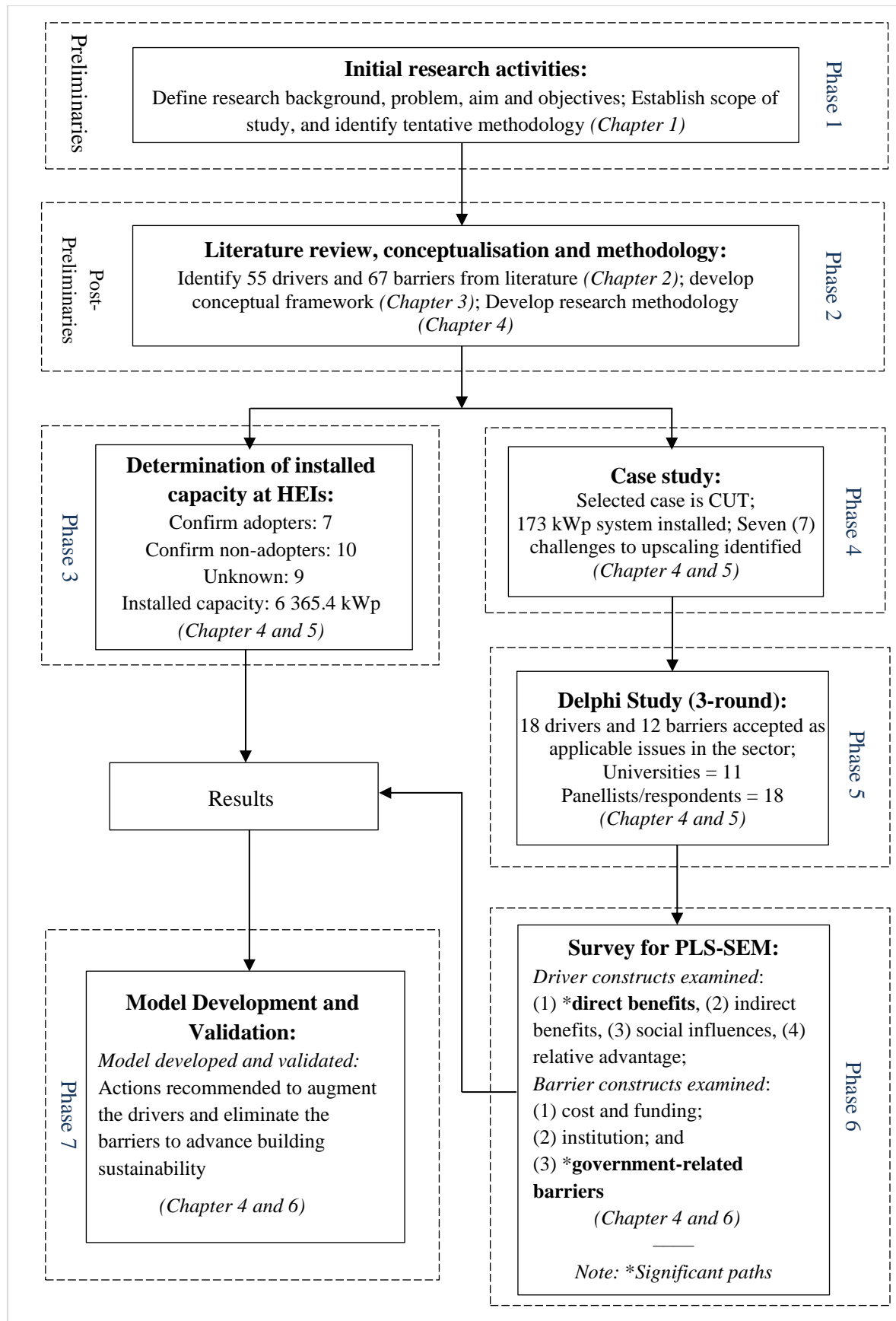
#### **4.7. Time Horizon**

Research can provide either a profile of a phenomenon at a particular time or a series of records over a given period. Saunders *et al.* (2019) classified these two conditions as cross-sectional studies or longitudinal studies, respectively. While cross-sectional studies are carried out once, longitudinal studies are repetitive and are executed over a longer timeframe (Cooper and Schindler, 2008). It is not uncommon for researchers to opt for cross-sectional studies because of time constraints. This study was cross-sectional, and it only provided a profile of the sector at a particular time.

#### **4.8. Data Collection and Data Analysis**

Generally, research can be viewed as being either exploratory or formal in nature. While exploratory studies tend to have loose structures with the objective of identifying future

research opportunities, formal studies begin where the exploratory studies end, and they involve precise procedures and data source specifications (Cooper and Schindler, 2008). This study was aligned with formal research and has precise procedures and data source specifications. To facilitate easier comprehension of the research processes and presentation of the data, the methods of data collection and analysis are explained chronologically, under the various phases, in the sections below. The phases of the study are illustrated in Figure 4.3 and extensively elaborated in Section 1.7.



**Figure 4.3: Overview of research phases**

With reference to the research objectives, the instruments that were adopted for collecting and analysing the data are partly presented in Table 4.2. In summary, a literature review was used to achieve partly Objectives 1, 2, 3, and 5. A questionnaire survey was used throughout to gather data to answer all the research questions. The data collection was augmented further with an expert interview to address only Objective 3. For the analysis of the data, the following techniques were used: (1) thematic analysis (Objective 1), mean score ranking (Objectives 2-5), inter-quartile range analysis (Objective 2-3), and partial least squares structural equation modelling (Objective 4).

**Table 4.2: Methods for data collection and analysis**

Research Objectives	Methods Applied						
	Data Collection			Data Analysis			
	LR	QS	I	TA	MSR	IQR	PLS-SEM
1. Ascertain the progress made in the deployment of PVs	√	√		√			
2. Identify and evaluate the drivers for the deployment of PVs	√	√			√	√	
3. Identify and evaluate the barriers to the deployment of PVs	√	√	√	√	√	√	
4. Evaluate the influence of the drivers and barriers on deployment		√			√		√
5. Develop a model to advance building sustainability	√	√			√		

*Notes: LR = Literature Review; QS = Questionnaire Survey; I = Interviews; TA = Thematic Analysis; MS = Mean Score Ranking; Inter-Quartile Range; PLS-SEM = Partial Least Squares Structural Equation Modeling*

#### **4.8.1. Literature Review and Development of Conceptual Model (Phase 2)**

A comprehensive literature review was conducted to understand the transition to renewable energies, which is currently ongoing globally. Specifically, an in-depth examination of the literature was carried out to identify the drivers and barriers to PV adoption, campus sustainability, and green building. This review produced a list of 55 drivers and 67 barriers

which are presented in Tables 2.2 and 2.3, respectively. The presentation of the detailed findings of the literature review is provided in Chapter Two. Additionally, various theories/models – DOI, TAM, UTAUT/ UTAUT2, TOE, and EDI models – were examined and adopted in developing the conceptual model (see Figure 3.7). The examination of the methodologies adopted by scholars also shaped the research methodology adopted for this study.

#### ***4.8.2. Deployment of PVs on Public University Campuses (Phase 3)***

The installation of PVs on university campuses has commenced, although it appears it is happening at a very slow pace. While information about the installation of PVs and GB projects is available on some university websites, a significant portion of the information is not available to the public from university websites. For this reason, the plausible means of gathering data was either to conduct interviews, deploy questionnaires, or undertake site visits to observe systems that have been installed. Owing to COVID-19 restrictions and risks at the time of the research, a questionnaire survey approach was adopted to gather the necessary data to produce a profile of deployment within the public university sector.

To collect the data, a letter of invitation was sent to all universities, specifically addressed to the directors of the departments/units that were responsible for the construction and/or maintenance of university infrastructure. These departments were named differently in each university. For example, some institutions named them ‘Properties and Services’, ‘Facilities Department’, or ‘University Estates’. The purpose of the letter sought was to achieve two goals: (1) to know whether the universities had PVs installed on any of their campuses, and (2) to know the installed capacity and ancillary technical details, in the case of universities that were adopters. The questionnaire provided background information and instructions at the beginning for completing the form. Thereafter, seven questions were

asked regarding the installed capacity of PVs, the total capacity of the energy storage systems, the first and last year of installation, how the PVs were installed, how they were acquired, and whether the design, installation and maintenance of the systems were handled internally or were contracted to third parties. Finally, space was provided for general comments to be shared on the subject. The quantifiable data that were collected were collated and presented in charts. The remaining information acquired was reported descriptively.

The findings on the deployment of PVs on public university campuses are presented in Section 5.2. Due to anonymity requirements, the names of the universities that participated in the study have been coded and reported accordingly.

#### ***4.8.3. Examination of Deployment of PVs at CUT (Phase 4)***

A case study is an in-depth inquiry into a topic or phenomenon within its real-life setting (Yin, 2018). A case-study research strategy was adopted in this phase of the study. This approach was preferred because it offered the opportunity to conduct a detailed and intensive analysis of issues exclusively pertinent to the case study (dos Santos *et al.*, 2021).

##### ***4.8.3.1. Data Collection***

A two-step approach was adopted to collect the data from CUT. Firstly, information was gathered from the documents and websites of the institution and site visits were undertaken to ascertain the level of deployment of PV systems at the institution. In addition, information gathered at this stage was verified by the institution's Estates and Infrastructure Department. Secondly, semi-structured interviews with key stakeholders were conducted to identify key factors which influenced deployment adversely and to determine the strategies to enhance the upscaling of the technology. The interview protocol was structured into two parts. The purpose of the first section was to obtain background

information, and the second section comprised three questions regarding participants' views on barriers to adoption, the solution to the barriers, and general comments. The interview protocol was submitted to the university's research committee and approval was received before the data were collected.

A purposive sampling technique was used to select participants for the study (Bryman, 2004). This approach was deemed most suitable because the objective was to select only participants who were well-informed about the subject. Participants were selected and invited to participate in the study if they were involved in infrastructure development and building maintenance, and/or SD implementation in the university. Owing to COVID-19 restrictions, communication with the selected participants was by email. The interview protocol was sent to all 15 selected staff members requesting them to grant an interview. Follow-up emails were sent to those who did not respond to the email after two weeks. A total of seven staff members participated in the study. Five participants (P1, P2, P3, P4, P5) were interviewed using Zoom in May-June 2020 when university staff members were working remotely because of COVID-19 restrictions. After restrictions were partly lifted, one face-to-face interview (P6) was conducted at the Bloemfontein Campus in July 2020. Interview sessions lasted for an average of thirty minutes and sessions were recorded with the permission of the interviewees. Before ending the interview sessions, the interviewer reiterated the points highlighted by the interviewees before requesting general comments from them at the end. This ensured re-affirmation of the views of the respondents and also enhanced accuracy in the reporting of their views. One participant (P7) could not be interviewed, hence the interview questions were emailed to the participant and they were completed and returned.

#### *4.8.3.2. Analysis of Qualitative Data*

The recordings from the interviews were transcribed verbatim manually and the textual data were then analysed thematically. The analysis was carried out manually in line with the guidelines recommended by Kumar (2011). The process of analysis included identifying the main themes which emerged from the data, organising the responses under the main themes, and integrating themes and responses in the text in the report (Kumar, 2011, p. 278).

The findings on the deployment of PVs at CUT and the factors influencing the upscaling of the technology at the institution are presented in Section 5.3.

#### *4.8.4. Identifying Applicable Drivers and Barriers in the University Sector (Phase 5)*

Owing to the limited information on the factors that drive or hinder the deployment of PVs within HEIs in general, a Delphi study method was used to identify the relevant drivers and barriers that prevail in SA. The Delphi method, established by Dalkey and Helmer (1963), was adopted because it is a valuable technique that can help to achieve consensus between experts when empirical evidence is scarce or contentious. This method has gained popularity among researchers and also has the advantage of providing the opportunity for research participants to re-assess their initial judgements based on group feedback (von der Gracht, 2012). A three-round Delphi survey was conducted to achieve consensus among panellists sampled from 11 public universities in SA.

The format of the Delphi survey rounds, the background of the panellists who participated in the surveys, and information on how the data were analysed are presented below.

#### 4.8.4.1. *Data Collection*

- **Delphi survey format**

During Round 1 (R1), the panellists received a questionnaire that presented the research objectives and included the guidelines for completion of the questionnaire. Then, questions were raised that required participants to provide demographic information and rate 22 drivers and 23 barriers that were retrieved from literature. In addition, participants were asked to recommend and rate additional drivers and barriers that they believed were relevant but were omitted from the questionnaire.

For Round 2 (R2), the panellists received controlled feedback in the form of mean scores for the rated items, including their ratings from R1. The tasks for R2 was for the panellists to: (1) review their initial ratings in view of the consolidated results and make changes if necessary, and (2) rate the additional drivers and barriers that were recommended.

In Round 3 (R3), being the final round, the panellists were presented with the consolidated results for the additional drivers and barriers that were recommended and were asked to review their initial ratings and make changes if they wished.

The drivers and barriers directly identified from literature and rated by panellists were terminated in R2, and these are sometimes referred to as the “R2 terminated batch of drivers” or “R2 terminated batch of barriers” in the thesis. Similarly, the drivers and barriers that were recommended by some of the panellists were terminated at R3, and these are sometimes referred to as “R3 terminated batch of drivers” or “R3 terminated batch of barriers”. Since the sample sizes varied for R2 and R3, the drivers and barriers were ranked separately in the respective tables (see

Tables 5.7, 5.8, 5.9, and 5.10). If two indicators happened to have the same mean score, the one with the lowest standard deviation was allotted the highest rank.

During all the Delphi rounds, the factors were rated using a 5-point Likert Scale (1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree). The questionnaires were emailed as a Microsoft Word file to the panellists and were returned by email. The surveys were conducted during January–April 2021.

- **Delphi participants**

The participants included in the Delphi study were academic and non-academic staff members, sampled from public universities in SA, who had insight into the matters affecting the deployment of PVs on campuses. The research participants were recruited in two ways. Firstly, a letter of invitation was sent by email and courier service to 22 universities to recruit non-academic staff. The letters included a brief about the research objectives and the requirements of research participants, including a web-link where additional information about the research could be accessed. Contact had already been established with four universities, hence emails were sent only to these universities. The letters were addressed to the managers/directors of the departments responsible for university property development and maintenance (e.g. estates, facilities, etc.). In the letters, the heads of departments were requested to recommend staff members in their department for participation in the surveys; the heads were also informed that they could participate personally. Secondly, academic staff were recruited using a snowball sampling technique. Three academic staff members known to the researcher, who were involved in implementing campus sustainability and green building-related projects on campuses, were invited to partake and recommend other staff. Additionally,

from the availability of the contact information of academic staff and their areas of research on websites, academic staff who had research interests/publications related to PV deployment, green buildings, and campus sustainability were contacted. They were informed about the research objectives and asked whether they had insight into the subject under investigation and were available to participate in the surveys.

#### 4.8.4.2. *Data Analysis (Delphi Study)*

Before the commencement of the analysis, the data from all the rounds were checked for errors. While there were no missing values, double answers were detected, and the respondents in question were contacted to clarify their intended answers. By so doing, all the errors were rectified, making all the data valid for analysis. The approach to analysis used in this study was similar to that used by Anderhofstadt and Spinler (2019), Chun and Nam (2019) and (Walters *et al.*, 2018a).

The mean standard deviation (SD), inter-quartile range (IQR), and coefficient of variation (CV) were calculated using the Statistical Package for Social Sciences (SPSS) Version 27. Based on the 5-point Likert Scale and mathematical approximation principles, barriers that had mean values greater than or equal to 3.50 were accepted as critical factors. In contrast, barriers which scored mean values less than 3.50 were deemed to be non-critical and, therefore, were rejected. This was the first of two criteria used to identify barriers applicable in the public university sector. The 3.50 cut-off point was adopted because it allowed for the inclusion of only the most critical factors. For instance, Mahamadu *et al.* (2017) adopted the same principle to identify critical building information modeling qualification criteria for construction pre-qualification and selection.

The IQR, which depicts 50% of assessments between the lower quartile (Q1) and upper quartile (Q3), has been used widely to measure consensus in Delphi studies (von der

Gracht, 2012). Owing to its robustness, the IQR was used in this study to measure consensus among the panellists. A threshold of  $IQR \leq 1$  was applied to select barriers on which consensus was obtained, as this is an acceptable standard when a 5-point Likert Scale is used (von der Gracht, 2012). This was the second criterion that was used to determine whether to accept or reject a barrier.

Consequently, all barriers that recorded an acceptable mean value (mean  $\geq 3.50$ ), as well as an acceptable value of IQR denoting consensus ( $IQR \leq 1$ ), were accepted as barriers which were pertinent within the public university sector in SA.

Regarding the termination of the Delphi round, Dajani *et al.* (1979) proposed that group stability is a relevant criterion to use to terminate a Delphi survey. Stability is defined as the consistency of feedback between successive rounds; it is the difference in the CV between successive Delphi rounds and should not be more than 0.10 (Anderhofstadt and Spinler, 2019). The coefficient of variation is calculated as the standard deviation divided by the mean (von der Gracht, 2012). Thus, the CV change  $\leq 0.1$  standard was used to measure stability to end the survey.

The findings from Phase 5 are presented in Section 5.4.

#### ***4.8.5. Assessment of the Influence of the Drivers and Barriers on Deployment (Phase 6)***

The processes that were followed to collect data and how they were analysed to determine the influence of the drivers and barriers on deployment are discussed below. The findings from this phase are presented in the next two chapters.

#### 4.8.5.1. *Data Collection*

To collect the data, printed questionnaires and online versions were made available on the QuestionPro platform. The directors of the departments/units that were responsible for construction and/or maintenance of university infrastructure ensured that staff members from their departments completed the questionnaire (i.e., non-academic staff). Contact was also made directly with some non-academic staff either through email or in person, and members of the Higher Education Facilities Management Association of Southern Africa (HEFMA) were also contacted to participate in the study. In addition, the researcher contacted academic staff to complete the questionnaire, and some academic staff also shared the questionnaire with their colleagues to complete. Background information and instructions for completing the form were included at the beginning of the questionnaire. The purpose of the next section was to gather background information from the respondents and, in the subsequent parts, the respondents were requested to rate their level of agreement with the statements made regarding the drivers, barriers, and PV deployment activities. A web link to the research project website (<https://greencampus.africa/research>) was also provided in the questionnaire. The website provided additional information about the research. The purpose of doing this was to provide all the relevant information that could not be captured on the questionnaire so that the respondents were well-informed about what had already been done and how the current study was informed by the results from the previous studies. The data was collected during June–December 2021.

The demographic information of the respondents is presented in Section 6.2.

#### 4.8.5.2. *Data Analysis (PLS-SEM)*

To assess the significance of the influence of the drivers and barriers on the deployment of PVs on public university campuses, a PLS-SEM approach was adopted. PLS-SEM is a

variance-based, structural equation modelling technique that has gained popularity recently amongst researchers (Hair *et al.*, 2014). As a second-generation, multi-variate analysis technique, it merges elements of the first-generation principal components and linear regression analysis (Hair *et al.*, 2017). It is also regression-based and, therefore, is used to explore the linear relationships between multiple independent variables and single or multiple dependent variables (Janadari *et al.*, 2016). PLS-SEM is applicable when the objective is to predict key target constructs and when the study is exploratory in nature (Hair *et al.*, 2017). Furthermore, PLS-SEM can be adopted as a statistical tool for data analysis when the dataset is relatively small. According to the guidelines given, the minimum sample size required to conduct PLS-SEM analysis should be equal to the larger of the following: (1) ten times the largest number of formative indicators used to measure one construct or (2) ten times the largest number of structural paths directed at a particular construct in the structural model (Hair *et al.*, 2017). In this study, the most structural paths directed at a particular construct were the four paths of the construct of drivers. The minimum sample size required, therefore, was 40. The total number of respondents who completed the questionnaire was 61. Therefore, the minimum sample size required was exceeded.

The SmartPLS Version 3.3.7 Statistical Package was used to conduct the PLS-SEM analysis.

- **Part 1. Initial Assessment of Data**

Before running the PLS-SEM analysis, the Shapiro-Wilk Test was carried out to assess data normality, as required for parametric statistical analysis. When the p-value of the Shapiro-Wilk Test is  $< 0.05$ , it signifies that the data deviate significantly from a normal distribution (Laerd Statistics [LS], 2019). The Shapiro-

Wilk Test showed that all the indicators deviated significantly from a normal distribution, with p values  $< 0.001$ . Therefore, the dataset could be used for the PLS-SEM analysis (Hair *et al.*, 2014, 2017).

- **Part 2. Assessment of Models in the Study**

Two models were developed and assessed in this study. The first model was used to investigate the influence of the drivers on PV deployment (referred to as the ‘drivers model’), which was used to examine the effect of the barriers in the same manner (referred to as the ‘barriers model’). The two SEM models were evaluated in a two-step manner, as recommended by Fornell and Larcker (1981), firstly, by assessing the outer model (measurement model) and then assessing the inner model (structural model).

- ***Outer Model (Measurement) Assessment***

Assessment of validity and reliability are the two key requirements to assess the measurement model (Hair *et al.*, 2014, 2017; Ramayah *et al.*, 2011). Reliability tests are used to assess the stability and the consistency of the measuring instrument, whereas validity tests assess how accurately an instrument measures a particular concept it is designed to measure (Janadari *et al.*, 2016). The assessment of reliability and validity was carried out by analysing indicator reliability, internal consistency reliability, convergent validity, and discriminant validity:

- (i) ***Indicator Reliability***

According to Hulland (1999), reflective indicator loadings should be  $\geq 0.5$  to demonstrate that the measurement item is a reliable measurement of a latent construct. Based on this guideline, indicators that had loadings lower than 0.50 were

removed from the measurement models for both drivers and barriers to meet the indicator reliability requirement.

*(ii) Internal Consistency Reliability*

Internal consistency reliability is assessed by using Composite Reliability (CR) and Cronbach's alpha ( $\alpha$ ). According to Hair *et al.* (2014), CR provides a more appropriate measure of internal consistency reliability because it does not assume that all indicator loadings are equal in the population, and it accommodates the differences in the indicator loadings to avoid under-estimation, which is associated with the estimation of Cronbach's alpha. According to Gefen *et al.* (2000), CR should be  $> 0.7$  to indicate adequate internal consistency reliability. Moreover, Hair *et al.* (2017) noted that, in exploratory research, a lower boundary of 0.60 to 0.70 is considered to be an acceptable value for  $\alpha$ , because  $\alpha$  under-estimates internal consistency reliability.

*(iii) Convergent Validity*

The assessment of convergent validity is based on the estimated Average Variance Extracted (AVE) value. AVE is the average variance shared between a construct and its measures (Janadari *et al.*, 2016). Scholars recommend that an acceptable measure of validity is achieved when the AVE value is  $> 0.50$  (Bagozzi and Yi, 1988; Fornell and Larcker, 1981). When the AVE value is  $> 0.50$ , it shows that a construct explains more than half of the variance of its indicators (Hair *et al.*, 2014).

*(iv) Discriminant Validity*

Discriminant validity measures the level to which a construct is truly distinct from other constructs in the model (Hair *et al.*, 2017). The discriminant validity of the measurement models was assessed using three criteria: (1) cross-loadings, (2)

Fornell and Larcker criteria, and (3) heterotrait-monotrait ratio (HTMT) criteria. Firstly, cross-loadings are reported in a table where the indicators are presented in the rows and the latent constructs are shown in the columns. Validity is achieved when the indicator's outer loading on the associated construct is greater than any of its cross-loadings (i.e. its correlation) on other constructs. Secondly, the Fornell-Larcker criterion assessment is used to compare the square root of the AVE values with the latent variable correlations, and validity is achieved when the square root of each construct's AVE is greater than its highest correlation with any other construct. Thirdly, for HTMT, an acceptable measure of validity is achieved when the HTMT ratio value does not exceed 0.90 (Hair *et al.*, 2017).

- Inner Model (Structural Model) Assessment

The structural model assessment was conducted in a five-step manner as outlined below. Prior to the assessment, the models were analysed for collinearity issues using the variance inflation factor (VIF) assessment approach. For collinearity among the predictor constructs to be not a critical issue in the structural model, it is advised that the VIF should be below 5 (Hair *et al.*, 2017).

- i. Assessment of the Significance and Relevance of the Structural Model Relationships

After the assessment of the measurement models, the structural models were assessed. The testing of the significance of the hypothesised paths was carried out using bootstrapping. The bootstrapping was run with a sub-sample of 5 000 using two-tailed tests. The path coefficient values, which are estimated, range from  $-1$  to  $+1$  and the coefficients which are close to  $+1$  represent a strong positive relationship, while the values closer to  $-1$

indicate a strong negative relationship (Hair *et al.*, 2017). By using the commonly used critical values for two-tailed tests, which are 1.65 (significance level = 10%), 1.96 (significance level = 5%), and 2.57 (significance level = 1%), the coefficients were interpreted as being statistically significant with the respective error probability (Hair *et al.*, 2017).

ii. Assessment of the Coefficient of Determination ( $R^2$ )

The  $R^2$  is a measure of a model's predictive relevance (Hair *et al.*, 2014), and it represents the proportion of variance in a latent endogenous construct that is explained by exogenous constructs, expressed as a percentage (Chin, 1998). This variance ranges from 0 to 1, with 1 representing complete predictive accuracy (Hair *et al.*, 2014). In this study, there was only one endogenous construct (PV deployment) which did not serve as an independent variable in any other equation in the models. According to Cohen (1992),  $R^2$  values of 0.12 or below indicate a low effect size, values between 0.13 to 0.25 values indicate a medium effect size, and values of 0.26 or above indicate a high effect size, and this scale was used to interpret the predictive relevance of the models.

iii. Assessment of Effect Size ( $f^2$ )

The effect size is an assessment carried out to determine the strength of impact of one construct (i.e. independent construct) on another construct (dependent construct) in terms of  $R^2$ . The  $f^2$  is calculated using Equation (1) below, and it includes estimating the PLS path model twice. Firstly, the path is estimated with the exogenous latent variable included (yielding  $R^2_{included}$ )

and, then, with the exogenous latent variable excluded (yielding  $R^2_{excluded}$ ) (Hair *et al.*, 2014, 2017).

$$f^2 = (R^2_{included} - R^2_{excluded}) / (1 - R^2_{included}) \quad \text{Equation (1)}$$

According to Cohen (1988),  $f^2$  values of 0.02, 0.15, and 0.35, respectively, represent small, medium, and large effects of the exogenous latent variable. Effect size values of less than 0.02 indicate that there is no effect (Hair *et al.*, 2014).

iv. Evaluation of Cross-Validated Redundancy ( $Q^2$ )

The predictive relevance of the inner model is determined using Stone-Geisser's cross-validated redundancy ( $Q^2$ ) value (Hair *et al.*, 2014).  $Q^2$  values larger than zero suggest that the model has predictive relevance for the endogenous construct under consideration, and values of 0 and below indicate a lack of predictive relevance. The  $Q^2$  values for the models of the drivers and barriers were estimated by using the blind-folding procedure at the 7th omission distance, as suggested by (Hair *et al.*, 2017).

v. Evaluation of Predictive Relevance ( $q^2$ ) Effect Size

Whilst  $Q^2$  values estimated using the blind-folding procedure represent a measure of how well the path model can predict the originally observed values, the relative impact of predictive relevance can be assessed using the  $q^2$  effect size, which is calculated using Equation 2 (Hair *et al.*, 2017).

$$q^2 = (Q^2_{included} - Q^2_{excluded}) / (1 - Q^2_{included}) \quad \text{Equation (2)}$$

As a relative measure of predictive relevance, values of 0.02, 0.15, and 0.35 indicate that an exogenous construct has a small, medium, or large

predictive relevance, respectively, for the endogenous construct under consideration (Hair *et al.*, 2017).

#### **4.8.6. Model Development and Validation (Phase 7)**

The model was developed to highlight the most significant issues that should be addressed to help improve the sustainability of building through the use of PVs in public universities. This was achieved by recommending actions that re-inforce the significant factors that drive the installation of the technology (i.e. the drivers), and by proffering solutions that ameliorate the factors that hinder deployment (i.e. the barriers). The approach used to develop the model is similar to the method used by Darko *et al.* (2018) to develop an implementation strategy to facilitate the promotion of green buildings. The model was developed based on the PLS-SEM results. Specifically, the drivers and barriers that had a significant positive and negative influence on the deployment of PVs, respectively, were identified. These were the hypotheses that were supported. Afterwards, based on logic and recommendations cited by scholars in the literature, suitable actions that were deemed appropriate to re-inforce the drivers and overcome the barriers were proposed. These are presented graphically in Figure 6.6.

To validate the model, a survey was carried out and the questionnaire was completed by experts who were initially invited to partake in the research in Phases 4, 5 or 6. The questionnaire was analysed using mean score ranking and the results are presented in Section 6.4.

#### **4.9. Ethical Considerations**

Ethics in research is the application of ethical standards and principles in research (Zikmund *et al.*, 2019). It helps to conduct research in conformity with accepted norms and values, and in a responsible manner (Jakoet-Salie *et al.*, 2022). It is necessary that no harm

is caused, privacy is not invaded, consent is given, and the confidentiality and anonymity of the research participants are ensured (dos Santos *et al.*, 2021; Saunders *et al.*, 2019). Therefore, this study was designed and executed according to accepted norms and values. The research project was granted ethical clearance by the CUT regulation unit for Institutional Planning and Quality Enhancement. During the research, the participants were duly informed about the background and purpose of the research, and what they would be required to do when they consented to participate in the research. Since not all information could be provided verbally or on the questionnaires, additional information was provided on the research project website ([www.greencampus.africa](http://www.greencampus.africa)) for participants to access. Research participants were informed that the research was for academic purposes and they were given the guarantee of confidentiality. With regards to obtaining consent, oral consent was given by the respondents who were interviewed, and the participants who completed the printed or online questionnaires indicated their consent to participate in the research by returning the completed forms. Also, the privacy and confidentiality of all research participants were maintained throughout this study. The data were anonymised completely with no use of identifiable personal/organisation details of any of the research participants, except the mention of the name of the institution involved in the case study in Phase 4.

#### **4.10. Chapter Summary**

This chapter contains the details of the research methodology. A positivist philosophical stance was adopted in the study to address the areas where quantitative data were collected, and an interpretive philosophical stance was adopted where qualitative data were collected. A sequential, exploratory, mixed-methods research design was adopted. Case study and survey strategies were chosen as the best options for research strategy to achieve the research targets. The study was cross-sectional and provided a profile of the sector at a

particular time, rather than over a period. The next chapter contains the results and discussion of the activities in Phases 3, 4, and 5.

## CHAPTER 5: DATA ANALYSIS AND INTERPRETATIONS

### 5.1. Introduction

This chapter contains a presentation of the results and discussion of the findings regarding the progress that the universities have made in installing PVs on their campuses, and the identification of the drivers and barriers that influence deployment in the public university sector. The results from Phase 3 (objective 1) are presented in Section 5.2, Section 5.3 covers Phase 4 (Objectives 1 and 3) and, lastly, Phase 5 (Objectives 2 and 3) is presented in Section 5.4.

### 5.2. Deployment of PVs on Public University Campuses (Phase 3)

Out of the 26 institutions that were contacted to provide information, feedback was received from 17 universities. Five universities (19.2%) completed the questionnaire and provided details about their installations, which are presented in Table 5.1. Also, 10 universities (38.5%) indicated that no PV systems were installed on their campuses and, while 2 institutions (7.7%) confirmed that they had installed PV systems, the questionnaires were not returned. The remaining 9 universities (34.6%) did not provide feedback, hence it could not be ascertained whether these institutions were adopters or non-adopters.

Altogether, the 5 institutions that were PV adopters, installed PV systems that generate a total of 6 365.4 kWp, and no energy storage systems were installed. University B installed the largest system (3 292 kWp) during 2018-2019 on three campuses. The next highest installation was a 1 700 kWp system at University E, which was deployed between 2019 and 2020. The other installations were 1 000, 200, and 173.4 kWp systems, deployed at Universities A, C and D, respectively.

With regard to deployment counts, University A deployed the technology only once, and Universities C and E installed their systems in two phases. University D installed PVs on

three occasions, and University B has done installations six times. The results also indicated that the installation of PVs in the public university sector was commended at University D in 2013.

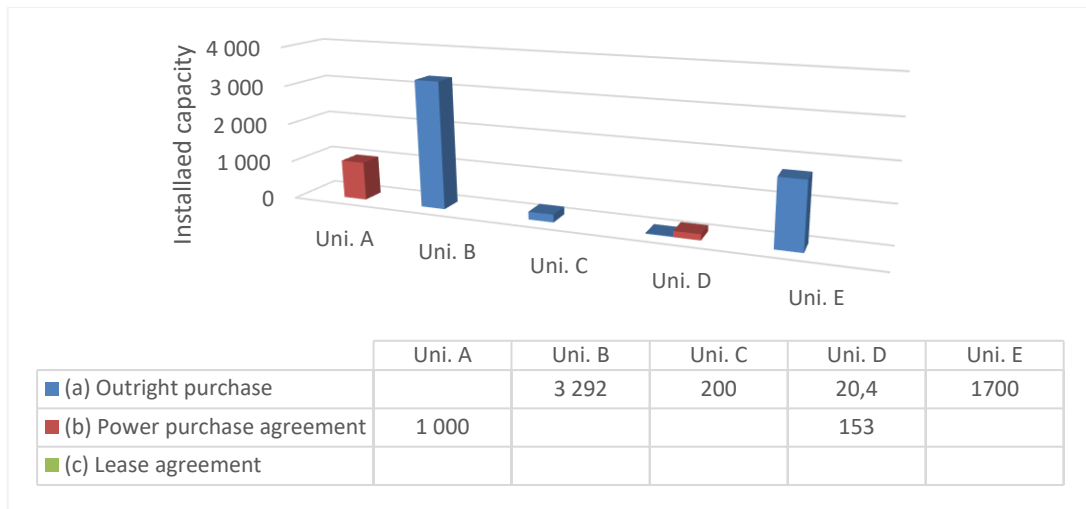
**Table 5.1: Details of PV installations at universities**

No.	Questions	Uni. A	Uni. B	Uni. C	Uni. D	Uni. E
1	Installed capacity (kWp)*	1 000	3 292	200	173.4	1 700
2	Energy storage system installed	0	0	0	0	0
3	Time of first installation	2019	2018	2017	2013	2019
4	Time of last installation	n/a	2019	2020	2018	2020
5	Deployment count	1	6	2	3	2
6	Method of installation:					
	(a) Rooftop mounted		√	√	√	√
	(b) Ground mounted (low level)**	√	√			
	(c) Pole mounted (high level)***	√			√	
	(d) Building Integrated PV					
	(e) Mounted as roof for carport					√
7	Method of acquisition of PV system:					
	(a) Outright purchase		√	√	√	√
	(b) Power purchase agreement	√			√	
	(c) Lease agreement					
8	Stakeholder involvement:					
	(a) <i>Design of PV system</i>					
	In-house expertise				√	
	External contractor	√	√	√	√	√
	(b) <i>Installation of PV system</i>					
	In-house expertise				√	
	External contractor	√	√	√	√	√
	(c) <i>Maintenance of PV system</i>					
	In-house expertise		√		√	
	External contractor	√	√	√	√	√

Note: \* PV systems generating a total of 6 365.4 kWp have been installed in the five universities

\*\* Ground-mounted systems are installed in open space and are without trackers

\*\*\* Pole-mounted systems are installed with trackers

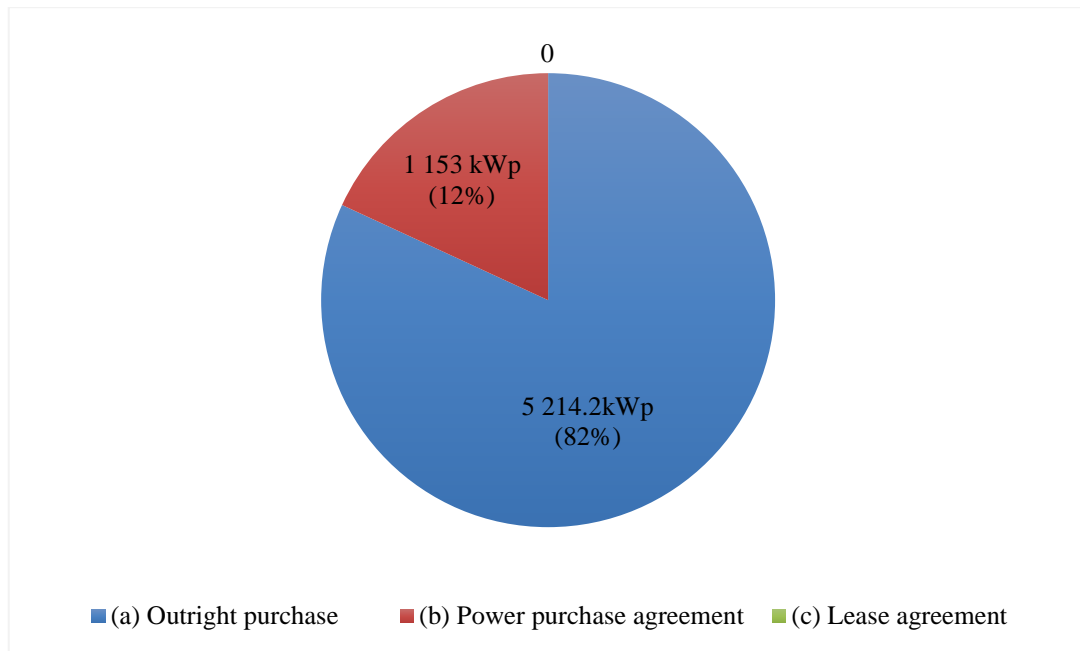


**Figure 5.1: Breakdown of methods of acquisition per university**

The installation of PVs can be carried out in several ways. To some degree, the method might be determined by the prevailing conditions at the installation site, the maximum amount of energy to be generated relative to the space that is available or the preference of the consumer. The panels can be installed on rooftops, mounted on the ground (normally at a low level without trackers) or on a pole, which is usually high, and with trackers. It can also be installed as part of the building fabric (which is referred to as BIPV) or mounted as a roof for carports. The results showed that all of the above methods of installation were practised, except for the case where PVs are installed as ‘building integrated PVs’. Roof-mounted systems appeared to be the most common method of installation, practised in four universities (University B, C, D, and E). Only University E incorporated the panels as the rooftop for the carports on their campus. University A and B also adopted the ground-mounted approach. Two of the universities installed some panels on high pole-mounted systems with trackers to maximise the generation of electricity.

Outright purchase, PPA, and lease agreement are popular options that can be utilised to source solar electricity (Dutta and Das, 2020; Geh *et al.*, 2022a; Rai *et al.*, 2016; Sigrin *et al.*, 2015). Apart from lease agreements, it was evident that the five universities either

purchased and owned the PV systems and/or used PPA acquisition options. University D used both acquisition methods, University A acquired the system using only PPA, and Universities B, C, and E used outright purchase only. In all, systems generating 5 212.4 kWp (82%) were acquired via outright purchase and systems generating 1 153 kWp (18%) were acquired using PPA acquisition options (Figure 5.2).



**Figure 5.2: Method of acquisition of total installed capacity**

The design, installation, and maintenance of PV systems could either be done in-house by universities if the required human resources were available, or it could be outsourced to a third-party. The purpose of this study was also to ascertain how these aspects of the adoption process were managed by universities. The results indicated that most of the institutions outsourced the design, installation, and maintenance work to third-parties. For instance, Universities A, C, and E engaged contractors entirely for the design, installation, and maintenance of their systems. A special case was mentioned by University D where it was necessary for the engineering students to have practical experience and, so, 20 kWp of the 173.4 kWp system owned by the institution was designed, installed and maintained

internally by the students. The results, therefore, established that third-parties were always involved in the deployment of PVs on campuses, and universities did not exclusively undertake these projects alone.

### **5.3. Examination of Deployment of PVs at CUT (Phase 4)**

The Central University of Technology is one of the 26 public universities in SA, with the main campus located in Bloemfontein and a second campus in Welkom. The institution was established in 1981 as Technikon Free State and it was in 2004, during the re-branding and merging of universities in SA, that the institution received its new name and unique identity as a University of Technology (UoT). The university provides a wide range of programmes at under-graduate, graduate, and post-graduate levels. CUT had a student population of 21 103 by the end of 2020 (DHET, 2021).

The objective of the case study that was carried out at CUT, and reported in this section, was to understand what the university had done in terms of deploying PVs, and the prevailing challenges to upscaling the PV system portfolio. A detailed account of how the data were collected and analysed is presented in Section 4.8.3.

#### **5.3.1. Results and Discussion**

##### **5.3.1.1. Part A: Installed PV Capacity at CUT**

The institution's first solar project was launched in 2013, and this was the installation of ten 40 W solar-powered charging stations for mobile phones around the Bloemfontein and Welkom Campuses for the use of students. The charging stations were called solar-flower, and each of the 10 stations can charge up to four devices simultaneously. The solar-flower was designed, fabricated and installed by CUT's internal experts (CUT, 2014). Furthermore, in 2018, the institution completed a 153 kWp capacity solar project to install 12 dual-axis, solar tracking PV systems, mounted on masts 8m high. The project was

executed in collaboration with a private partner, Karah Assets (Pty) Limited, and is located at the Bloemfontein Campus (CUT, 2018). Energy storage systems were not installed, hence the power generated is not stored but is fed directly into the local grid of the university. The 153 kW system was funded by Karah Assets (Pty) Limited and the private partner is also responsible for maintenance of the system, and the university pays for the power consumed at an agreed price which is lower than the market price. The 153 kWp system is also used for educational and research purposes. In addition, since 2014, the Faculty of Engineering, Built Environment and Information Technology has been carrying out PV installations in phases on BHP Billiton Building at the Bloemfontein Campus. This project has been executed mainly for educational and research purposes. Currently, installation on the rooftop of the BHP Billiton Building has reached a total capacity of 20 kWp, and the electricity generated is used in the building.



**Figure 5.3: PV trackers installed on the sides of the football field at Bloemfontein Campus**

(Source: Author's field survey, 2019)



**Figure 5.4: Solar trackers at CUT Bloemfontein Campus**

(Source: Author's field survey, 2019)



**Figure 5.5: PVs installed by students at CUT**

(Source: Raath, 2020)



**Figure 5.6: PVs installed by students at CUT**

(Source: Raath, 2020)



**Figure 5.7: PV installation called 'Solar flowers' at CUT**

(Source: CUT, 2014)

#### 5.3.1.2. Part B: Factors Influencing Upscaling of PV Systems and Remedial Measures

- **Demographics of Interviewees**

A total of seven staff members (referred to as P1, P2, P3, P4, P5, P6, and P7) participated in the study and they had been working with CUT for 13.7 years, on

average (Table 5.2). The participants consisted of four non-academic staff and three academic staff. Since the focus of the study was to elicit information on factors hampering progress, it was felt that respondents would be more open to sharing their views when they were assured of confidentiality and anonymity in the reporting of their views on the phenomenon. Therefore, the interviewees were given this assurance before engaging them in the study. This was also the reason for the limited information provided regarding the demographics of the interviewees (Table 5.2).

**Table 5.2: Information on interviewees**

No.	Stakeholder Group	Code	Years of Employment
1	Academic staff	P1	5
2	Non-academic staff	P2	20
3	Non-academic staff	P3	15
4	Academic staff	P4	25
5	Non-academic staff	P5	8
6	Non-academic staff	P6	10
7	Academic staff	P7	13

Interviewees identified various factors which they perceive were adversely influencing the upscaling of the PV system at CUT. Overall, seven main factors emerged from the data, as shown in Table 5.3 and discussed below.

(1) Funding challenges:

It is widely acknowledged that PV systems are still quite expensive and the high initial cost is a major factor that can hamper deployment (Kurata *et al.*, 2018). Apart from the panels, there are other expensive components, such as cabling and energy storage systems (P2, P4, P6). All the interviewees perceived that a major challenge hindering the upscaling of PVs at CUT was related to

funding. According to P2, ‘Obviously the first one is financial’, and P1 said that, ‘Funding is a major challenge’. The respondents were mainly of the view that PV projects were not receiving the required funding because of two major reasons. Firstly, it was believed there was a lack of funds and, secondly, because the university had other pressing needs which required financial resources, hence funds were allocated to these needs which were perceived to be of higher priority. Respondent P5 expounded on the later phenomenon by saying:

When you bring solar power and other requirements you find that if you try to categorise, it doesn’t rise to the level where it is funded in the categories. (P5).

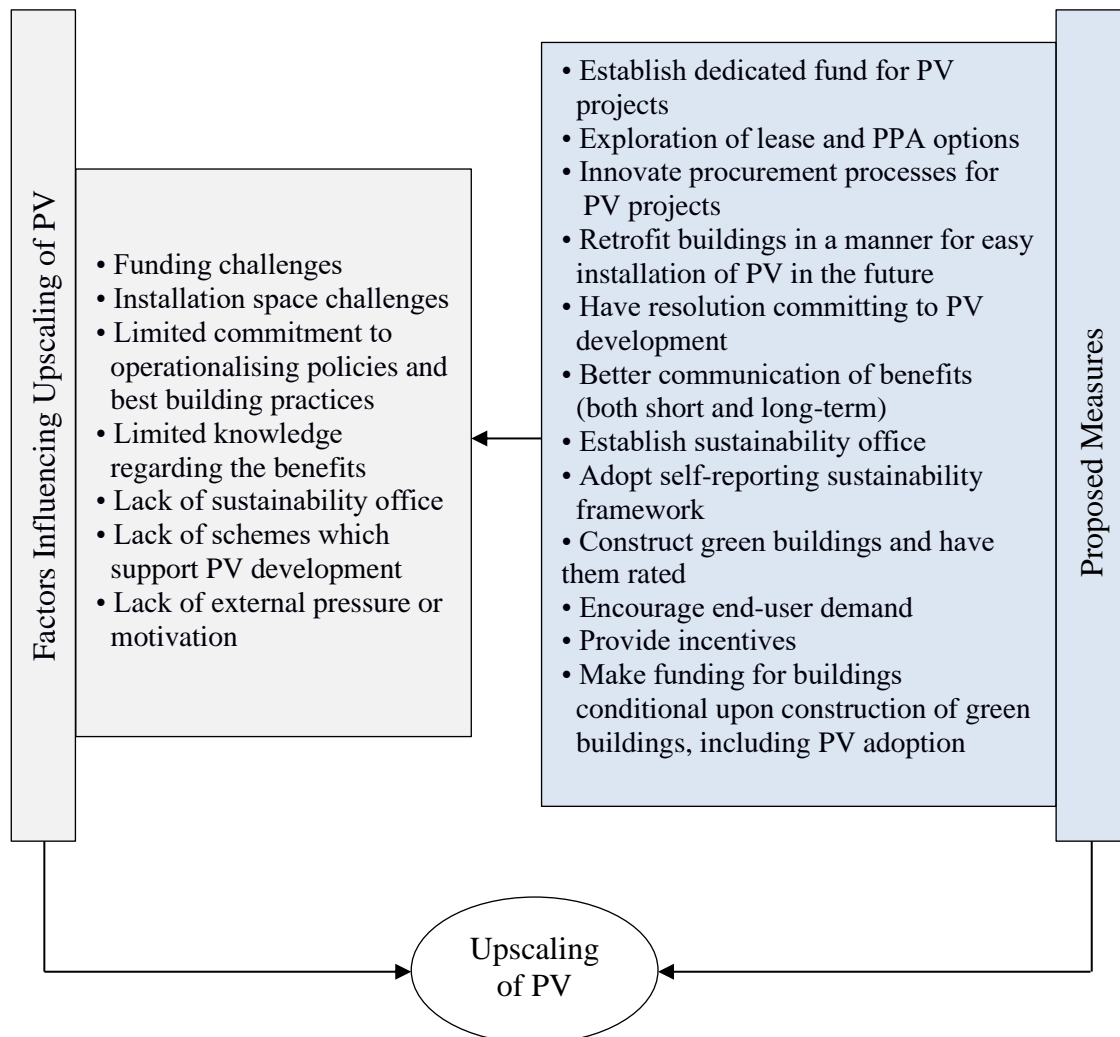
Additionally, one of the respondents spoke on the same subject by explaining that, although money is being made available for infrastructure development by the DHET, the funds are not invested in PV systems when decisions are taken, because it is considered as being too expensive (P3).

**Table 5.3: Factors influencing upscaling of photovoltaic systems**

No.	Description	Interviewees						
		P1	P2	P3	P4	P5	P6	P7
1	Funding challenges	√	√	√	√	√	√	√
2	Installation space challenges	√			√		√	√
3	Limited commitment to operationalising policies and practices	√		√	√			
4	Limited knowledge regarding the benefits	√						
5	Lack of sustainability office		√	√				
6	Lack of schemes which support PV development	√		√		√		
7	Lack of external pressure or motivation	√				√		

In offering solutions to the funding challenges, it was suggested that there should be long-term planning to make sure there is dedicated funding for

PV projects (P5). It was also advocated that general procurement systems are not best suited to PV procurement, especially when only PV is being procured and not a building project, hence the need to innovate procurement processes that give more value for money (P2, P5). The university's current 153 kW PV system is based on a public-private partnership, where the university pays for the power that is generated, and this option was regarded by some of the respondents as a viable option for acquisition that the university could continue to explore in upscaling PV systems on campus, as opposed to acquiring the systems on an outright purchase basis (P1, P2, P6).



**Figure 5.8: Challenges and proposed solutions**

(2) Challenges relating to installation space:

Unavailable or limited space could also lead to non-adoption or hamper upscaling of PV projects (Mah *et al.*, 2018; Walters *et al.*, 2018a; Zhang *et al.*, 2012). One of the challenges identified in this study that CUT was facing was finding suitable spaces in which to install the PV systems at an affordable price and also to ensure that they perform at an optimal level without affecting the campus aesthetics. Specifically, it was confirmed by interviewees P4 and P6 that the university was currently planning to expand the 153 kWp installation and this required the installation of additional solar trackers, similar to the existing systems, at convenient positions on campus or installing fixed systems. The spatial challenge noted by the interviewees was peculiar to the Bloemfontein Campus (P1, P4, P6, P7). However, it was wholly acknowledged that Welkom, as a developing campus, had a lot of space for PV installations.

In overcoming the challenge relating to space, interviewees recommended careful planning and assessment of spaces that could be used to install more PV systems, both within and outside the university campus. For instance, interviewee P4 confirmed that the university was in consultation with the owners of an adjoining private property to secure space for the expansion of the PV systems.

(3) Limited commitment to operationalising policies and practices:

In their quest to implement SD tenets, universities have realised the need to set out clear visions and policies that will guide action and development. Therefore, it is laudable and not surprising that CUT adopted its Vision 2020 in 2010. Consequently, the institution's commitment to its transformation

agenda is affirmed and revealed in several policy documents, such as: (a) Transformation Plan 2016-2020, (2) the 2016-2020 Strategic Plan, (3) the special project for the period 2018-2022, approved at the Management Lekgotla held from 28-29 September 2017, and (4) the ongoing development of Vision 2030 and Strategic Plan 2021-2025 (CUT, 2010, 2017a, 2017b, 2020).

According to Richardson and Lynes (2007), and Shriberg (2003), top leadership commitment and support is a significant driver for delivering sustainable practices in universities. Also, Ávila *et al.* (2017, 2019) established that limited commitment from decision-makers can significantly impair innovation and operationalisation of SD within universities. Similarly, the findings from this study suggested that limited commitment to operationalising university policies and GB practices, such as PV deployment during new construction/refurbishment projects, are major factors which influence the PV deployment rate at CUT (P1, P3, P4). Providing insight into this institution-related barrier, respondent P3 stated:

The barrier is commitment as far as I am concerned. The university does have sustainable development policy and it's got a commitment. So the commitment [has to go] beyond paper. The major barrier is operationalising your commitment. Because by operationalising you need to commit resources, financial resources. (P3).

To overcome the commitment barrier, it was suggested that there should be a system in place that compels the university to ensure that new buildings incorporate PV systems at the time of construction or that provision is made

for easy installation at a later time. It was also suggested that refurbishment of existing buildings should be executed, with similar principles, to afford the same opportunities (P1, P3, P4).

(4) Limited knowledge regarding the benefits gained from existing projects:

There is consensus among scholars that people or organisations adopt innovations because of the perceived benefits (Balcombe *et al.*, 2014; Davis, 1989; Iacovou *et al.*, 1995). However, it has also been recognised that, when people perceive that the benefits are too small, this could lead to non-adoption or rejection. For example, Balcombe *et al.* (2014) found that some people would reject PVs because of the perception that the environmental benefits are too small. In like manner, a respondent postulated that, although the university was planning to upscale, the motivation was very low and the university had not attained the level it could have in terms of deployment because there was limited buy-in from stakeholders. According to this respondent, there was limited buy-in because the benefits accrued from existing projects might not be satisfactory or acknowledged sufficiently to motivate a speedy upscaling of the institution's PV portfolio (P1). Reiterating the importance of knowing the benefits of existing projects to engender further deployment, interviewee P1 stated that:

Before you go in to say you want to undertake a bigger one, a large scale one, what is the impact this one has made now on the balance sheet of the university, on occupant comfort in the building . . . do we see light from the solar being used during load-shedding? . . . so limited knowledge

concerning the impact of what we have now, or the Phase One we have now can serve as a barrier because you can't secure buy-ins (P1).

The main point was that better communication of the impact of existing projects is essential in motivating and securing maximum support for scaling up from decision-makers. It was suggested also that there was a need to compute the life-cycle cost of projects, and showcase the benefits that are accruable across the whole life-cycle of the PV.

(5) Lack of sustainability office:

Evidence from the literature indicated that sustainability offices are crucial to strengthening collaboration among stakeholders, and an effective means to drive and support the implementation of sustainable initiatives within universities (Adomßent *et al.*, 2019; Leal Filho, Will, *et al.*, 2019). Sustainability offices can also be useful in fostering awareness among students and staff regarding matters relating to sustainable development (Adomßent *et al.*, 2019; Leal Filho, Will, *et al.*, 2019). In congruence with the literature, another factor noted by some interviewees was the lack of a sustainability office at CUT. According to some interviewees, there used to be a sustainability office at CUT but it was shut down for unknown reasons (P2, P3).

Although the lack of a sustainability office at CUT was not a direct barrier to the deployment of PVs, the lack of an office had an indirect effect because of the vacuum it created in terms of advocacy roles. Therefore, the findings suggested that, perhaps, the presence of a sustainability office could further enhance the implementation of sustainable initiatives at CUT, including the deployment of PV systems.

(6) Lack of schemes which support photovoltaic development:

The scores allocated to energy in green building rating systems are substantial. Scores are awarded for energy efficiency as well as for RE generation. Therefore, green certification of university buildings could encourage the adoption of PVs as a green energy generation instrument in buildings. According to P1, a green building rating could be a subtle way to encourage universities to adopt PVs. Similarly, self-reporting frameworks, for example, the Sustainability Tracking, Assessment and Rating System (STARS), could encourage universities to implement sustainable initiatives and report their sustainability performance. Conversely, the absence of such schemes could diminish the sustainability drive on campus. The lack of green-rated buildings and a self-reporting framework for campus sustainability was affirmed by interviewees as a factor which might have diminished the drive to upscale PVs at CUT (P1, P3, P5). Interviewee P5 expressed this view by saying:

So if you look at all these public institutions in South Africa and you ask which ones have any kind of certification, there is nothing, simply because that is not a requirement and, the second, nobody is demanding that. So again, if you certify it is a luxury, it is you who want to pursue that one.  
(P5).

Although universities are not mandated to certify their buildings, the interviewees agreed that it would be impactful if universities were encouraged to construct green buildings and have them certified (P1). Also, according to P5, the adoption of a self-reporting framework for campus sustainability could

boost PV deployment and it was confirmed by the same respondent that the university was in the process of filling this gap.

(7) Lack of external motivation and incentives:

The lack of incentives also emerged as a relevant factor that lessens the determination for the deployment of PVs at CUT. Other scholars, such as Kasai and Jabbour (2014), and Richardson and Lynes (2007), also found incentives to be an essential driver for the construction of green buildings in universities. Furthermore, the absence of demand for solar electricity or pressure from institution stakeholders, such as students and staff, were cited as factors that indirectly influence PV deployment decisions. A comment from an interviewee was:

Because we are educating people for sustainability and they always know that using solar is more sustainable . . . so now if there is pressure from users that we want more of solar electricity . . . that pressure group will make the university dedicate more funding for it (P5).

The findings from the literature review affirmed that government legislation and policies are highly instrumental in RE development (Mah *et al.*, 2018; Shah *et al.*, 2019). It was identified in this study that there was a belief that the lack of appropriate legislation that promotes RE development in universities affects PV deployment decisions at CUT (P1). In addition, it was acknowledged that DHET, which is the financier of most university buildings, does not make the construction of green buildings (by extension PV adoption) mandatory (P5). Therefore, it is the view of some interviewees that incentives, legislation, end-

user demand, and DHET ‘motivation’ could help to encourage installing more PVs on campus.

#### **5.4. Identifying Applicable Drivers and Barriers in the University Sector (Phase 5)**

The identification of the drivers and barriers followed the processes, described in detail earlier in Section 4.8.4, using a three-round Delphi study. Briefly, the panellists rated 22 drivers, which were identified from the literature, and an additional five drivers that were recommended by some panellists. The list of all the drivers is presented in Table 5.4. Similarly, 23 barriers were identified from the literature, and four additional barriers recommended were rated. The list of all the barriers is presented in Table 5.5. The results and discussions are presented below.

**Table 5.4: Drivers of photovoltaic deployment pertinent to the education sector**

<b>Code</b>	<b>Description</b>	<b>Reference to driver in Table 2.2</b>
<b>Direct Benefits (DB)</b>		
DB1	Reduction of energy cost to university	D1, D2, D46
DB2	Minimisation of impact from power cuts	D9
DB3	Enhancement of university image	D11
DB4	Increased value of university properties	D14
DB5	Enhancement of university sustainability performance	D37, D45
DB6	Contribution to attainment of Sustainable Development Goals	D47
DB7	Potential use for teaching students	D55
DB8	Potential use for research opportunities for students and staff	D55, D50
DB9	Enhancement of university productivity (i.e. directly or indirectly)	Delphi R1 recommended
DB10	Provision of in-service training opportunities for students	Delphi R1 recommended
<b>Indirect Benefits (IB)</b>		
IB1	Reduction of energy-related greenhouse gases	D12
IB2	Creation of job opportunities	D34
IB3	Opportunity for staff to observe and use technology	D48
IB4	Opportunity for students to observe and use technology	D48
IB5	Opportunity for public to observe technology	D49
IB6	Enhancement of technology demonstration	Delphi R1 recommended
<b>Social Influences (SI)</b>		
SI1	Expectation from students	D53
SI2	Expectation from university staff	D54
SI3	Expectation from society	D18
SI4	Expectation from university bodies/associations	D18
SI5	People/organisations in the community use PV	D17
SI6	Other universities use PV	D17
SI7	International organisation incentives (e.g., UN, ISCN, etc.)	Delphi R1 recommended
SI8	Demonstration projects showcasing different PV technologies	Delphi R1 recommended
<b>Relative Advantage (RA)</b>		
RA1	Ease of installation	D25
RA2	Ease of maintenance	D26
RA3	No noise pollution from PV usage	D28

Note: Factors have been reworded to suit their applicability in a university context

**Table 5.5: Barriers pertinent to the education sector**

<b>Code</b>	<b>Description</b>	<b>Reference to barriers in Table 2.3</b>
<b>Cost and funding-related barriers (CFB)</b>		
CFB1	High cost of solar photovoltaic (i.e. technology is expensive)	B1
CFB2	Long investment pay-back period	B3
CFB3	Lack of financial resources	B4
CFB4	Challenges of energy storage system requirements	B15
CFB5	Decision-makers' uncertainty about recouping investment cost	B10
CFB6	High upfront cost (i.e. outright purchase option)	B2
CFB7	Scarcity of favourable PPA acquisition options	B7
CFB8	Scarcity of favourable lease acquisition options	B27
CFB9	Lack of favourable credit/financing schemes	B8
CFB10	Limited locally manufactured materials for photovoltaic	Delphi R1 recommended
CFB11	Liability and cost for preventing unauthorised access to and theft of PV systems	Delphi R1 recommended
<b>Institution-related barriers (IRB)</b>		
IRB1	Lack of suitable installation space	B14, B30
IRB2	Resistance to change	B43
IRB3	Limited commitment to operationalising university policies	B49
IRB4	Lack of green building targets for university	B61
IRB5	Lack of reporting university sustainability performance	B65
IRB6	Limited motivation to reduce operational cost of buildings	B66
IRB7	Lack of dedicated sustainability advisor/promoter	B67
IRB8	Limited appreciation of benefits of PV usage	B19, B50, B58
IRB9	Lack of demand from electricity end-users	B41
IRB10	Lack of clear policy direction on PV deployment	B42
IRB11	Red tape with university procurement policies	Delphi R1 recommended
IRB12	Prevalence of higher competing needs of universities	Delphi R1 recommended
<b>Government-related barriers (GRB)</b>		
GRB1	Lack of incentive to adopt technology	B44
GRB2	Lack of enabling policies	B45
GRB3	Lack of demand from government project financiers	B52
GRB4	Inadequate funding for infrastructure development	B51

Note: *The barriers have been re-worded to suit their applicability in a university context*

#### **5.4.1. Demographics of Panellists**

The enlistment of panellists yielded a total of 24 staff members from 13 universities who agreed to participate in the surveys. The total consisted of 11 non-academic staff (46%)

and 13 academic staff (54%). Ultimately, only 18 staff (75% of those who agreed to take part in the survey) participated in both R1 and R2. During R3, two panellists could not return the questionnaire, and this resulted in 16 panellists participating in the R3 survey. The panellists represented 11, 11, and 9 universities during the R1, R2, and R3 surveys, respectively. The non-academic staff who participated were decision-makers from university departments that were responsible for the construction and maintenance of buildings/infrastructure and/or campus sustainability initiatives.

**Table 5.6: Demographics of panellists and participation in Delphi rounds**

Item Code	University affiliation	Category	YoE	NoU	Qualification	R1 <i>n</i> =18	R2 <i>n</i> =18	R3 <i>n</i> =16
P1	U1*	NAS	29	≥ 2	Master's	√	√	√
P2	U1*	AS	6	1	Doctorate	√	√	√
P3	U1*	NAS	1	1	Diploma	√	√	√
P4	U2*	NAS	2	1	1 <sup>st</sup> degree	√	√	√
P5	U2**	AS	3	≥ 2	Doctorate	√	√	√
P6	U3*	NAS	2	1	Master's	√	√	√
P7	U3*	AS	8	≥ 2	Doctorate	√	√	√
P8	U3*	AS	25	1	Doctorate	√	√	√
P9	U4*	AS	13	≥ 2	Doctorate	√	√	√
P10	U4*	NAS	2	≥ 2	Doctorate	√	√	√
P11	U5**	AS	19	≥ 2	Doctorate	√	√	√
P12	U5**	AS	7	1	Doctorate	√	√	√
P13	U6**	NAS	1	1	Master's	√	√	x
P14	U7**	AS	17	≥ 2	Doctorate	√	√	√
P15	U8*	NAS	7	1	Doctorate	√	√	√
P16	U9**	NAS	11	1	1 <sup>st</sup> degree	√	√	√
P17	U10*	NAS	20	≥ 2	1 <sup>st</sup> degree	√	√	x
P18	U11*	NAS	23	≥ 2	1 <sup>st</sup> degree	√	√	√

Notes: \* = University has installed PV; \*\* = University has not installed PV; YoE = Years of experience in public universities; NoU = Number of universities worked at; AS = Academic staff; NAS = Non-academic staff

Participants were either directors or managers of the departments or the units responsible for electrical works or sustainability. The academic panellists (i.e. deans, lecturers and professors) were people who had insight into the issues that drive the deployment of innovations on campuses and/or were involved in the implementation of campus sustainability initiatives or PV-related research projects. The average years of experience of panellists was 10.8 years, 50% of the panellists had worked in only one university, and the remaining 50% had worked in two or more universities (Table 5.6).

#### **5.4.2. Drivers of Deployment of Photovoltaics**

##### **5.4.2.1. Delphi Survey Results**

###### **(1) Delphi Round 1:**

The findings from R1 revealed that out of the 22 factors identified directly from the literature, 15 factors were believed to positively influence deployment. These include seven direct benefits, four indirect benefits, three social influences, and one relative advantage. The following 7 factors were deemed not to be applicable drivers in the sector: DB4, IB2, SI1, SI5, SI6, RA1 and RA2, and the mean values ranged from 3.50 - 3.00. Overall, the direct benefit of 'reduction of energy cost to university' was allotted the highest mean score of 4.72, and the relative advantage of 'ease of installation' scored the lowest mean value of 3.00.

The determination of consensus based on the IQR rule indicated that consensus was reached on 17 factors (77.3%) at R1 (i.e.  $IQR \leq 1.0$ ) and the values ranged from 0 - 1.0. Out of the 5 factors on which consensus was not reached, four of these scored 1.75 (DB2, DB4, DB7, and SI6) and the remaining factor scored 2.0 (RA1). Although DB2 (minimisation of impact

from power cuts) showed a high mean score of 4.11, the IQR value was 1.75, indicating weak consensus among the panellists. All the results for R1 are presented in Tables 5.7 and 5.8.

Since the panellists were also free to recommend additional drivers, at the end of R1, the following five drivers were proposed: DB9 (enhancement of university productivity), DB10 (provision of in-service training opportunities for students), IB6 (enhancement of technology demonstration), SI7 (international organisation incentives), and SI8 (demonstration projects showcasing different PV technologies), as shown in Table 5.4.

**Table 5.7: Delphi Rounds 1 and 2 results (a) – Drivers retrieved directly from literature**

Code	Round 1 ( <i>n</i> = 18)				Round 2 ( <i>n</i> = 18)				
	Mean	SD	IQR	CV	Mean	SD	IQR	CV	Rank
DB1	4.72	0.46	0.75	0.10	4.72	0.46	0.75	0.10	1
DB2	4.11	1.06	1.75	0.26	4.06	1.06	1.75	0.26	11
DB3	4.17	0.86	1.00	0.21	4.17	0.86	1.00	0.21	9
DB4	3.39	1.14	1.75	0.35	3.44	1.20	1.75	0.35	17
DB5	4.61	0.70	0.75	0.15	4.56	0.70	1.00	0.15	3
DB6	4.61	0.78	0	0.17	4.56	0.78	0.75	0.17	4
DB7	4.28	0.92	1.75	0.21	4.28	0.83	1.00	0.19	6
DB8	4.50	0.70	1.00	0.16	4.44	0.70	1.00	0.16	5
IB1	4.67	0.59	0.75	0.13	4.67	0.59	0.75	0.13	2
IB2	3.28	1.06	1.00	0.33	3.22	1.06	1.00	0.33	19
IB3	4.17	0.73	1.00	0.19	4.22	0.73	1.00	0.17	7
IB4	4.06	0.87	1.00	0.22	4.11	0.90	1.00	0.22	10
IB5	3.61	0.98	0.75	0.27	3.61	1.04	1.00	0.29	13
SI1	3.17	0.71	1.00	0.22	3.17	0.71	1.00	0.22	20
SI2	3.56	1.04	1.00	0.29	3.56	1.04	1.00	0.29	15
SI3	3.72	0.98	1.00	0.27	3.61	0.98	1.00	0.27	12
SI4	3.56	0.62	1.00	0.17	3.56	0.62	1.00	0.17	14
SI5	3.06	0.94	0.75	0.31	3.06	0.94	0.75	0.31	22
SI6	3.28	0.96	1.75	0.29	3.28	0.96	1.75	0.29	18
RA1	3.00	1.11	2.00	0.38	3.17	1.20	1.75	0.38	21
RA2	3.50	1.34	1.00	0.37	3.56	1.29	1.00	0.36	16
RA3	4.22	0.94	1.00	0.22	4.22	0.94	1.00	0.22	8

Notes: *SD* = Standard Deviation; *CV* = Coefficient of Variation; *IQR* = Inter-Quartile Range

**Table 5.8: Delphi Rounds 1 and 2 results (b) – Drivers retrieved directly from literature**

Code	CV Change (R1-R2)	*Mean $M \geq 3.50$	*IQR $\leq 1$	**Stability Achieved	Decision
DB1	0.00	Yes	Yes	Yes	Accept
DB2	0.00	Yes	No	Yes	Reject
DB3	0.00	Yes	Yes	Yes	Accept
DB4	0.00	No	No	Yes	Reject
DB5	0.00	Yes	Yes	Yes	Accept
DB6	0.00	Yes	Yes	Yes	Accept
DB7	0.02	Yes	Yes	Yes	Accept
DB8	0.00	Yes	Yes	Yes	Accept
IB1	0.00	Yes	Yes	Yes	Accept
IB2	0.00	No	Yes	Yes	Reject
IB3	0.02	Yes	Yes	Yes	Accept
IB4	0.00	Yes	Yes	Yes	Accept
IB5	0.02	Yes	Yes	Yes	Accept
SI1	0.00	No	Yes	Yes	Reject
SI2	0.00	Yes	Yes	Yes	Accept
SI3	0.00	Yes	Yes	Yes	Accept
SI4	0.00	Yes	Yes	Yes	Accept
SI5	0.00	No	Yes	Yes	Reject
SI6	0.00	No	No	Yes	Reject
RA1	0.00	No	No	Yes	Reject
RA2	0.01	Yes	Yes	Yes	Accept
RA3	0.00	Yes	Yes	Yes	Accept

Notes: \* Evaluation is based on Round 2 results; \*\* Stability is achieved when CV Change  $\leq 0.10$

**Table 5.9: Delphi rounds 2 and 3 results (a) – Drivers recommended by panellists**

Code	Round 2 (n = 18)				Round 3 (n = 16)				
	Mean	SD	IQR	CV	Mean	SD	IQR	CV	Rank
DB9	3.72	0.96	1.00	0.26	3.75	1.00	1.25	0.27	3
DB10	4.17	1.10	1.00	0.26	4.44	0.63	1.00	0.14	1
IB6	4.22	0.73	1.00	0.17	4.38	0.62	1.00	0.14	2
SI7	3.17	1.04	1.00	0.33	3.06	1.00	0	0.33	5
SI8	3.67	1.03	1.00	0.28	3.56	1.09	1.00	0.31	4

Notes: SD = Standard Deviation; CV = Coefficient of Variation; IQR = Inter-Quartile Range

**Table 5.10: Delphi Rounds 2 and 3 results (b) – Drivers recommended by panellists**

Code	CV Change (R2-R3)	*Mean $M \geq 3.50$	*IQR $\leq 1$	**Stability Achieved	Decision
DB9	0.01	Yes	No	Yes	Reject
DB10	0.12	Yes	Yes	No	Accept
IB6	0.02	Yes	Yes	Yes	Accept
SI7	0.00	No	Yes	Yes	Reject
SI8	0.03	Yes	Yes	Yes	Accept

Notes: \* Evaluation is based on Round 3 results; \*\* Stability is achieved when CV Change  $\leq 0.10$

(2) Delphi Round 2:

Only panellists who participated in R1 participated in R2, and the results for R2 are presented in both Tables 5.7 and 5.10. At the end of R2, regarding the terminated batch of drivers, it was noted that there was not a significant change in the rating of the factors. Eight of the factors with  $M \geq 3.5$  remained unchanged [DB1 (4.71), DB3 (4.17), DB7 (4.28), IB1 (4.67), IB5 (3.61), SI2 (3.56), SI4 (3.56), RA3 (4.22)]. Also, 3 factors with  $M < 3.5$  remained unchanged [SI1 ( $M = 3.17$ ), SI5 ( $M = 3.06$ ), and SI6 ( $M = 3.28$ )]. Also, 6 factors recorded a decrease in mean value: DB2 (4.11 - 4.06), DB5 (4.61 - 4.56), DB6 (4.61 - 4.56), DB8 (4.50 - 4.44), IB2 (3.28 - 3.22), and SI3 (3.72 - 3.61), and an increase in mean value was recorded for 5 factors: [DB4 (3.39 - 3.44), IB3 (4.17 - 4.22), IB4 (4.06 - 4.11), RA1 (3.00 - 3.17), and RA2 (3.50 - 3.56)]. In summary, the highest mean value during R2 was recorded for DB1 (4.72) and the lowest was for SI5 (3.06).

The panellists also reached a strong consensus on 18 of the drivers (i.e.  $0.75 \leq IQR \leq 1.0$ ), while a weak consensus ( $IQR = 1.75$ ) was recorded for the remaining 4 factors (DB2, DB4, SI6 and RA1).

Finally, based on the two criteria that a driver would be accepted as an applicable factor within the public university sector if it scored a mean value denoting acceptance ( $M \geq 3.5$ ), as well as an acceptable value of IQR denoting consensus ( $IQR \leq 1$ ), it was observed that 15 factors met these criteria. Therefore, the 15 drivers were accepted as factors that drove the deployment of PVs in SAPUs. However, it was noted that, although DB2 (minimisation of impact from power cuts) scored a mean value of 4.11, there was weak consensus among the panellists ( $IQR = 1.75$ ) and, so, this factor was rejected. By using the CV change  $\leq 0.1$  rule to measure stability, it was noted that the difference in CV for all the factors during R1 and R2 fell below the acceptable value. For this reason, the rating of all the 22 drivers that were retrieved from the literature was terminated in R2.

At the end of R2, regarding the drivers that were recommended by the panellists, out of the 5 proposed factors (which were DB9, DB10, IB6, SI7 and SI8), 4 had a mean score  $\geq 3.5$  (DB9, DB10, IB6, SI8). The remaining factor (SI7) scored the lowest mean value of 3.17. The highest-scored driver was IB6 ( $M = 4.22$ ), and the lowest factor was SI7 ( $M = 3.17$ ). Furthermore, the 5 factors all scored 1.00 for IQR.

### (3) Delphi Round 3:

The R3 survey involved rating only the 5 drivers that were recommended by panellists. The mean score for all the factors changed during the final round. Factors DB9, DB10 and IB6 increased in mean value (from 3.72 to 3.75, 4.17 to 4.44, and 4.22 to 4.38, respectively). However, the mean value for SI7 and SI8 decreased; there was a drop from 3.17 to 3.06 and 3.67 to

3.56, respectively. Regarding consensus, the IQR value increased from 1.00 to 1.25 for DB9, dropped from 1.00 to 0 for SI7, and the remaining factors (DB10, IB6 and SI8) remained unchanged (IQR = 1.00).

Based on the same criteria used to accept the drivers that were retrieved directly from the literature, factors DB10, IB6 and SI8, being 60% of the recommended factors, met the two criteria and, therefore, were accepted as factors that drove the deployment of technology. At the end of R3, the CV changed value for 4 factors during R2 and R3 and was less than 0.10. The only factor that was more than 0.10 was DB10 (0.12). Since the difference between the recommended value and the actual value was minimal (i.e. 0.02), it was deemed unnecessary to execute another survey only for this factor and so the survey was terminated at the end of R3.

#### 5.4.2.2. *Discussion of the Drivers*

Based on the constructs from the conceptual model, the discussion of the findings regarding the drivers is presented under the four major areas below.

##### (1) Direct benefits:

Logically, the benefits to be garnered from using technology will engender its adoption. According to Davis (1989), the perceived usefulness of innovation is a major driver of the adoption of an innovation. The usefulness of PVs and the direct benefits they bring to individual adopters or communities have been well discussed in the literature (Schelly and Letzelter, 2020; Walters et al., 2018a). Within the context of adoption in the university sector, the findings of this study also confirmed that direct benefits significantly influence deployment in a positive manner. Overall,

the factor with the highest mean value, which denotes that it is the highest influencing factor, was the direct benefit of ‘reduction of energy cost to university’ (DB1). This finding was consistent with previous studies (Balcombe *et al.*, 2014; Lee and Shepley, 2020; Rai *et al.*, 2016; Ugulu and Aigbayboa, 2019). The reduction in energy costs can be attributed to the monetary gains made from lower bills and/or increasing energy costs (Gastaldo *et al.*, 2019). Also, monetary gains can be made from the lower rates paid for energy consumed in the case of PPAs (Geh *et al.*, 2022a). This, therefore, suggested that universities would deploy more PV systems when the expected financial gains are appreciated.

Additionally, with respect to the R2 terminated batch of drivers, the other significant drivers that scored high mean values, and were ranked 3rd, 4th, 5th, 6th, and 9th, also belonged to the category of direct benefits. In their descending order of rank, these factors were: ‘enhancement of university sustainability performance’ (DB5), ‘contribution to attainment of SDGs’ (DB6), potential use for research opportunities for students and staff’ (DB8), ‘potential use for teaching students’ (DB7), and enhancement of university image (DB3). All of the above findings were consistent with previous studies. For instance, the deployment of PVs enhanced the sustainability performance of universities in Saudi Arabia (Alshuwaikhat *et al.*, 2016). The SDGs are presently a prominent agenda in all countries, and Awuzie and Emuze (2017) suggested that universities adopt RE technologies because they are perceived as being a cheaper alternative and they also helped to conform to SD-related policies. Therefore, it was not surprising that, as confirmed by the panellists, universities deployed PV systems to

contribute also to the achievement of the SDGs. Teaching and research are an integral part of what universities do and, as established by Li et al. (2013), the adoption of GBs can contribute to the performance of such a vital role. Therefore, it was consistent that, in this study, PVs, which are a GB feature, were found to be useful for teaching, in-service training and research in SAPUs. It was found in this study also that PV adoption helps to enhance university image. This finding parallels the work of Andelin et al. (2015) who suggested that the adoption of sustainable buildings enhances corporate image. Similarly, within a campus sustainability context, Shriberg (2003) found that universities that are striving to improve their external and internal image are likely to be open to sustainability initiatives. The favourable image that universities will gain from installing PVs can help to aid publicity further to attract staff and students (Richardson and Lynes, 2007). Therefore, it will be worthwhile for institutions to continue to deploy PVs to enhance university sustainability performance and image, contribute to the achievement of the SDGs, and provide opportunities for teaching, research and in-service training.

Although the installation of PVs can increase the value of properties (King *et al.*, 2014; Palm, 2018), it was found that this was not the case within SAPUs. The reason for this could be that some universities acquire the systems using PPAs and, so, the systems are not for the universities, although they are installed on university properties. For example, Geh et al. (2022a) found that CUT entered into a PPA agreement with a private partner and a system with a capacity of 153 kW was installed. The university pays for the energy consumed at a rate lower than the usual rate for power from

the national grid. Therefore, in this case, the installation of the PV system will not add value to the university property. This indicates that, depending on the acquisition option used by a university to acquire a PV system, it might or might not be a venture that adds value.

Due to load shedding or maintenance work-related shutdowns, it has been affirmed in the literature that PV systems can be adopted to minimise the impact of power cuts (Kiprop *et al.*, 2019; Qureshi *et al.*, 2017; Ugulu and Aigbayboa, 2019). In this study, although the factor of ‘minimisation of impact from power cuts’ (DB2) had a high mean score ( $M = 4.06$ ), the level of consensus among the panellists was weak ( $IQR=1.75$ ). Similarly, ‘enhancement of university productivity’ (DB9) scored 3.75 for the mean, but 1.25 for the IQR, which also indicated a lack of consensus. As a result, the above two factors were rejected. However, despite the lack of consensus on these two factors and their subsequent rejection, the findings suggested that these two direct benefits were not completely non-existent in the sector. Overall, the findings provided empirical evidence which suggested that the benefits that universities enjoy directly from installing PVs, or would enjoy if they installed them, are important indicators of adoption in the public university sector.

(2) Indirect benefits:

Similar to the direct benefits, indirect benefits also play a key role in deployment. It has been suggested that SA’s contribution to global GHG emissions is one of the highest in Africa (UNDP, 2016), and this can be attributed partly to the use of coal for energy generation (SSA, 2019). A

measure taken by the SAG to curb GHG emissions was to facilitate the deployment of RE on a large scale through the REIPPPP (SSA, 2019). Also, a carbon tax was recently introduced to discourage investment in non-renewable energy sources (SAG, 2019). At the organisational level, the findings of this study showed that the aim of public universities' diversifying their energy mix through PV deployment is to contribute to 'reduction of energy-related GHG' (IB1). Other scholars discussed this factor in the literature as being an important driver (Kastner and Wittenberg, 2019; Kiprop *et al.*, 2019; Lee and Shepley, 2020).

Besides the benefit of reducing GHG emissions, it is believed that staff, students, and the community benefit when universities install PVs. Li *et al.* (2013) found that the adoption of GBs by universities offers indirect benefits by 'providing the locals with a good opportunity to experience an outstanding example of sustainability' (p. 175). Similarly, it was found in this study that the deployment of PVs creates the opportunity for students, staff and the public to observe the technology. Since the diffusion of a technology is more likely to occur the more people observe that technology in use (Dutta and Das, 2020; Wolske *et al.*, 2017), it can be said that the extended benefit of this would be that students, staff and community members could become adopters later because of what they have observed at universities.

Contrary to the findings of previous studies (Dutta and Das, 2020; Korcaj *et al.*, 2015; Pickerill, 2018), creating employment opportunities through PV

adoption was found not to be a motive in the case of the public university sector in SA.

(3) Social influences:

Positive discussion or expectation by acquaintances and society, or the desire to demonstrate commitment to social responsibility can drive the uptake of PVs (Curtius *et al.*, 2018; Palm, 2017; Qureshi *et al.*, 2017; Sigrin *et al.*, 2015). Within a university context, the activism of students, staff, and alumni can drive sustainability within HEIs (Shriberg, 2003). Similar to the findings in the literature regarding expectancy, it was found in this study that expectations from university staff, community, and university organisations engendered the deployment of PVs in the public university sector. However, expectations from students or student societies was found not to be an applicable driver in the sector.

It has been suggested that potential adopters might be motivated to adopt PVs because someone known to them has already installed them (Aggarwal *et al.*, 2019; Mundaca and Samahita, 2020), and this happens because it decreases the perceived uncertainties associated with usage (Curtius *et al.*, 2018; Karakaya *et al.*, 2015). However, in this study, it was found that universities were not driven to install PVs because other universities had installed PVs or because people/organisations in the community used PVs. This could mean that people or organisations in the communities where the universities operate do not use PVs or that it is just not a motivating factor. However, the findings concur with the findings of Kastner and Wittenberg (2019), which demonstrated that households were not motivated to adopt

PVs because people important to them owned them or because they were available in their neighbourhoods. Lastly, international incentives were also found not to be an applicable driver in the public university sector. Generally, the findings suggested that the role of social influences should not be under-estimated. To drive deployment, for example, university associations can support and motivate institutions to make PV deployment a priority.

(4) Relative advantage:

The significance of relative advantage in the diffusion of innovation was established in the work of Rogers (1995). By exploring the relevant characteristics, scholars have largely established that, if potential adopters consider PVs to be better than other contemporary options, then the likelihood of adoption will be high. Similar to previous studies, it was established from this study that the ease of maintenance (Eronini, 2014; Pickerill, 2018) and noiselessness of PVs (Ugulu and Aigbayboa, 2019) provided strong motivation for universities to adopt PVs. Gastaldo et al. (2019) showed that ease of installation of PVs spurs adoption, which was specifically within the context of household adoption. In this study, it was found that ease of installation was a non-significant driver within the public university sector.

### ***5.4.3. Barriers to the Deployment of Photovoltaics***

#### ***5.4.3.1. Delphi Survey Results***

(1) Delphi Round 1:

The results from R1 are presented in Tables 5.11 and 5.12. During this round, the panellists rated 23 barriers, and the results showed that 14 of the obstacles were deemed to be applicable in the public university sector. Also, the following 6 institution-related barriers and 3 cost and funding-related barriers were considered to be factors that did not hinder deployment: IRB1, IRB2, IRB3, IRB6, IRB8, IRB9, CFB5, CFB8, and CFB9. The highest and lowest mean values were 4.39 and 2.61, and these were recorded for GRB2 (lack of enabling policies) and CFB5 (decision-makers' uncertainty about recouping investment cost), respectively.

The determination of consensus based on the IQR rule ( $IQR \leq 1.0$ ) revealed that, out of the 23 barriers, consensus was reached on 13 items (56.5%), while there was disagreement on the remaining 10 barriers. The barrier that recorded the highest level of consensus ( $IQR = 0$ ) among the panellists was CFB2 (long pay-back period of investment). It was also observed that, although high mean values were recorded for CFB1, CFB4, and IRB7 (3.83, 3.94, and 3.61, respectively), there was no consensus among the panellists regarding these factors, since their IQR values were 1.75, 1.75, 3.00, respectively.

Furthermore, because the panellists were also permitted to recommend additional barriers, at the end of R1, the following four barriers were proposed: CFB10 (limited locally manufactured materials for photovoltaic), CFB11 (liability and cost for preventing unauthorised access to and theft of PV systems), IRB11 (Red tape of university procurement policies), and

IRB12 (prevalence of higher competing needs of universities). The four barriers recommended by panellists are shown in Table 5.5.

**Table 5.11: Delphi Rounds 1 and 2 results (a) – Barriers retrieved directly from literature**

Code	Round 1 ( <i>n</i> = 18)				Round 2 ( <i>n</i> = 18)				
	Mean	SD	IQR	CV	Mean	SD	IQR	CV	Rank
CFB1	3.83	1.11	1.75	0.31	3.89	1.13	1.75	0.30	8
CFB2	3.67	1.09	0	0.28	3.61	1.09	0	0.31	13
CFB3	4.11	0.90	1.00	0.22	4.11	0.90	1.00	0.22	3
CFB4	3.94	0.87	1.75	0.25	3.89	1.13	1.75	0.30	8
CFB5	2.61	1.14	1.00	0.44	2.61	1.14	1.00	0.44	23
CFB6	4.17	0.92	1.00	0.22	4.11	0.90	1.00	0.22	3
CFB7	3.61	1.04	0.75	0.29	3.61	1.04	0.75	0.29	12
CFB8	3.50	0.99	1.00	0.28	3.56	1.04	1.00	0.30	15
CFB9	3.11	0.99	1.75	0.33	3.17	0.99	1.00	0.32	17
IRB1	2.89	1.37	2.00	0.52	3.00	1.37	2.00	0.46	21
IRB2	3.11	1.17	2.00	0.38	3.17	1.25	1.75	0.40	18
IRB3	3.17	1.17	2.00	0.38	3.22	1.17	1.75	0.37	16
IRB4	4.11	1.00	1.00	0.28	4.22	1.00	1.00	0.24	2
IRB5	3.89	0.97	0.75	0.28	4.00	0.97	0.75	0.25	6
IRB6	3.33	1.37	1.75	0.40	3.17	1.38	2.00	0.44	19
IRB7	3.61	1.72	3.00	0.48	3.61	1.72	3.00	0.48	14
IRB8	3.33	1.87	2.00	0.55	3.11	1.53	2.00	0.50	20
IRB9	3.00	1.43	2.00	0.51	2.94	1.43	2.00	0.49	22
IRB10	4.06	1.16	1.00	0.29	4.06	1.16	1.00	0.29	5
GRB1	4.28	0.96	1.00	0.22	4.28	0.96	1.00	0.23	1
GRB2	4.39	0.61	1.00	0.14	3.94	1.06	1.75	0.27	7
GRB3	3.78	0.94	1.00	0.25	3.78	0.94	1.00	0.25	10
GRB4	3.72	1.07	0.75	0.29	3.72	1.07	0.75	0.29	11

Notes: *SD*=Standard Deviation; *CV*=Coefficient of Variation; *IQR*=Inter-Quartile Range

**Table 5.12: Delphi Rounds 1 and 2 results (b) – Barriers retrieved directly from literature**

<b>Code</b>	<b>CV Change (R1-R2)</b>	<b>*Mean <math>M \geq 3.50</math></b>	<b>*IQR <math>\leq 1</math></b>	<b>**Stability Achieved</b>	<b>Decision</b>
CFB1	0.01	Yes	No	Yes	Reject
CFB2	0.03	Yes	Yes	Yes	Accept
CFB3	0.00	Yes	Yes	Yes	Accept
CFB4	0.05	Yes	No	Yes	Reject
CFB5	0.00	No	Yes	Yes	Reject
CFB6	0.00	Yes	Yes	Yes	Accept
CFB7	0.00	Yes	Yes	Yes	Accept
CFB8	0.02	Yes	Yes	Yes	Accept
CFB9	0.01	No	Yes	Yes	Reject
IRB1	0.06	No	No	Yes	Reject
IRB2	0.02	No	No	Yes	Reject
IRB3	0.01	No	No	Yes	Reject
IRB4	0.04	Yes	Yes	Yes	Accept
IRB5	0.03	Yes	Yes	Yes	Accept
IRB6	0.04	No	No	Yes	Reject
IRB7	0.00	Yes	No	Yes	Reject
IRB8	0.05	No	No	Yes	Reject
IRB9	0.02	No	No	Yes	Reject
IRB10	0.00	Yes	Yes	Yes	Accept
GRB1	0.01	Yes	Yes	Yes	Accept
GRB2	0.13	Yes	No	No	Reject
GRB3	0.00	Yes	Yes	Yes	Accept
GRB4	0.00	Yes	Yes	Yes	Accept

Notes: \*Evaluation based on round 2 results; \*\* Stability is achieved when CV Change  $\leq 0.10$

**Table 5.13: Delphi Rounds 2 and 3 results (a) – Barriers recommended by panellists**

Code	Round 2 ( <i>n</i> = 18)				Round 3 ( <i>n</i> = 16)				
	Mean	SD	IQR	CV	Mean	SD	IQR	CV	Rank
CFB10	3.11	1.41	2.00	0.45	3.00	1.41	2.00	0.47	3
CFB11	3.00	1.33	2.00	0.44	2.81	1.28	2.00	0.45	4
IRB11	3.28	1.27	1.00	0.39	3.31	1.30	1.25	0.39	2
IRB12	3.61	1.04	1.00	0.29	3.75	0.93	1.00	0.25	1

Notes: *SD* = Standard Deviation; *CV* = Coefficient of Variation; *IQR* = Inter-Quartile Range

**Table 5.14: Delphi Rounds 2 and 3 results (b) - Barriers recommended by panellists**

Code	CV Change (R2-R3)	*Mean $M \geq 3.50$	*IQR $\leq 1$	**Stability Achieved	Decision
CFB10	0.02	No	No	No	Reject
CFB11	0.01	No	No	No	Reject
IRB11	0.00	No	No	No	Reject
IRB12	0.04	Yes	Yes	Yes	Accept

Notes: \*Evaluation is based on round 3 results; \*\* Stability is achieved when CV Change  $\leq 0.10$

(2) Delphi Round 2:

R2 was open only to panellists who participated in the earlier round. The results are presented in Tables 5.11-14. Tables 5.11 and 5.12 shows the results for the barriers that were retrieved from the literature and were terminated at R2. Tables 5.13 and 5.14 shows the results for the barriers that were recommended by some panellists and were terminated at R3.

At the end of R2, regarding the R2 terminated batch of barriers, it was found that 7 barriers having  $M \geq 3.50$  remained unchanged [(CFB3 (4.11), CFB7 (3.61), IRB7 (3.61), IRB10 (4.06), GRB1 (4.28), GRB3 (3.78), and GRB4 (3.72)]. One barrier with  $M < 3.50$  was an exception and remained unchanged [CFB5 ( $M = 2.61$ )]. Eight barriers recorded an increase in mean

value [CFB1 (3.83 - 3.89), CFB8 (3.50 - 3.56), CFB9 (3.11 - 3.17), IRB1 (2.89 - 3.00), IRB2 (3.11 - 3.17), IRB3 (3.17 - 3.22), IRB4 (4.11 - 4.22), IRB5 (3.89 - 4.00)], while a decrease in mean value was recorded for seven barriers [CFB2 (3.67 - 3.61), CFB4 (3.94 - 3.89), CFB6 (4.17 - 4.11), IRB6 (3.33 - 3.17), IRB8 (3.33 - 3.11), IRB9 (3.00 - 2.94), GRB2 (4.39 - 3.94)]. The highest mean value was 4.28, and it was recorded for GRB1 (lack of incentive to adopt technology), and the lowest was 2.61 for CFB5 (decision-makers' uncertainty about recouping investment cost). The panellists also reached a strong consensus on 13 of the barriers (i.e.  $0.75 \leq \text{IQR} \leq 1.0$ ), and there was no consensus on the remaining 10 barriers (i.e.  $1.75 \leq \text{IQR} \leq 3.0$ ).

Overall, regarding the R2 terminated batch of barriers, 11 barriers scored a mean value denoting acceptance ( $M \geq 3.50$ ) as well as an acceptable value of IQR denoting consensus ( $\text{IQR} \leq 1$ ). Hence these were accepted as barriers that hindered PV deployment in the public university sector. However, it was found that, although CFB1, CFB4 and GRB2 scored 3.89, 3.89, and 3.94 as mean values, respectively, there was a lack of consensus among the panellists ( $\text{IQR} > 1$ ) and, for this reason, these barriers were rejected. By using the  $\text{CV change} \leq 0.1$  rule to measure stability, it was noted that the difference in CV for 22 of the barriers during R1 and R2 fell below the acceptable value, and only GRB2 scored 0.13. Since the difference between the recommended and actual values was minimal for GRB2 (i.e. 0.03), it was deemed unnecessary to include this barrier in the next survey.

At the end of R2, regarding the barriers recommended by panellists, out of the 4 proposed barriers that were rated for the first time, three of the factors

(CFB10, CFB11 and IRB11) had mean scores  $< 3.50$  and IQR value  $\geq 1.0$ .

The remaining barrier, which was IRB12, had the highest mean value of 3.61 and an IQR value of 1.0.

(3) Delphi Round 3:

During the R3 survey, only the 4 barriers recommended by panellists were rated. The mean score for all the barriers changed at R3. The mean value increased from 3.61 to 3.75 for IRB12 (prevalence of higher competing needs of universities), and from 3.28 to 3.31 for IRB11 (red tape of university procurement policies). There was also a decrease from 3.11 to 3.00 for CFB10, and from 3.00 to 2.81 for CFB11. Regarding the measure of consensus, the IQR value increased from 1.00 to 1.25 for IRB11, and remained unchanged for the remaining 3 barriers.

Based on the same criteria used to accept the barriers directly retrieved from the literature, only IRB12, being 25% of the barriers recommended by panellists, met the two criteria and, therefore, was accepted as an applicable barrier in the public university sector. At the end of R3, the CV change value for the 4 factors between R2 and R3 was less than 0.10 and, for this reason, the survey was terminated.

#### 5.4.3.2. *Discussion of the Barriers*

The discussion of the findings about the barriers is presented below, based on the constructs of the conceptual model.

(1) Cost and funding-related barriers:

It has been demonstrated extensively through research that cost and funding-related matters significantly affect the adoption rate of PV technology worldwide. For instance, the unavailability of funds can affect the purchasing power of potential adopters (Balcombe *et al.*, 2014). The findings suggested that one of the critical barriers that hamper PV deployment in the public university sector was the lack of financial resources (CFB3). Insight from the literature also indicated that, apart from outright purchase, the availability of other acquisition methods, such as leasing and PPA, can lead to adopting the technology, especially for potential adopters who do not have the capital for upfront payment (Rai and Sigrin, 2013). Thus, the unavailability or complexity of lease or PPA contracts in some markets can hinder adoption (Rai *et al.*, 2016; Rosales-Asensio *et al.*, 2019). Similar to previous findings, it was noted in this study that there was consensus that when acquiring the system through outright purchase, high upfront cost (CFB6) was a barrier, including the scarcity of favourable options to acquire PVs through a power purchase agreement (CFB7) or lease (CFB8).

Owing to the efficiency of PV modules and the high initial capital cost, the estimated pay-back period is usually long and, because it takes so long to recoup the capital investment, this can foster non-adoption (Garlet *et al.*, 2019; Mah *et al.*, 2018; Nandal *et al.*, 2019; Palm, 2018; Qureshi *et al.*, 2017; Sindhu *et al.*, 2016b). Vasseur and Kemp (2015), in exploring the adoption of PVs in the Netherlands, confirmed that potential adopters showed interest only if the pay-back were a maximum of approximately five

years. Therefore, it was not surprising that, in this study, panellists agreed that the long pay-back of investment (CFB2) was a hindrance.

Lack of access to credit and uncertainty about recouping investments can hinder the adoption of PVs (Mah *et al.*, 2018; Pode, 2010; Rosales-Asensio *et al.*, 2019) but, in this study, it was found that the above barriers were not applicable within the public university sector in SA. Likewise, the lack of sufficient local manufacturing of PVs (Garlet *et al.*, 2019; Shah *et al.*, 2019) and the liability and cost of preventing unauthorised access to or theft of PV systems (CFB11) were not issues that hindered the installation of PVs at universities.

Scholars have suggested that the rate of PV deployment would have been much more significant, especially in developing countries, had it not been that the technology was perceived to be too expensive (Balcombe *et al.*, 2014; Garlet *et al.*, 2019; Kurata *et al.*, 2018; Pode, 2010). Also, the energy produced by PVs is intermittent, and integration with energy storage systems (ESS) can result in maximum benefit but doing this involves challenges and a substantial increase in the cost of PV systems. This has been cited as a barrier to adoption (Ansari *et al.*, 2013). In this study, although it was found that the high cost of PVs (CFB1) and challenges associated with the requirements of energy storage systems (CFB4) appeared to be a concern in the sector (the barriers had a mean score of 3.83 and 3.94, respectively), the panellists did not reach consensus on the matter.

(2) Institution-related barriers:

The benefits accrued from adopting green buildings have been made known (Darko et al., 2017b). Therefore, it is not surprising that the construction or adoption of green buildings is increasing globally. Richardson and Lynes (2007) investigated the factors that caused the lack of construction of green buildings on a university campus. It was identified that the lack of quantifiable sustainability targets was a contributing factor. Similarly, it was found in this study that, under the institution-related category of barriers, the lack of green building targets (IRB4) and lack of clear policy direction on PV deployment (IRB10) were significant factors that contributed to deterring the deployment of photovoltaics. Therefore, this suggested that the availability of well-defined green building targets and a clear policy could assist universities in installing PV systems when existing buildings are retrofitted or when new buildings are constructed.

The total energy consumption on university campuses is substantial. Hence, in the quest to drive campus sustainability, it is vital that universities measure and report their energy performance. Some universities have voluntarily reported their energy performance on their websites or other official university publications (UCT, 2021). For institutions that have signed campus sustainability assessment frameworks, reporting on energy performance is a mandatory requirement. In this study, it was confirmed by the panellists that the lack of reporting of the sustainability performance of universities (IRB5) contributes to the low deployment of PVs on public university campuses in SA. Therefore, it can be suggested that, when it

becomes mandatory for public universities to report their sustainability performance, the institutions will be compelled to do better by securing energy from sustainable sources to reduce their carbon emissions.

When financial resources are scarce, the allocation of resources is a matter of priority, and so it is challenging to fund PV projects even if there is interest (Geh *et al.*, 2022a). In this study, there was consensus among the panellists that the prevalence of higher competing needs of universities (IRB12) accounted for the low patronage of PVs by universities.

It was evident from the literature that factors, such as the lack of installation space, resistance to change, limited commitment to operationalising university policies, limited motivation to reduce the operational costs of buildings, limited appreciation of benefits of PV usage, and lack of demand from electricity end-users are barriers that can hamper the adoption of PVs (Garlet *et al.*, 2019; Geh *et al.*, 2022a; Mah *et al.*, 2018; Walters *et al.*, 2018a,b). However, the findings of this study suggested that the above barriers were not critical factors in the public university sector in SA.

(3) Government-related barriers:

As the name implies, public universities are government institutions established by acts of parliament, and they receive substantial funds from the government for their operations (DHET, 2004). In addition to ‘institution-related barriers’ and ‘cost and funding-related barriers’, three significant barriers were identified in this study, which are grouped as ‘government-related barriers’. Firstly, there was consensus that there was inadequate funding for infrastructure development, which has impacted the

deployment of PVs in the sector. Secondly, it was found that the lack of demand for the integration of PVs in projects that government agencies finance gives leeway that diminishes the drive for the installation of photovoltaics. Thirdly, the findings revealed that the lack of incentives from the government hinders deployment as well. These findings concurred with the conclusions of previous studies. For instance, Chan et al. (2018), in a similar manner, identified a lack of government incentive as a critical barrier to adoption in the context of green building. In conclusion, the findings suggested that to boost the deployment of PVs on public university campuses, the government has vital contributions to make. For example, the government should incentivise universities that install PVs, ensure that the integration of PVs is specified for building projects, and ensure that special funds are made available to finance PV projects on campuses.

## **5.5. Chapter Summary**

The results and discussion of the findings regarding the progress that universities have made in installing PVs on their campuses was presented in this chapter, and also the identification of the drivers and barriers that influence deployment in the public university sector. Specifically, it was found that a total capacity of at least 6 365.4 kWp has been installed in five universities. Also, it was found that 18 drivers and 12 barriers exist in the public university sector in SA. The results and discussion of the findings for Phase 6 are presented in the next chapter.

## CHAPTER 6: MODEL DEVELOPMENT AND VALIDATION

### 5.5. Introduction

The results and discussion of the findings on the statistical significance of the influence of the drivers and barriers on PV deployment are presented in this chapter. Information on how the proposed model was developed and validated is also provided. Specifically, in this chapter, all the research activities in Phases 6 and 7 which addressed Objectives 4 and 5 are reported; the PLS-SEM analysis is covered in Section 6.2; and the development and validation of the model are presented in Sections 6.3 and 6.4.

### 5.6. Modelling the Influence of the Drivers and Barriers on PV Deployment (Phase 6)

During the Delphi study, 18 drivers and 12 barriers were generated that panellists believed were either driving or hampering the deployment of PVs in the public university sector. As shown in Table 6.2. The drivers were categorised into four main groups and the barriers into three groups. To evaluate how significantly these factors affected deployment, a PLS-SEM technique was used. This technique was considered to be suitable because of its usefulness in assessing how independent variables influence dependent variables. The usefulness of the technique is evident in the literature, and it has gained much popularity among researchers in recent times. For example, Darko *et al.* (2018b) used PLS-SEM to evaluate the impact of barriers and drivers on green building adoption. Durdyev *et al.* (2018a) used this technique to analyse the effect of barriers on sustainable construction. Similarly, Adabre (2021) used PLS-SEM to evaluate how barriers, risks and critical success factors impact sustainable housing development. Other scholars have reviewed the use of the technique and made recommendations to improve its application (Sarstedt *et al.*, 2022; Xiong *et al.*, 2015; Yin and Huang, 2021).

Regarding the measurement items for the dependent construct (i.e. solar PV deployment), the findings of the literature review showed a scarcity of previous studies with suitable measurement items that could be adapted. Some studies, such as those undertaken by Kim *et al.* (2014), Korcaj *et al.* (2015), Pathania *et al.* (2017), used constructs such as ‘purchase intention’ and ‘intention to use’, with measurement items that could have been adapted easily if this study were examining adoption within households or by individuals. However, this study was undertaken to explore PV deployment within the public university sector and, for this reason, these constructs and measurement items could not be adapted for use in this study. Therefore, owing to the unavailability of identical empirical literature, in developing the measurement items for the ‘PV deployment’ construct in this study, the reflective measurement items for this construct, which are PV\_1, PV\_2, PV\_3, PV\_4, and PV\_5 were developed based on logic. According to Hair *et al.* (2017, p. 46), measurement items (indicators) in a reflective measurement model should represent the effects (or manifestations) of an underlying construct. Hence, for the ‘PV deployment’ construct, PV\_1 to PV\_5 were deemed to be appropriate and were chosen to represent the manifestations of PV deployment because these activities are common practices in the built environment, which engender (or reflect) installation/deployment of PVs. The measurement items (PV\_1 to PV\_5) are presented in the last part of Table 6.2.

### ***5.6.1. Profile of Respondents***

The profile of the respondents is summarised in Table 6.1. Respondents included non-academic staff and academic staff. There were 35 non-academic staff (57.4%) and 26 academic staff (42.6%). Forty-one of the respondents (67.2%) had worked in only one university, 17 of the participants (27.9%) had work experience in two universities, and the remaining 3 participants (4.9%) had worked in three universities. Regarding the years of working experience, the results indicated that the lowest range was 1-5 years and 17 (28%)

people fell within this group. It was found that 5 (8.2%) people had over 25 years of experience ( $\geq 26$ ). However, the majority of the respondents ( $n = 20$ , 32.8%) had working experience of 6-10 years. The 61 respondents were from 16 universities and, whilst 28 (45.8%) were from institutions where PVs had been installed, 33 respondents were from institutions that had not installed PVs yet. Almost half of the respondents had a doctorate ( $n = 29$ , 48%), followed by a master's degree ( $n = 11$ , 18%). It was also found that two people had a diploma and nine people had a first degree. The data were collected between June and December 2021.

**Table 6.1: Profile of respondents**

Characteristics	Frequency [N=61]	Percentage (%)
Staff status		
Non-academic staff	35	57.4
Academic staff	26	42.6
No. of universities worked in		
1 university	41	67.2
2 universities	17	27.9
3 universities	3	4.9
Years of experience		
1-5 years	17	27.9
6-10 years	20	32.8
11-15 years	11	18.0
16-20 years	6	9.8
21-25 years	2	3.3
26 years or more	5	8.2
Qualification		
Diploma	2	3.3
First degree	9	14.8
Post-graduate Diploma	9	14.8
Master's degree	11	18.0
Doctorate Degree	29	47.5
Others	1	1.6

**Table 6.2: Constructs and their measurement items**

Constructs	Code	Measurement items
<b>(a) Drivers of PV Deployment</b>		
Direct benefits (DB)	DB_1	Reduction of energy cost to university
	DB_2	Enhancement of university image
	DB_3	Boosting university sustainability performance
	DB_4	Contribution to attainment of SDGs
	DB_5	Potential use for teaching students
	DB_6	Potential use for practical-work opportunities for students
	DB_7	Potential use for research opportunities for students and staff
Indirect benefits (IB)	IB_1	Reduction of energy-related greenhouse gases
	IB_2	Opportunity for staff to observe and use technology
	IB_3	Opportunity for students to observe and use technology
	IB_4	Opportunity for the public to observe technology
	IB_5	Booting of PV technology demonstration
Social influences (SI)	SI_1	Expectation from university staff
	SI_2	Expectation from society
	SI_3	Expectation from university bodies/associations
	SI_4	Demonstration projects showcasing different PV applications
Relative advantage (RA)	RA_1	Ease of maintaining PV
	RA_2	No noise pollution from PV usage
<b>(b) Barriers to PV Deployment</b>		
Cost and funding-related barriers (CFB)	CFB_1	Long pay-back period of investment
	CFB_2	High initial cost (i.e. for outright purchase option)
	CFB_3	Scarcity of favourable opportunities to acquire PV through power purchase agreement
	CFB_4	Scarcity of favourable opportunities to acquire PV through lease
	CFB_5	Lack of financial resources
Institution-related barriers (IRB)	IRB_1	Lack of green building targets for university
	IRB_2	Lack of reporting energy sustainability performance by university
	IRB_3	Lack of clear policy direction on PV deployment
	IRB_4	Prevalence of higher competing needs of universities
Government-related barriers (GRB)	GRB_1	Lack of incentives to adopt technology
	GRB_2	Lack of demand from government project financiers
	GRB_3	Inadequate funding for infrastructure development

Constructs	Code	Measurement items
<b>(c) Adoption Options</b>		
PV deployment (PVD)	PVD_1	Design new buildings to include PV installation during the time of construction
	PVD_2	Design new buildings to allow for easy PV installation in the future if PV is not installed during the time of construction i.e. construct solar-ready buildings
	PVD_3	Design renovation projects to include PV installation during the time of renovation works
	PVD_4	Design renovation projects to allow for easy PV installation in the future if PV is not installed during the time of renovation works i.e. create solar-ready buildings out of existing buildings
	PVD_5	Utilise non-building attached/integrated PV installation options (for example, installation of PV at car-parks, ground-mounted PV installations etc.)

### 5.6.2. Research Hypotheses

Based on evidence from the literature review, presented in Chapter 2, and the conceptual framework, presented in Chapter 3, it was conceived that the adoption of PVs is influenced by drivers and barriers. The deployment of PVs by universities is: (1) positively influenced by ‘direct benefits’, ‘indirect benefits’, ‘social influences’, and ‘relative advantage’; (2) negatively influenced by ‘cost and funding-related barriers’, ‘institution-related barriers’, and ‘government-related barriers’. The hypothetical models are shown in Figures 6.1 and 6.2.

Thus, premised on the understanding from the literature that drivers foster the adoption of PV technology, the hypothesised paths *H1*, *H2*, *H3*, and *H4* were established:

*H1*: Direct benefits have a significant positive influence on the deployment of PVs.

*H2*: Indirect benefits have a significant positive influence on the deployment of PVs.

*H3*: Social influences have a significant positive influence on the deployment of PVs.

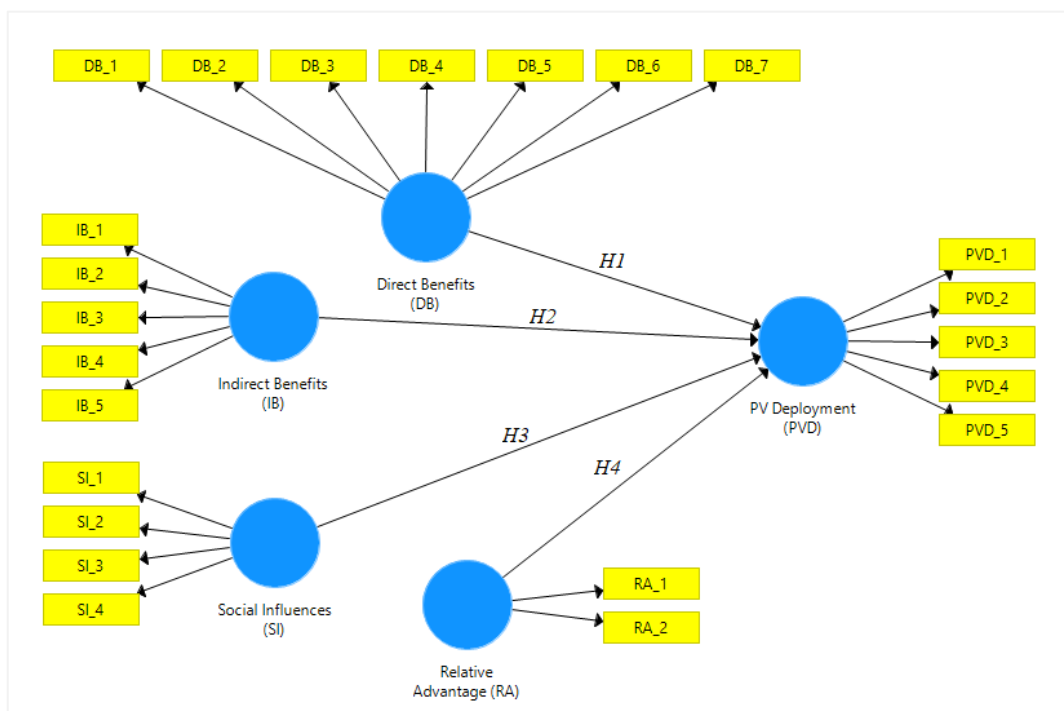
*H4*: Relative advantage has a significant positive influence on the deployment of PVs.

Based on the understanding from empirical literature that barriers hamper the diffusion of PV technology, the hypothesised paths *H5*, *H6*, and *H7* were established:

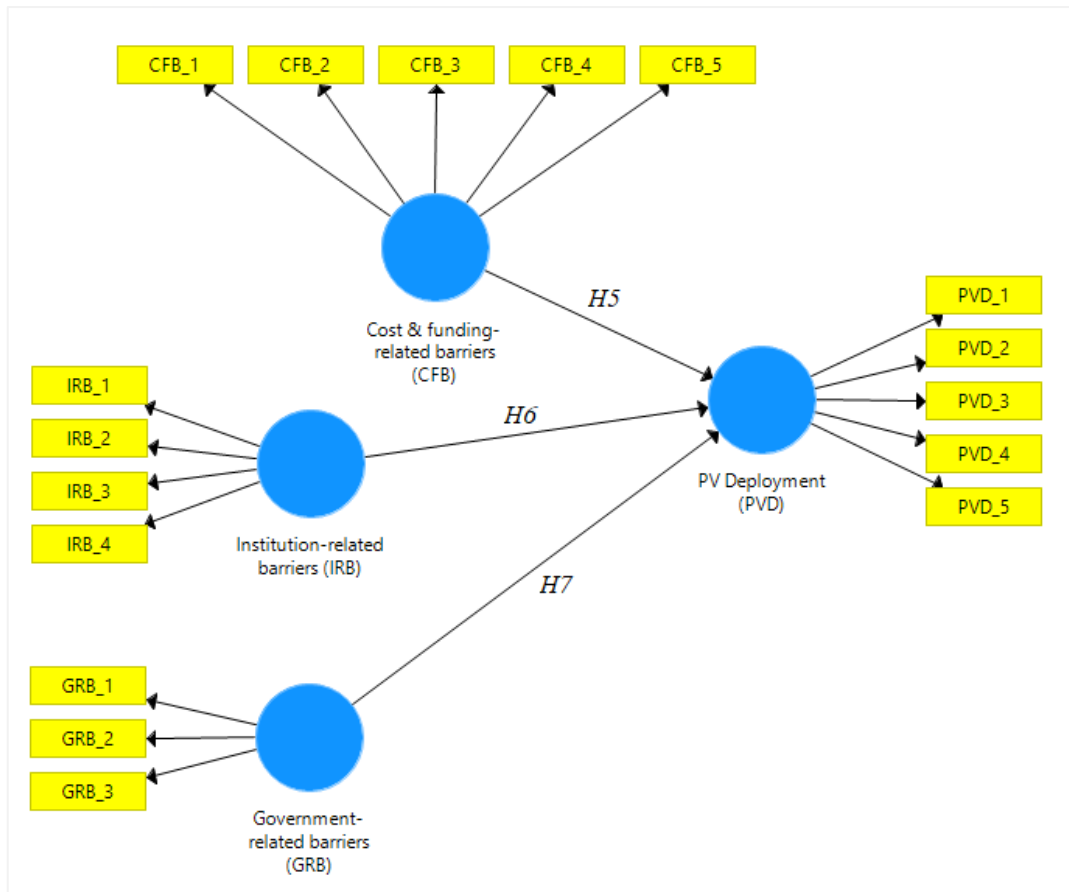
*H5*: Cost and funding-related barriers have a significant negative influence on the deployment of PVs.

*H6*: Institution-related barriers have a significant negative influence on the deployment of PVs.

*H7*: Government-related barriers have a significant negative influence on the deployment of PVs.



**Figure 6.1: The model for drivers**



**Figure 6.2: The model for barriers**

### 5.6.3. Assessment of Model for Drivers

#### 5.6.3.1. Evaluation of Measurement Model for Drivers

(i) Indicator reliability:

As mentioned in Chapter 4, specifically in Section 4.8.5, indicator reliability is achieved when the factor loading is greater or equal to 0.50 (Hulland, 1999). Accordingly, indicators that had loadings lower than 0.50 were deleted and the PLS algorithm was re-run until reliable and valid measurement models were achieved. The indicators that were removed were DB\_5, DB\_6, DB\_7, IB\_5, SI\_3, SI\_4, and RA\_2. By deleting RA\_2 for the 'relative advantage' construct, it was left with only one indicator, which was RA\_1. Since the advantages that the usage of PV can offer (i.e. relative advantage) could not be measured appreciably by only one item (i.e. a

single-item construct), it was deemed to be more beneficial to delete the construct completely to strengthen the model. The model entails only reflective measurement items. All indicator loadings for the model for drivers are presented in Table 6.3.

(ii) Internal consistency reliability:

The Composite Reliability (CR) and Cronbach's alpha ( $\alpha$ ) of all items were above the 0.70 thresholds prescribed by Gefen et al. (2000) and Hair et al. (2014), as shown in Table 6.3. The lowest values for CR and  $\alpha$  were 0.825 and 0.754, respectively, so the model displayed an acceptable level of internal consistency reliability.

(iii) Convergent validity:

The AVE values for 'direct benefits', 'indirect benefits', 'social influences' and 'PV deployment' were 0.576, 0.545, 0.725, and 0.531, respectively. The results showed that the construct explains more than half of the variance of its indicators (i.e. the AVE values were  $\geq 0.50$ ) and, therefore, an acceptable measure of validity was achieved (Fornell and Larcker, 1981; Janadari *et al.*, 2016).

**Table 6.3: Results of measurement model for drivers**

Construct	Indicators	Factor loadings <sup>a</sup>	$\alpha$ <sup>b</sup>	CR <sup>c</sup>	AVE <sup>d</sup>
Direct Benefits (DB)	DB_1	0.857	0.756	0.843	0.576
	DB_2	0.730			
	DB_3	0.803			
	DB_4	0.626			
Indirect Benefits (IB)	IB_1	0.876	0.828	0.825	0.545
	IB_2	0.659			
	IB_3	0.675			
	IB_4	0.723			
Social Influences (SI)	SI_1	0.677	0.754	0.836	0.725
	SI_2	0.996			
PV Deployment (PVD)	PVD_1	0.809	0.777	0.848	0.531
	PVD_2	0.691			
	PVD_3	0.816			
	PVD_4	0.568			
	PVD_5	0.730			

<sup>a</sup> Indicator loading  $\geq 0.5$  shows indicator reliability

<sup>b</sup> Cronbach's alpha ( $\alpha$ )  $> 0.7$  indicates reliability

<sup>c</sup> Composite reliability (CR)  $> 0.7$  indicates internal consistency

<sup>d</sup> Average Variance Extracted (AVE)  $> 0.5$  shows convergent validity

(iv) Discriminant validity:

As explained in Section 4.8.5, discriminant validity was assessed using cross-loadings, Fornell-Larcker criterion, and HTMT ratio. As shown in Table 6.4, since all the indicators that had the highest loadings on each construct (shown in bold) did not load higher on any other construct, the discriminant validity requirement was met. The results for the Fornell-Larcker criterion are presented in Table 6.5. The results showed that the square root of the AVE of each latent variable was higher than any correlation with any other latent variable, hence the discriminant validity of the measurement model, using the Fornell-Larcker criterion, was further confirmed as being satisfactory. Lastly, the results for the HTMT ratio, presented

in Table 6.6, established that no HTMT ratio exceeded 0.90, proving that the model exhibited discriminant validity.

**Table 6.4: Indicator cross-loadings**

Indicators	Direct benefits	Indirect benefits	Social influences	PV deployment
DB_1	<b>0.857</b>	0.315	0.115	0.606
DB_2	<b>0.730</b>	0.274	0.043	0.401
DB_3	<b>0.803</b>	0.373	0.236	0.579
DB_4	<b>0.626</b>	0.300	0.106	0.332
IB_1	0.442	<b>0.876</b>	0.253	0.314
IB_2	0.167	<b>0.659</b>	0.159	0.075
IB_3	0.140	<b>0.675</b>	0.269	-0.014
IB_4	0.200	<b>0.723</b>	0.321	0.184
SI_1	0.161	0.248	<b>0.677</b>	0.011
SI_2	0.168	0.323	<b>0.996</b>	0.088
PVD_1	0.497	0.139	-0.052	<b>0.809</b>
PVD_2	0.462	0.336	0.103	<b>0.691</b>
PVD_3	0.594	0.372	0.141	<b>0.816</b>
PVD_4	0.294	-0.106	0.040	<b>0.568</b>
PVD_5	0.474	0.230	0.050	<b>0.730</b>

Note: *Bold values indicate that each indicator had the highest loading on its respective construct*

**Table 6.5: Fornell-Larcker criterion**

Constructs	Direct benefits	Indirect benefits	Social influences	PV deployment
Direct benefits	<b>0.759</b>			
Indirect benefits	0.415	<b>0.738</b>		
Social influences	0.174	0.328	<b>0.851</b>	
PV deployment	0.655	0.309	0.082	<b>0.729</b>

Note: *The diagonal values are the square root of the AVE of the latent variables and indicate the highest in any column or row*

**Table 6.6: HTMT ratio**

<b>Constructs</b>	<b>Direct benefits</b>	<b>Indirect benefits</b>	<b>PV deployment</b>	<b>Social influences</b>
Direct benefits				
Indirect benefits	0.365			
PV deployment	0.802	0.298		
Social influences	0.235	0.367	0.152	

### 5.6.3.2. Evaluation of Structural Model for Drivers

The assessment of the structural model for drivers was conducted in five stages, as discussed below. The initial assessment using VIF values indicated that collinearity was not a critical issue, as the inner VIF values obtained were 1.211, 1.315 and 1.123.

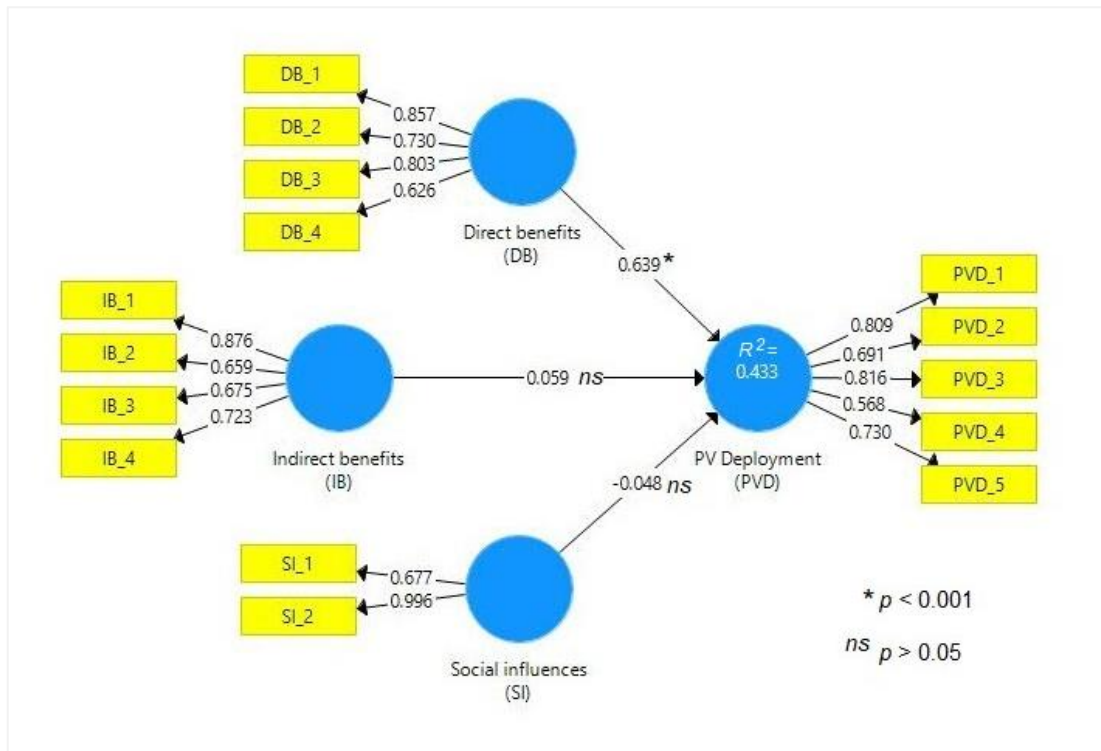
(i) Evaluation of the significance and relevance of the structural model relationships:

Bootstrapping was used to assess the significance of the path model relationships, using 5000 sub-samples, bias-corrected and accelerated bootstrap, and two-tailed test options. The results for the structural model are presented in Table 6.7 and Figure 6.3. The results indicated that only ‘direct benefits’ had a statistically significant influence on PV deployment, while the two other drivers, ‘indirect benefits’ and ‘social influences’ did not exert any significant influence. Specifically, ‘direct benefits’ had a positive statistically significant relationship at the 0.01 level ( $\beta = 0.639$ ,  $t = 6.207$ ,  $p < 0.01$ ). Thus, hypothesis *H1* was supported. The  $t$  values for the ‘indirect benefits’ ( $\beta = 0.059$ ,  $t = 0.368$ ,  $p > 0.10$ ) and ‘social influences’ ( $\beta = -0.048$ ,  $t = 0.389$ ,  $p > 0.10$ ) were below 1.65 and, since these did not have a statistically significant effect on PV deployment, hypotheses *H2*, and *H3* were not supported (Hair *et al.*, 2014, 2017).

**Table 6.7: Results of structural model for drivers**

Hypothetical path	Std Beta	Std Error	t-value	p-value	f <sup>2</sup>	q <sup>2</sup>	Interpretation
H1: DB -> PVD	0.639	0.103	6.207*	0.000	0.492	0.223	Supported
H2: IB -> PVD	0.059	0.161	0.368	0.713	0.007	-0.017	Not supported
H3: SI -> PVD	-0.048	0.125	0.389	0.698	0.006	-0.004	Not Supported

Note: \* indicates  $p < 0.01$



**Figure 6.3: Final SEM model of drivers influencing deployment**

(ii) Evaluation of the coefficient of determination ( $R^2$ ):

A graphical representation of the final model is shown in Figure 6.3. As shown, the  $R^2$  value for the target construct of PV deployment was 0.433. This meant that ‘direct benefits’, ‘indirect benefits’, and ‘social influences’ altogether explained 43.3% of the variance in the PV deployment construct. According to Cohen (1992),  $R^2$  values of 0.12 or below indicate low predictive power, values between 0.13 to 0.25 indicate medium predictive power, and values of 0.26 or above indicate high

predictive power. Using these guidelines, it was evident that the model had high predictive power.

(iii) Evaluation of effect size ( $f^2$ ):

The results of the estimation of the effect of one construct on another are presented in Table 6.7. The results indicated that ‘direct benefits’ had a large effect on ‘PV deployment’, as the  $f^2$  value was more than 0.35 (i.e. 0.492). It was also noted that ‘indirect benefits’ and ‘social influences’, with scores of 0.007 and 0.006, respectively, did not have any impact on ‘PV deployment’.

(iv) Evaluation of cross-validated redundancy ( $Q^2$ ):

The cross-validated redundancy ( $Q^2$ ) is a means for assessing the predictive relevance of the inner model (Hair *et al.*, 2014). The  $Q^2$  value of the antecedents of ‘PV deployment’ was estimated using a blindfolding procedure with an omission distance of 7. The analysis yielded a  $Q^2$  value higher than 0 (i.e. 0.190), thus confirming the model’s predictive relevance (Hair *et al.*, 2014, 2017).

(v) Evaluation of predictive relevance ( $q^2$ ) effect size

The results from the estimation of  $q^2$  effect size presented in Table 6.7 indicated that the only driver that has significant predictive relevance for PV deployment is ‘direct benefits’, and the endogenous construct has a  $q^2$  value of 0.223, indicating a medium predictive relevance (Hair *et al.*, 2017). As expected, the two remaining drivers, ‘indirect benefits’ and ‘social influences’, and the related hypotheses which were not supported (i.e.  $H5$  and  $H6$ ), were found to be lacking predictive relevance. These constructs scored -0.017 and -0.004  $q^2$  values, respectively.

### 5.6.3.3. Discussion of the Influence of Drivers on the Deployment of PVs

The drivers of the deployment of PVs are explored in a wide range of scientific literature and within several contexts. In the public university sector in SA, what appears to be missing is empirical data that identify the significant factors that promote the adoption of the technology. In this study, the PLS-SEM results showed that ‘direct benefits’ had a strong positive influence (i.e. path coefficient = 0.639) on ‘PV deployment’. Therefore, hypothesis *H1* was supported ( $t_{0.01} > 2.58$ ) ( $t = 6.207, p = 0.000$ ). Also, the impact of ‘direct benefits’ on deployment was large, as the  $f^2$  value was above 0.35 (i.e.  $f^2 = 0.492$ ) (Cohen, 1988; Hair *et al.*, 2017). Also, ‘direct benefits’ had a medium predictive relevance for deployment (i.e.  $q^2 = 0.223$ ) according to Cohen (1988). Therefore, it can be taken to mean that the more universities are aware and desirous of realising the benefits attainable from adopting PVs, the higher the level of deployment will be in the sector. Previous studies substantiated that there is a positive relationship between perceived benefits and adoption. For example, it was affirmed by Zahari and Esa (2018), and Kim *et al.* (2014) that perceived benefits have a positive influence on the intention to use PVs in Malaysia and South Korea, respectively. Similarly, Korcaj *et al.* (2015) also found that perceived individual and environmental benefits were crucial for the prediction of attitudes toward PV adoption. Other scholars have highlighted the importance of benefits or perceived usefulness in leading to the adoption of PVs (Ahmad *et al.*, 2017; Wolske *et al.*, 2017). Therefore, the findings of the current study concurred with previous studies in general.

According to the PLS-SEM results, the factors that contributed to the significant positive relationship with ‘PV deployment’ were: ‘reduction of energy cost’, ‘enhancement of university image’, ‘boosting university sustainability performance’ and ‘contributing to the attainment of the SDGs’. The above findings did not diverge from what is already known in the literature. Undoubtedly, financial benefits are major drivers of PV adoption globally.

Scholars have highlighted that monetary gains could result from lower electricity bills because of the self-generation of energy consumed, or money earned from selling PV-generated electricity to the power grid (Ahmad *et al.*, 2017; Lan *et al.*, 2020; Lee and Shepley, 2020; Schelly and Letzelter, 2020). In some instances, the belief that electricity might be costlier in the future could be the reason for adopting the technology (Balcombe *et al.*, 2014; Karakaya *et al.*, 2015). Image and reputation are also important to PV adopters (Korcaj *et al.*, 2015; Mundaca and Samahita, 2020) and the results indicated that this was important to universities too. Regarding sustainability within HEIs, Sharp (2009) commented that, to many people, the idea of universities teaching about sustainability without demonstrating it is highly problematic. To eliminate this disparity, institutions are increasingly making an effort to perform better on their scale of sustainability. To achieve this target, some are constructing green buildings or refurbishing existing buildings to conform to sustainable standards. Therefore, it follows that the need to boost university sustainability performance is causing the installation of PVs on campuses. Lastly, because input is needed from every sector to achieve the SDGs, HEIs are equally expected to make their contribution. Therefore, it is not surprising that projects, targeted at the SDGs, are being implemented on campuses. For example, Awuzie and Emuze (2017), and Mawonde and Togo (2019) reported the implementation of sustainable development at CUT and UNISA, respectively. Sometimes, universities prepare reports exclusively to outline their SDG achievements. An example of this is the SDG report released by the University of Pretoria (UP) in 2019 (UP, 2019). Since HEIs are vital champions of sustainability in society because they can establish themselves as models and nurseries of SD (Alshuwaikhat *et al.*, 2016), there are initiatives such as HESI from which to gather momentum for HEIs to achieve the SDGs. According to the PLS-SEM results, the need to

make contributions towards the achievement of the SDGs has also contributed to making the relationship between ‘direct benefits’ and ‘PV deployment’ a significant positive path.

Unexpectedly, three indicators under ‘direct benefits’, ‘potential uses for teaching, practical-work and research opportunities, did not contribute to the variance in the endogenous constructs in the final model. They were deleted because the indicator loadings were below the prescribed threshold. These results were obtained possibly because not every institution runs built environment or engineering-related programmes and, for this reason, not every respondent saw these benefits as drivers of the adoption of the technology.

When universities adopt PVs, it does result in shared benefits for the environment and the public, as well as for the staff and students. The construct measuring this effect was ‘indirect benefits’ as stated in hypothesis *H2*. The results showed that the above relationship was not significant. Therefore, the interpretation was that, although the installation of PVs on campuses could boost the demonstration of the technology to the public and offer an opportunity for staff and students to observe and use the technology, these ‘indirect benefits’ were not substantial in promoting the deployment of the technology on campuses. Additionally, contrary to the findings in some previous studies, ‘social influences’ and ‘relative advantage’ (or perceived ease of use) were also found not to have a significant influence on the deployment of PVs (Ahmad *et al.*, 2017; Curtius *et al.*, 2018; Kastner and Wittenberg, 2019). Although the PLS-SEM results established that the relationships were not significant, it does not, however, mean that these drivers are completely non-existent in the public university sector in SA, because it was pointed out by Geh *et al.* (2021) that they do exist. Therefore, depending on the prevailing conditions at a certain campus, these drivers could cause a significant effect on deployment.

Overall, for universities to be successful in establishing sustainable campuses, for example, the deployment of PVs is key to garnering support for the transition to renewable energy within the whole education sector and beyond. As Sharp (2009, p. 1) mentioned, ‘if universities would not change, then who can and who will?’. Therefore, it is important to give cognisance, especially, to the significant drivers of the deployment of the technology in the sector so that actions can be taken to boost deployment.

#### ***5.6.4. Assessment of the Model for Barriers***

##### *5.6.4.1. Evaluation of Measurement Model for Barriers*

(i) Indicator reliability:

All constructs were measured reflectively and the indicators that had loadings lower than 0.50 were removed from the measurement model to meet the 0.5 threshold as indicated by Hulland (1999). The indicators that were removed were CFB\_4 and IRB\_4. All indicator loadings for the model for barriers are shown in Table 6.8. The highest and lowest loadings were 0.932 and 0.538 respectively. The results prove that all indicator loadings were above the 0.5 threshold prescribed by Hulland (1999). Therefore, it could be concluded that the outer model exhibited sufficient indicator reliability.

**Table 6.8: Measurement model results - Barriers**

Construct	Indicators	Factor loadings <sup>a</sup>	$\alpha$ <sup>b</sup>	CR <sup>c</sup>	AVE <sup>d</sup>
Cost and funding-related barriers (CFB)	CFB_1	0.753	0.829	0.868	0.631
	CFB_2	0.538			
	CFB_3	0.893			
	CFB_5	0.932			
Institution-related barriers (IRB)	IRB_1	0.906	0.835	0.884	0.718
	IRB_2	0.805			
	IRB_3	0.827			
Government-related barriers (GRB)	GRB_1	0.884	0.755	0.854	0.662
	GRB_2	0.790			
	GRB_3	0.762			
PV deployment (PVD)	PVD_1	0.837	0.777	0.848	0.531
	PVD_2	0.658			
	PVD_3	0.784			
	PVD_4	0.614			
	PVD_5	0.729			

<sup>a</sup> Indicator loading  $\geq 0.5$  shows indicator reliability

<sup>b</sup> Cronbach's alpha ( $\alpha$ )  $> 0.7$  indicates reliability

<sup>c</sup> Composite reliability (CR)  $> 0.7$  indicates internal consistency

<sup>d</sup> Average Variance Extracted (AVE)  $> 0.5$  shows convergent validity

(ii) Internal consistency reliability:

As shown in Table 6.8, the Composite Reliability (CR) and the Cronbach's alpha ( $\alpha$ ) of all items were greater than the 0.70 thresholds prescribed by Gefen et al. (2000). The CR was between 0.884 and 0.848 and  $\alpha$  was between 0.835 and 0.755. Therefore, it was supported that all the constructs displayed an acceptable level of internal consistency reliability.

(iii) Convergent validity:

As shown in Table 6.8, the AVE of all the constructs in the measurement model was above the 0.5 threshold prescribed by Fornell and Larcker (1981), thereby indicating convergent validity of all constructs.

(iv) Discriminant validity:

Firstly, the cross-loadings were used to assess the discriminant validity of indicators. According to scholars, an indicator's outer loading on the associated construct should be greater than any of its cross-loadings (i.e. its correlation) on other constructs) (Hair *et al.*, 2017). The cross-loadings for the model for barriers are presented in Table 6.9. From the table, it can be observed that the indicator loadings of each construct (shown in bold) did not load higher on any other construct. Therefore, the cross-loading results established that the requirement for discriminant validity was met.

The Fornell-Larcker criterion was also used in assessing discriminant validity. Specifically, the square root of the AVE of each construct was assessed to determine whether it was greater than its highest correlation with any other construct (Fornell and Larcker, 1981). The square root of the AVE of each latent variable is shown diagonally in bold in Table 6.10, together with the correlations of the latent variable with other latent variables. It was observed that the square root of the AVE of each latent variable was higher than any correlation with any other latent variable. Therefore, the results for the second assessment method were satisfactory.

**Table 6.9: Indicator cross-loadings**

Indicators	Cost and funding-related barriers	Institution-related barriers	Government-related barriers	PV deployment
CFB_1	<b>0.753</b>	0.110	0.237	-0.133
CFB_2	<b>0.538</b>	0.203	0.099	0.005
CFB_3	<b>0.893</b>	0.277	0.267	-0.189
CFB_5	<b>0.932</b>	0.211	0.193	-0.223
IRB_1	0.212	<b>0.906</b>	0.172	-0.158
IRB_2	0.248	<b>0.805</b>	0.278	-0.073
IRB_3	0.140	<b>0.827</b>	0.147	-0.061
GRB_1	0.141	0.107	<b>0.884</b>	0.243
GRB_2	0.325	0.166	<b>0.790</b>	0.127
GRB_3	0.245	0.317	<b>0.762</b>	0.160
PVD_1	-0.196	-0.195	0.217	<b>0.837</b>
PVD_2	-0.202	-0.029	0.061	<b>0.658</b>
PVD_3	-0.118	0.027	0.245	<b>0.784</b>
PVD_4	-0.166	-0.019	0.136	<b>0.614</b>
PVD_5	-0.123	-0.212	0.140	<b>0.729</b>

Note: *Bold values indicate that each indicator had the highest loading on its respective construct*

**Table 6.10: Fornell and Larcker criterion**

Constructs	Cost and funding-related barriers	Institution-related barriers	Government-related barriers	PV deployment
Cost & funding-related barriers	<b>0.794</b>			
Institution-related barriers	0.238	<b>0.847</b>		
Government-related barriers	0.263	0.223	<b>0.814</b>	
PV deployment	-0.218	-0.135	0.230	<b>0.729</b>

Note: *The diagonal values are the square root of the AVE of the latent variables and indicate the highest in any column or row*

The last method used to confirm discriminant validity was the HTMT ratio of the correlations. The results are presented in Table 6.11, and it was established that no HTMT

ratio exceeded 0.9. Therefore, the results indicated that the measurement model for barriers also met the HTMT assessment criteria (Hair *et al.*, 2017; Henseler *et al.*, 2015).

**Table 6.11: HTMT ratio**

<b>Constructs</b>	<b>Cost and funding-related barriers</b>	<b>Government-related barriers</b>	<b>Institution-related barriers</b>	<b>PV deployment</b>
Cost and funding-related barriers				
Government-related barriers	0.337			
Institution-related barriers	0.281	0.304		
PV deployment	0.250	0.269	0.202	

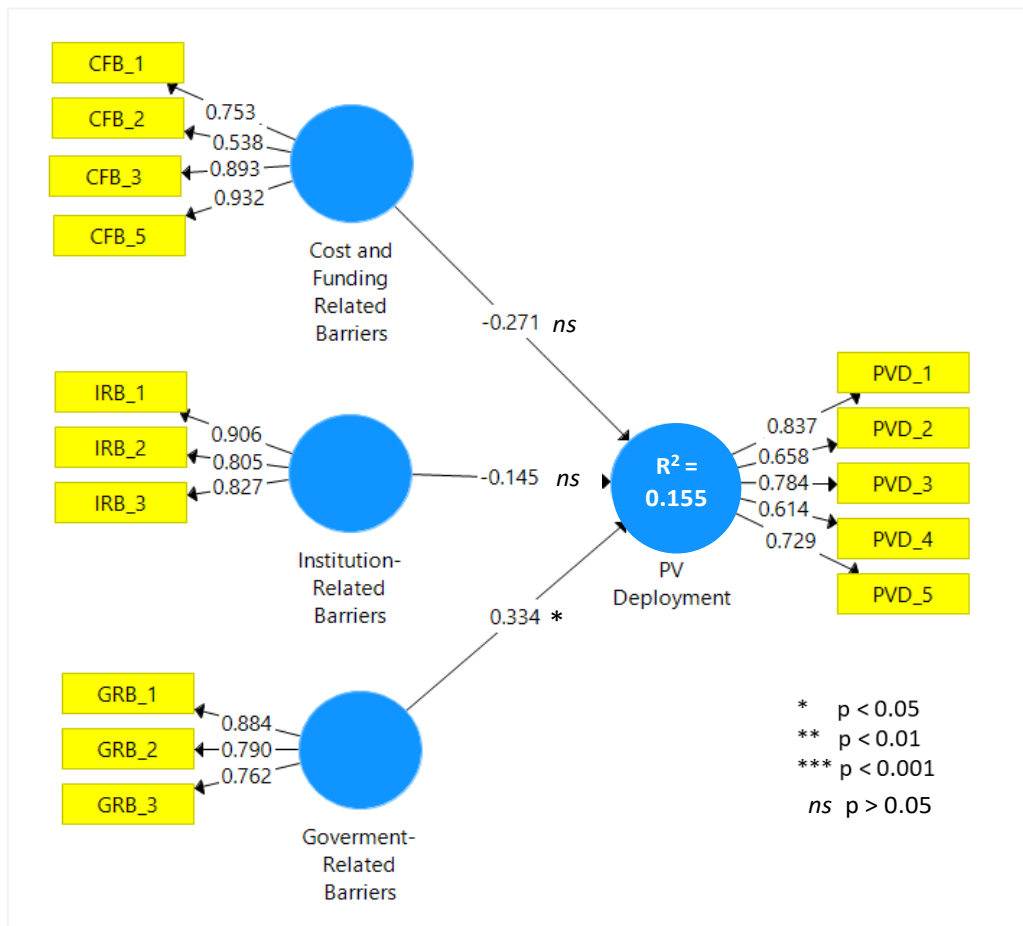
#### 5.6.4.2. Evaluation of Structural Model for Barriers

The assessment of the structural models of the study was conducted in five stages, as discussed below. As recommended by Hair *et al.* (2017), the inner VIFs were checked before the main assessment. The values obtained for all the constructs (CFB, IRB, and GRB) were 1.115, 1.092, and 1.107, respectively, which were satisfactory as the values were  $< 5$  (Hair *et al.*, 2017).

- (i) Evaluation of the significance and relevance of the structural model relationships:

To evaluate the hypothesised paths within the inner model, several steps were taken. Firstly, the bootstrapping analysis was executed with 5000 sub-samples and a two-tailed test. The bootstrapping results are presented in Table 6.12. As shown in the table, it was observed that there was only one construct that had a statistically significant relationship with ‘PV deployment’ with a  $p$ -value that was smaller than 0.05, indicating that there was a positive statistically significant relationship between ‘government-related barriers’ and ‘PV deployment’ ( $\beta = 0.334$ ,  $t = 2.423$ ,  $p = 0.015$ ). Therefore, hypothesis  $H7$  was supported. However, the results

established further that ‘cost and funding-related barriers’ ( $\beta = -0.271, t = 1.347, p = 0.178$ ) and ‘institution-related barriers’ ( $\beta = -0.145, t = 0.797, p = 0.425$ ) did not have a statistically significant relationship with ‘PV deployment’. Accordingly, hypotheses *H5* and *H6* were not supported.



**Figure 6.4: Final SEM model of barriers influencing deployment**

**Table 6.12: Structural model results - Barriers**

Hypothetical path	Std Beta	Std Error	t-value	p-value	f <sup>2</sup>	q <sup>2</sup>	Interpretation
<i>H5</i> : CFB -> PVD	-0.271	0.201	1.347	0.178	0.064	0.036	Not supported
<i>H6</i> : IRB -> PVD	-0.145	0.182	0.797	0.425	0.022	0.005	Not supported
<i>H7</i> : GRB -> PVD	0.334	0.138	2.423*	0.015	0.112	0.044	Supported

\* $p < 0.05$

(ii) Evaluation of the coefficient of determination ( $R^2$ ):

A graphical representation of the final SEM barriers model is shown in Figure 6.4. The  $R^2$  value for PV deployment, the only endogenous construct in the model, is 0.155. This means that the exogenous constructs altogether explain 15.5% of the variance in the PV deployment construct. According to Cohen (1992),  $R^2$  values of 0.12 or below indicate a low effect size, values between 0.13 to 0.25 values indicate a medium effect size, and values of 0.26 or above indicate a high effect size. From the above rules of thumb, it can be seen that the model has a medium predictive power.

(iii) Evaluation of effect size ( $f^2$ ):

Similar to how the calculation was done for the drivers, the calculation of the  $f^2$  values for the barriers was estimated using Equation 1, which was specified in Section 4.8.5.2. The purpose of the estimation was to determine which category of barriers had a substantial impact on the deployment of PVs (Hair *et al.*, 2017). The results obtained confirmed that ‘government-related barriers’, being the only statistically significant relationship, had a small impact on ‘PV deployment’ because the  $f^2$  value of 0.112 was within the 0.02 - 0.15 range given by Cohen (1988) (see Table 6.12).

(iv) Evaluation of cross-validated redundancy ( $Q^2$ ):

The cross-validated redundancy ( $Q^2$ ) is a means for assessing the predictive relevance of the inner model (Hair *et al.*, 2014). The blindfolding analysis, which was run at an omission distance of 7, produced a  $Q^2$  value higher than 0 (i.e. 0.057), thus confirming the predictive relevance of the model (Hair *et al.*, 2014, 2017).

- *Evaluation of predictive relevance ( $q^2$ ) effect size:*

The relative impact of predictive relevance was determined using the  $q^2$  effect size. The results from the estimation of  $q^2$  presented in Table 6.12 indicated that ‘government-related barriers’ had significant predictive relevance for PV deployment. The exogenous construct had a  $q^2$  value of 0.044, (i.e.,  $0.02 > q^2 < 0.15$ ), therefore the predictive relevance was significant at a medium level (Hair *et al.*, 2017).

#### 5.6.4.3. *Discussion of the Influence of the Barriers on the Deployment of PVs*

The demand for PVs is growing globally as it becomes the most competitive option for electricity generation in a sustainable manner, either for residential or commercial applications. In 2021, it was estimated that approximately 175 GW were installed, thereby increasing the cumulative global PV capacity to 942 GW (REN21, 2022, p. 126). As shown in Section 5.2 and Table 5.1, SAPUs are generating renewable electricity using PVs, and systems generating a total of at least 6,365.4 kWp have been installed by five universities. Although the institutions were adopting the technology, it was also evident that they could have been performing better than they were currently, had it not been for the many challenges they faced. The results from the PLS-SEM analysis indicated the significant and non-significant factors that were believed to be negatively influencing the deployment of the technology in the public university sector.

The analysis revealed that only one of the hypothesised paths was significant ( $H7$ ), while two were not ( $H5$  and  $H6$ ). From the significant path, it was ‘government-related barriers’ that had a negative influence on ‘PV deployment’ and, so, hypothesis  $H7$  was supported ( $t_{0.05} > 1.96$ ) ( $t = 2.423$ ,  $p = 0.015$ ). In accordance with recommended interpretation, the path coefficient was 0.334, which fell between 0.3 and 0.5, hence it could be concluded

that the factor of ‘government-related barriers’ had a medium negative influence on deployment (Hair *et al.*, 2017). The impact of the factor on deployment was small, according to the interpretation of  $f^2$  value postulated by Cohen (1988). Also according to Cohen (1988), the factor had a small predictive relevance for deployment (i.e.  $q^2 = 0.044$ ). The findings, generally, concurred with the findings of previous studies in the literature. As shown in Seetharaman *et al.* (2019) and Sambodo *et al.* (2022), government-related factors play a major contributing role in the non-deployment of RE. Additionally, although not directly related to the subject of RE or within the HEI context, Darko *et al.* (2018), and Durdyev *et al.* (2018a) found that government-related barriers were a significant hindrance to the adoption of green buildings, and some key issues that were highlighted were the lack of government incentives, promotion and enforcement.

Concerning ‘government-related barriers’ in this study, the specific factors that accounted for this variance in the endogenous constructs were ‘lack of incentives’, ‘lack of demand from project financiers’, and ‘inadequate funding for infrastructure development’. In view of the high prices of PV systems, incentive mechanisms are used as a way of encouraging adopters (Schelly and Letzelter, 2020), hence it was no surprise that deployment would be low if this were lacking. Public universities are government institutions and they do receive funds for infrastructure development, among other things. According to DHET, approximately R294.3 billion was given to public universities between 2010 to 2019 for their operations (DHET, 2020). Currently, when funds are not sufficient, universities weigh priorities and direct funds to the most critical needs. For instance, universities need electricity to operate and, even if they do not install PV systems, they will rely on electricity from the grid. Therefore, for example, when a hostel facility is to be constructed, normally, the essential need in such cases is to provide sufficient bed space for the students, rather than installing PVs to generate green energy. In other words, at that moment, providing

sufficient bed space for students is the topmost priority and not generating solar electricity. Therefore, the former will be addressed immediately while the latter will be postponed to be addressed in the future. This scenario was highlighted in a study by Geh *et al.* (2022a, p. 111) when the comment was made that “when you bring solar power and other requirements you find that if you try to categorise, it doesn’t rise to the level where it is funded in the categories”. Additionally, it was observed in a previous study that the lack of demand from government project financiers produces a lack of motivation for universities to install PVs (Geh *et al.*, 2022a) and, as shown from the PLS-SEM results, this factor was found to contribute significantly to the relationship between ‘government-related barriers’ and ‘PV deployment’. As such, it can be concluded that, in order to motivate universities to install PV systems, there should be incentives and sufficient funds should be made available to undertake deployment projects. Also, there is a need to make the funding of carefully evaluated and selected projects conditional upon the installation of PVs. In situations where PVs cannot be installed immediately at the time of construction or renovation, provisions should be made to install the system easily in the future without causing much disturbance/alterations to the physical structure. Therefore, the issues above should receive maximum attention from stakeholders to facilitate the deployment of the technology in the sector.

Regarding the relationship paths that were not significant, the variance contributed through the path of ‘cost and funding-related barriers’ was explained by four indicators: ‘long pay-back period of investment’, ‘high initial cost’, ‘scarcity of favourable options to acquire PV through PPA’, and ‘lack of financial resources’. Interestingly, although the above issues have been noted to account for the non-adoption of PVs (Mah *et al.*, 2018; Rai and Sigrin, 2013; Roberts and Sims, 2008; Shah *et al.*, 2019), their collective influence on PV deployment in the university sector was not significant. Similarly, for the path of

‘institution-related barriers’, the following three indicators did not have a significant negative influence on deployment: ‘lack of green building targets’, ‘lack of reporting university energy sustainability performance’ and ‘lack of clear policy direction’.

### **5.7. Development of Model to Enhance Building Sustainability (Phase 7)**

The development of the proposed model was based mainly on the final structural equation models that were derived after the PLS-SEM analysis. That is, only the issues that had a statistically significant influence on deployment were incorporated and addressed. The final results of the PLS-SEM for the drivers and barriers were presented in Figure 6.3 and Table 6.7, and Figure 6.4 and Table 6.12, respectively.

In the proposed model, the approach used to address the drivers and barriers is explained, and the expected outcomes when the issues are addressed are outlined. The initial model that was proposed is presented in Figure 6.5, and the revised version, after being validated, is presented in Figure 6.6.

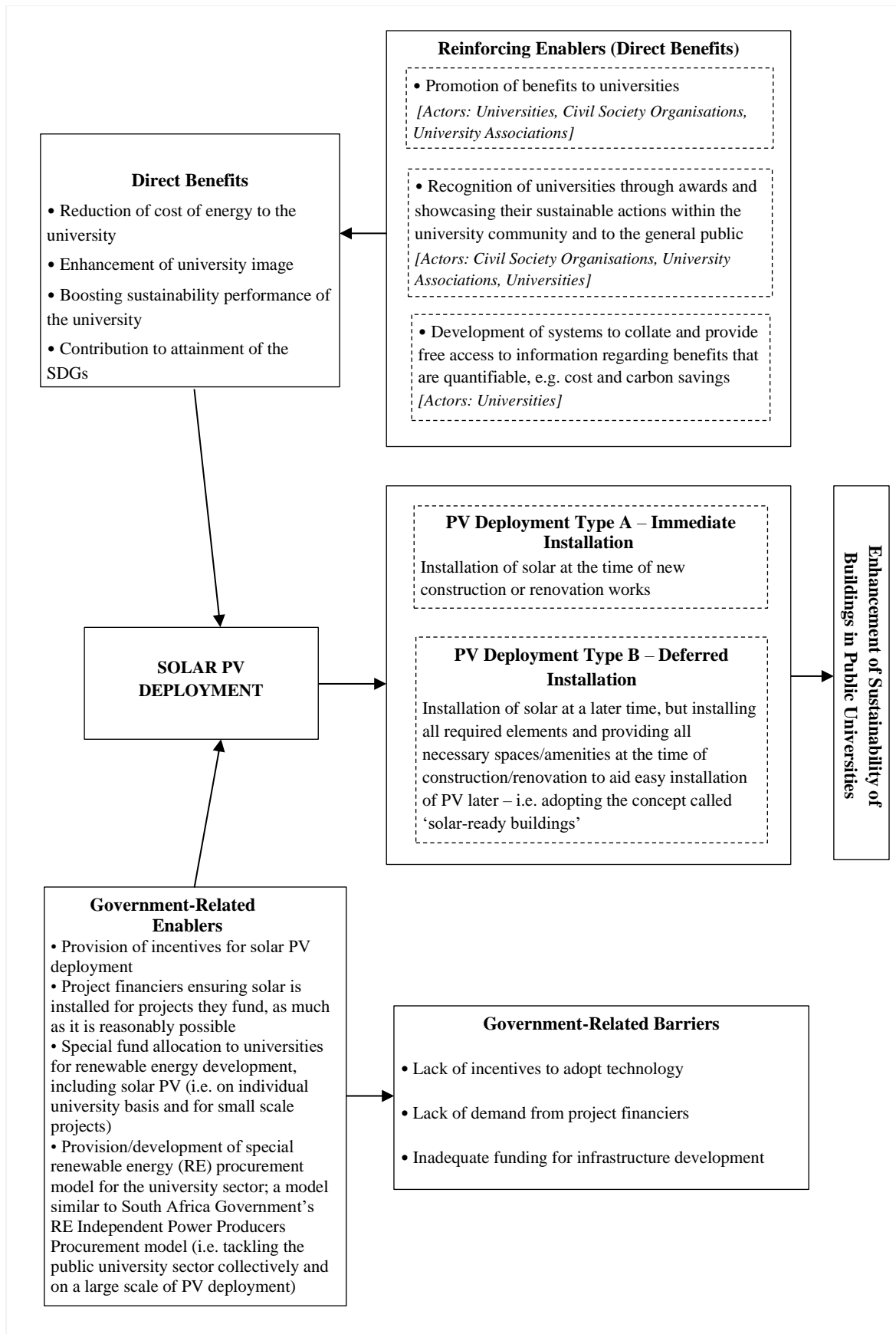
#### **5.7.1. Model Components Reinforcing the Drivers**

Regarding the drivers, the final results showed that only ‘direct benefits’ had a significant positive influence on the deployment of the technology, thus *H1* was supported. Therefore, only this category of drivers was deemed to be a vital element to be included in the model. There were four direct benefits in total: (1) reduction of cost of energy to the university, (2) enhancement of university image, (3) boosting sustainability performance of the university, and (4) contribution to attaining the SDGs. Naturally, these benefits will promote the installation of PVs but it is necessary to give adopters sufficient motivation to make the transition to RE quicker and to maximise the benefits. To engender deployment further, it is necessary to reinforce the factors that already drive adoption. For this reason, three main actions are recommended and these are labelled: ‘Reinforcing enablers (Direct

benefits)' in Figures 6.5 and 6.6. It requires various stakeholders to offer the necessary support for the sector, and so the actors identified are the universities, including external stakeholders such as civil society organisations and university associations. External stakeholders could include USAf, the UN's HESI, or HEFMA.

Firstly, attesting to the benefits of installing PVs within the university community will remind member institutions that are already aware and enlighten institutions that might not be fully aware. Hence, this activity is highly recommended. There has not been any known effort in the past to advocate the benefits more vocally in a proactive and organised manner. Therefore, there is an opportunity to promote the benefits currently.

Secondly, award schemes could be instituted to reward and recognise universities that are greening their campuses through the deployment of PVs. The award schemes could be instituted within a green campus sustainability framework, with the deployment of PVs being a sub-category award. To ensure credibility, the awards would have to be organised by third-party institutions, such as civil society organisations or university associations. According to Sharp (2009), when HEIs are able to demonstrate that sustainable living is attainable, it will encourage others to follow their example. Therefore, in addition, it is necessary that the PV projects taking place on campuses are showcased and promoted. This second recommended action achieves two things: firstly, the universities will benefit from the awards they receive and, secondly, the promotion will establish the PV projects as being demonstration projects that people can observe and use to inform their decisions to adopt the technology. It has been asserted that demonstration projects can spur the diffusion of innovations (Abdmouleh *et al.*, 2015; Kaplan, 1999; REN21, 2020). As such, the promotion will fill a gap in the area of knowledge/information that eventually could promote the diffusion of the technology.



**Figure 6.5: Proposed model (before validation)**

This line of thought is similar to what was recommended in SACREEE and REN21 (2018). It was mentioned in the SACREEE and REN21 Report (2018) that, in order to promote the diffusion of off-grid installations in SA, an option was to ‘establish demonstration projects – for example, in urban areas and in public sector institutions – to increase credibility of the systems’ (p. 59). Accordingly, the public universities could position themselves as the ‘public institutions’ that were referred to in SACREEE and REN21 (2018).

Thirdly, it was suggested that universities that are early adopters and are benefiting from the technology could share data to encourage other universities and the public to make a decision to adopt, with the objective being to provide the necessary data that confirm for people that the technology works. The information should be provided free of charge and be readily available to anyone via online platforms or in print or through other means that are deemed to be appropriate. It is believed that all three actions above will act together to engender the deployment of the technology further within the public university sector and cause a ripple effect in society.

### ***5.7.2. Model Components Addressing the Barriers***

Unlike the drivers that should be reinforced, the barriers are negative influencers that ideally should be eliminated. According to the findings, only ‘government-related barriers’ had a significant negative influence on the deployment of the technology. The result was affirmed by the findings in the literature that government legislation and policies are highly instrumental in RE deployment (Mah *et al.*, 2018; Shah *et al.*, 2019). Accordingly, only this category of barriers was addressed as being a vital element in the model. The specific barriers were: (1) lack of incentives to adopt technology, (2) lack of demand from project financiers, and (3) inadequate funding for infrastructure development. Consequently, four

major actions are initially recommended to address the above barriers, and are labelled: ‘Government-Related Enablers’ in Figures 6.5 and 6.6.

Firstly, it is proposed that government should motivate institutions to install PVs by providing incentives. The incentives could be financial and/or non-monetary incentives. For instance, as financial incentives, the government could provide cash-back to universities for every kilowatt of solar electricity that is generated. The cash-back would be computed based on the cost difference between the going rate for a kilo-watt of electricity from the grid and the calculated cost of a kilo-watt of electricity generated by PV. Alternatively, the monetary incentive could be calculated based on the reduction of CO<sub>2</sub> emissions by generating green energy. This approach would be the reverse of a Carbon Tax because, instead of being a tax, it would be a reward. The more PVs that are installed the higher the CO<sub>2</sub> saving will be and this would contribute immensely to the government's carbon reduction requirements/targets.

Also, as submitted in the literature, when institutions are left alone without appropriate external pressure, this results in PVs not being installed (Geh *et al.*, 2022a). Thus, secondly, as a measure to address this issue of a lack of demand from project financiers for PV installation, it is strongly suggested that, as far as reasonably possible, funders should ensure that PV installation is part of the projects they fund. The PVs can be installed immediately at the time of construction/renovation or deferred to a later time within the tenets of the solar-ready building concept.

Thirdly, to address the issue of inadequate funding for infrastructure development, it is proposed that there should be a special fund allocation to universities for RE development, including PVs. This particular fund should be given to individual universities to undertake small-scale RE projects only. However, as explained in detail in the subsequent section,

this particular recommendation was later deleted from the model according to recommendations from some panellists during the validation process (see Section 6.4 for the validation results).

Since 2011, a large-scale grid-connected RE development programme (REIPPPP) has been implemented in South Africa to source electricity from renewable sources in the private sector (SSA, 2019). By March 2021, it was reported that 5,078 MW of electricity generated from hydro-power, biomass, landfill gas, concentrated solar power, photovoltaic and wind have been contracted from 79 REIPPPP projects and connected to the grid (DMRE, 2021). Since universities are considered to be small towns with very high levels of electricity consumption (Dave *et al.*, 2014), a special RE procurement model, similar to REIPPPP, could be developed for the university sector. The aim of this approach would be to address the public university sector collectively and promote large-scale deployment of PVs on the different campuses, or on equally suitable, available land identified close to the institutions. A single or more than one contractor could be sourced, through appropriate tendering procedures, to provide RE to the 26 public universities. As established earlier in Section 5.2 (Table 5.1), all of the five universities that were surveyed already engaged third-parties to design, install and service the PV systems they have. Therefore, consolidating the operation would simplify the process and remove the unnecessary red-tape that is encountered during procurement policies in the universities (Geh *et al.*, 2022b). The success of this endeavour would depend on a careful, collaborative effort between all the public universities and the government so that a workable plan, which is acceptable to all parties involved, can be developed. Depending on what is deemed to be most appropriate by the parties concerned, the contractor (Independent Power Producer) could fund the project or the government would bear the cost.

### **5.7.3. Types of PV Deployment**

The deployment of PVs in the model is categorised into Type A and Type B, based on when the system is installed completely. Type A refers to complete installations that are carried out immediately at the time of new constructions or when existing buildings are renovated. Type B refers to all types of installations that are completed at a later time, but all requisite PV components are installed at the time of new construction or renovation to facilitate easy and faster completion of the installation process at a later time. For example, the conduits that will contain the wiring for the PV system will be provided in the walls/ceilings, and the roof will be constructed to carry the extra weight of the PV components. Other aspects that are attended to under this type of installation include the provision of spaces in the distribution board to fit surge protection devices, breakers etc., and the provision of places/spaces to install inverters and batteries. The objective of making the above provisions, among others, is to ensure that minimal or no disturbance is caused to the building and that the PV system can be installed easily, faster and at a lower cost. This approach is termed the ‘solar-ready buildings’ concept. By installing PVs, whether Type A or B, it is envisaged that this will contribute in part to advancing the sustainability of buildings in public universities.

### **5.8. Model Validation**

Validation of research output is the final, important step of the research process. Validation is undertaken to assess the credibility and acceptability of research findings. The approach to validation that is adopted in a study depends highly on the purpose of the research (Law, 2007). The process might involve the use of numerical and objective data to test hypothesised relationships among variables (referred to as a quantitative approach) or use of opinion-based data (referred to as a qualitative approach) (Lucko and Rojas, 2010). According to Saunders *et al.* (2019), validation techniques can be delineated as

triangulation or as participant or member validation. Triangulation involves using more than one source of data and method to confirm the validity/authenticity of research data, analysis and interpretation. Participant validation involves sharing research data with participants to enable them to confirm their accuracy, and requesting the participants to comment on and correct the data to validate them (Saunders *et al.* 2019)). A participant validation technique or opinion-based data approach was adopted for this study, using a questionnaire survey to collect the data required. This method was adopted because of its applicability to the type of model that was developed. The survey questionnaire used for validation was modified from previous studies, specifically by Adabre (2021) and Osei-Kyei (2017). The questionnaires were sent to the participants and returned to the researcher by email. A total of 15 panellists participated in the validation process. The results are presented in Sections 6.4.1 to 6.4.2.

#### **5.8.1. Background of Participants in the Validation Survey**

The initial model (Figure 6.5) was validated by 15 public university staff members, who were invited to participate during one or more phases of the research project. A total of seven academic staff (46.7%) and eight non-academic staff (53.3%) completed the questionnaire. Adabre (2021) used four panellists to validate a model for bridging the gap between sustainable and affordable housing, and Darko *et al.* (2018b) used five panellists to validate a green building promotion model. In a study conducted in SA, Okorafor *et al.* (2020) validated an artefact for improving the delivery of retrofit projects for building energy, using 17 member panellists. Therefore, guided by the previous studies, a total of 15 participants was deemed to be satisfactory for the validation of the model proposed in this study. As shown in Table 6.13 below, the panellists had at least 6 - 10 years of working experience. Two of the participants had over 25 years ( $\geq 26$  years) of experience. Most of the participants were 41 - 50 years old, four participants were 51 - 60 years old, and the

remaining five staff members were 30-40 years old. The minimum qualification of the respondents was a first degree (20%) and most of the participants had a doctorate degree (53.3%).

**Table 6.13: Background of participants in the validation survey**

Description		Frequency <i>N</i> = 15	Percentage (%)
Staff category	Academic	7	46.7
	Non-academic	8	53.3
Years of experience	6-10 years	5	33.3
	11-15 years	5	33.3
	16-20 years	2	13.3
	21-25 years	1	6.7
	≥ 26 years	2	13.3
Age	31-40 years	5	33.3
	41-50 years	6	40.0
	51-60 years	4	26.7
Qualification	First degree	3	20.0
	Master's degree	4	26.7
	Doctorate Degree	8	53.3

### 5.8.2. Results of Validation

The final assessment of the model was based on the responses to the six validation questions that were asked and the additional information provided by the panellists in the comment section of the questionnaire. The participants responded to the questions by indicating their level of agreement with the validation statements using a 5-point Likert Scale (i.e. 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree). The validation results are shown in Table 6.14.

It was observed that all the statements had a mean score above 3.5, indicating that, collectively, the panellists scored all the statements above average. The purpose of the first

question (Q1) was to determine whether the drivers and barriers identified as significant influencers of PV deployment were reasonable. To reiterate, the drivers and barriers included in the model were only the factors that were found to have either a significant positive or negative influence on deployment, according to the PLS-SEM results. All other drivers and barriers that did not have a significant influence were not included in the model. Q1 had a mean score (MS) of 4.07 and Q2 had a value of 4.00, which confirmed that the panellists believed that the actions that were proposed to address the significant barriers and drivers were appropriate.

The purpose of the third question (Q3) was to determine whether the proposed actions, defined under ‘Government-related enablers’ and ‘Reinforcing benefit enablers’, were comprehensive. Q3 had a mean score of 3.67 and comments were provided by some panellists regarding this particular question. Specifically, some panellists who gave a low rating for this question recommended additional actions that were not related to any of the significant drivers and barriers that were identified in the study, based on the PLS-SEM results. This suggested that some panellists thought that the model was not comprehensive enough because other valid actions could have been proposed by the researcher. However, since actions that related only to significant drivers and barriers were proposed in the study, there was a limit to what could be added to, and excluded from, the model. Therefore, it was understandable that Q3 was rated low ( $M = 3.67$ ). Nevertheless, Q3 was rated above average, hence the comprehensiveness of the model was deemed to be satisfactory. Also, based on the score for Q4 ( $M = 4.20$ ), it was believed that the model is easy to understand and can be used by stakeholders.

Q5 was scored the lowest, with a mean value of 3.6. The purpose of Q5 was to determine whether ‘the structure and relationships among all the constructs in the model are organised

appropriately’. The reason for the low score for Q5 was explained in the comments section by some of the panellists. It was suggested that all the proposed actions (i.e. ‘Government-related enablers’ and ‘Reinforcing enablers’) should be on one side, either left or right, and the significant drivers and barriers at which they are directed should be on the opposite side, rather than placing ‘Government-related enablers’ on the left and ‘Reinforcing enablers’ on the right. The recommendation above was accepted and the model was amended accordingly, as shown in the final model in Figure 6.6.

**Table 0.14: Validation questions**

No.	Validation questions	Mean score
Q1	The drivers and barriers identified as significant influencers of PV deployment are reasonable	4.07
Q2	The actions proposed to address the significant barriers and augment the significant drivers are appropriate	4.00
Q3	The actions proposed to address the significant barriers and augment the significant drivers are comprehensive	3.67
Q4	The model is easily understandable and can be used by stakeholders	4.20
Q5	The structure and relationships among all the constructs in the model are organised appropriately	3.60
Q6	Appropriate use of the model would certainly help to advance the sustainability of buildings through the deployment of PVs	4.53

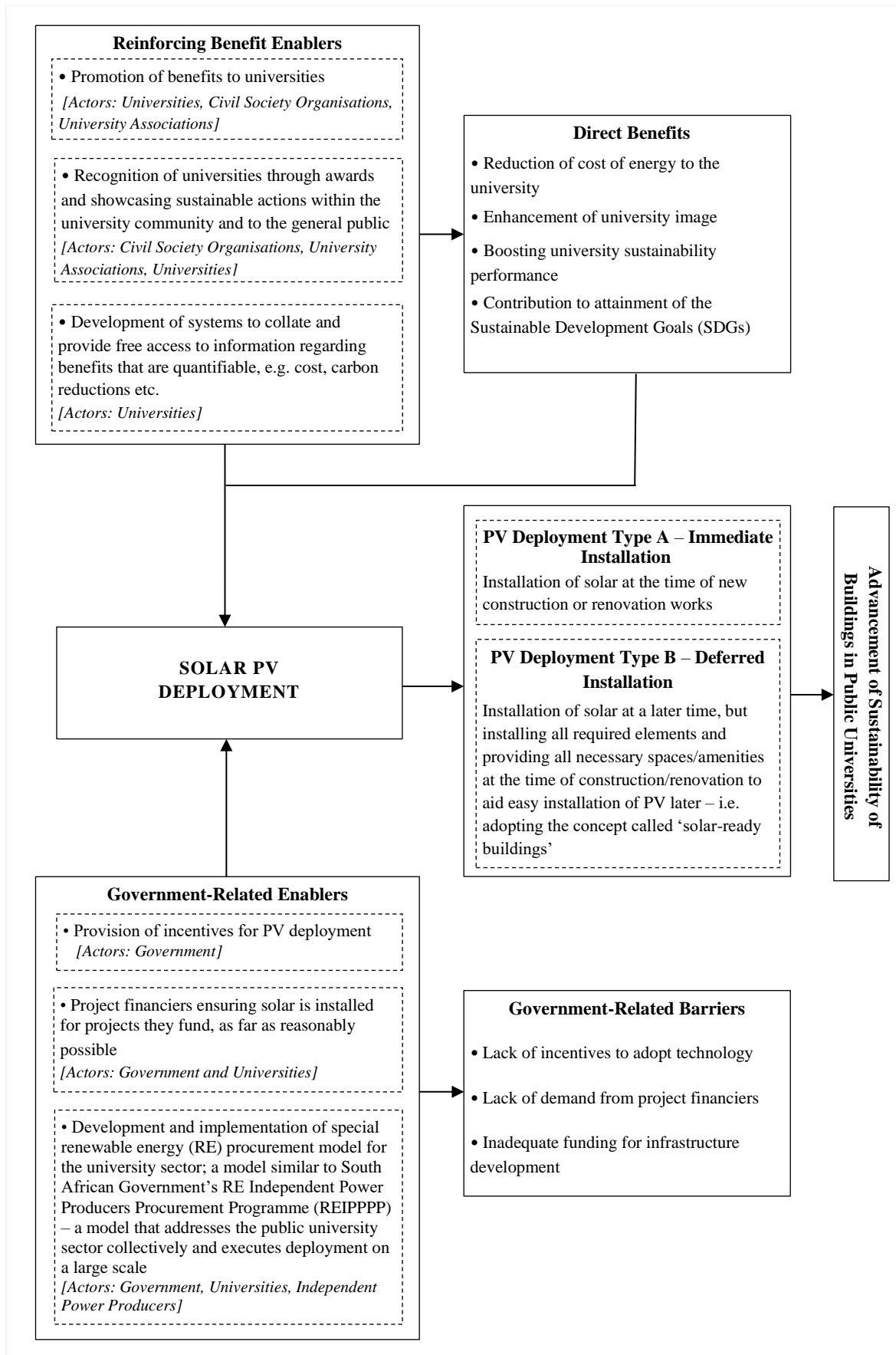
The purpose of the last question (Q6), which obtained the highest mean value ( $M = 4.53$ ), was to ascertain whether the panellists believed that the appropriate use of the model would certainly help to advance the sustainability of buildings through the deployment of photovoltaics. The result suggested that the panellists generally agreed with the statement.

Overall, the high mean scores (> 3.50) obtained for all aspects of the validation indicated that the results of the research were satisfactory and the model was deemed to be suitable by the panellists.

### ***5.8.3. Revision of the Model***

The model proposed initially (Figure 6.5) was revised by incorporating the recommendations from the panellists. The final PV Deployment Acceleration Model is shown in Figure 6.6. The main revision to the model was to position ‘Government-related enablers’ and ‘Reinforcing enablers’ on one side (i.e. on the left side), and the significant drivers and barriers on the right (i.e. ‘Direct benefits’ and ‘Government-related barriers’). This recommendation was made by panellists with reference to Q5, the purpose of which was to obtain agreement on the appropriate organisation of the components of the model. There was also a recommendation regarding the proposed actions under ‘Government-related enablers’. It was suggested that allocating special funds to universities for RE development (i.e. on a small scale) and having a procurement model similar to the SAG’s RE Independent Power Producers model (i.e. to address the public university sector collectively on a large scale) would be a duplication of activities. For this reason, it was advised that the former should be deleted and only the latter retained.

In addition, the need to link ‘Direct benefits’ directly to ‘Solar PV deployment’ became evident. Hence, this linkage was established. Furthermore, the operationalisation of the ‘Government-related enablers’ would not be executed only by the government. Hence, it was necessary to specify the relevant actors needed to execute the recommended actions, as specified for the ‘Reinforcing benefit enablers’. Therefore, the model was amended further to include the government, universities, and independent power producers. The final model is shown in Figure 6.6 below.



**Figure 6.6: PV Deployment Acceleration Model (PVDAM)**

## 5.9. Chapter Summary

In this chapter, the results and discussion of the findings on the statistical significance of the influence of the drivers and barriers on deployment were presented. The processes for the development and validation of the proposed model were also explained in the chapter. All of the above provided evidence in support of how research Questions 4 and 5 were answered. It was found that only ‘direct benefits’ had a statistically significant positive influence on deployment, and only ‘government-related barriers’ had a statistically significant negative influence on deployment. Based on the findings, actions were recommended to reinforce the drivers and minimise the barriers. The model was validated by engaging panellists from public universities, and the results showed that there was general agreement amongst the participants that the proposed acceleration model would certainly help to advance the sustainability of buildings through the deployment of PVs.

## CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

### 7.1. Introduction

This final chapter contains a summary of the major findings from the research. The findings are presented in relation to each of the five research objectives. Furthermore, the significance of the study and the study's limitations are considered. Lastly, possible areas for future research are suggested.

### 7.2. Overview of the Study

The sustainability of buildings has received much attention globally in recent times and individuals and organisations know that business cannot continue as usual. It has been suggested that the limited availability of buildings in which the principles of sustainability are demonstrated is a significant barrier to the implementation of sustainable development and innovation at universities (Ávila *et al.*, 2017, 2019). Therefore, it is appropriate that universities procure sustainable buildings to support the quest for sustainability on campuses. Also, since universities are similar to small towns (Dave *et al.*, 2014) with several buildings that need energy to operate (Bekker *et al.*, 2010), the adoption of PVs is an ideal alternative for advancing the sustainable performance of the vast portfolio of buildings.

Premised on the above, the aim of this study was to develop a model to advance the sustainability of buildings through the deployment of PVs in public universities in SA. All 26 public universities in the country, both adopters and non-adopters, were invited to participate in the research. The study was undertaken to achieve the following five research objectives:

1. To ascertain the progress made in installing PVs at universities;
2. To identify and evaluate the drivers for the deployment of PVs at universities;

3. To identify and evaluate the barriers to the deployment of PVs at universities;
4. To evaluate the influence of the drivers and barriers on the deployment of PVs;
5. To develop a model to advance building sustainability, through the reinforcement of the drivers and the elimination of the barriers to solar electricity generation.

The research was conducted using different approaches organised into seven phases. The foundation of the research was established in Phase 1 of the study, including the research background, research problem, aim and objectives. Also, during this phase, insight was gleaned into possible methods that could be adopted for the collection and analysis of the data. The information from Phase 1 was reported in Chapter 1. In the second phase, an in-depth analysis of relevant literature was carried out and reported in Chapter 2. The development of the conceptual model and explanation of the methodology was also completed in Phase 2 and were presented in Chapters 3 and 4, respectively. Chapter 4 contains a report on how all the phases of the methodology were executed. During Phase 3, the universities were contacted to report the PV capacity they had installed and answer related questions. In Phase 4, a case study was conducted, followed by a 3-round Delphi study in Phase 5. The results and discussion of the case study and Delphi study were presented in Chapter 5. Phase 6 entailed the collection and analysis of data to determine the significant factors that drove/hindered deployment. In the final phase, the PV Deployment Acceleration Model was developed and validated. The details of Phases 6 and 7 were discussed extensively in Chapters 4 to 6.

### **7.3. Review of the Research Objectives and Conclusions**

The realisation of the five main objectives for the study is discussed below.

**Objective 1: To ascertain the progress made in installing PVs at universities:**

The deployment of PVs on public university campuses is ongoing but information about what universities are doing is dispersed over the various university websites, reports, and many other sources. To collate this information and determine the total capacity of PVs installed on the campuses, a questionnaire was distributed and feedback was received from 17 of the 26 public universities. The results showed that 7 universities had installed PV systems, of which 5 institutions returned the questionnaire and 2 indicated only their status but could not return the completed questionnaire. Also, it was confirmed that 10 institutions had not installed any systems. Since feedback was not received from 9 institutions, it could not be established whether these institutions were adopters or non-adopters. The results, based on the information provided by the 5 universities, showed that, altogether, systems with a capacity of at least 6,365.4 kWp had been installed. The highest total capacity installed by a single university was 3,292 kWp and the lowest was 173.4 kWp. The PV systems were installed on the rooftops of buildings and were also used as roof coverings for carports. Some systems were mounted in open spaces on the ground, and on high poles/masts with tracking devices. The results showed further that the Building Integrated PV type of system had not been adopted by any of the universities. It was also observed that the universities either purchased the systems outright (82%) or entered into PPAs (18%), and none of the systems was leased. The results also showed that most of the universities were engaging third-party energy service providers to design, install and service the systems.

**Objective 2: To identify and evaluate the drivers for the deployment of PVs at universities:**

A three-step approach was used to identify the drivers that engendered deployment in the public university sector. Firstly, an in-depth review of a broad range of literature was

conducted to identify generic factors that are believed to drive the deployment of PVs in general, and 55 drivers were listed in Table 2.3. Secondly, by drawing upon theories/models in which the diffusion of innovations was considered, a conceptual model was developed (Figure 3.7) that included four constructs: direct benefits, indirect benefits, social influences, and relative advantage. The influence of the constructs on the deployment of PVs in the public university sector was hypothesised. By matching the 55 factors identified from the literature with the conceptual model, 22 factors that were relevant to the study were selected, reworded, and used to design the questionnaire. Thirdly, a 3-round Delphi study was used to validate the drivers. Finally, 27 drivers, comprising 22 drivers that were retrieved directly from the literature and 5 additional drivers that were recommended by panellists, were rated. The panellists agreed that 15 of the 22 drivers were applicable to SAPUs, and it was agreed that 3 of the 5 recommended drivers engendered deployment.

Based on the results, it was concluded that PV deployment was engendered by direct and indirect benefits, social influences, and the relative advantage of PV usage. It was confirmed that there was a total of 18 drivers in the sector, as listed in Tables 5.7 and 5.8. Specifically, in decreasing order, the top five drivers were: ‘reduction of cost of energy to the university’, ‘reduction of energy-related GHGs’, ‘enhancement of the sustainability performance of the university’, ‘contribution to attaining the SDGs’, and ‘potential use for research opportunities for students and staff’. In addition, the teaching and in-service training opportunities created were important reasons why SAPUs adopted the technology. Enhancement of university image and the opportunity for the public to observe the technology were also identified as key drivers. Apart from the benefits, expectations from university associations, staff and society also encouraged the deployment of PVs.

Similarly, are easy to maintain and do not make a noise when in use, which are advantages over other alternatives that favour the use of PVs in the sector.

**Objective 3: To identify and evaluate the barriers to the deployment of PVs at universities:**

The same, three-step approach used to achieve Objective 2 was followed to identify the barriers to deployment. In this case, a total of 27 barriers was rated, of which 23 barriers were retrieved directly from the literature, and 4 additional barriers were recommended by panellists. The barriers were examined under three main categories, namely: ‘cost and funding-related barriers’, ‘institution-related barriers’, and ‘government-related barriers’. The results of the Delphi survey are presented in Tables 5.9 and 5.10.

Based on the results, it was concluded that a total of 12 barriers hampered deployment in SAPUs, and were critical issues that should be addressed to accelerate the uptake and upscaling of the technology in the sector. With regard to barriers related to cost and funding, 5 barriers were found to be critical: lack of financial resources, high upfront cost, long pay-back period, and a scarcity of favourable PPA or lease acquisition options. Regarding institution-related barriers, it was discovered that there was a lack of green building targets, a lack of clear policy direction, and a lack of reporting sustainability performance. In addition, it was found that universities had other needs to address that resulted in the adoption of PVs being given less priority. Finally, in the category of government-related barriers, it was found that a lack of incentives, lack of demand from project financiers, and inadequate funding for infrastructure were prevailing issues that must be addressed to boost deployment.

**Objective 4: To evaluate the influence of the drivers and barriers on the deployment of PVs:**

Once the drivers and barriers had been identified (to achieve Objectives 2 and 3), it was important to determine the statistical significance of the influence of the factors on deployment. To do this, a PLS-SEM approach was adopted. To generate the data to carry out this analysis, the 18 drivers and 12 barriers that were validated by the panellists during the Delphi study, including 5 measurement items/indicators of PV deployment, were rated by 61 respondents. Specifically, it was hypothesised that the deployment of PV was: (1) positively influenced by ‘direct benefits’, ‘indirect benefits’, ‘social influences’, and ‘relative advantage’; (2) negatively affected by ‘cost and funding-related barriers’, ‘institution-related barriers’, and ‘government-related barriers’.

The results supported the conclusions that: (1) only ‘direct benefits’ had a statistically significant positive influence on deployment; (2) only ‘government-related barriers’ had a statistically significant negative influence on deployment. According to the results of the PLS-SEM, the factors that had a significant positive relationship with deployment were: ‘reduction of energy cost’, ‘enhancement of university image’, ‘boosting sustainability performance of the university’ and ‘contributing to the attainment of the SDGs’. On the other hand, it was the ‘lack of incentives’, ‘lack of demand from project financiers’, and ‘inadequate funding for infrastructure development’ that contributed to the significant negative influence of ‘government-related barriers’ on deployment. Therefore, it is important, especially, to take cognisance of these significant factors that influence the deployment of the technology in the sector so that actions can be taken to boost deployment. The final results of the SEM are presented in Figure 6.3 and 6.4.

**Objective 5: To develop a model to advance building sustainability, through the reinforcement of the drivers and the elimination of the barriers to solar electricity generation:**

The final outcome of the study was the ‘PV Deployment Acceleration Model’ (Figure 6.6). The model was developed based on the factors that had the highest statistically significant influence on deployment in the sector i.e. direct benefits, and government-related barriers.

With regard to the direct benefits, it was envisaged that they would naturally engender the deployment of PVs. However, it is necessary to be more proactive in promoting PVs in order to maximise the benefits or to increase the output to make the transition to RE quicker. For this reason, it is necessary to take action to reinforce the benefits. Three main actions were recommended (labelled ‘Reinforcing benefit enablers’ in Figure 6.6). Firstly, it was suggested that the benefits should be promoted consciously, and with quantifiable data, where applicable. For example, it is possible to quantify the cost savings, but not possible to put a figure directly on how PV deployment enhances university image, so there should be flexibility in determining what is supported with quantitative data. Secondly, there could be award schemes to reward universities which are making significant progress in RE development, and sustainable initiatives on campuses should be promoted so that others can be informed. The award schemes could be instituted within a green campus framework, with PV deployment being a sub-category award. Thirdly, it was recommended that institutions, which are already benefiting from the technology, as early adopters, should share data to encourage other universities and the public to make a decision to adopt, with the objective being to provide the data necessary to confirm for people that the technology works.

The conclusion was that government-related barriers were the key determinants of the non-deployment of PVs in the education sector. This was caused by the lack of incentives, lack of demand from project financiers and inadequate funding. Thus, the actions recommended were to ameliorate the barriers above by applying the ‘government-related enablers’, as shown in Figure 6.6. Specifically, it is necessary to provide incentives for universities, and project financiers should specify the inclusion of PV installation in the projects that they fund, as far as reasonably possible. Lastly, to overcome the inadequate funding for infrastructure development, instead of pre-funding for PV projects from the government, it would be worthwhile to explore the opportunities that independent power producers offer in the form of a special RE procurement model, similar to REIPPPP, that could be developed and implemented in the sector to accelerate deployment on a large scale. The success of this endeavour would depend on careful collaborative effort between all the public universities and government so that a workable plan, that would be acceptable to all parties involved, could be developed.

Finally, another important dimension included in the model would be for universities, in addition to installing PVs immediately during new construction/refurbishment projects, to make their buildings ‘solar ready’. This means that, when funds to install PVs immediately are limited, measures should be taken to install/construct all the PV components required to facilitate the completion of the installation process at a later time. For example, amongst other things, the conduits for the wires should be embedded in the walls/ceilings, and the roof should be constructed to carry the extra weight of the PVs. The benefits of adopting this method would be that the installation can be completed with minimal or no disturbance to the building (or building use), and would be easier, faster, and less costly compared with having to demolish, break and replace parts of a building.

#### **7.4. Contributions of the Study**

Higher education institutions have evolved over the years, and an increasing number of institutions have made considerable progress in pursuing sustainability through teaching/learning, research, campus operations, and community outreach. Unfortunately, it has been argued that research on sustainability in HEIs has been focused mainly on universities that are located outside Africa (Ulmer and Wydra, 2019). Thus, in a bid to fill the gap in the literature and contribute to theory, by focusing on public universities in SA, this study has contributed to research on CS and provided insight into how campus sustainability can be achieved partly by developing a PV Deployment Acceleration Model to advance the sustainability of buildings.

A deeper understanding of the drivers and barriers influencing the sector could lead to radical progress in the uptake and upscaling of PVs in SAPUs. Therefore, the findings of this study have practical implications. Specifically, the factors that drive and hinder PV deployment have been identified in the study, and guidelines have been provided to university stakeholders on how to reinforce the drivers to deliver more results, and to overcome the barriers to accelerating solar electricity generation. Through the application of the recommended actions, institutions will increase their RE portfolio and, considering the number of buildings on university campuses, deployment will contribute significantly to improving the sustainability of the buildings in the area of green electricity generation.

As part of the SDGs, the purpose of Goal 7 is to advance access to energy globally, and the aim of target 7.2 is to increase the share of RE in the global energy mix substantially by 2030 (United Nations [UN], 2014). At the level of policy, the findings of the study provided insight into the contribution that SAPUs have made to SDG 7, and the path that should be taken to support the universities to perform better than their present achievements. Since

buildings and construction-related activities play a major role in climate action (GABC, 2021), these findings also provided important empirical evidence that can help policy-makers to develop relevant policies and targets for the public university sector related to RE development.

Lastly, the study has social implications. Specifically, it has been asserted that a higher frequency of seeing or hearing about PVs raises the likelihood of adoption (Mundaca and Samahita, 2020), and demonstration sites that increase visibility have positive effects on the adoption of green technologies (Bollinger, 2012). Hence, it can be added that, through improvements in the capacity of universities to generate green energy, institutions will be more equipped to serve as demonstration sites to provide visibility of the technology in society, and experiential learning opportunities for students and staff which, in due course, can reduce the uncertainties regarding the expected benefits of PVs, confirm that the technology works and, ultimately, inspire the adoption of the technology in society.

## **7.5. Limitations of the Study and Recommendations for Future Research**

Although the aim of this study was achieved, some limitations and constraints are noted. Firstly, the drivers and barriers were identified based on the views of internal stakeholders only, and no external stakeholders were involved. As a result of the outbreak of COVID-19 during the time of the study, university staff were working mainly from home and travel restrictions were in place. For these reasons, the methods that could be employed to engage participants in the study were limited and only emails and phone calls were used. To provide further insight into deployment in the public university sector, there is an opportunity to conduct future studies that involve key external stakeholders, such as government agencies/officials, to understand their views on the subject as well. Furthermore, since this study was specific to the public university sector, future studies

could be conducted to examine the phenomenon within private HEIs in South Africa to gain an all-inclusive understanding of the subject throughout the higher education sector. This would reveal underlying issues so that measures can be taken to make the transition to RE quicker. Furthermore, to extend knowledge on the benefits of PV usage on campuses and the factors that could advance its adoption, future studies could engage students to solicit their views on the subject.

With regard to the recommendation to develop a special RE procurement model for the public university sector, the exact details and how this could be operationalised were not expounded because this was outside the scope of the study. Therefore, there is an opportunity to initiate future research projects to work with the government and SAPUs to develop a procurement model that would benefit all stakeholders.

In addition, PV was the only GBT examined in the study, hence scholars can also explore how the adoption of other GBTs unfolds in the sector or how universities are embracing the construction and certification of GBs. This will reveal the underlying issues so that holistic measures can be established to ensure that the built environment delivers its quota to accomplish campus sustainability targets.

## **7.6. Concluding Remarks**

The deployment of PVs is essential to diversifying the energy mix and making buildings more sustainable. Since universities are large units and adoption and deployment must take place in phases over a period, it can be concluded that the success of the first PVs installed on a campus will strongly influence the decision to deploy additional systems. For instance, if decision-makers believe that a project did not yield many benefits, then the likelihood of not expanding an existing PV portfolio will be very high. For this reason, it is important for institutions to record the benefits purposefully so that data will be readily available to

inform future development decisions. Furthermore, institutions should set specific targets for RE deployment, because without specific objectives, there would be less motivation to act in a timely manner.

To improve the effect of the drivers and eliminate the barriers, relevant stakeholders must work in synergy to devise solutions to accelerate the transition. Also, universities should embrace the tenets espoused in the concept of ‘solar-ready buildings’ so that new buildings and refurbishment works are engineered to allow for easy PV integration in the future. Furthermore, there should be a deliberate effort on the part of decision-makers to acquire green-building certification for buildings, especially for new buildings. Staff members and students alike should make themselves available to participate actively in the implementation of sustainability principles on campuses. In concurrence with Sharp (2009), the important question that should be answered is if educational institutions cannot demonstrate to society that it can be done, then who can and who will? Sustainable living is the new normal, and educational institutions should embrace all the opportunities it offers and chart the path to adopting new paradigms to empower society to improve continuously, for the standard can only be upgraded, not downgraded. By so doing, educational institutions will truly be fulfilling their purpose as progenitors' of knowledge, not only of knowledge that is established in research papers or talked about at conferences, but also of knowledge that is visible, experiential, creates tangible benefits, and builds the world we want.

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## APPENDICES

### Appendix 1:

Director: Department of .....  
University of .....  
P. O. Box .....

Dear Sir/Madam,

#### **REQUEST FOR PARTICIPATION IN RESEARCH ON SOLAR PHOTOVOLTAIC DEPLOYMENT WITHIN SOUTH AFRICAN PUBLIC UNIVERSITIES**

We write to cordially invite University of ..... in an ongoing doctoral research which is examining the deployment of solar photovoltaics in public universities in South Africa”.

The research is carried out by Mr. Nutifafa Geh under the supervision of Prof. Fidelis Emuze at Central University of Technology, Free State (CUT). In brief, the study among other things seeks to identify the benefits that universities get for installing solar photovoltaics (PVs) and the challenges/barriers they face in installing solar PVs or upscaling existing systems on campus. Consequently, this will help to develop a model to strengthen the drivers and overcome the barriers to deployment. The study is funded under the NRF-TWAS African Renaissance Doctoral Scholarship programme.

The research is carried out in different phases and we kindly need your assistance to collect the relevant data to develop the model. For the moment, we would like to know whether solar PVs have been installed at University of ..... If the university has installed solar PVs, we would like you to kindly help us get the attached questionnaire filled by the relevant department/person (please see brief about this at ‘PRELIMINARY PHASE’ below). Also, we kindly request of you to recommend two (2) staffs to participate in an upcoming Delphi survey in January-February 2021. Please see the purpose of the survey and what will be required of research participants at ‘PHASE 1: DELPHI SURVEY’ below to help you with the recommendation. We will gladly welcome staffs from the estates department and/or from top-management, and it will be an honour to have you participate in the survey as well if your schedule will allow it.

#### **PRELIMINARY PHASE: SOLAR PV DEPLOYMENT AT PUBLIC UNIVERSITIES**

The goal for this exercise is to know how much solar PVs have been installed at South African public universities, and to understand other pertinent questions regarding how deployment of the technology is operationalised. Please fill the attached questionnaire for us if the university has installed any solar PVs, but if this is not the case, we will also await your feedback to know for certainty that the university is yet to deploy the technology.

#### **PHASE 1: DELPHI SURVEY**

For this study, we are inviting experts from South African public universities to give their opinion on what they believe are the drivers and barriers to solar PV deployment within the public university sector as a whole. The number of Delphi rounds (or surveys) will be 2 or 3 rounds. A third round will be required only if, at round 2, consensus is not reached

among the research participants. The goal of the Delphi survey is to produce a final list of drivers and barriers which will be used to design a questionnaire for the general survey at Phase 2 of the research.

**What will be required of research participants during the Delphi survey/rounds?**

**Round 1:** Participants will be presented with a list of drivers, barriers, and general statements pertinent to solar PV deployment, and they will be required to indicate the level to which they agree or disagree with the questions presented in the questionnaire. In addition, they will have the option to add any new driver(s) and/or barrier(s) they deem relevant to the general public university sector.

**Round 2:** At round 2, participants will be provided with the consolidated result from all the research participants from round one. The result will be anonymous and will show the factors that have been agreed upon and those that were rejected. Participants will then have the opportunity to review their opinions/judgements in view of the consolidated result from all the experts.

In conclusion, we would like to mention that the participation of University of ..... will be highly beneficial to the overall success of the research hence we will be glad to have the university participate. We will gladly share the research findings with you after the project is completed.

Please send your responses and queries to the student (Mr. Geh) and the supervisor (Prof. Emuze) using the contact details provided below. You may read more about the research project at: <[www.greencampus.africa](http://www.greencampus.africa)>. If you wish to contact the host university directly for further information, please use: Research Office, Central University of Technology, Free State, Private Bag X20539, Bloemfontein, 9300, South Africa, .....@cut.ac.za, +27 .....

Thank you.

Sincerely,

Mr. Nutifafa Geh (Research student)

Email: ..... @stud.cut.ac.za | Phone: .....

Prof. Fidelis Emuze (Research Supervisor)

Email: ..... @cut.ac.za | Phone: .....

**Annexure:**

## QUESTIONNAIRE

### Background Information

This survey is executed as part of a research project aimed at examining the deployment of solar photovoltaics in public universities in South Africa.

**Purpose of Survey:** To ascertain progress on solar photovoltaic (PV) deployment within South African public universities

### Section A: Guidelines

1. Kindly provide information for solar PV installations on project basis.
2. Please note that only one filled questionnaire is required from the university/department.
3. Return completed form to [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za)

### Section B: Contact Information

1. Kindly provide email to be used to request clarification or additional information if the need arises. Email: \_\_\_\_\_
2. Name of University: \_\_\_\_\_

### Section C: Solar Photovoltaic Installations

Kindly provide information for solar PV installations in your university on project basis in the columns provided. Use additional sheet if there are more than six projects.

#### *PROJECT 1 to 3*

No.	Questions	Project 1	Project 2	Project 3
Q1	What is the installed capacity of PV system?			
Q2	Is energy storage system also installed?			
Q3	Which campus is PV system installed?			
Q4	What year was PV project completed?			
<b>Q5. Method of installation of PV system: Please mark appropriate box(es) with the letter "X"</b>				
	Rooftop mounted			
	Standard ground mounted (low level)			
	Pole mounted (high level)			
	Building Integrated Photovoltaic (BIPV) type			
	Others:(Provide state)			
<b>Q6. Method of acquisition of PV system: Please mark appropriate box with the letter "X"</b>				
	Outright Purchase			

	Power Purchase Agreement (PPA)			
	Lease Agreement			
	Others:( <i>Provide state</i> )			
<b>Q7. Project Implementation:</b>				
	Which stakeholders were involved in the design, installation, and are presently responsible for maintenance services? <i>Please mark appropriate box with the letter "X"</i>			
<b>Design</b>	In-house expertise			
	External contractor			
<b>Installation</b>	In-house expertise			
	External contractor			
<b>Maintenance</b>	In-house expertise			
	External contractor			

PROJECT 4 to 6

No.	Questions	Project 4	Project 5	Project 6
<b>Q1</b>	What is the installed capacity of PV system?			
<b>Q2</b>	Is energy storage system also installed?			
<b>Q3</b>	Which campus is PV system installed?			
<b>Q4</b>	What year was PV project completed?			
<b>Q5. Method of installation of PV system: <i>Please mark appropriate box(es) with the letter "X"</i></b>				
	Rooftop mounted			
	Standard ground mounted (low level)			
	Pole mounted (high level)			
	Building Integrated Photovoltaic (BIPV) type			
	Others:( <i>Provide state</i> )			
<b>Q6. Method of acquisition of PV system: <i>Please mark appropriate box with the letter "X"</i></b>				
	Outright Purchase			
	Power Purchase Agreement (PPA)			
	Lease Agreement			
	Others:( <i>Provide state</i> )			
<b>Q7. Project Implementation:</b>				
	Which stakeholders were involved in the design, installation, and are presently responsible for maintenance services? <i>Please mark appropriate box with the letter "X"</i>			
<b>Design</b>	In-house expertise			
	External contractor			
<b>Installation</b>	In-house expertise			
	External contractor			

	<b>Maintenance</b>	In-house expertise			
		External contractor			

Q15. Please do you have any general comments or concerns you would like to share?

*Comment:*

—The End—

Thank you very much for taking time to complete the questionnaire

## Appendix 2:

Date: .....

Dear Sir/Madam,

Request to participate in an interview: PV deployment at CUT

We write to humbly request your participation in an interview as part data collection process for an ongoing doctoral study being carried out by Nutifafa Geh under the supervision of Professor FA Emuze at the Central University of Technology, Free State.

The aim of this phase of the project is to identify the challenges related to the deployment of solar photovoltaic and the strategies for scaling up the use of the technology in the institution.

Your participation in this research will be highly appreciated due to your expertise and role in the university. Please, be assured that your response will be treated with outmost confidentiality and shall be used for academic purposes only, both in the research report and future publication. We will therefore be glad if you can participate.

It would have been best to conduct the interview face-to-face, however, due to the COVID-19 lockdown, possible suggestions are to have the interview via Microsoft Team, Zoom, or Skype. We will therefore be glad if you can indicate the mode that will be most convenient for you, and also the date and time. If possible, kindly consider granting an appointment next week. Please find the interview protocol attached.

If you have any questions regarding this research, please feel free to contact Mr Geh at [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za) and the supervisor Prof Emuze at [.....@cut.ac.za](mailto:.....@cut.ac.za)

Thank you for your attention. We are looking forward to your reply.

Sincerely,

Nutifafa Geh (Doctoral Candidate)

Prof FA Emuze (Research Supervisor)

## **Interview Protocol**

### **Section A: Interviewee Personal Information**

Code name of interviewee: #1

Sex: Male

Age: .....

Position held in university: .....

Years of working in university: .....

Department affiliation:

Qualification:

### **Section B: Interview Information**

Date of Interview:

Duration of Interview:

Mode of interview:

### **Section C: Questions**

1. Overall, with respect to all the university campuses, how would you rate the sustainability performance of buildings at the institution?

Very High    Above Average    Average    Below Average    Very Low

*Reason(s):*

2. It is largely agreed that solar photovoltaics can improve the sustainability performance of buildings through the supply of 'green' electricity'. CUT has undertaken some solar projects and it can be said that the university can do more than what it has achieved. Please, in your opinion, what are the barriers hindering scaling up deployment of solar photovoltaics in the university?

*Barriers:*

- a.  
b.

3. In your opinion, what are the strategies or the things that could be done to overcome the barriers in order to increase the deployment of solar photovoltaics at the institution?

*Strategies:*

- a.  
b.

4. Please do you have any general comments or concerns you would like to share?

*Comments/Concerns:*

—The End—

Thank you very much for granting this interview.

### Appendix 3:

Date: .....

Dear Sir/Madam,

#### **DELPHI SURVEY ROUND 1: SOLAR PHOTOVOLTAIC DEPLOYMENT WITHIN SOUTH AFRICAN PUBLIC UNIVERSITIES**

First, thank you for accepting the invitation to participate in the **Delphi survey** which is part of an ongoing doctoral research investigating deployment of solar photovoltaic (PV) within South African public universities. This is **Round 1** of the Delphi survey and please find the questionnaire attached for completion.

#### **Brief on Delphi survey**

Through review of literature and application of appropriate diffusion of innovation theories, a list of drivers and barriers to solar PV deployment have been identified and categorised under various themes as shown in the questionnaire. Also included are some general statements regarding solar PV deployment. The main goal of the Delphi survey is to identify the drivers and barriers that are applicable within South African public university sector. This exercise will produce a final list of factors which will be used to design a questionnaire for the next stage of the research (i.e. general survey). The number of Delphi rounds for this study will be two/three rounds. Please see below a brief of what will be required of you.

**Round 1 (Current Stage):** At this stage you are presented with a list of drivers, barriers, and general statements pertinent to solar PV deployment. You are kindly requested to share your opinion by indicating the level to which you agree or disagree about the questions presented in the questionnaire. You are also provided the opportunity to recommend additional driver(s) and/or barrier(s) to the list.

At the next stage (Round 2), you will be provided with the consolidated results from all the participants from Round 1, including your initial rating of the factors. At that stage, you can review your ratings (from Round 1) in view of the consolidated results, and also rate any new drivers/barriers that were recommended from the previous survey.

Please send the completed questionnaire to the student via [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za)

You may read more about the research project at: <https://greencampus.africa/phd-research/>

Thank you.

Yours sincerely,

Mr. Nutifafa Geh (Doctoral Student)

Email: [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za)

Mob: .....

Attachment: Round 1 Delphi Questionnaire

Prof. Fidelis Emuze (Supervisor)

Email: [.....@cut.ac.za](mailto:.....@cut.ac.za)

Tel: .....

## DELPHI SURVEY QUESTIONNAIRE – ROUND 1

### Information/Guidelines

1. This is **Round 1** of the Delphi survey, and please draw upon your understanding of solar photovoltaic (PV) deployment or non-deployment in the public university sector in South Africa to complete the survey.
2. The term ‘deployment’ refers to both initial installation of PV (PV uptake) and the continuous installation of PV (PV upscale) on university campuses.
3. If you consider any drivers/barriers applicable to the sector but it has been omitted, kindly add it in the spaces provided in the tables and rate it accordingly.
4. Kindly return completed form to [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za) or, if preferred, via post to: Mr. Nutifafa Geh, Department of Built Environment, Central University of Technology, Free State, Private Bag X20539, Bloemfontein, 9300, South Africa.

### Section A: Demographic Information

Please provide your answer by clicking the box to mark it (i.e. ) or by typing your response.

Panel ID: A01		
1	Please indicate the category that best describes your status	<input type="checkbox"/> Academic staff <input type="checkbox"/> Non-academic staff
2	Please state your position at the university	
3	Please state the department where you work	
4	How many years have you been working at your current university?	
5	Have you also worked at a different public university in South Africa?	<input type="checkbox"/> Yes <input type="checkbox"/> No
6	If you answered ‘Yes’ in <i>Question 5</i> , please state the total number of years	
7	Please indicate your highest level of qualification	<input type="checkbox"/> Diploma <input type="checkbox"/> 1 <sup>st</sup> Degree <input type="checkbox"/> Master’s <input type="checkbox"/> Doctorate    Others:

### Section B: Drivers promoting solar photovoltaic (PV) deployment

Please indicate the level to which you agree or disagree about how applicable the following drivers are within the public university sector in South Africa.

Please rate each driver based on the 5-point Likert scale below (click a box to mark it as ):

1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree

Code	Drivers	Low <span style="font-size: 1.2em;">↔</span> High				
		1	2	3	4	5
<b>Direct benefits (DB)</b>						
DB1	Reduction of energy cost of university	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB2	Minimisation of impact from power cuts	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

DB3	Enhancement of university image	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB4	Increased value of university properties	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB5	Enhancement of university sustainability performance	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB6	Contribution to attainment of SDGs	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB7	Use potentials for teaching purposes (i.e., students)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB8	Use potentials for research opportunities for students & staff	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Indirect benefits (IB)</b>						
IB1	Reduction of energy-related greenhouse gasses	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IB2	Creation of job opportunities	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IB3	Opportunity for staffs to observe & use technology	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IB4	Opportunity for students to observe & use technology	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IB5	Opportunity for the public to observe technology	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Social Influence (SI)</b>						
SI1	Expectation from students/student activist groups	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
SI2	Expectation from university staff	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
SI3	Expectation from society to use PVs	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
SI4	Expectation from university bodies/associations	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
SI5	People/organisations in the community use PVs	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
SI6	Other universities use PVs	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Relative Advantage (RA)</b>						
RA1	Ease of installation	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
RA2	Ease of maintenance	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
RA3	Noiseless during use	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Please recommend any drivers that have been omitted in the questionnaire and rate them</b>						
1		<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
2		<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
3		<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
4		<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

### **Section C: Barriers inhibiting solar photovoltaic deployment**

Please indicate the level to which you agree or disagree about how applicable the following barriers are within the public university sector in South Africa.

Please rate each barrier based on the 5-point Likert scale below:

1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree.

Code	Barriers	Low ←————→ High				
		1	2	3	4	5
<b>Cost &amp; funding-related barriers</b>						
CFB1	High cost of solar PV (technology is expensive)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
CFB2	Long pay-back period of investment	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

CFB3	Lack of financial resources	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CFB4	Energy storage system requirement challenges	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CFB5	Decision makers uncertainty of recouping investment cost	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CFB6	High upfront cost (i.e. outright purchase option)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CFB7	Scarcity of favourable PPA acquisition options	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CFB8	Scarcity of favourable lease acquisition options	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
CFB9	Lack of favourable credit/financing schemes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>Institution-related barriers</b>						
IRB1	Lack of suitable installation space	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB2	Resistance to change	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB3	Limited commitment to operationalising university policies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB4	Lack of green building targets for university	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB5	Lack of reporting university sustainability performance	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB6	Limited motivation to reduce operational cost of buildings	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB7	Lack of dedicated sustainability advisor/promoter	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB8	Limited appreciation of benefits of PV usage	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB9	Lack of demand from electricity end-users	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
IRB10	Lack of clear policy direction on PV deployment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>Government-related barriers</b>						
GRB1	Lack of incentive to adopt technology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GRB2	Lack of enabling policies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GRB3	Lack of demand from government project financiers	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
GRB4	Inadequate funding for infrastructure development	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>Please recommend any barriers that have been omitted in the questionnaire and rate them</b>						
1		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

— The End —

Thank you very much for your valuable contribution to the study 🤝

## Appendix 4:

### DELPHI SURVEY QUESTIONNAIRE (ROUND 2)

PANEL ID: A01

#### Information/Guidelines

5. This is Round 2 of the Delphi survey and below is the controlled feedback from all the staffs (i.e., academic & non-academic staffs) who participated in Round 1.
6. Please you are needed at this phase to:
  - (i) Check the consolidated results from Round 1 and see if you would like to review or reconsider your ratings in view of the consolidated results (Mean scores) of all the participants (*Please see Section B & C*). If you wish not to adjust/change your initial score for any item, please leave the relevant space in the table blank.
  - (ii) Rate the additional drivers and barriers that have been recommended by some of the participants (*Pease see Section A*).

#### Section A: Additional drivers and barriers recommended by panellists

Please rate each item based on the 5-point Likert scale below (click a box to mark it as ☐):

1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree

No.	Factors	Low $\longleftrightarrow$ High				
		1	2	3	4	5
<b>Drivers</b>						
D1	Enhances university productivity (i.e. directly or indirectly)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D2	Provides in-service training opportunities for students	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D3	Enhances technology demonstration	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D4	International organisation incentives (e.g., UN*, ISCN**, etc.)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
D5	Demonstration projects showcasing different PV technologies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>Barriers</b>						
B1	Limited locally manufactured materials for PV	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
B2	Liability & cost for preventing unauthorised access to and theft of PV systems	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
B3	Dreadful red tape with university procurement policies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
B4	Prevalence of higher competing needs of universities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

\* UN = United Nations

\*\*ISCN = The International Sustainable Campus Network

**Section B: Statistical feedback on drivers and adjustment of Round 1 ratings**

**(Drivers which are applicable within the public university sector in South Africa)**

Please change your initial rating by writing the new score in the last column in the table.

Leave the relevant space blank if you are not making adjustment to your initial rating/score.


The rating scale is: 1=Strongly Disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly Agree

Code	Drivers	Mean score (18 staff) <i>n=18</i>	Your initial score in Round 1	Your adjusted score in Round 2 <i>(if deemed necessary)</i>
<b>Direct benefits (DB)</b>				
DB1	Reduction of energy cost of university			
DB2	Minimisation of impact from power cuts			
DB3	Enhancement of university image			
DB4	Increased value of university properties			
DB5	Enhancement of university sustainability performance			
DB6	Contribution to attainment of SDGs			
DB7	Use potentials for teaching purposes (i.e., students)			
DB8	Use potentials for research opportunities for students & staff			
<b>Indirect benefits (IB)</b>				
IB1	Reduction of energy-related greenhouse gasses			
IB2	Creation of job opportunities			
IB3	Opportunity for staffs to observe & use technology			
IB4	Opportunity for students to observe & use technology			
IB5	Opportunity for the public to observe technology			
<b>Social Influence (SI)</b>				
SI1	Expectation from students/student activist groups			
SI2	Expectation from university staff			
SI3	Expectation from society to use PVs			
SI4	Expectation from university bodies/associations			
SI5	People/organisations in the community use PVs			
SI6	Other universities use PVs			
<b>Ease of Use (EU)</b>				
EU1	Ease of installation			
EU2	Ease of maintenance			
EU3	Noiseless during use			

**Section C: Statistical feedback on barriers and adjustment of Round 1 ratings**  
**(Barriers which are applicable within the public university sector in South Africa)**

Code	Barriers	Mean score (18 staff) <i>n=18</i>	Your initial score in R 1	Your adjusted score in Round 2 (if deemed necessary)
<b>Cost &amp; funding-related barriers</b>				
CFB1	High cost of solar PV (technology is expensive)			
CFB2	Long pay-back period of investment			
CFB3	Lack of financial resources			
CFB4	Energy storage system requirement challenges			
CFB5	Decision makers uncertainty of recouping investment cost			
CFB6	High upfront cost (i.e. outright purchase option)			
CFB7	Scarcity of favourable PPA acquisition options			
CFB8	Scarcity of favourable lease acquisition options			
CFB9	Lack of favourable credit/financing schemes			
<b>Institution-related barriers</b>				
IRB1	Lack of suitable installation space			
IRB2	Resistance to change			
IRB3	Limited commitment to operationalising university policies			
IRB4	Lack of green building targets for university			
IRB5	Lack of reporting university sustainability performance			
IRB6	Limited motivation to reduce operational cost of buildings			
IRB7	Lack of dedicated sustainability advisor/promoter			
IRB8	Limited appreciation of benefits of PV usage			
IRB9	Lack of demand from electricity end-users			
IRB10	Lack of clear policy direction on PV deployment			
<b>Government-related barriers</b>				
GRB1	Lack of incentive to adopt technology			
GRB2	Lack of enabling policies			
GRB3	Lack of demand from government project financiers			
GRB4	Inadequate funding for infrastructure development			

— The End —

Thank you very much for your *continual contribution* to the study 

## Appendix 5:

Date: .....

The Director  
Estates/Facilities/Projects/  
.....

Dear Sir/Madam,

### **Invitation to participate in a research on solar photovoltaic (PV) deployment within the public university sector in South Africa**

We write to humbly request the assistance of staffs who work in the office/department responsible for the construction and maintenance of university buildings/infrastructure to participate in a questionnaire survey. The survey is aimed at examining the drivers and barriers to solar photovoltaic (PV) deployment within the public university sector in South Africa.

The research is carried out by Mr. Nutifafa Geh who is a student at Central University of Technology, Free State (CUT). The study is jointly funded by National Research Foundation (NRF) and The World Academy of Sciences (TWAS). To know more about the research, please visit the project website at: <https://greencampus.africa/phd-research>

Prior to this current questionnaire survey, a 3-round Delphi survey was conducted from January to May this year. A total of 18 staffs from 11 public universities participated in the Delphi survey, and the findings of the survey provided a list of drivers and barriers which the research participants had consensus on as factors which were applicable to the public university sector in South Africa. The list of drivers and barriers which reached consensus from the Delphi survey is now used in this current questionnaire survey.

This present questionnaire survey is ongoing at all public universities to enable other staffs (who did not participate in the Delphi survey) to also share their views so that a larger set of data can be generated to enable further statistical analysis of the drivers and barriers. The findings of this survey will help to develop a model of recommendations to strengthen the drivers and provide measures to overcome the barriers to deployment in the sector.

If possible, we would like to have about four (4) questionnaires completed by staffs from your department/office. This will contribute immensely in generating sufficient data for analysis. We therefore humbly ask for your assistance and make this two proposals:

**Option 1:** Four (4) set of questionnaires are attached to this letter. Staffs can complete the printed copies and the research student (or research assistant) will pick it up in person when it is ready.

**Option 2:** Alternatively, staffs who will participate can complete the same questionnaire online by going to this website: <https://greencampusafrika.questionpro.com>

Please use the details provided on the next page to contact the research student and/or the supervisor if you would like us to provide clarification on any issue.

Thank you.

Yours sincerely,

Mr. Nutifafa Geh (Research student)

Email: [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za)

Phone: .....

Prof. Fidelis Emuze (Research supervisor)

Email: [.....@cut.ac.za](mailto:.....@cut.ac.za)

Phone: .....

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Attachment:

1. Questionnaire: Drivers of and barriers to solar photovoltaic (PV) deployment within the public university sector in South Africa

## Appendix 6:

Date: .....

Dear Sir/Madam,

### **Invitation to participate in a research on solar photovoltaic (PV) deployment within the public university sector in South Africa**

You are humbly invited to participate in a questionnaire survey aimed at generating data to examine the drivers and barriers to solar photovoltaic (PV) deployment within the public university sector in South Africa.

The research is carried out by Mr. Nutifafa Geh who is a student at Central University of Technology, Free State, and jointly funded by National Research Foundation (NRF) and The World Academy of Sciences (TWAS). Further information about the research can be accessed via the project website at: <https://greencampus.africa/phd-research>

Prior to this current questionnaire survey, a 3-round Delphi survey was conducted from January to May this year. A total of 18 staffs from 11 public universities participated and there was consensus on factors which are believed to drive and hinder solar PV deployment in the public university sector (i.e., 18 drivers and 12 barriers). The list of drivers and barriers which reached consensus from the Delphi survey is what is now used in this current questionnaire survey to enable other staffs who did not participate in the Delphi to also share their views. This will help generate a larger set of data to enable further statistical analysis of the factors and other related issues.

We therefore kindly request your participation by completing the questionnaire which is attached. The guidelines for completing and returning the questionnaire (i.e., the printed copy) are provided on the first page of the questionnaire.

Alternatively, if you prefer, you can complete the same questionnaire online by going to this website: <https://greencampusafrica.questionpro.com>

Please use the details provided below to contact the research student and/or the supervisor if you have any questions.

Thank you.

Yours sincerely,

Mr. Nutifafa Geh (Research student)

Email: [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za)

Phone: .....

Prof. Fidelis Emuze (Research supervisor)

Email: [.....@cut.ac.za](mailto:.....@cut.ac.za)

Phone: .....

Attachment: *1. Questionnaire*

## QUESTIONNAIRE SURVEY:

### **Drivers of and barriers to solar photovoltaic (PV) deployment within the public university sector in South Africa**

#### **Brief about the purpose of the survey**

This survey forms part of an ongoing doctoral research project, and the purpose is to collect data to examine the drivers and barriers to deployment of solar photovoltaic within the public university sector in South Africa. To know more about the research, you may please visit the project website at: <https://greencampus.africa/phd-research/>

#### **Information and guidelines**

7. This questionnaire is to be completed by only people who are affiliated to a public university in South Africa, and are able to comment on what the drivers and barriers are to deployment of solar PV in the public university sector.
8. The term ‘*deployment*’ is used here to refer to both initial (first time) installation of solar PV (PV uptake) and the continuous installation of solar PV (PV upscale). Deployment can also be interchanged with the word ‘*adoption*’.
9. Kindly return the completed questionnaire to the student at [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za)

#### **Section A: Background information of respondents**

Please provide your answer by ticking/marking the box (i.e. ) or by typing your response.  
(If you are filling this form on a computer, click on the box to either select or de-select it)

1	Please indicate the category that best describes your status in the university.	<input type="checkbox"/> Non-academic staff (Administrative/ Support Staff) <input type="checkbox"/> Academic staff (Teaching staff) <input type="checkbox"/> Postdoctoral Fellow
2	Please indicate whether solar PV has been installed by the university where you presently work.	<input type="checkbox"/> Solar PV is installed by my university <input type="checkbox"/> Solar PV is not installed by my university <input type="checkbox"/> I don't know (I am unsure)
3	How many public universities have you worked in?	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 & more
4	What is your total years of experience in the public university sector?	<input type="checkbox"/> 1-5 yrs. <input type="checkbox"/> 6-10 yrs. <input type="checkbox"/> 11-15 yrs. <input type="checkbox"/> 16-20 yrs. <input type="checkbox"/> 21-25 yrs. <input type="checkbox"/> 26 or more
5	Please indicate your highest level of qualification.	<input type="checkbox"/> Diploma <input type="checkbox"/> First degree (BSc, BCom., BTech., etc) <input type="checkbox"/> Master's degree (MSc, MTech, MEng, etc) <input type="checkbox"/> Postgraduate Diploma <input type="checkbox"/> Doctorate Degree (PhD, DTech, DEng, etc) <input type="checkbox"/> Others (please state):

## **Section B: Drivers promoting solar photovoltaic (PV) deployment in public universities**

The items listed in the table below are believed to be *factors which drive solar PV deployment* in public universities in South Africa.

Please indicate your level of agreement regarding whether each factor drives deployment using this 5-point scale: 1=Strongly Disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly Agree

Code	Drivers	Low ←————→ High				
		1	2	3	4	5
<b>Direct benefits (DB)</b> <i>[These are benefits that universities directly enjoy for installing solar PV or will enjoy if they install solar PV]</i>						
DB1	Reduction of energy cost of university	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB2	Enhancement of university image	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB3	Boosting university sustainability performance	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB4	Contribution to attainment of Sustainable Development Goals	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB5	Use potentials for teaching students	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB6	Use potentials for practical-work opportunities for students	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
DB7	Use potentials for research opportunities for students & staff	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Indirect benefits (IB)</b> <i>[These are benefits that others/society enjoy and not directly by universities]</i>						
IB1	Reduction of energy-related greenhouse gasses	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IB2	Opportunity for staff to observe & use technology	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IB3	Opportunity for students to observe & use technology	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IB4	Opportunity for the public to observe technology	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IB5	Booting of solar PV technology demonstration	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Social influence (SI)</b> <i>[These are factors which influence the decision of universities to install solar]</i>						
SI1	Expectation from university staff	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
SI2	Expectation from society	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
SI3	Expectation from university bodies/associations	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
SI4	Demonstration projects showcasing different PV applications	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Relative advantage (RA)</b> <i>[These are advantages associated with solar PV usage]</i>						
RA1	Ease of maintaining solar PV	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
RA2	No noise pollution from PV usage	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

### Section C: Barriers inhibiting solar photovoltaic deployment in public universities

The items listed in the table below are believed to be *factors which hinder solar PV deployment* in public universities in South Africa.

Please indicate your level of agreement regarding whether each factor hinders deployment using this 5-point scale: 1=Strongly Disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly Agree

Code	Barriers	Low $\longleftrightarrow$ High				
		1	2	3	4	5
<b>Cost and funding-related barriers (CFB)</b> <i>[These are economic factors relating to PV acquisition methods]</i>						
CFB1	Long pay-back period of investment	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
CFB2	High initial cost (i.e. for outright purchase option)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
CFB3	Scarcity of favourable opportunities to acquire solar PV through power purchase agreement	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
CFB4	Scarcity of favourable opportunities to acquire solar PV through lease	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
CFB5	Lack of financial resources	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Institution-related barriers (IRB)</b> <i>[These are factors which are identified within universities]</i>						
IRB1	Lack of green building targets for university	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IRB2	Lack of reporting university energy sustainability performance	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IRB3	Lack of clear policy direction on PV deployment	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
IRB5	Prevalence of higher competing needs of universities	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
<b>Government-related barriers (GRB)</b> <i>[These are factors which are associated with government]</i>						
GRB1	Lack of incentives to adopt technology	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
GRB2	Lack of demand from government project financiers	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
GRB3	Inadequate funding for infrastructure development	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

### **Section D: Solar photovoltaic (PV) deployment activities**

The table below lists activities that universities should consider undertaking to promote solar PV deployment at their facilities.

Please indicate your level of agreement regarding these activities using this 5-point Likert scale:

1=Strongly Disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly Agree

Code	Description of activities	Low $\longleftrightarrow$ High				
		1	2	3	4	5
PVD1	Design new buildings to include solar PV installation during the time of construction	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PVD2	Design new buildings to allow for easy solar PV installation in the future if PV will not be installed during the time of construction — i.e., construct solar ready buildings	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PVD3	Design renovation projects to include solar PV installation during the time of renovation works	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PVD4	Design renovation projects to allow for easy PV installation in the future if PV will not be installed during the time of renovation works — i.e., create solar ready buildings out of existing buildings	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
PVD5	Utilise non-building attached/integrated solar PV installation options (for example, installation of PV at car-parks, ground-mounted PV installations etc.)	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

*	If you wish to receive the results of this survey later, please provide your email address.	Email:
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— **The End** —

Thank you for your valuable contribution to the study 🤝

## Appendix 7:

Date: .....

Dear Sir/Madam,

### **Invitation to participate in a survey to validate a model developed to advance the sustainability of buildings through the deployment of solar photovoltaic (PV)**

You are humbly invited to participate in a survey aimed at generating data to validate and improve a model which was developed to advance the sustainability of buildings through the deployment of solar photovoltaic (PV) in public universities in South Africa.

The research is carried out by Mr. Nutifafa Geh who is a student at Central University of Technology, Free State (CUT). The study is jointly funded by National Research Foundation (NRF) and The World Academy of Sciences (TWAS).

Your participation in this survey will help immensely in concluding the research project and we would be very glad if you can participate. The questionnaire is attached and all necessary information required to adequately complete the questionnaire is provided at the beginning pages.

If you have any questions, please use the details provided below to contact the research student and/or the supervisor.

Thank you.

Yours sincerely,

Mr. Nutifafa Geh (Research student)  
Email: [.....@stud.cut.ac.za](mailto:.....@stud.cut.ac.za)  
Phone: .....

Prof. Fidelis Emuze (Research supervisor)  
Email: [.....@cut.ac.za](mailto:.....@cut.ac.za)  
Phone: .....

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Attachment:

*1. Questionnaire*

## **MODEL VALIDATION SURVEY:**

### **Validation of model to advance the sustainability of buildings through the deployment of solar photovoltaics (PVs) in public universities in South Africa**

#### **SECTION A:**

##### **1. Purpose of this survey**

This survey forms part of an ongoing research project and the purpose is to collect data to validate and improve the model developed to advance the sustainability of buildings through the deployment of solar photovoltaics (PV) in public universities in South Africa.

##### **2. Research project brief**

The research project was segmented into different phases: (1) an extensive literature review was conducted, (2) a questionnaire survey was carried out to determine the level of deployment of solar PV on university campuses, (3) a semi-structured interviews ( $n=7$ ) was conducted to solicit the opinion of selected experts, (4) a 3-round Delphi study ( $n=18$ ) involving staff from 11 public universities was executed to identify the drivers and barriers that were applicable in the public university sector in South Africa (see Table 1), and (5) a questionnaire survey ( $n=61$ ) was executed to generate a larger dataset to quantitatively examine the influence of the drivers and barriers on solar PV deployment. Several (16) universities participated in the survey and the data were analysed using Partial Least Square-Structural Equation Modelling (PLS-SEM) approach. SmartPLS software was used.

To know more about the research project, kindly visit the project website at:

<https://greencampus.africa/research/>

##### **3. Model to advance building sustainability through solar PV use**

The development of the model was founded on the final structural equation models that were derived after the PLS-SEM analysis. The PLS-SEM results for the drivers and barriers are presented in Figures 1 and 2 respectively (the codes for the measurement items in the models are provided in Table 1).

The model was developed to contribute to the body of knowledge through significant issues that should be addressed to help improve the sustainability of building using solar PV in public universities. First, it aims to re-enforce the significant factors that drive the installation of the technology (i.e., the drivers), and second, to ameliorate the factors that hinder deployment of PV (i.e., the barriers).

##### **3.1 Drivers: Structural model & recommended actions**

According to the PLS-SEM results (Fig. 1), it was only “*Direct benefits (DB)*” that had a significant positive influence on PV deployment (level of significance at  $p<0.001$ ). The remaining constructs were not found to have a significant influence on deployment.

To further engender deployment, there is the need to re-enforce the factors that already drive the adoption of the technology. For this reason, three major actions are recommended and these are labelled as “*Re-enforcing enablers (Direct benefits)*” in Figure 3. The recommended actions can be implemented by the universities, including external stakeholders such as the civil society (see Figure 3 for details). For example, award schemes can be instituted to reward and recognise

universities that are greening their campuses through PV deployment. Also, universities that are early adopters and benefiting from the technology can share data to encourage other universities and the public to make a decision to adopt.

### **3.2 Barriers: Structural model & recommended actions**

According to the PLS-SEM results (Table 2 & Fig. 2), it was only “*Government-related barriers (GRB)*” that had a significant negative influence on PV deployment (level of significance at  $p < 0.5$ ). The remaining two constructs, which are “*Cost & funding-related barriers (CFB)*” and “*Institution-related barriers (IRB)*” did not have a significant influence on deployment. No measurement item was deleted under “*Government-related barriers*” but items CFB4 and IRB4 were deleted for the other constructs because the respective factor loadings were lower than 0.50.

In order to reduce and eliminate the “*Government-related barriers*” which were identified to be significant negative influences on PV deployment, four actions are recommended to help address the above barriers. This is labelled as “*Government-related enablers*” in Figure 3. The proposed actions entail the provision of incentives and the need for project financiers to ensure that building projects make provision for incorporation of PV. It is also suggested that PV special funds should be made available to universities to install PV, and also special renewable energy procurement models should be developed for the university sector.

### **3.4 Deployment of solar PV**

The model categorised the deployment of PV into Type A and Type B: Type A has to do with the deployment of PV immediately at the time of new construction or renovation works, while Type B is the installation of PV at a later time, but installing all requisite elements and providing all necessary spaces/amenities at the time of construction/renovation to aid easy installation of PV later—i.e., adopting the concept called ‘solar ready buildings’. By installing PVs, it is envisaged that it will contribute in part to enhancement of sustainability of buildings in public universities.

### **Guidelines on completing questionnaire**

**10. Please review Table 1-3 and Figures 1–3, especially Figure 3 which is the proposed model, and answer the questions presented in Section A & B below (Page 5 & 6).**

11. Kindly return the completed questionnaire via email to [219000670@stud.cut.ac.za](mailto:219000670@stud.cut.ac.za)

**Table 1: Constructs and measurement items**

<b><u>DRIVERS:</u></b>		
<b>Construct</b>	<b>Code</b>	<b>Measurement Items</b>
<b>Direct Benefits (DB)</b>	DB_1	Reduction of energy cost of university
	DB_2	Enhancement of university image
	DB_3	Boosting university sustainability performance
	DB_4	Contribution to attainment of Sustainable Development Goals
	DB_5	Use potentials for teaching students
	DB_6	Use potentials for practical-work opportunities for students
	DB_7	Use potentials for research opportunities for students & staff
<b>Indirect Benefits (IB)</b>	IB_1	Reduction of energy-related greenhouse gasses
	IB_2	Opportunity for staff to observe & use technology
	IB_3	Opportunity for students to observe & use technology
	IB_4	Opportunity for the public to observe technology
	IB_5	Booting of solar PV technology demonstration

<b>Social influence (SI)</b>	SI_1	Expectation from university staff
	SI_2	Expectation from society
	SI_3	Expectation from university bodies/associations
	SI_4	Demonstration projects showcasing different PV applications
<b>Relative advantage (RA)</b>	RA_1	Ease of maintaining solar PV
	RA_2	No noise pollution from PV usage

### **BARRIERS:**

<b>Cost &amp; funding-related barriers (CFB)</b>	CFB_1	Long pay-back period of investment
	CFB_2	High initial cost (i.e. for outright purchase option)
	CFB_3	Scarcity of favourable opportunities to acquire solar PV through power purchase agreement
	CFB_4	Scarcity of favourable opportunities to acquire solar PV through lease
	CFB_5	Lack of financial resources
<b>Institution-related barriers (IRB)</b>	IRB_1	Lack of green building targets for university
	IRB_2	Lack of reporting university energy sustainability performance
	IRB_3	Lack of clear policy direction on PV deployment
	IRB_4	Prevalence of higher competing needs of universities
<b>Government-related barriers (GRB)</b>	GRB_1	Lack of incentives to adopt technology
	GRB_2	Lack of demand from government project financiers
	GRB_3	Inadequate funding for infrastructure development

### **DEPLOYMENT:**

<b>PV Deployment (PVD)</b>	PVD_1	Design new buildings to include solar PV installation during the time of construction
	PVD_2	Design new buildings to allow for easy solar PV installation in the future if PV will not be installed during the time of construction—i.e., construct solar ready buildings
	PVD_3	Design renovation projects to include solar PV installation during the time of renovation works
	PVD_4	Design renovation projects to allow for easy PV installation in the future if PV will not be installed during the time of renovation works—i.e., create solar ready buildings out of existing buildings
	PVD_5	Utilise non-building attached/integrated solar PV installation options (for example, installation of PV at car-parks, ground-mounted PV installations etc.)

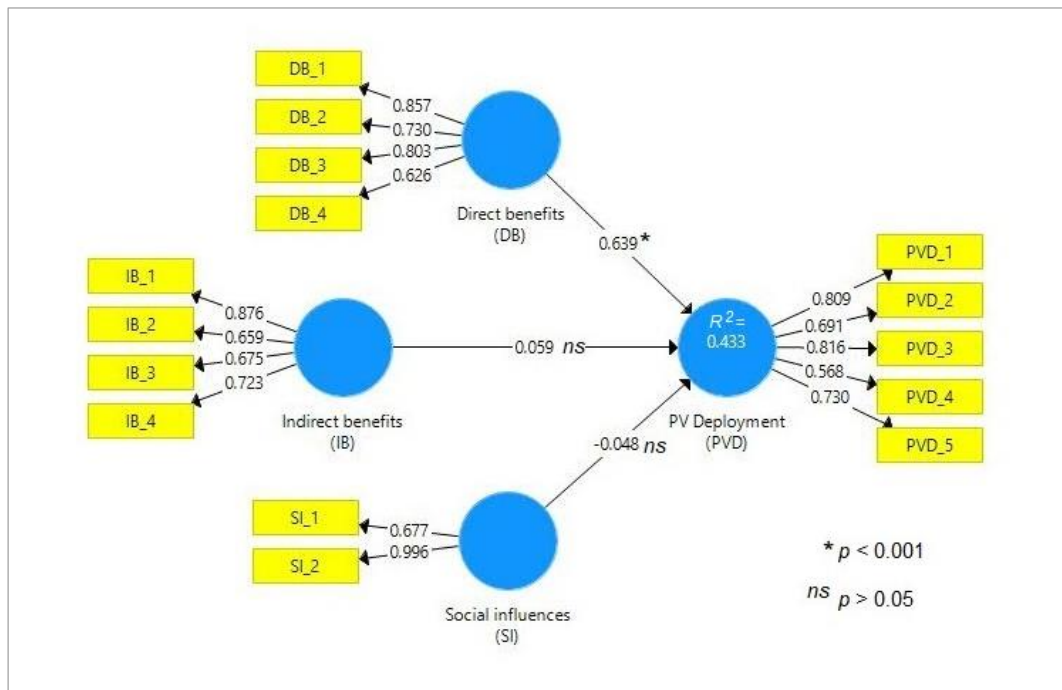
**Table 2: Structural model results—Drivers model**

<b>Relationship</b>	<b>Path coefficient</b>	<b>T Value</b>	<b>P Values</b>	<b>Interpretation</b>
Direct Benefits -> PV Deployment	0.639	6.135	0.000	Supported
Indirect Benefits -> PV Deployment	0.059	0.372	0.710	Not supported
Social Influences -> PV Deployment	-0.048	0.397	0.692	Not supported

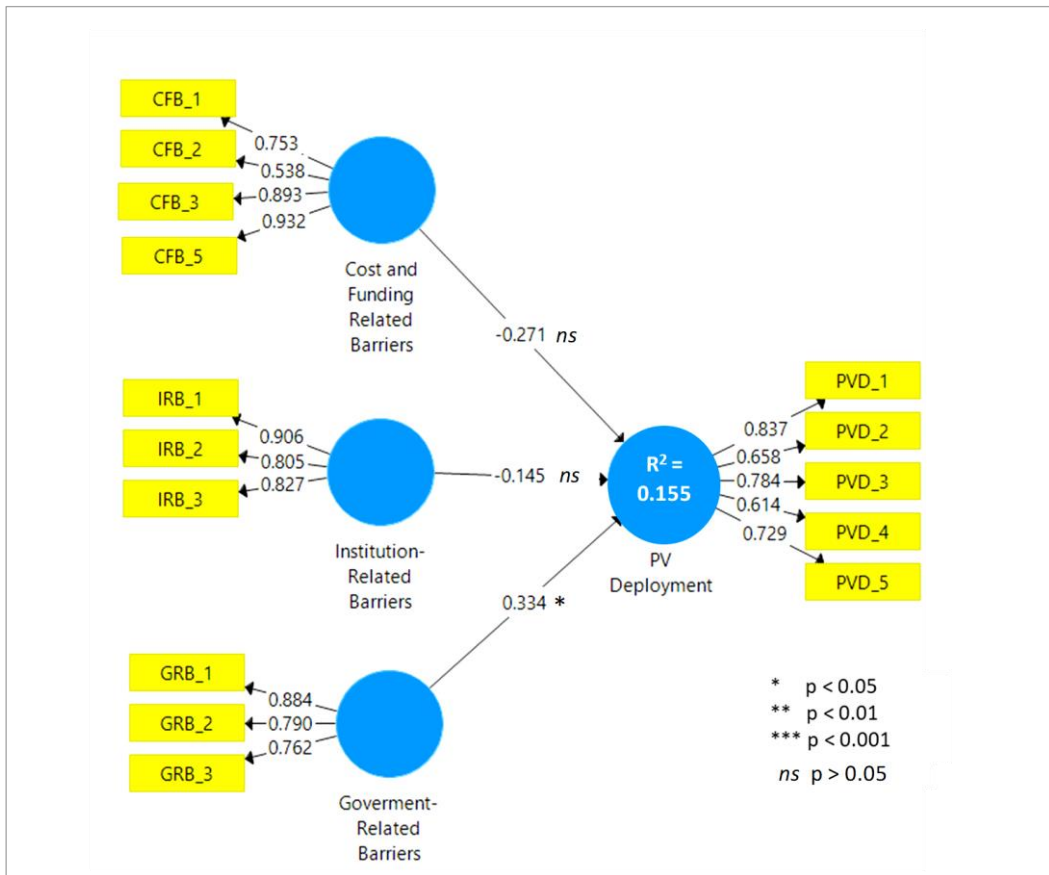
**Table 3: Structural model results—Barriers model**

Relationship	Path coefficient	T Value	P Values	Interpretation
Cost & funding-related barriers -> PV deployment	-0.271	1.347	0.178	Not supported
Government-related barriers -> PV deployment	0.334	2.423	0.015	Supported
Institution-related barriers -> PV Deployment	-0.145	0.797	0.425	Not supported

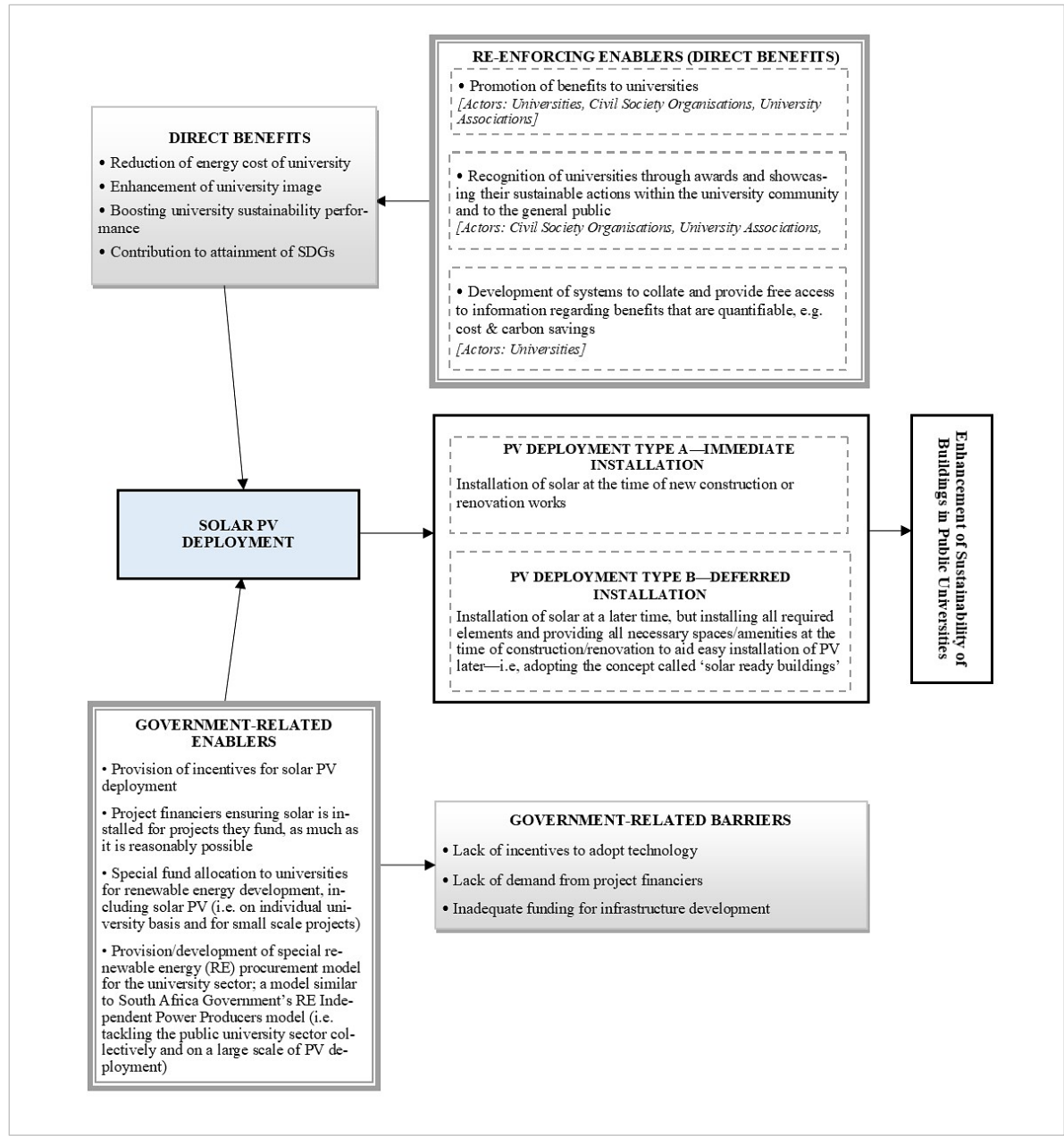
**Structural Equation Models**



**Figure 1. Final structural equation model of drivers influencing solar PV deployment**



**Figure 2. Final structural equation model of barriers influencing solar PV deployment**



**Figure 3. Proposed Model for Advancing Sustainability of Buildings**

### Section B: Background information

Please provide your answer by ticking/marking the box (i.e. ) or by typing your response.  
(If you are filling this form on a computer, click on the box to either select or de-select it)

1	Please indicate the category that best fits you	<input type="checkbox"/> I am non-academic staff (Administrative/ Support Staff, etc.) <input type="checkbox"/> I am academic staff (Teaching staff) <input type="checkbox"/> I work in industry
2	Total years of working experience	<input type="checkbox"/> 1-5 yrs. <input type="checkbox"/> 6-10 yrs. <input type="checkbox"/> 11-15 yrs. <input type="checkbox"/> 16-20 yrs. <input type="checkbox"/> 21-25 yrs. <input type="checkbox"/> 26 or more

3	Age	<input type="checkbox"/> 20-30 yrs. <input type="checkbox"/> 31-40 yrs. <input type="checkbox"/> 41-50 yrs. <input type="checkbox"/> 51-60 yrs. <input type="checkbox"/> 61-70 yrs. <input type="checkbox"/> 71 or more
4	Please indicate your highest level of qualification	<input type="checkbox"/> Diploma <input type="checkbox"/> First degree (BSc, BCom, BTech, etc) <input type="checkbox"/> Postgraduate Diploma <input type="checkbox"/> Master's degree (MSc, MTech, MEng, etc) <input type="checkbox"/> Doctorate Degree (PhD, DTech, DEng, etc) <input type="checkbox"/> Others (please state):

### Section C: Model validation

With particular reference to the proposed model presented in Figure 3, please indicate your level of agreement regarding the statements below. Use this scale:

1=Strongly Disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly Agree

No	Description of activities	Low $\longleftrightarrow$ High				
		1	2	3	4	5
1	The drivers and barriers identified as significant influencers of solar PV deployment are reasonable	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
2	The actions proposed to tackle the barriers and augment the drivers are appropriate	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
3	The proposed actions are comprehensive	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
4	The model is easily understandable and can be used by stakeholders	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
5	The structure and relationships among all the constructs in the model are organised appropriately	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5
6	The appropriate use of the model would certainly help advance sustainability of buildings through the deployment of solar PV	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> 4	<input type="checkbox"/> 5

### Section C: Suggestion/recommendations

*	Please provide any general comments and suggestions that could help improve the proposed model	
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— **The End** —

Thank you very much for contributing to the study 