DEVELOPMENT OF A GIS-BASED DECISION SUPPORT TOOL FOR ENVIRONMENTAL IMPACT ASSESSMENT AND DUE-DILIGENCE ANALYSES OF PLANNED AGRICULTURAL FLOATING SOLAR SYSTEMS

by

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Abstract

In recent years, there have been tremendous advances in information technology, robotics, communication technology, nanotechnology, and artificial intelligence, resulting in the merging of physical, digital, and biological worlds that have come to be known as the "fourth industrial revolution". In this context, the present study engages such technology in the green economy and to tackle the techno-economic environmental impact assessments challenges associated with floating solar system applications in the agricultural sector of South Africa. In response, this exploratory study aimed to examine the development of a Geographical Information System (GIS)-based support platform for Environmental Impact Assessment (EIA) and due-diligence analyses for future planned agricultural floating solar systems, especially with the goal to address the vast differences between the environmental impacts for land-based and water-based photovoltaic energy systems.

A research gap was identified in the planning processes for implementing floating solar systems in South Africa's agricultural sector. This inspired the development of a novel GIS-based modelling tool to assist with floating solar system type energy infrastructure planning in the renewable energy discourse. In this context, there are significant challenges and future research avenues for technical and environmental performance modelling in the new sustainable energy transformation. The present dissertation and geographical research ventured into the conceptualisation, designing and development of a software GIS-based decision support tool to assist environmental impact practitioners, project owners and landscape architects to perform environmental scoping and environmental due-diligence analysis for planned floating solar systems in the local agricultural sector.

In terms of the aims and objectives of the research, this project aims at the design and development of a dedicated GIS toolset to determine the environmental feasibility around the use of floating solar systems in agricultural applications in South Africa. In this context, the research objectives of this study included the use of computational modelling and simulation techniques to theoretically determine the energy yield predictions and computing environmental impacts/offsets for future planned agricultural floating solar systems in South Africa. The toolset succeeded in determining these aspects in applications where floating solar systems would substitute Eskom grid power. The study succeeded in developing a digital GIS-based computer simulation model for floating solar systems capable of (a) predicting the anticipated energy yield, (b) calculating the environmental offsets achieved by substituting coal-fired generation by floating solar panels, (c) determining the environmental impact and land-use preservation benefits of any floating solar system, and (d) relating these metrics to water-energy-land-food (WELF) nexus parameters suitable for user project viability analysis and decision support.

The research project has demonstrated how the proposed GIS toolset supports the body of geographical knowledge in the fields of Energy and Environmental Geography. The new toolset, called *EIAcloudGIS*, was developed to assist in solving challenges around energy and environmental sustainability analysis when planning new floating solar installations on farms in South Africa. Experiments conducted during the research showed how the geographical study in general, and the toolset in particular, succeeded in solving a real-world problem. Through the formulation and development of GIS-based computer simulation models embedded into GIS layers, this new tool practically supports the National Environmental Management Act (NEMA Act No. 107 of 1998), and in particular, associated EIA processes. The tool also simplifies and semi-automates certain aspects of environmental impact analysis processes for newly envisioned and planned floating solar installations in South Africa.

KEY TERMS:
Data Science; Knowledge economy; Energy Geography; Environmental Geography; Sustainable development; Floating solar systems; Solar energy technology; Design thinking; Decision support system; Geographic information systems; Virtual reality landscape; Environmental impact assessment; Environmental offsets; Due-diligence analysis; Fourth Industrial Revolution; Agricultural systems; Precision farming; Digital technology; Innovation system research

Nomenclature

Abbreviations and Acronyms

AIR	Application Information Requirements
APP	Mobile Phone Application
ArcGIS	GIS system developed by ESRI
CDM	Clean Development Mechanism
CEF	Carbon Emission Factor
CER	Certified Emission Reduction
CFT	Carbon Footprinting Tool
CMS	Computer Modelling and Simulation
CPV	Concentrated Photovoltaic
DDA	Due Diligence Analysis
DER	Distributed Energy Resource
DES	Discrete Event Systems
DG	Distributed Generation
DNI	Direct Normal Irradiation
DHI	Diffuse Horizontal Irradiation
DSS	Decision Support System
EA	Environmental Approvals
EAP	Environmental Assessment Practitioner
EAR	Environmental Application Review
EIM	Environmental Impact Model
EGIS	Environmental GIS platform
EIA	Environmental Impact Assessment
EMPr	Environmental Management Program
EIAR	EIA Report
ESR	Environmental Scoping Report
ESS	Environmental Scoping Study
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiation
GIS	Geographical Information System
GPS	Global Positioning System
ICT	Information Communication Technology
KML	Keyhole Markup Language
LSA	Liquid Solar Array
NCV	Net Calorific Values
NEG	non-Eskom Generator
NEMA	National Environmental Management Act
NEPA	National Environmental Policy Act
PDA	Personal Digital Assistant
PDF	Portable Document Format
PV	Photovoltaic
QGIS	Quantum GIS platform
RE	Renewable Energy
RES	Renewable Energy Systems
SE4All	UN Sustainable Energy for All
SME	Subject Matter Expert
TMY	Typical Meteorological Year data
URL	Uniform Resource Locator
WELF	Water, Energy, Land, Food (nexus)
WWW	World Wide Web
WUI	Web User Interface
ZNE	Zero Net Energy

Analysis Element Abbreviations

aLP	agricultural land preserved
aPE	airborne particle emissions
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CO_x	carbon oxides
H_2O	water or dihydrogen monoxide
NO_x	nitrogen oxides
P_e	solar power
SO_x	sulphur oxides

Units of Measure

kg	kilogram
kl	kilolitre
kW	kilowatt
kWh	kilowatt hour
l	litres
MW	megawatt

MWh	megawatt hour
W	watt
Wh	watt hour

Companies, Institutions and Countries

AAG	American Association of Geographers
ASSAf	Academy of Science of South Africa
CSI	Committee on Spatial Information
CSIR	Centre for Scientific Industrial Research
DEA	Department of Environmental Affairs
DOE	Department of Energy
DST	Department of Science and Technology
EC	European Commission
ESRI	Environment Systems Research Institute
EU	European Union
ESKOM	Electricity Supply Commission
GISSA	Geo-Information Society of South Africa
GIZ	German Federal Intl Cooperation
IAIA	Intl Association of Impact Assessment
IAIAsa	Intl Association of Impact Assessment South Africa
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ISO	Intl Organisation for Standardisation
MP	Mpumalanga Province
NC	Northern Cape Province
NCPC	National Cleaner Production Centre
NDP	National Development Plan
NERSA	National Energy Regulator of South Africa
NPC	National Planning Commission
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NRF	National Research Foundation
OGC	Open Geospatial Consortium
OSGF	Open Source Geospatial Foundation
OECD	Organization for Economic Co-operation and Development
RSA	Republic of South Africa
SA	South Africa
SAEON	South African Environmental Observation Network
SARS	South African Revenue Services
SAURAN	South African Universities Radiometric Network
SADEC	Southern Africa Development Community
SI	Sustainability Institute
SNL	Sandia National Laboratory
SSAG	Society of South African Geographers
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNISA	University of South Africa
USA	United States of America
USAID	USA Agency for Intnl Development
USGS	United States Geological Society
WC	Western Cape Province
WMO	World Meteorological Organisation

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1. Introduction

This applied research study deals with the development of a GIS-based decision-supporting tool for environmental impact assessment and due-diligence analyses of future planned agricultural floating solar systems. The investigation and study are framed in the broad paradigm of sustainable development. The main research activity is the development of a GIS toolset to evaluate the environmental impacts and energy generation potential of floating solar systems through a computerised simulation research method. The toolset comprises a solar model, an energy simulation model, and an environmental simulation model. The study succeeded in developing a digital GIS-based computer simulation model for floating solar systems capable of predicting the anticipated energy yield for floating solar systems, calculating the environmental offsets achieved by substituting coal-fired generation by floating solar panels, determining the environmental impact and land-use preservation benefits of any floating solar system, and relating the above metrics to water-energy-land-food nexus parameters suitable for user project viability analysis and decision support. Three case studies of farms in the Northern Cape, Western Cape and Mpumalanga Lowveld were used to demonstrate the capabilities of the GIS toolset.

This chapter presents a background to the study in Section 1.1, detailing the potential role of floating solar system technology in the South African agricultural context. The topic of the research, detailed in Section 1.2, focus on concepts around the computer modelling of floating solar systems as a means to determine the energy performance as well as to compute the environmental impact and environmental offsets offered by a particular modelled floating solar system. The problem statement of the research, formulated in Section 1.3, defines the research gap and defines the proposed solution to address the gap with the development of a proposed GIS toolset and technology. In Section 1.4, the discussion continues with the formulation of the research questions aimed at filling the research gap, while the research aim and objectives to achieve the study goals and answer the research questions are outlines in Section 1.5. The study and the boundaries of the study area are explained in Section 1.6. The research location and scope is the focus of Section 1.7. The feasibility of the research project and the significance of the research are detailed in Section 1.8 and Section 1.9 respectively. Finally, Section 1.10 presents a brief synopsis of the structure and layout of the dissertation.

1.1. Background to the study

Environmental impact assessment practitioners in South Africa are operating in an environment where international market forces are placing increasing pressure on the agricultural sector to adopt environmentally beneficial and sustainable practices (European Commission, 2008). While environmental awareness in the food and wine sectors inspires local food and wine producers to consider the implications of their respective carbon footprints (Sirieix and Remaud, 2010), the environmental practitioner is to conduct sophisticated environmental assessments in respect of new carbon mitigation solutions (Engelbrecht *et al.*, 2015). Along with various sustainable farming and conservation agriculture practices, a range of renewable energy technology configurations presents opportunities for South Africa's agricultural sector. It can especially assist farms to reduce its carbon footprint and to strengthen its product brands according to international sustainability and quality standards (VinIntell, 2012). However, such conservation farming activities also challenges the work of the environmental practitioner to provide accurate quantitative estimations on how such proposed technology systems would impact on the environment.

Our country's energy sector is predominantly based on coal and fossil fuels, and is currently facing the challenge of finding new opportunities for reducing its carbon footprint (Eskom, 2014*b*; Herman *et al.*, 2015; Ntombela, 2019). In this context, Figure 1.1 depicts a typical hazardous gasses in terms of the international classification of greenhouse gases (EPA, 2018). Many of these hazardous gas pollutants are resulting from the combustion of coal and fossil fuel in coal-fired power stations, adverse environmental impacts for which new energy systems need to be designed to help counterbalance the negative effects of coal-based environmental degradation.

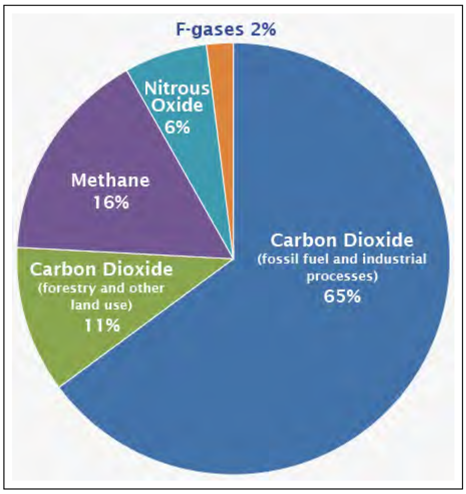


Figure 1.1: Proportional key greenhouse gases emitted by human activities on a global scale compiled by the Environmental Protection Agency in the United States (EPA, 2018), highlighting the environmental offset potential for floating solar renewable energy.

At the same time, South Africa has some of the highest levels of solar energy potential on the planet (van Niekerk, 2010). By harvesting this distributed energy resource at the point-of-delivery, the agricultural industry can reduce the carbon footprint of its establishments whilst becoming less reliant on the coal-powered national energy grid (Akorede *et al.*, 2010). This trend could have a significant environmental impact as the agriculture industry in South Africa is wide-spread and well established. Solar energy is recognised globally as a sustainable resource able to support the generation of clean electricity to the agricultural sector (Flint and Golicic, 2009; Nowak and Washburn, 2002; Virginia Tech, 2017).

In this context it becomes important to determine the air quality offsets offered by renewable energy systems (such as floating solar systems), as these systems inherently focuses on counterbalancing the adverse environmental impacts of atmospheric emissions on air quality (and consequently human health) (Department of Environmental Affairs, 2015).

From the viewpoint of an environmental assessment practitioner, it is anticipated that South African farmers will soon be considering the installation of space-saving floating solar energy systems as mitigatory solutions to reduce the carbon footprint of their farming operations. Floating solar systems (see example in Figure 1.2) offer a dual benefit to farmers in that they enable them to implement solar power generation as a sustainable agricultural practice while preserving their available farmland and utilising water bodies (dams, reservoirs, ponds, canals) more efficiently. Some farmers worldwide (America, China, South Korea, UK, Taiwan and Belgium) already introduced floating solar power systems as part of sustainable farming practices and to support the product brands for their agricultural produce (Broome and Warner, 2008; Ge *et al.*, 2017; Trapani and Santafe, 2015).

Figure 1.2: Aerial view of a typical agricultural floating solar installation layout over an farming irrigation pond (Pentland, 2011).

Predicting land-use preservation and environmental benefits for such floating solar power systems poses significant challenges to the business of the environmental assessment practitioner. It happens because the potential reduction in the carbon footprint for a planned floating solar system of any configuration must be determined scientifically for incorporation into the environmental impact assessment plans (also in the facility's long-term agricultural management plan). Incorporating such scientific evidence in a project's environmental impact assessment plans is further motivation for project viability and emphasises the addition of value offered by the project through future business branding opportunities (Akorede *et al.*, 2010; Prinsloo, 2017*a*).

Adopting sustainable and environmentally-friendly production practices in South Africa will in the future also be financially beneficial to farmers. The National Treasury made South Africa's environmental carbon tax bill effective in 2019 through the Carbon Tax Act (Act 15 of 2019) (Republic of South Africa, 2019). The Carbon Tax Act of 2019 aims to provide for the imposition of a tax on the carbon dioxide (CO_2) equivalent of greenhouse gas emissions (GHG) and to provide for matters connected therewith (Ministry of Finance, 2015; Ntombela, 2019). This new legislation offers eco-tax deduction benefits to development projects that assist in the reduction of GHG emissions. From the perspective of decentralised energy generation based on distributed energy resources, the self-generation tax incentive makes it particularly important for the environmental impact practitioner to accurately predict and report on the full scope of environmental offset benefits offered by any planned floating solar power system.

The proposed eco-taxation scheme forms part of the country's National Development Plan (NDP) and aims to achieve certified emission reductions (CER) of approximately 13-14.5% by the year 2025, and around 26-33% by the year 2035 (National Planning Commission, 2012). Internationally, carbon tax benefits relating to the reduction of carbon dioxide (CO_2) emissions, in conjunction with subsidies granted for the potential development of renewable energy and for the implementation of mechanisms to promote carbon pricing, offer attractive financial incentives to funding-planned renewable energy projects (Van de Ven, 2016). In South Africa specifically, such financial instruments offer incentives to support the agricultural sector where global warming, water scarcity, environmental awareness, and the associated market forces are placing increased pressure on production processes (Blignaut, 2017; Winkler and Marquard, 2015).

Scientific research in the field of Energy and Environmental Geography could play a significant role in supporting the agricultural sector with regard to planning, making projections, and in fostering an understanding of the entire spectrum of environmental impact factors associated with the application of renewable energy (Engelbrecht *et al.*, 2015; Wang-Helmreich and Kreibich, 2019). There is also a growing need to develop spatially-integrated Geographic Information System (GIS) models to assist project investors and farm owners with the implementation of analytical tools to assess project viability in terms of technical and economic due-diligence measures. While geomatics tools and techniques can help to assess and exemplify the value proposition of floating solar technology, computer science and data science techniques can support the process of gaining environmental approval for renewable-energy-type improvements on the farm property. From an agricultural perspective, it is especially important to identify the entire spectrum of expected environmental impacts and to assess the possible variations over time (Van Niekerk *et al.*, 2015).

New GIS planning tools and support mechanisms, therefore, need to be conceptualised and developed to overcome challenges associated with due-diligence analyses and environmental impact approvals and to assist in effectively avoiding or minimising the anticipated negative environmental impacts resulting from the application of renewable energy sources (ESRI, 2010). Since environmental scores for solar energy projects have to be determined accurately during the planning phases of a project, environmental impact assessments metrics should best be computed empirically through computer modelling and simulation projections before the project enters the environmental approval phases (Prinsloo, 2017*a*; Royal Haskoning DHV, 2015).

To this end, the present study builds on the international body of knowledge concerned with solar energy system analyses (da Silva and Branco, 2018; Hernandez *et al.*, 2014; Patton *et al.*, 2013) to design and develop novel digital analytical services for floating solar systems in local agricultural applications (Prinsloo and Lombard, 2015*c*; Prinsloo, 2017*a*). The specific aim of the applied research study is to develop a flexible GIS toolset for the digital characterisation of energy yields and environmental profiles associated with planned floating solar systems around South Africa (Prinsloo, 2017*b*). The study is novel in that it incorporates GIS-based spatial awareness and model-based design features to resolve system complexity challenges associated with practical environmental impact assessments and due-diligence procedures.

GIS systems are valuable geomatic tools for project developers and environmental assessment practitioners to use in measuring and comparing the performance of various renewable energy resources. A GIS platform is a powerful digital tool that can be used to store, maintain, distribute, extract, and analyse a variety of complex sets of geospatial data in different planning scenarios. The cyber-physical infrastructure of certain GIS platforms offer valuable processing attributes, such as geo-tagging and spatial referencing, with powerful back-end processing (DEA, 2018). It ultimately works to achieve environmental planning in agricultural landscapes by taking into account the needs of energy systems engineers and farmland developers. Since the spatial analyses associated with GIS platforms are developed to deal with the quantitative attributes and locational features, in combination with associated inter-linkages and variabilities, GIS platforms can be particularly supportive in managing natural resources and in devising effective environmental monitoring plans.

The conceptual strategy behind this study is to exploit the geospatial referencing, data analyses, and object-oriented attributes of GIS platforms (ESRI, 2017; QGIS, 2015). With the integration of solar energy into agricultural applications at ever-rising rates (Mather and Yuan, 2017; Sahu *et al.*, 2015), there is an increasing need to develop geographical tools for generating intelligent maps that report on the environmental due-diligence aspects of renewable energy systems. These maps can shed light on the design of projects from a cost-based, incentive-inspired perspective. They can also evaluate the impact of tax incentives or other financial support structures on the prospective cash flow model of a floating solar project.

1.2. Research Topic

GIS systems are valuable geomatic tools for project developers and environmental assessment practitioners to use in measuring and comparing the performance of various renewable energy resources. This study developed a flexible GIS-based toolset with spatial awareness attributes to resolve some of the challenges associated with environmental impact assessment and other due-diligence procedures applicable to floating solar systems in agricultural applications. The conceptual strategy behind this study is to exploit the geospatial referencing, data analyses, and object-oriented computer language programming and scripting attributes of GIS platforms (ESRI, 2017; Teodoro, 2018; QGIS, 2015). With the integration of solar energy into agricultural applications at ever-rising rates (Mather and Yuan, 2017; Sahu *et al.*, 2015), there is an increasing need to develop geographical tools for generating maps that focus on the environmental impacts of renewable energy systems. These maps can shed light on the design of projects from a cost-based, incentive-inspired perspective. They may also depict evaluations on the impact of tax incentives or other financial support structures on the prospective cash flow model of a floating solar project.

To achieve this goal, this study employs the capabilities of GIS computer technology to simulate the energy operation of a floating solar system, from which to determine the required environmental impact factors. Apart from predicting the anticipated energy yield, environmental impact and land-use preservation benefits of floating solar systems, the tool can calculate the environmental offsets achieved through the reduction in impacts resulting from substituting coal-fired generation by floating solar panels. The environmental offset for a floating solar system generally forms part of the environmental impact of the particular system installation (planned activity is undertaken) to counterbalance the residual impact of a prescribed activity (buying electricity) on a prescribed environmental matter (environmental pollution). The GIS-based toolset can thus determine the extent to which a floating solar system's environmental offset can achieve a conservation outcome for the impacted environmental matter. The toolset can thus help to determine the extent to which a conservation outcome is achieved by the floating solar system's environmental offset, while the system parameters can be selected, designed and managed to maintain the viability of the prescribed environmental matter. With the above-mentioned GIS tool capabilities, the study is further able to relate the energy/environmental offset and impacts metrics to water-energy-land-food (WELF) nexus parameters suitable for user project viability analysis and decision support.

An important aspect of the study is that it employs a framework for analysing environmental impacts on floating solar systems based on the water, energy, land and food (WELF) nexus concerned with sustainability (Hoff, 2011). The WELF nexus calls on the geographer to formulate and create one or more dedicated GIS layers to address challenges concerning sustainability analyses for agricultural and environmental stakeholders. The spatiotemporal parameters (location and time) are particularly important when it comes to evaluating linkages between the production resources (in this case, energy, land, water) (Smith *et al.*, 2017). Of particular interest in the present study are the differences between water-based floating photovoltaic solar systems versus land-based photovoltaic systems in terms of their environmental impacts.

1.3. Problem Statement

A research need has been identified in the field of sustainable development, in particular a gap in the field of environmental analyses associated with the planning of floating solar technology and systems in South Africa. From a geographical perspective, novel research is required to fill the gap in determining the environmental offsets and impacts of floating solar technology prior to system installation. This gap limits the ability of decision-makers (land-owners, policy-makers, practitioners) from making decisions around the implementation of new floating solar (water-based) solar renewable systems, or to compare the benefits to that of traditional land-based solar renewable energy systems.

In the context of the research gap defined above, the real-world challenge for the agricultural sector is that fertile, productive land resources are scarce, and that such land spaces/resources should preferably not be used to set up land-based renewable energy systems (Movellan, 2013). Water-based floating solar technology offers a favourable solution to environmental problems and aids in overcoming the challenges of the availability of valuable farmland (Sharp Corporation, 2008). At the same time, adopting floating solar as sustainable and environmentally-friendly energy production practice will in the future also be rewarded with tax benefits in South Africa (Ministry of Finance, 2015; Ntombela, 2019). However, environmental regulations still prescribe that this type of technology can only be installed at sites where these developments would prove technically feasible and environmentally friendly (Prinsloo and Lombard, 2015*b*). A planned floating solar project can thus only enter the EIA process following mandatory compliance to regulations that require project owners to provide scientific evidence to prove the standard environmental viability aspects of the project (S.A. Government, 1998).

From an EIA perspective on floating solar installations, the critical research challenge centres around the complexities of the environmental impacts associated with floating solar systems as one of the Application Information Requirements (AIR) in the Environmental Application Review (EAR) phase. Conventional EIA techniques developed to assess the environmental impacts for land-based solar systems do not translate well for floating solar systems (Choi, 2014). This can be attributed mainly to the fact that there are significant differences in the environmental impacts for land-based and water-based floating photovoltaic solar systems (Prinsloo, 2017*a*). The environmental interaction between a floating solar system and the underlying aquatic environment is mainly responsible for these discrepancies, which include water shadowing, cooler photovoltaic operating conditions, and land conservation benefits (Choi, 2014). In fact, floating solar technologies offer a wealth of possibilities for studying the environmental impacts and natural resource interactions for such installations on farms.

There is thus a need to develop a new geographical EIA toolset to assist in determining environmental offsets for floating solar systems as part of the process of performing environmental impact assessments dedicated to planned floating solar systems. This research proposes the development of such a toolset to assist environmental assessment practitioners and project owners in conducting environmental impact analyses for planned floating solar energy systems. Furthermore, the GIS toolset outputs, in the form of energy and environmental offset metrics, should also be suitable for application as screening factors to clarify the economic and environmental viability of a planned floatovoltaic system (Malczewski, 2004). At the same time, the proposed GIS toolset should also offer predictions for the feasibility of future solar energy harvesting projects through the implementation of floating solar installations, with due consideration being given to the results of GIS-based land-use surveys and analyses pointing to the suitability of farm sites for floating solar harvesting technologies. For such a toolset to be available on a GIS platform, it should be developed as a dynamic and flexible digital software tool that can operate in the cyber-physical domain. Ultimately, such a toolset would be dedicated to interactive climate remediation support to facilitate the transition to a low carbon-generating economy in the farming environment.

1.4. Research Question

The primary research question in this study is: Would GIS offer an effective way to develop a geographical tool with technical computational modelling and spatial-awareness (location sensitive) capabilities for studying the environmental impact implications of floating solar systems in South Africa from a theoretical perspective?

Forthcoming from the research question above, this geographical research addresses the following sub-questions:

- what are the most effective way to develop a geographical toolset to theoretically predict the extent of environmental impact of an agricultural floating solar system at any location in South Africa?
- to what extent can underlying theoretical principles from the field of environmental geography be used to determine the environmental impact of a floating solar system in relation to Eskom grid power substitution parameters in a predictive manner?

- how can theoretically-predicted environmental impacts of floating solar systems be expressed in terms of water, energy, land-use and food interactions associated with the WELF nexus?
- how can a GIS tool present the energy yield and environmental impacts for floating solar systems in a format suitable for decision support?

1.5. Research Aim and Objectives

This research aims to develop a dedicated GIS toolset to determine the environmental feasibility of using floating solar systems in agricultural applications in South Africa.

The research objectives of this study are:

1. to develop a GIS-based toolset for predicting the energy yields of agricultural floating solar systems in South Africa.
2. to use theoretical computer-modelling techniques in a GIS-based toolset to determine the environmental offsets and environmental impacts of agricultural floating solar systems in South Africa.
3. to demonstrate the anticipated differences in environmental impacts associated with a floating solar energy system as opposed to those issuing from Eskom grid power.
4. to theoretically predict the anticipated energy yield, environmental impact and land-use preservation benefits of a floating solar system in terms of the WELF nexus parameters.
5. to demonstrate the ability of a GIS-based solar analytical toolset in a decision-supporting application of a floating solar system.

The research aims and objectives are expressed through the development of a geographical tool on a GIS platform that will be able to provide information for answering the above-mentioned research questions.

1.6. Theoretical Paradigm and Study Area

The Department of Environmental Affairs (DEA) in South Africa is working with the Committee on Spatial Information (CSI), as well as the broader GIS community in the country, to define environmental data, applications, policies, systems, architectures, standards and processes to ensure a fully-integrated and effective spatial data infrastructure for the country (DEA, 2018). Furthermore, the DEA has established the South African Environment Geographic Information System (EGIS) to provide universal countrywide access to these baseline geospatial services to geo-data users though the EGIS topograpic map interface displayed in Figure 1.3.

According to the research area of this study, the DEA further promotes the development of custom designed geographical systems tools to interface directly with the EGIS platform (DEA, 2018). As floating solar photovoltaic systems are emerging as a new technology for the agricultural sector (Sahu *et al.*, 2015), there is an increased need to develop GIS-based analytical tools for floating solar-type EIA studies. From a strategic decision-making perspective, these analytical tools should directly interface with the DEA's EGIS platform to perform associated EIA studies. By then logging onto the EGIS interface (illustrated in

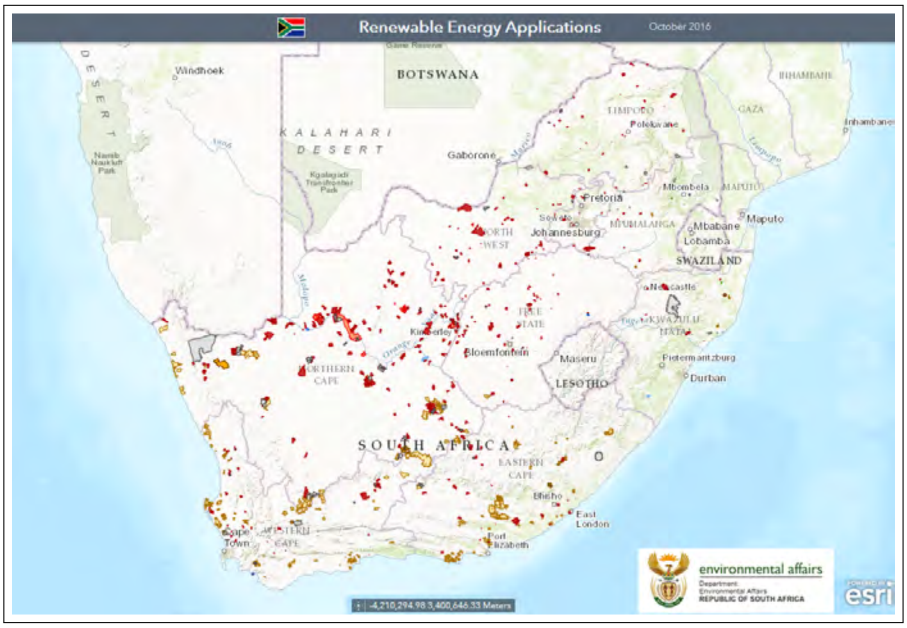


Figure 1.3: South Africa as study area for the present study in relation to the South African Renewable Energy EIA Application Database on the EGIS platform display (DEA, 2018).

Figure 1.3), floating solar-planning applications can be submitted online for environmental approval on the EGIS platform. In this way, geographers can develop custom-designed GIS software objects to aid EIA studies through the EGIS platform.

The present study thus supports online EIA submissions to the DEA and will assist in determining/evaluating compliance with South African EIA legislation and regulations (Government Gazette, 2014). In the present study, the real world model refers to the energy and environmental modelling aspects of a floating solar power system installed over a water body on a farm. Within this GIS context, the theoretical paradigm of computer-modelling and -simulation (CMS) models can be applied as embedded GIS objects in object-oriented GIS platforms. Figure 1.4 thus offers a conceptual illustration on how computer modelling and simulation can extend the scientific research method through the representation of a real-time system through a computational mathematical model that represents the real-life physical model (Donatelli, 2008).

In a layered GIS platform tool context as associated with Figure 1.4, the use of CMS in any of the GIS platform layers calls for the development of digital computational models to emulate real-life environmental impact situations through computer simulation models. These models/objects must have the ability to generate quantitative data that reflect the real-time situation and can often be even more realistic than real-time experiments. The computer simulation process further enables the researcher the freedom to configure the model parameters to best fit the operational application for a specific floating solar technology, location or systems configuration (Redón Santafé *et al.*, 2014).

Within the context of the present study, the EGIS system in Figure 1.3 further represents the demarcated study area within the borders of South Africa. Within these boundaries, the GIS tool proposed in this study incorporates underlying theoretical paradigms from environmental Geography, to study environmental due diligence for floating solar systems (Noel *et al.*, 2009). A proposed set of WELF nexus decision metrics will assist project owners

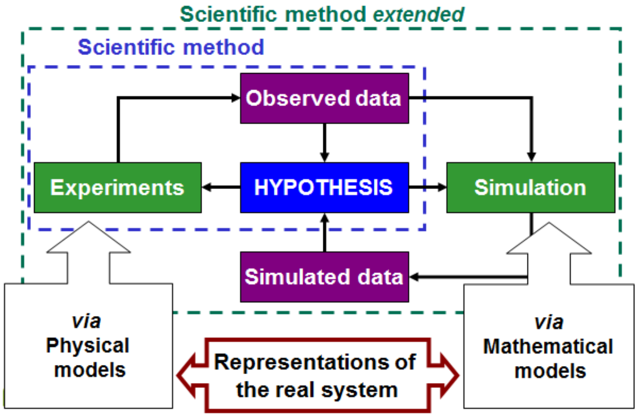


Figure 1.4: Conceptual illustration of computer modelling and simulation suitable for application to a layered GIS (Donatelli, 2008).

to make sense of the complexities around energy and environmental impacts of floating solar systems in agricultural applications. In this way, the GIS tool will further guide environmental assessment practitioners within the context of floating solar platforms to address broader geographical challenges raised by environmental degradation owing to growing energy usage (Noel *et al.*, 2009).

1.7. Research Location and Scope

The desktop GIS toolset for the EIA analysis of floating solar systems proposed in this study would serve to encourage sustainable agriculture within South Africa by offering predictive environmental analyses for planned floatovoltaic systems. The development of this GIS-toolset entails the development of a geographical simulation model with supporting methodological and analytical techniques to predict the environmental impacts for a hypothetically-planned floating solar system through computer-modelling and -synthesis techniques (Prinsloo, 2017*a*). The coverage area for the DEA's EGIS system defines the perimeter within which the proposed digital GIS-based environmental analysis toolset will be able to perform predictive floating solar energy and environmental analyses.

Technically, the scope for the development of the proposed GIS-toolset for a predictive simulation analysis of the environmental performance for planned floating solar energy systems is restricted to the following research activities:

(a) preparing a GIS interface for the environmental assessment practitioner to introduce the geographical location coordinates for a planned static floatovoltaic installation;

(b) preparing a GIS software code to acquire *solar model* input parameters, namely Typical Meteorological Year Data data (TMY), predictive Direct Normal Irradiance (DNI) and statistical weather data for that location;

(c) developing a computer software code to model and predict *floatovoltaic model* outputs/parameters (P_e) from a virtual simulation model of a planned static floatovoltaic system/location, and

(d) preparing a GIS software simulation code to model and predict the *environmental model* outputs in relation to the relevant greenhouse gas compounds, including carbon oxides (CO_x), sulphur oxides (SO_x), nitrogen oxides (NO_x), and airborne particle emissions (aPE).

In the study context, particulate matter pollution (aPE) can be defined as the total amount of suspended particulate matter in the atmosphere present as a mixture of liquid droplets or solid particles (including coal dust) in the air (Satein, 2009). The *Environmental model* metrics for WELF-nexus-related parameters for the planned floatovoltaic system, including energy generated (P_e in kW), water preserved (H_2O in litres) and agricultural land preserved (aLP in m^2), will be computed in terms of the Eskom's grid substitution model.

The study does recognise and anticipate that there may be better scope for the installation floating solar devices in areas where the cultivation intensity is much higher and where there are dams with water which can be used for floating solar system panels. The application of floating solar systems would thus be better suited in areas where water is commonly used for storage in agricultural practices or where water bodies are more available than land to place the photovoltaic units (such as the wine-growing region of the Western Cape and other similar parts of South Africa). It is also contemplated that the technology could be more suitable (the proposed GIS tool of more value) for analysis in areas where there are lagoons on the coast or where enclosed seawater is calm enough to allow for solar panels to be floated without damage. In areas where there are far too much of a water shortage to create ponds on which to float the photovoltaic units, the development strategy should rather be to consider the more traditional land-based photovoltaic installations, which can be erected on land with very poor grazing potential.

1.8. Research Project Feasibility

The development of the proposed GIS toolset is feasible in that it allows for the application of theoretical principles using desktop environmental programmes to create executable computer-object models in the field of environmental geography. In this way, predictions pertaining to the simulation and analysis of floating solar installations can be made. Promising results were obtained in a very basic preliminary investigation, where the author developed an entry-level computer model for predictive analytical simulations aimed at studying the anticipated environmental impacts for planned floating solar systems on wine farms in the Western Cape (Prinsloo and Lombard, 2015*a*).

This entry-level floating solar analysis model was originally developed on the Transient System Simulation Tool (TrnSys) platform, with the computer model reflecting the components of the floating solar energy and environmental systems in a simulated environment (University of Wisconsin-Madison, 2009). By extending these energy and environmental simulations into the GIS field through a flexible GIS toolset, it will also be possible to raise the value of these simulations and make environmental proposals that would enable environmental assessment practitioners to predict and study the environmental impact effects for any future planned floating solar system at any farming location in South Africa.

In the newly-proposed and developed GIS toolset, the floating solar analysis system was produced on a web-based GIS platform and fitted with an EAP interface that enables the user to design the floating solar system layout graphically. The energy and environmental simulation models were embedded onto a GIS platform, with custom developed Python software simulation models that run as a computer or mobile application on a GIS platform. Python software modules promote better compatibility for the GIS platform environment and can use plug-ins on either proprietary or open-source GIS platforms. Instead of using the TrnSys simulation platform, the set of newly-developed object-orientated software simulation models that have been re-developed as GIS enabled Python software models (Enthought, 2017) will be used. Since the toolset predicts the environmental impact for floating solar systems as Eskom grid energy substitution as well as WELF nexus parameters, the redevelopment of the simulation model and settings were also closely aligned to the evaluation criteria metrics for NEMA related EIA and scoping exercises (Government Gazette, 2014). Finally, the newly proposed GIS toolset models engage global positioning system (GPS) coordinates when simulating energy-output and environmental impacts. The aim of this location sensitive strategy was for the toolset to enable environmental assessment practitioners to predict the energy yield and environmental profiles for future planned floating solar systems at any GPS location in South Africa.

The proposed tool development and experimental study highlight the fact that environmental suitability analysis for floating solar systems is an inter-disciplinary research approach, enabled by the GIS workbench in an integrated development environment. The proposed GIS-based decision-supporting tool will eventually be able to conduct predictive EIA analyses for the future through a desktop or web-based GIS platform, with underlying collective energy/environmental models synthesising floating solar data for local EIA scenarios. As regards data collection, the computer simulation objects will be able to interface with other GIS layers to access statistical solar and weather forecast data from the Meteonorm or SolarGIS platforms (Meteonorm, 2016; SolarGIS, 2018). Furthermore, these locationally-sensitive weather and climatic TMY databases can support projects evaluated through GIS-based predictive analytical capabilities. With such data interfaces, the integrated GIS toolset will be able to determine the anticipated environmental-impact parameters for any planned floating solar system at any location in South Africa.

A crucial aspect of the present research is for these predictive simulation models to be GIS-enabled in order for them to be feasible propositions for future applications. The afore-mentioned are supported by the development of object-oriented computer-simulation modules integrating geographical information systems (GIS). The development of the proposed GIS toolset will thus make it possible for the operation of the floating solar and EIA due-diligence modules to be simulated within the GIS environment, thus facilitating planning for the future. GIS systems offer a broad spectrum of opportunities to determine the environmental impacts of floating solar installations as distinguished from environmental information gathered through computer simulation models embedded in the GIS platform. The environmental impacts of floating solar systems are modelled on the Eskom environmental impact framework for the South African power generation scenario (Eskom, 2014*b*). This model will help to empirically compute the environmental impacts resulting from the consumption of coal, water and other resources used by Eskom in the generation of grid electricity (Prinsloo and Lombard, 2015*c*). The environmental outputs of a floating solar installation are communicated to a new GIS layer, where future applications will make it possible to process and display the energy-/environmental-output parameters of the GIS-toolset.

1.9. Significance of Research

The first aspect that highlights the significance of this research revolves around mandatory legislative requirements. In this respect, the context of environmental legislation in South Africa, discussed in the literature review (Section 2.4), serves as context (Government Gazette, 2014). It highlights the importance of the current research and the GIS toolset in helping to meet rigorous legal EIA requirements, particularly in providing inputs of knowledge and information from experts, and scientifically-based evidence concerning the environment (see the detailed flow diagram of the EIA process in Figure 2.1). As a mandatory legal requirement (for this process), an actual floating solar power installation may only start to perform once the proposal for it has successfully passed the EIA application review phase. Only then will an authorised environmental assessment certificate be issued for the commencement of its actual installation (Government Gazette, 2010). The proposed GIS toolset thus enables the environmental assessment practitioner to meet future Application Information Requirements (AIR) in preparation for the Environmental Application Review (EAR) phase of the EIA process. A GIS toolset generally supports the sustainability assessment, where evidence confirming the environmental viability of a planned floating solar project is a pre-requisite for Sector Guidelines for Environmental Impact Assessment Regulations (Government Gazette, 2010).

From a geographical perspective, the significance of this research is regarded as a quest to develop and extend knowledge. In this respect, this planned research contributes to the concept of *geo-energy space* as a key to supporting the underlying theoretical (EIA) construct (Mañé-Estrada, 2006). This concept has inspired many GIS platform developers to develop predictive analytics and to present mechanisms to support the exploitation and conversion of renewable resources (ESRI, 2010). In the light of the complex nature and interplay of solar energy conversions and environmental impacts of floatovoltaic systems, the geo-energy space concept has become a novel geographical idea to strengthen policies and positions concerning renewable energy and the environment within particular regions (Casillas and Kammen, 2012; Mañé-Estrada, 2006). As the proposed GIS toolset will form the basis for an investigation into spatial and territorial domains, it plays directly into the conceptual geo-energy space construct of renewable and other energy flows within the environmental context (Mañé-Estrada, 2006). Strategically, therefore, geographical aspects of the geo-energy space support environmental impact assessment research. The currently proposed GIS toolset establishes an underlying foundation to support regional floating solar renewable projects down to the farming level (Zoeclein, 2008), including agricultural expansion projects based on the application of sustainable energy.

From a project-specific environmental assessment perspective, this research project offers significant proposals for the future in that the information gleaned from experts and their suggested guidelines are programmed into the GIS layers. Without such guidance, most role players would be unable to fully quantify the full range of environmental benefits emanating from a floating solar system, and would, as such, not be able to make projections into the future. This can be explained with regard to the various beneficial interconnections between the WELF nexus factors. In floating solar systems analysis, this would be missed if the environmental impact differences between land-based photovoltaic solar systems and water-based floating photovoltaic solar systems are not given the proper consideration that they deserve. The alternative would be to acquire the services of a professional expert in the EIA marketplace, such as a geographer or an environmental engineer, who will be in a position to evaluate the design and suggest equivalent scientific inputs.

To overcome this challenge, the proposed GIS toolset programmes all the relevant information from experts on subject matter relevant to floating solar installations into the GIS platform layers. Such inputs would allow for the presentation of a predictive analytical solution in the form of a full EIA value chain about floating solar installations. Thus environmental assessment practitioners and project owners would be given the opportunity to make sense of the complexities around the energy yield projections and environmental impacts of floating solar systems.

1.10. Dissertation Layout

This dissertation, sub-divided into five chapters, is set out as follows. Chapter 1 embodies an introduction to the dissertation and a statement of the research topic, posing the research questions and outlining the scope of the research, with the focus being on environmental analysis aspects. Chapter 2 presents a literature review: It includes information on geographic information systems, environmental impact assessment considerations and floating solar technology systems. A detailed methodology on the manner in which the energy and environmental simulation objects are integrated into a GIS platform, and how the research project is constructed and conducted, is presented in Chapter 3. This chapter also details the underlying energy and environmental models that constitute the proposed GIS toolset. Chapter 4 details the experimental results: The GIS toolset is used to determine and map the energy and environmental profiling characteristics for floating solar systems in the agricultural sector using the three case study areas. The research conclusions are summarised in Chapter 5, the objectives revisited, and are followed by an outline for future research.

2. Literature Review

2.1. Introduction

The literature review describes existing research literature within the context of the research gap identified in the Problem Statement (Chapter 1, Section 1.3). The first part of the literature review describes previous studies and existing research on energy and environmental analyses in solar energy systems. It provides a broad analysis of the critical issues towards developing a customised GIS-based carbon management tool for floating solar systems in the South African context. The second part of the review provides an overview of available GIS technologies to address the research gap from a geographical context perspective. In the third section of the review focuses on floating solar system research, unpacking relevant sources of literature concerning the impact that such systems might have on the energy balance prevailing in the agricultural sector, and the associated environmental impacts. In the fourth section, the review deals with the implications of the associated carbon footprint and improvements in water quality, as well as in the conservation of water resources. The fifth section proposes the use of WELF nexus parameters to address the research gap in the study in determining environmental offsets/effects of floating solar systems.

2.2. Previous Studies and Existing Technology

The main research activity centres around the development of a toolset to evaluate the environmental impacts and energy generation potential of floating solar systems. In terms of existing research, most of the systems available focus on land-based photovoltaic systems, which techniques do not sufficiently highlight the broad set of environmental offset benefits offered by the new trends in floating solar technology systems.

The System Advisor Model (SAM) developed at NREL and Sandia National Laboratories is an energy system decision support system that includes performance models for several of solar energy technologies (Gilman, 2018). The solution includes some GIS capabilities and offers a good model to study in the present context of decision support informatics research, The SAM model includes performance analysis for renewable energy projects using computer models that provide for an individual as well as diversified energy sources, but cannot be customised for floating solar systems in a local context.

The Carbon Trust in South Africa locally developed a carbon management tool designed to support financial investments into climate mitigation technology (Blue North, 2017). This Carbon Footprinting Tool (CFT) and associated methodology were developed on a GIS platform to ensure online web access to clients. The aim with the development of the CFT tool was to help clients meet the fundamental requirements for internationally accepted carbon foot-printing approaches in agricultural industry applications. While the CFT tool is proving valuable in the analysis of general carbon footprint reduction projects, it lacks specifics in terms of determining the full spectrum of environmental benefits offered by floating solar technology.

Rosa-Clot *et al.* (2017) investigated the use of computer models to simulate the integration of water-based solar power plants and to determine the impact of these systems on the environmental problem. The study includes the modelling, design and case study analyses for floating and submerged photovoltaic systems. It offers valuable theoretical and practical explanations on decision analysis around the design of photovoltaic energy systems using complementary simulations techniques to enhance the assessment practitioner's learning experience. Research by Tina *et al.* (2018) demonstrates that GIS technology offers valuable benefits for analysing the geographic and technical potential of floating photovoltaic designs. Novel terms such as the photovoltaic geographic potential (PVGP) was defined in this study to evaluate floating solar irradiation conversion rates for any such floating solar facility. Both these studies highlight the value of using GIS type tools in system performance analyses for submerged and floating solar systems.

In this context, the next section discusses the advantages and disadvantages in considering and selecting GIS technology as a platform for the development of a South African dedicated floating solar analysis toolset as proposed in the present study.

2.3. Layered GIS Platform Options

While technological tools such as GIS can assist geographers to better comprehend the nature, flow and storage of energy, and in the broader context, the environment, the systems approach effectively serves to enlighten the reader on carbon management in the energy/environmental sphere. In this way, the GIS platform can help to clarify the geographical relationships between energy and the environment at specific locations. The GIS platform can thus help geographers and environmentalists to make informed business and environmental decisions about feasibility and due-diligence issues in the context of energy generation and its environmental impact (DOE, 2015).

Based on the multi-layered structural characteristics of the GIS platform, GIS practitioners can apply communication-integrated raster and vector layers as fundamental data sources in geographic toolset design. While this offers snap-shot-like views of GIS raster data, the transactional layers of GIS offer the facility to link remote-sensing or external input data (including GPS and unmanned aerial vehicle data) and allow the data to be plugged into the GIS platform. Furthermore, critical environmental management benefits could emanate from the combined use of object-oriented GIS and computer-simulated object models. In this way, when it comes to information flow and access to information, raster data and geospatial analytics can be used in a controlled manner and be integrated into energy and environmental models. The data output can then be saved in GIS formats suitable for integration into government databases and GIS systems such as the Environmental Geographical Information Systems (EGIS) database (DEA, 2018).

Another benefit of considering a GIS platform for floating solar analyses is that the system would be able to interface more easily with existing environmental approval GIS systems. This is because the DEA records all spatial data in respect of applications for environmental authorisation for the installation of renewable energy systems in their EIA Application Database (DEA, 2018). This multi-layered EGIS suite populates information regarding attributing and spatial aspects for active renewable energy (RE) applications (approved environmental applications, and those in the process of being validated and authorised). The database also includes non-active RE applications, those environmental applications that might have lapsed or those that might have been replaced by amendments.

A further benefit in considering GIS technology as a platform for accommodating floating solar analyses is that the DEA maintains the Renewable Energy Development Zones database (REDZs) on a GIS platform. This GIS platform offers strategic environmental assessment datasets for South Africa's natural wind and solar energy resources (Cape-Ducluzeau and van der Westhuizen, 2015). While this database contains valuable spatial data on solar irradiation and the potential for wind harvesting within the boundaries of the renewable energy development zones for South Africa, the tool interfacing with these datasets would be simplified if GIS technology is engaged in the proposed GIS toolset.

Within the context of the advantages offered by GIS technology in floating solar analysis, the only disadvantage that can be identified with the use of GIS technology is the cost of GIS system licenses. The next section will focus on the environmental and legislative context, and the impact this context may have on determining and interpreting floating solar system energy yield and environmental offset performances.

2.4. Environmental and Legislative Contexts

South African environmental legislation requires that floating solar power installations must be subjected to the same rigorous environmental impact assessment processes as those associated with any other development projects (Government Gazette, 2014; Republic of South Africa, 2019). This environmental legislation requires that any agricultural installation can be approved only as long as the installation site is deemed to be environmentally and technically feasible. This approval means that planning for any energy development project for a farming enterprise must include environmental scoping studies (ESS) and a financial due-diligence analysis (DDA) as part of the environmental feasibility study (EFS). The South African Environmental Observation Network (SAEON) further encourages collaboration in international research as part of the United Nations Green Growth Knowledge Platform (Evaluation *et al.*, 2017), a global network of international experts and organisations which aim to identify and address major knowledge gaps in green growth theories and practices.

In support of these initiatives, a standard environmental impact assessment must be performed as per the procedures outlined in Figure 2.1 before any solar installation can be implemented on a farm. An evaluation of the environmental impacts, associated with any proposed land-based or floating solar project, requires investigation in compliance with the Environmental Impact Assessment Regulations (2014) and the National Environmental Management Act (NEMA Act). An EIA report focusses on the reduction in greenhouse gases (GHGs), which could also be registered as Certified Emission Reductions (CERs), with NERSA (2017) (National Energy Regulator of South Africa). The NEMA Act (Government Gazette, 2014) stipulates that any feasibility study around newly-planned solar and floating solar installations must include a thorough environmental scoping analysis.

It makes sense to use computer-aided GIS toolsets and methods to simulate the impacts, as such tools would help to accelerate the rate at which applications are approved and rolled out following environmental authorisation. If a GIS toolset were to be available to assist with floating solar environmental assessments, environmental assessment practitioners (EAPs) considered to be experts in the relevant subject matter would be able to promote floating solar technology. This toolset would thus support the legislative processes for floating solar systems, help to promote floating solar systems as a potentially viable option in the Environmental Plan (EP) for the farms in question, and could form part of their Environmental Impact Assessment (EIA) reports.

Furthermore, carbon tax regulations, as well as stipulations by international project financiers, have resulted in a set of mandatory requirements that enable agricultural project developers to examine the environmental, financial and technical aspects of any planned solar photovoltaic (PV) project (Votteler and Brent, 2016). The agricultural project developers usually call for an environmental impact analysis as part of photovoltaic project planning, which would naturally include computerised predictions of the potential for solar harvesting at the proposed site of the planned installation. This analysis provides an excellent opportunity for geographers to participate in the EIA process and the financial DDA in planning for the implementation of floating solar systems in any farming region.

South Africa's carbon tax policy constitutes part of our country's National Development Plan (NDP) and is outlined in the Carbon Tax Policy Paper (CTPP) (Ministry of Finance, 2015; Ntombela, 2019). The relevant environmental and tax laws help to foster an active interest in the installation of solar-driven energy technologies in the agricultural sector. Carbon tax legislation is currently being implemented by the South African Revenue Service (SARS) and offers the agricultural sector an opportunity to benefit from a reduction in its carbon tax liability. Securing a reduction in their carbon tax liabilities in the form of income tax credits can benefit farmers. These credits can range between R6 to R48 per ton of CO_2 equivalent saved through environmentally-friendly project developments, namely land-based or floating renewable-energy installations (Blignaut, 2017). The Treasury recently published a carbon tax report in which it models the impact of the proposed CTPP on the country's economy. In this CTPP model, the carbon tax instrument is set to reduce CO_2 emissions in the country to levels of approximately 13-14.5% by 2025 and 26-33% relative to current levels by 2035 (Ministry of Finance, 2015).

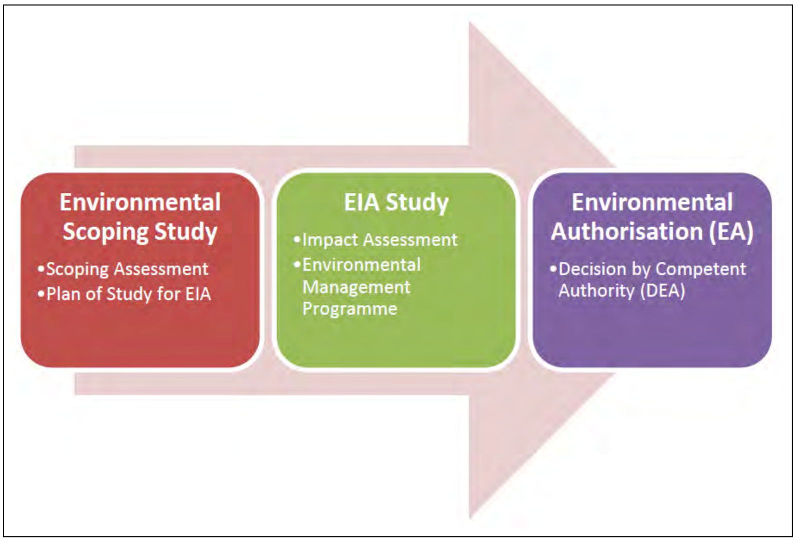


Figure 2.1: Overarching EIA process (Royal Haskoning DHV, 2015).

This computer model offers a valuable assessment of the envisaged impacts of the carbon tax policy on reducing greenhouse gas emissions, thus promoting employment, economic growth and industrial competitiveness. The next section will focus on the solar renewable energy context, and the value this field may provide on determining the system energy yield and environmental offset performances for floating solar systems.

2.5. Solar Renewable Energy Context

Global warming, water scarcity, environmental awareness, and market forces are placing increasing pressure on farmers in the Southern African region to adopt renewable energy as part of their environmentally-friendly and sustainable production practices. To adapt to international standards for sustainable agriculture, many food-producing farmers are starting to adopt environmentally-friendly practices. Their ultimate aim is to associate their food labels with environmental development, thus promoting sustainable farming and creating opportunities for linking eco-friendly labels to their brands.

Floating solar energy technology is seen as a potential solution to the environmental challenges facing agriculture and aquaculture industries (Pringle *et al.*, 2017). Floating solar can offer either photovoltaic energy generation (floating photovoltaic panels as illustrated in Figure 1.2), or combined heat-and-power systems (concentrated floating solar as illustrated later in Figure 2.5). In the latter configuration floating solar can offer a combination of electrical energy and waste heat that can be recovered when solar energy is harvested to generate solar power (Connor, 2015).

The Solar Atlas for South Africa (see Figure 2.2) shows that large areas in South Africa have a relatively good solar availability in a region with above-average harvesting potential (around 1900 kWh/m^2) (SolarGIS, 2018). In general, the sun radiates around one (1) kilowatt (kW) of energy to reach every square metre of both the land and water surfaces (GeoModel Solar, 2017). With modern technological methods, photovoltaic conversion currently offers an approximate 20-30% conversion efficiency (El Chaar *et al.*, 2011) in a static (non-tracking) configuration model for solar PV power generation systems (Filik *et al.*, 2018). Approximately 0.2 to 0.3 kW of solar energy are thus available to an agricultural business or farm for every square metre of the surface that is covered by an array of solar panels in a static tracking-alignment configuration (Alwitt *et al.*, 2012; Lee *et al.*, 2014).

The solar energy yield, however, also varies over time. This is because solar illumination varies as a function of both space and time, with the annual amount of incoming solar energy radiation varying considerably from tropical latitudes to polar latitudes and from season to season. Furthermore, the daily insolation at noon during the twelve months of the year for both the southern latitudes and northern latitudes Figure 2.3 demonstrates that the seasonal change at high southern latitudes (green traces) and northern latitudes (blue traces) is a significant factor in the variability of the power-generation performance of a solar photovoltaic system (NASA, 2018). Figure 2.3 further illustrates how the solar irradiation and thus the solar system energy budget also vary considerably as a function of latitude and as a function of the season of the year.

Other factors that affect the resultant energy yield of a solar renewable energy system are the variations in environmental conditions, as well as in the weather pattern and cloud cover over time. This is illustrated in Figure 2.4, showing an example of the daily energy yield profiles for a solar energy system corresponding to a sequence of cloudy days.

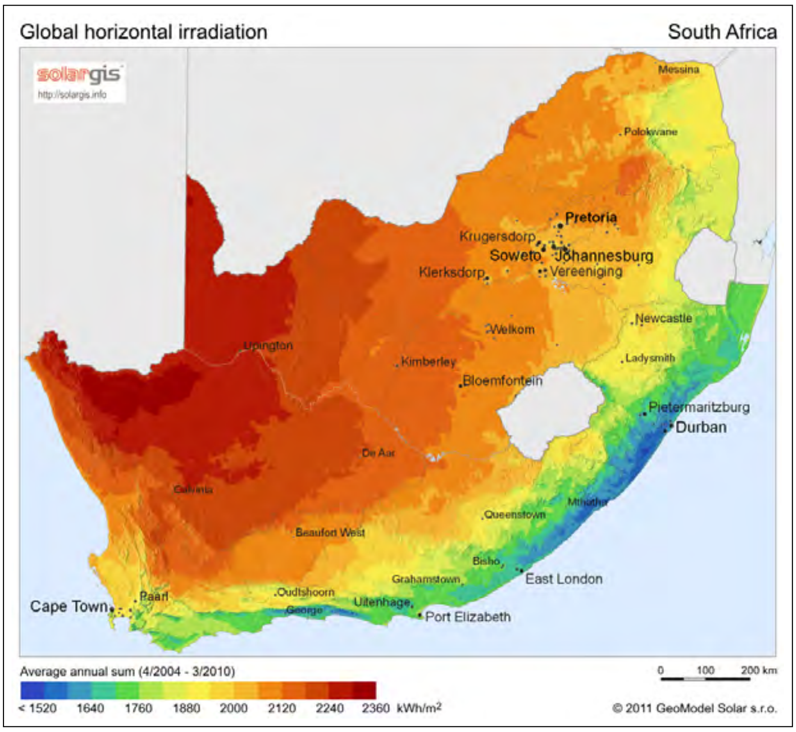


Figure 2.2: Solar Atlas depiction of the potential for solar energy harvesting for agricultural areas in South Africa (SolarGIS, 2018).

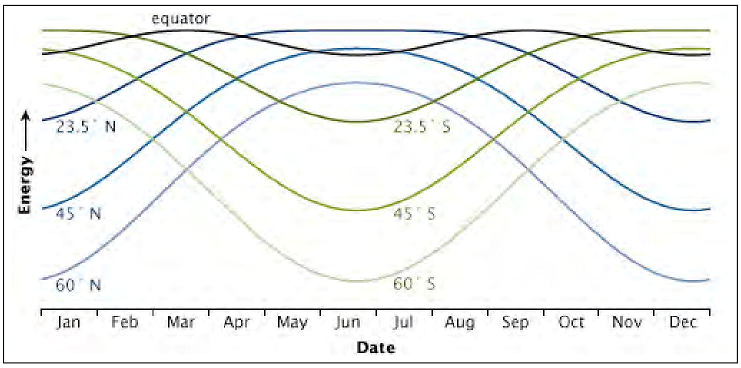


Figure 2.3: Solar energy received by the earth at noon each day of the year varies with latitude and the seasons (NASA, 2018).

While Figure 2.4 reflect the different daily photovolatic yield profiles recorded on cloudy days for the months of May, June, July, and August, it highlights the varying profiles of the same photovoltaic modules recorded in cloudy days in Niamey (Niger) for the months of May, June, July and August. At this site, the cloud impacts are more pronounced in August and July, where on 7th of August 2015, the maximum power yield was below 25% of the rated panel power (25W). This demonstrates how very high cloudy conditions in months of peak rainfall can impact on solar energy yield for overland solar (similar trends may be observed for water-based floating solar) (Bonkaney *et al.*, 2017).

In the present study, cloud modulation and weather variation effects impacting on solar

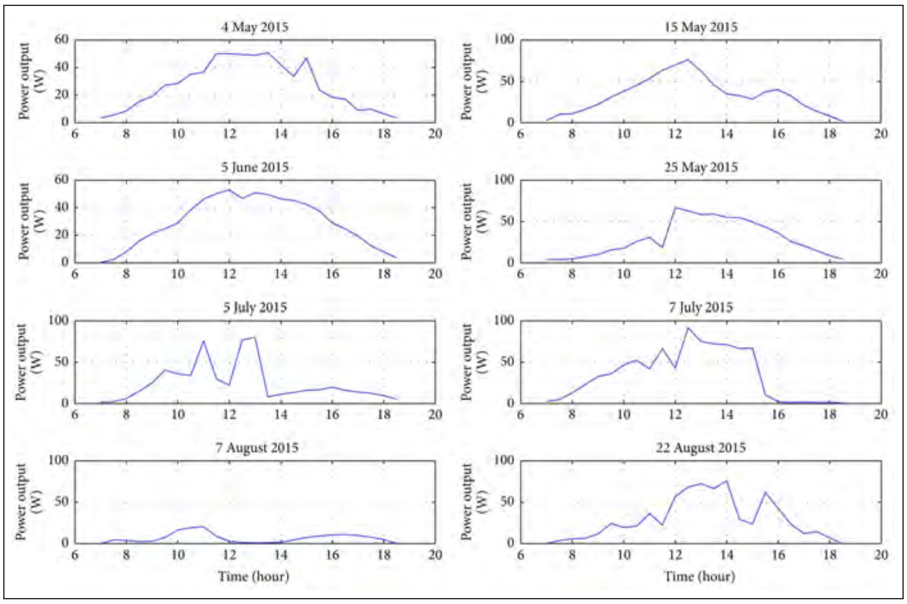


Figure 2.4: Solar energy yield profile variations corresponding to daily weather patterns and cloud-cover impacts measured in Niamey, Niger (Bonkaney *et al.*, 2017).

irradiation levels will be modelled using historical weather data models developed by Meteonorm, SolarGIS, and GeoSun (Meteonorm, 2016; SolarGIS, 2018; Suri *et al.*, 2014). The next section will focus on the floating solar technology context, and the impact technology aspects may have on system energy yield and environmental offset performances.

2.6. Floating Solar Technology Context

Because fertile land is used for growing food and viticultural produce at high net-profit, the productive, fertile land at most agricultural sites is more valuable than the financial benefits that would arise from installing solar power systems on the land. Removing crops, vineyards or other plants in order to set up solar energy units on agricultural land is neither a viable nor a sustainable solution owing to the fact that farmers need all the land/space to produce as much agricultural produce as possible for their enterprises to be economically sustainable.

The fact that agricultural land is very scarce calls for new technological concepts to bring the vision of sustainable agriculture and farming activities that neutralise the carbon footprint effect closer to reality. Solar energy technologies offer access to cost-effective and environmentally-sustainable supplies and are perceived as having the potential to contribute to a reduction in the carbon footprint of the agricultural sector (Redón Santafé *et al.*, 2014). Emerging technological concepts, such as solar farms, have also taken on a new meaning since the advent of the floating solar photo-voltaic system (Sahu *et al.*, 2015).

Since environmental impact considerations support the application of renewable energy technologies, floating solar energy systems over water surfaces (e.g. dams, ponds) are gaining in popularity in the agricultural sector (Smyth, 2011). Floating solar systems on agricultural land serve as cleaner environmental measures for harnessing power than the more traditional methods of generating electricity (e.g. coal-based power stations). However, more importantly, such installations serve to reserve land space for food production.

A solar energy system on a farm could be in the form of a floating photovoltaic system, as earlier illustrated in Figure 1.2. Alternatively, a floating solar configuration could be generating heat and power through a solar tracking system on a dynamic floating pontoon (Seaflex, 2017). A tracking Liquid Solar Array (LSA), such as the concentrated floating photovoltaic energy plant illustrated in Figure 2.5 (Dickinson, 2011), would generate different energy output curves at different locations.

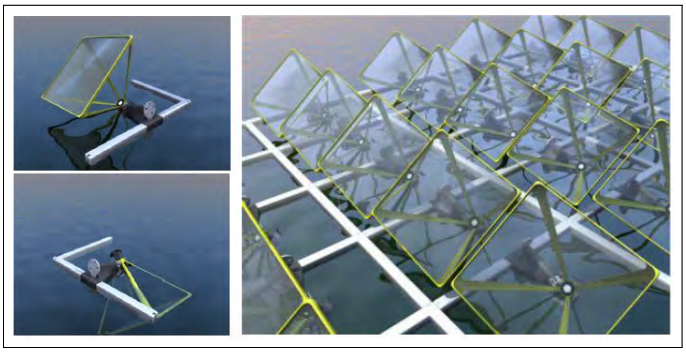


Figure 2.5: A concentrated floating solar system by Sunergy (Dickinson, 2011).

Concerning the system's impact on the environment, an existing land-based photovoltaic installation on a farm could be integrated with a floating solar installation. The premium use of land and energy efficiency are the primary motivations for installing floating photovoltaic (PV) systems. Such a floating solar system would offer the added benefit of securing valuable agricultural land for the cultivation of crops and livestock (Redón Santafé *et al.*, 2014). Depending on the latitudinal location of the floating solar installation, the energy output profile would vary according to the latitude of the site of the installation. Such variations can be observed in the energy yield curves in the profiles shown in Figure 2.6.

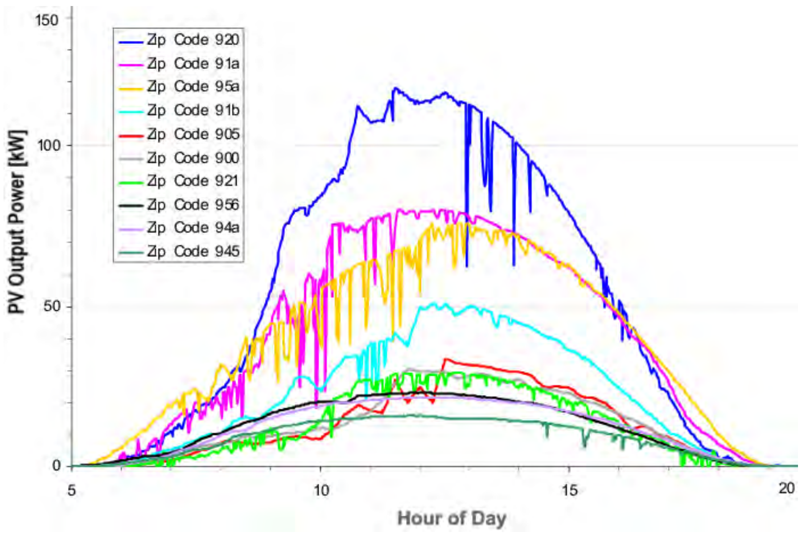


Figure 2.6: Example of energy profile variations in solar systems at different locations in the USA (based on Post Office zip-codes) (Lew *et al.*, 2010).

Empirical research conducted in a study on the efficiency of a floating photovoltaic system on a lake in Korea as opposed to that of an overland photovoltaic system proved that the temperatures of the floating photovoltaic system were lower than those of the land-based photovoltaic system (Choi, 2014). Figure 2.7 shows the power output differences measured for 100 kW and 500 kW land-based (red) and water-based (blue) solar systems.

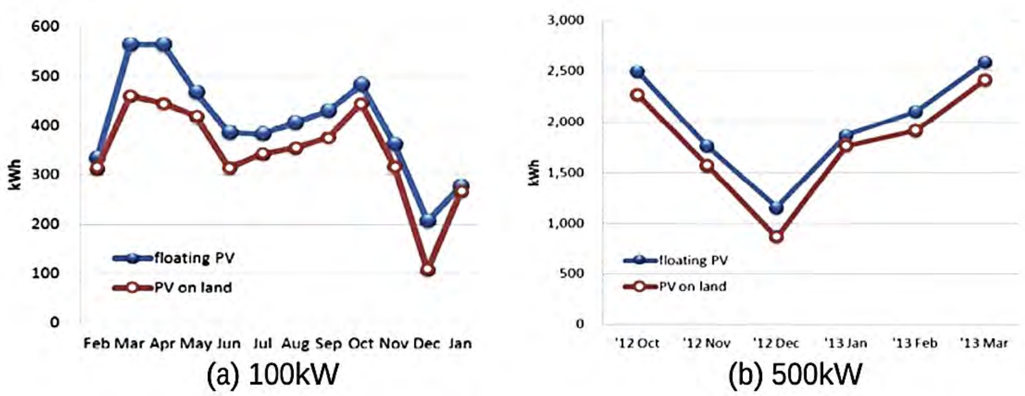


Figure 2.7: Comparison between average daily generating capacity for a floating solar and overland solar system for (a) 100 kW and (b) 500 kW system (Choi, 2014).

Floating solar panel outputs in Figure 2.7 shows a remarkable 11% increase in the energy output efficiency of the floating solar system as opposed to that of a land-based photovoltaic system. The improved solar efficiency for floating solar systems in Figure 2.7 could be explained relative to the lower ambient temperatures closer to the water surface in the case of the floating system.

Figure 2.7 confirms that, while solar photovoltaic power systems installed on a floating pontoon, the temperature parameter of the photovoltaic module significantly influences the efficiency of the energy conversion system and the energy outputs in a positive sense (Choi *et al.*, 2013). This is because floatovoltaic systems inherently keep the reservoir water for irrigation purposes cooler, resulting in additional benefits that limit evaporation and help to control toxic algal growth (SPG Solar, 2010). Water and water moisture in the air keep the solar panels cool, thus making the solar panels more energy efficient with respect to sunlight-to-electricity conversion (Ho *et al.*, 2015).

Since the carbon footprint of a floating solar system is directly proportional to the power generating output of such a system, the results in Figure 2.7 essentially highlight the fact that the environmental impact of the floating photovoltaic panels can be positively enhanced even more during the day by further cooling the solar panels through spraying them with water at regular intervals. Furthermore, it should be noted that the solar power conversion and performance ratios, as well as the related carbon-footprint implications, are dependent on other factors such as climate, weather, and cloud density. In practice, this means that locational sensitivity is typically compensated for by applying a conversion efficiency metric that is dependent on the climate of the area in question, as well as the combination of the proposed solar conversion equipment (Dierauf *et al.*, 2013).

From an environmental impact perspective, these conversions are critical in environmental impact assessments and carbon footprint studies. The next section describes the environmental and carbon footprint legislative contexts, and reviews the literature on the environmental impacts on EIA approvals for floating solar renewable energy systems.

2.7. Carbon Footprint Implications Context

The 2013 Conference of the People Colloquium (Derman, 2013), called on all South Africans to reduce their carbon footprints, to keep a greenhouse gas inventory, and to record the reductions in carbon dioxide emissions that they would be able to achieve. The greenhouse gases such as Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_20) and Hydro-fluoro-carbons (HFCs) are the most common gases contributing to the depletion of the ozone Layer and causing the greenhouse effect. The proportional contribution of these essential greenhouse gases, emitted by human activities on a global scale, is shown in Figure 1.1. Reducing these carbon emissions will help combat global warming and climate change (IPCC, 2014).

In the case of South Africa, solar energy could be used as a substitute for Eskom's grid power, the latter generated through Eskom's mainly coal-based network of carbon-intensive power stations (Letete *et al.*, 2010). It is alarming to note that the large volumes of water that are consumed in the actual coal-mining process and as a coolant in the coal-fired power stations have the potential to disturb the water balance in South Africa (De Villiers and de Wit, 2010). From an environmental perspective, the substitution of grid power to farms by solar energy would not only reduce the environmental footprint on the farm but also impact upon the national environment. This would include a reduction in greenhouse gas emissions as well as the conservation of water resources destined for consumption by Eskom in its power-generating endeavours (Pather, 2004). In the case of grid energy substitution, it is interesting to note that the annual impact of the carbon footprint, as calculated from the renewable energy savings factor for systems with a 1000 kWh solar power system reference, amounts to around 8.6 tons of CO_2.

This figure can be calculated using the Eskom Environmental Impact Model (EIM), the parameters of which relate to the consumption of coal, water, and other resources, in order to generate electricity in the country (Eskom, 2014*b*). The EEIM model in general helps to detail the great potential that solar renewable energy solutions have in reducing the carbon footprint of a farming enterprise. Positive implications relate to the impact of the carbon footprint for a floating solar system that are even better than those of a land-based solar system because of the raised energy production levels associated with the former. Owing to the cooling of the solar panels, these levels could increase by as much as 11% (Choi, 2014). This model, therefore, goes a long way towards supporting sustainable farming.

In terms of comparing carbon footprint equivalent contributions from wine farm business units in carbon reporting and disclosure, Figure 2.8 shows a comparison of units contributions in relation to their carbon footprint contributions. This graph shows that the use of electricity is by far the number one producer of carbon emissions on a wine producing farm. It highlights the fact that the generation of energy, and the reduction of energy consumption (especially grid power usage), on a farm would lead to a reduction in the carbon emissions to be released into the atmosphere.

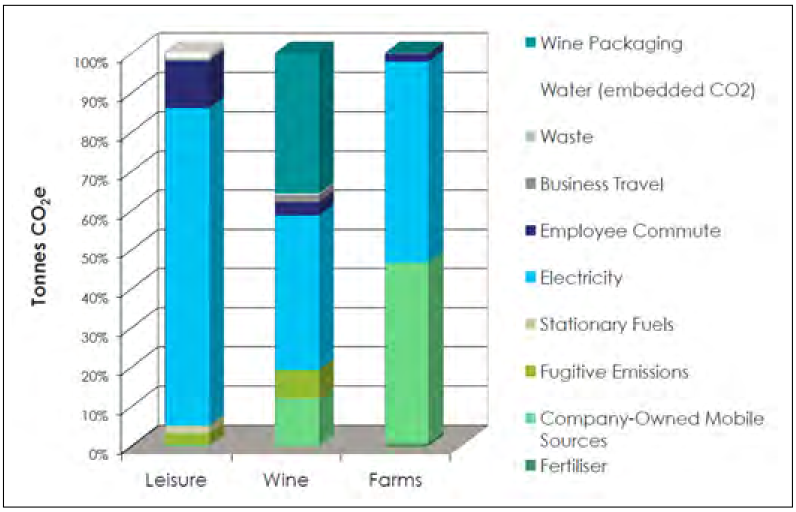


Figure 2.8: Comparing carbon footprint equivalent contributions from wine farm business units in carbon reporting and disclosure (James and Shachar, 2015).

In the context of the illustration of Figure 2.8, the World Business Council for Sustainable Development has recently introduced the carbon taxation protocol in the *Corporate Accounting and Reporting Standard* (Revised Edition) publication (WRI, 2004). This new standard sets strict requirements for carbon footprint reporting and will lead to the taxation of carbon emissions in the future should each industry, winery or fruit farm that not meet the specific saving targets (James and Shachar, 2015).

From an environmental perspective, there are several symbiotic relationships associated with floating solar systems that can be considered. These include an increase in the energy conversion efficiency owing to the cooling and regular cleaning of the surfaces of the photovoltaic modules, a significant reduction in the evaporation rates from the pond surfaces, as well as adaptations to the ecosystem, and improved growth rates for fish. All of the factors mentioned above would be achieved through integrated designs that use photovoltaic pumps to control the lighting and oxygenation levels (Pringle *et al.*, 2017).

Several positive environmental and carbon impact benefits could emanate from the use of floating solar energy systems on farmland ponds/dams since such systems allow for the substitution of grid power with renewable solar energy. Floating solar platforms also mitigate the generation of greenhouse gases in that they allow for the conservation of energy. These benefits, in turn, allow for greater independence for the consumer regarding the selection of the energy source to be used, and the creation of new job opportunities. They also show the potential for improved water quality (algal growth control is discussed in the following section) and promote new human development opportunities (Hernandez *et al.*, 2014).

The next section will focus on the value of WELF nexus thinking in a floating solar technology implementation context, and the impact this theoretical basis may have on depicting the linking between floating solar energy yield and environmental offset performances.

2.8. WELF Nexus Context

Growing scarcities in natural resources, combined with the interconnections between the respective resource sectors, are becoming more apparent, as is evident in the growing number of trade-offs in the search for cross-sector efficiencies. Floating solar PV panels provide electrical power without harming or causing damage to nature because they directly transform the sun's energy into electricity (Singh, 2013). Such energy conversion systems and floating solar methods could have substantial spill-over effects on other resources and particularly impact on the water and food sectors. The role that floating solar energy systems could play in the agricultural sector can be evaluated in the context of the WELF nexus domain, as it highlights the effects that energy has on water and land-use factors (Portney *et al.*, 2017). The nexus approach, depicted in the illustration of Figure 2.9, is generally characterised by nexus system parameters or as critical nexus impacts in the social and science arenas (Foran, 2015).

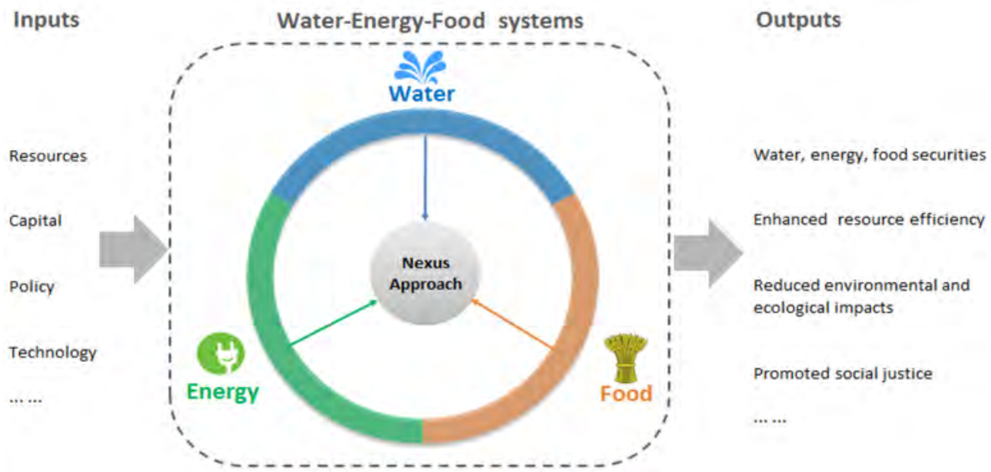


Figure 2.9: Water-energy-food nexus management in environmental modelling (Chang *et al.*, 2016), WELF nexus concept being applied to floating solar systems.

The WELF nexus concept shown in Figure 2.9, is a valuable tool for studying sustainability scenarios in relation to food production, land-, energy- and water-resource interactions, balancing and optimisation (Ringler *et al.*, 2013). The WELF nexus approach depicted in Figure 2.9 reflects a holistic vision of sustainability for floating solar or any other development that tries to strike a balance among the different goals, interests, and needs of people and the environment. It highlights the fact that WELF nexus thinking highlights how treats to water, food, land-use, and energy is an interconnected set of dependable elements. It takes into account the trade-offs and interactions between the elements, thus helping to analyse the effects of floating solar installations on water stress, land-use and energy supplies. In a decision-supporting system formulated as a GIS tool, the WELF nexus analysis would offer a holistic view that would help to identify and balance the many competing effects in an interconnected floating solar WELF nexus context.

While the WELF nexus takes a holistic view in clarifying the inter-dependencies between WELF security elements, two recurring criticisms regarding the WELF nexus are that it adds little to the existing integrated management approaches and that its trade-offs in food security farming are often overly expensive (Benson *et al.*, 2015; Terrapon-Pfaff *et al.*, 2018). In contrast to the approach taken by government entities, institutions, experts and academics, the WELF nexus has generally not been conceptually differentiated into its respective elements or part by local communities, rural farmers and fishermen, despite physical factors, such as climate change, that may alter the availability of resources such as water, energy and food. Droughts and floods may, for example, have significant adverse impacts on agricultural productivity, influencing community-based production processes and supply chains. Food security farming is thus a concept that implies that limited access to energy and water can reduce the availability of food since water is often needed for energy generation, while power is often required to extract, distribute and treat water (Terrapon-Pfaff *et al.*, 2018). WELF nexus research can therefore still make a valuable contribution to enhancing development at the local level.

Another criticism against the WELF nexus is that it stresses integration and coordination for the efficient, equitable, and sustainable management of resources but there is still a lack of a clear definition of an ideal nexus integration, making it difficult to establish what constitutes a successful nexus analysis (Kurian, 2017). This gap creates significant challenges for developing nexus-orientated strategies from a cleaner production point of view. While the WELF nexus may be recognised as a valuable conceptual framework for sustainable development, the nexus approach should shed more light on the governance dimension by introducing novel concepts of trade-offs, synergies and thresholds (Kurian, 2017; Zhang *et al.*, 2018). The first part of any WELF nexus approach should thus explain how nexus efforts increase the number of variables of interest in a particular domain, while the second aspect should explain the socio-economic relations that underpin the WELF nexus.

In a commercial farming context, the benefits of the WELF nexus framework overwhelm the criticisms. Therefore, this study proposes that a toolset be developed to analyse environmental impacts for Eskom grid energy substitution as WELF nexus parameters (WWF & SABMiller, 2014). In this application, the digital programming and map-based attributes of a GIS platform form an ideal environment for location-sensitive environmental-impact evaluations of floating solar energy systems. A consideration of the opportunities for optimising space in environmental management plans for the agricultural sector would also go a long way to encourage new attitudes to the application of renewable energy on farms, and concomitantly raise their productive capacity.

2.9. Summary

The distribution of solar energy over the entire globe makes solar energy an ideal resource to harvest with floating solar systems for agricultural purposes. With the aim of developing a geographically-based environmental impact analysis tool on a GIS platform, this chapter presents a brief literature review around GIS-based carbon-management tools, as well as layered GIS platform-context tools that may be able to help breach the present gap in research around floating solar EIA analyses. It describes past and present research on floating solar systems, as well as the environmental impact these systems may have on the energy balance and carbon footprint in agricultural applications. Further examples are presented where the positive effects of carbon footprints are effected by grid energy reduction and associated carbon footprint improvements, together with water quality improvement and the preservation of water resources. The aforementioned shows that analyses of floating solar sustainability and environmental suitability together constitute an inter-disciplinary research approach, enabled by the GIS workbench in an integrated development environment.

The literature study ultimately highlights the fact that solar farming has taken on a new meaning with the advent of floating solar photovoltaic systems. It shows how a farm can integrate existing land-based-type photovoltaic technology into any newly developed pontoon-type floating photovoltaic technology. The potential environmental value of these systems helps to sustain agricultural production and to preserve productive, fertile land for food production. This focus is especially true in areas where the land premium for the agricultural sector makes land-based solar systems expensive and unsustainable. Overall, the literature study highlights the need for the development of new GIS-based geographical tools to assist environmentalists and farmers in studying the environmental impact of floating solar systems. The study thus sets the scene for a new geographical perspective on environmental change that uses WELF nexus parameters in environmental impact assessment for floating solar systems, as detailed further in this dissertation.

3. Research Methodology and Design

This chapter presents an overview of the research methodology of the study and details of the research design for a proposed digital GIS toolset. The methodology is primarily concerned with the method of designing, implementing and testing the proposed GIS-based carbon management toolset for floating solar system models in the layered programming context of a GIS platform. The methodology is formulated against the background of the problem statement, literature review and research aims/objectives that logically support the environmental and legislative contexts. The research design, on the other hand, details the steps and processes to be followed towards the development of the proposed GIS toolset, as well as the steps involved in the evaluation of the tool as an experiment based on a case-based scenario.

3.1. Research Methodology

As regards the options for applying the scientific research method, the classification of research in the overlapping fields of Geography and the computer sciences includes a choice that must be made between the Experimental Method, the Theoretical Method, and the Simulation Method (Ayash, 2014). In the United States, the National Science Foundation categorises the computerised Simulation Method as a reliable scientific research instrument and as the third pillar of science in its methodology. It stands as an equal partner alongside the Theoretical and Experimental methodologies (Vos and Shults, 2015). Computer modelling and simulation as a quantitative research method represents a formal approach to objective research that uses numerical data in a systematic process to obtain information about a real-world problem (Burns and Grove, 2005). As one of the instruments of quantitative research, the computer modelling and simulation (CMS) technique uses a computational model to describe systems behaviour in a particular experimental design and setup configuration. With the emphasis on virtualisation, the CMS model typically consists of various systems components and variables, together with a set of mathematical equations, that describe the processes responsible for systems behaviour as variable changes over time (Jakhrani *et al.*, 2014).

From an environmental management perspective, CMS techniques are recognised as one of the most valuable scientific methods for the collection of environmental research data as part of climate change technology impact investigations (Fischlin, 1990). As a recognised quantitative data collection technique, CMS is particularly useful as a research instrument in that it offers functional technology options in a diagnostic type of environmental assessment research method (Frenkiel and Goodall, 1978). By building a virtual model to synthesise the behaviour and response of the floating solar system under investigation, experimental data collected by way of CMS in the digital domain can help to predict and validate the actual behaviour of a floating solar energy system during the planning phases of a project (Khaiter and Erechtchoukova, 2007; Wainwright and Mulligan, 2012). Furthermore, as a multi-variate, temporal and computational modelling technique and method, CMS can be combined with the spatial awareness and spatial referencing attributes offered by GIS platforms to further ensure contextual intelligence in location-based data architectures (Graser and Olaya, 2015). The CMS research method is thus a valuable tool for ensuring that a planned project would be delivering on the environmental promises of a feasible and sustainable energy system.

This present research project aims to exploit time-varying energy and environmental modelling aspects inherent to the field of energy cybernetics and to incorporate such models as objects in an object-oriented GIS. As such, the CMS research method avoids problems associated with real-world testing and allows for the virtual screening of environmental hypotheses. It enables the researcher to collect scientific evidence, while describing, predicting and exploring the occurrence of phenomena, and concomitantly maintaining objectivity in determining and expressing the parameter as variables of the environmental system in question (Yang *et al.*, 2013). Numerically-based CMS experimental studies generally help to examine relationships among the various systems variables and assist in statistically analysing and determining the cause-and-effect interactions between one or more inter-disciplinary variables (Kothari, 2004).

Experimentation with environmental ecosystems through the use of computer models enables the environmental assessment practitioner and the geographer to reach conclusions about and identify restrictions on the environmental impacts of floating solar systems before installation. It also offers flexible opportunities in decision-making and supports the utilisation of quantitative models to deal with predictive problems in the pre-installation phase (Khaiter and Erechtchoukova, 2007). Systematic and theoretical analyses based on computer simulation methods can also be applied in studies of the dynamics of environmental behaviour. Since computer modelling and simulation methods can produce quantitative data as an output, they are valuable as scientific research methods in the field of the applied social sciences. The fact that it can process statistical data and perform analytics mean that it can be used quantify feedback in environmental reporting.

3.2. Ethical Considerations

Ethical considerations require that the research should be conducted in a sensitive manner, that respect be shown to the research participants, and that their fundamental human rights be honoured. In this project, the researcher endorses the Ethical Codes of the University of South Africa (Unisa, 2007). It is confirmed that no conflicts of interest or financial benefit shall materially affect the outcome of the investigation or jeopardise the name of the university. Data collection and analysis took place with the appropriate controls, while all results, including any negative findings, were reported (Cossio, 2012; Unisa, 2007).

3.3. Research Design

The central role that renewable energy technologies play in holistic energy and environmental impact scenarios emphasises the importance of solar photovoltaic technologies for a specific end-use application. For this reason, decision-making in the field of environmental management calls for a scientific research method that involves the reliable prediction of the dynamics of a planned energy ecosystem for any newly-proposed development of a solar energy project (Sholarin and Awange, 2016). To this end, the study proposes a computerised simulation-based modelling method for the development of a GIS-based tool and procedural framework. Computer simulations will be used in the application of this particular geographical toolset and its organisational environment to determine EIA parameters, thus enabling the environmental assessment practitioner to perform strategic environmental impact and sustainability assessments.

The development of the GIS-toolset for the predictive simulation analysis of the environmental performance of planned floating solar systems will be conducted in three phases, namely, the literature review phase, the model or tool development phase, and the evaluation of the experimental toolset in the final phase.

3.3.1. Design Phase 1

The literature review of this study (Chapter 2) covers the existing body of knowledge related to the problem statement and outlines the purpose of this research. It provides an independent and justified point of view on the relevance and value of publications and theories relevant to the study. As such, the literature review has set the scene for defining a new geographical perspective on environmental changes anticipated in association with floating solar systems, and for describing the parameters to be considered in the environmental impact assessments for floating solar systems detailed in the rest of the study. Furthermore, the literature review examines spatial analysis and modelling in the context of Geographic Information Systems (GIS) for predictive analytics to determine the anticipated environmental impacts of any hypothetically-planned floating solar system. The analytics specified in this study is expected to reflect how a particular floating solar system might impact upon the environment in a given agricultural setting in terms of the energy balance and carbon footprint.

3.3.2. Design Phase 2

The model development phase of the research involves the development and implementation of a computer simulation model based on a modular design (Holcomb Research Institute, 1976). As discussed in Section 1.6, a computer simulation model is an appealing type of design to use when planning a GIS model for a particular simulation project as the simulation model can be tailored to the specifics of the design objectives of the toolset (Harrison, 1999). The application of the proposed GIS toolset model blocks (described in more detail in Section 3.4), includes the EAP interfacing, solar energy and the environmental object components of the GIS toolset. These toolset components are designed as objects in an object-oriented environment. The software objects, together with the associated predictive models for the analysis of energy and the environment, will be accommodated in two thematic GIS platform layers as a run-time environment for the development of the representative layers. The model will demonstrate EIA expressions related to the energy yield and environmental impact profiles. Two newly-defined GIS layers (energy and environmental model layers) will also enable the toolset model to determine the feasibility of a particular floating solar system design and its impact upon the environment.

The initial step in the design process is to implement a GIS interface block or layer for the proposed GIS tool by using web/desktop interfacing computer language and code. This software dialogue interface will enable the environmental assessment practitioner to input the system details and geographical location coordinates for a planned static floatovoltaic installation (as determined during the assignment phase or the fieldwork phase of this research project). The next step is to develop a GIS software code in Python computer language to acquire TMY solar and statistical weather pattern data for the location of the floating solar system from a large data platform such as Meteonorm or SolarGIS (Meteonorm, 2016; SolarGIS, 2018). With access to such data, the GIS tool will be able to use a computer software code that models the engineering dynamics of the floatovoltaic system. A *floatovoltaic model* will be defined to determine the variations in the solar energy outputs (P_e(t)) of the floating solar system over time. This will be done through virtual simulations with the planned static floatovoltaic system based on the historical solar and weather data for the given location.

The numerical calculations for this model will be based on an extensive library of equations for a software code that facilitates the computation of the energy outputs for solar panel surfaces that are static and resting on axes parallel to the water surface or on an arbitrarily-oriented surface (Andrews *et al.*, 2014; Stein *et al.*, 2017). The theoretical principles behind this Open Source PVLIB module for Python Photovoltaic System Modelling Platform is described in detail in the computer modelling research work of Duffie and Beckman (Duffie and Beckman, 2013). By using the PVLIB module API, the GIS tool model will be able to determine the behaviour of the energy system, as well as the manner in which it varies (from a set of initial conditions) according to given climatic conditions. It should be noted that the time resolution and the number of simulation iterations for a given set of floating solar conditions must be small enough to reveal the time-sensitive tendencies in the behaviour of the system. Since the environmental impact of a solar energy system is a function of the energy output of the system, the next step is to prepare a GIS software simulation code to describe a floating solar system: *Environmental model*. The set of calculations for this environmental model is based on the substance equivalence factors of the grid-substitution environmental impact model (EIM) developed by Eskom (Eskom, 2014*a*). This block model will predict the environmental impact parameters of the floating solar system as avoided physical and chemical compounds, namely water (H_2O) preserved, carbon dioxide (CO_2) reduced, sulphur dioxide (SO_x) reduced, nitrogen oxide (NO_x) reduced, and airborne particle emissions (aPE) reduced.

3.3.3. Design Phase 3

The third phase in the methodology of the quantitative research design demonstrates the performance of the digitally-implemented geographical toolset through an evaluative analysis of the experimental phase of the research. In this phase, the performance of the GIS toolset will be demonstrated under three case study scenarios (as described in Section 1.7). Generally, an experimental case study is a useful method for testing a geographical toolset in order to see how the scientific theories and models work in realistic simulations of the real world (Vos and Shults, 2015). While the experiment in this case study focuses on the GIS toolset in a particular agricultural setting, it does not limit the scope of application from going beyond the scope of the case. Therefore, three sample case studies will be considered to ensure that the focus is not only confined to an individual case, but also takes into account other geographical features and locations.

These case studies will offer the researcher the opportunity to analyse the influence of many variables, and how they play a role in potentially solving environmental problems associated with the agricultural solar energy system under consideration (see the scope of sample case scenarios described in Section 1.7).

The GIS toolset-driven computer-synthesised test running in the experimental phase of this study will enable the researcher/user to observe environmental impact predictions for specific demonstration sites. While certain aspects of hypothetically-planned floating solar systems at these locations (including their GPS location, the area of the water surface, and the technical details of the floating solar system) are fed into the developed desktop GIS model, the model will provide the required energy output/environmental impact metric values (P_e, H_2O, CO_2, SO_x, NO_x, aPE, and aLP) as output. The predicted EIA metrics for the floating solar systems at the three sample sites will be plotted as time graphs. These plots will demonstrate how the floatovoltaic Energy/Environmental model outputs vary over time for an arbitrary number of days and how the system is predicted to perform over a one-year period. Since the annual aggregated energy yield performance data and associated environmental impacts are needed as part of the environmental approval process, these metric values will be mathematically integrated over time and plotted as decision-supporting dashboard tables on a map of South Africa.

3.4. GIS Tool and Simulation Model Developments

The scientific research methodology of this study uses a holistic modelling approach to the sustainable development of energy, water and environmental systems in the planning and management of environmental and water resources in water-stressed regions (Urbaniec *et al.*, 2017). A wide variety of model-based engineering design tools for photovoltaic systems are available for the computer-based solar photovoltaic systems design, analysis and optimisation of systems of different sizes and dimensions (Deambi, 2016; Gurupira and Rix, 2016; Holmgren and Groenendyk, 2016). Such numerical modelling-design tools mathematically model and forecast the geospatial performance of the envisaged floating photovoltaic systems. Model-based simulations can further assist in optimising the floating solar system parameters towards improving the performance of a planned system during the process leading up to the installation of a floating photovoltaic system. Design parameters may include key floating solar system attributes, system requirements and specifications, their influence on the anticipated performance ratios, their impact on climate change, as well as the effects of fine tuning the site-specific parameters. This section describes the development and application of a computer-based simulation model using simulation procedures in an analytical methodology that determines the predicted performances of a floating solar system during the project-planning phases.

3.4.1. Energy simulation model block diagram

In this study, decision-supporting procedures for environmental engineering and management with a dedicated GIS toolset require that parametric meteorological, energy, and environmental models are embedded in thematic GIS layers. These layers characterise the respective meteorological, electrical and environmental aspects of a floating solar system in a computer-aided EIA synthesis. Mathematical model blocks use programming fundamentals in discrete event simulation (DES) procedures to artificially reproduce the operational behaviour of an equivalent virtual floating solar system in repetitive simulation time steps. It essentially implements a physics modelling technique on a web-based GIS platform, using open source software code available from the Sandia PVLIB solar library repositories (Holmgren *et al.*, 2015; Stein *et al.*, 2017). The GIS platform is thus able to simulate the operation for a future planned photovoltaic panel system by conducting a performance-modelling analysis. This overall simulation process virtually (and effectively) mimics the operation of an integrated energy/environmental system at discrete time intervals to facilitate a study of the productive capacity, operational aspects and environmental impacts of the floating PV micro-utility power-plant. From the energy performance data determined by the floatovoltaic *Energy Simulation Model*, the *Environmental Simulation Model* can predict the environmental impact of the floating solar system, basing it on the historical statistics of the solar irradiation and weather patterns for each selected area of operation.

The *Energy Simulation Model* hosted on the GIS toolset *EIA Object Layer* establishes the anchor simulation in respect of determining the energy and environmental performances of any planned floating solar system in this particular research study. Figure 3.1 depicts the integrated GIS toolset as a GIS object diagram with the proposed computer simulation model and object components developed for the simulation and collection of data based on solar position calculation models.

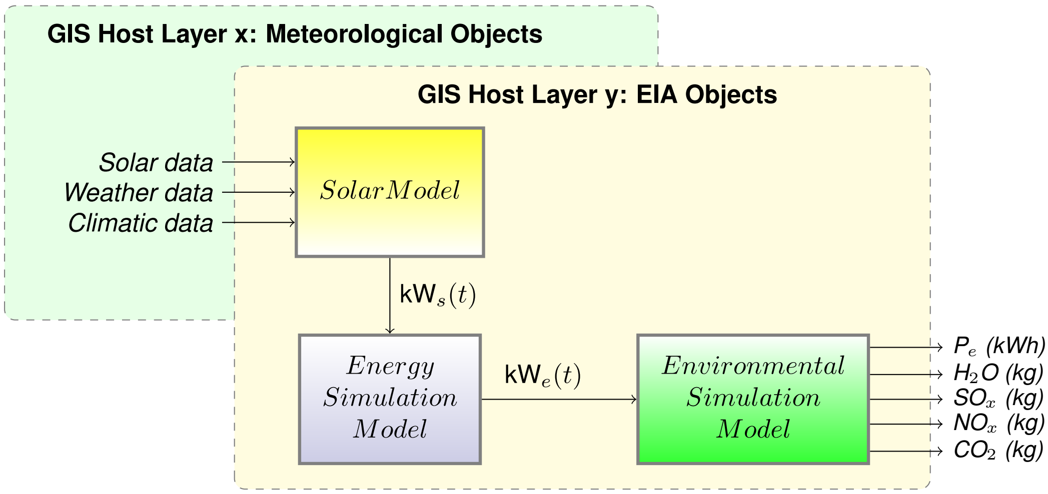


Figure 3.1: Block diagram for the *Energy Simulation Model*, the GIS tool object model for studying the predicted energy output performance for planned floatovoltaic solar systems.

The proposed model in Figure 3.1 computes and projects the output energy behaviour profile of a floating solar installation at any given geographical location (Prinsloo, 2017*a*). The model uses online weather data modelling tools for the GPS position in locationally-sensitive solar site prospecting and yield assessments of the photovoltaic panels (Geo-Model Solar, 2017). While the energy output of a solar system is dependent on the tracking capacity of the solar installation (Moradi *et al.*, 2016), this study models only non-tracking static/fixed floating floatovoltaic systems. The outputs of the energy model are used then to determine the environmental impact profile of the system, while future studies could also use the results to determine whether the floating solar-generated power will be sufficient to energise various activities on the farm.

In the GIS object layout of the computer software object models in Figure 3.1, the floatovoltaic *Energy Simulation Model* block engages a digital transient simulation platform to predict in synthesised performance-modelling procedures the energy outputs for a floating solar system. This block numerically models the computer-simulation model for energy as Python programming language scripts (Enthought, 2017). The Energy Simulation Model in Figure 3.1 thus performs synthesis runs to determine the energy output projections for a floating solar system over a given time horizon, typically over a one-year period (on a minute-by-minute, five minute-by-five minute, or hour-by-hour basis). The proposed energy model is embedded on a geographical information system, thus enabling a proposed GIS tool to perform real-time empirical estimations of solar energy outputs in terms of meteorological (solar irradiation, climatic data and weather data) inputs. The time resolution for the simulation of the energy outputs can be set to the desired time intervals, with the time-resolution preferably set small enough to reveal the time-sensitive tendencies in the behaviour of the system. The number of repetitive simulation time steps is set to cover a full year cycle of simulations over a 365 day period, while these simulated energy output levels are aggregated on a monthly basis to serve as input to the *Environmental Simulation Model* in the GIS EIA objects host layer (shown later in Figure 3.2).

For the floatovoltaic *Energy Simulation Model* to determine the energy outputs over time, the GIS toolset provides geospatial environmental input data from a *Meteorological Model Object* block hosted on the GIS toolset *Meteorological Object Layer*. The *Meteorological Model Object* block engage numerical weather prediction models to plug environmental data into the *Energy Simulation Model*, thus enabling it to determine the outputs of the planned floating solar energy installation over time. The *Meteorological Model Object* in the GIS data layer interface of Figure 3.1 thus feeds statistically modelled environmental data into the *Solar Model* block from the online SolarGIS/Meteonorm geographical interface feed (Meteonorm, 2016; SolarGIS, 2018). The numerical solar/climate/weather models represent historical geospatial environmental data (clear-sky solar irradiation, weather patterns, cloud cover, climatic data) as a statistically-based meteorological data model (Cebecauer and Suri, 2015; Gueymard and Myers, 2008). As illustrated in Figure 3.1, this meteorological data model serves as input to the *Energy Simulation Model* of the proposed GIS toolset to determine the measurable solar performance consequences for a given set of solar/weather system inputs. The SolarGIS/Meteonorm satellite/ground data associated with the *Meteorological Model Object* relate to the NREL medium resolution Typical Meteorological Year (TMY) datasets (Remund, 2015) for solar irradiation, statistical weather patterns and climatic conditions for the geographical location (GPS) of the water body host. The GIS object in Figure 3.1 is thus able to perform floating solar simulations over predefined time frames for data collection, while the TMY data enables the floatovoltaic *Energy Simulation Model* to repetitively compute the floating solar energy outputs over pre-set time intervals as input for determining the environmental profiles.

3.4.2. Environmental simulation model block diagram

The *Environmental Simulation Model* in the EIA GIS object layer of Figure 3.2 employs the sequential energy outputs (energy attribute dataset) of the *Energy Simulation Model* to determine the environmental impact parameters for a virtualised model of a planned floating solar PV system. The integration of the environmental model into the GIS toolset platform depicted in Figure 3.2 emphasise how the GIS layer is impleme nted on a different layer from the energy model in Figure 3.1. This aspect of the model is uniquely developed in this research to facilitate the study of the fundamental elements of the environmental impact assessment of floating solar systems as substitutes for national grid power. To this end, the study engages the South African EIM model (Eskom, 2014*a*) for registered Carbon Development Mechanism (CDM) projects, engaging grid Net Calorific Value (NCV) calculations to determine the Carbon Emission Factors (CEF) for the South African grid (Spalding-Fecher, 2011).

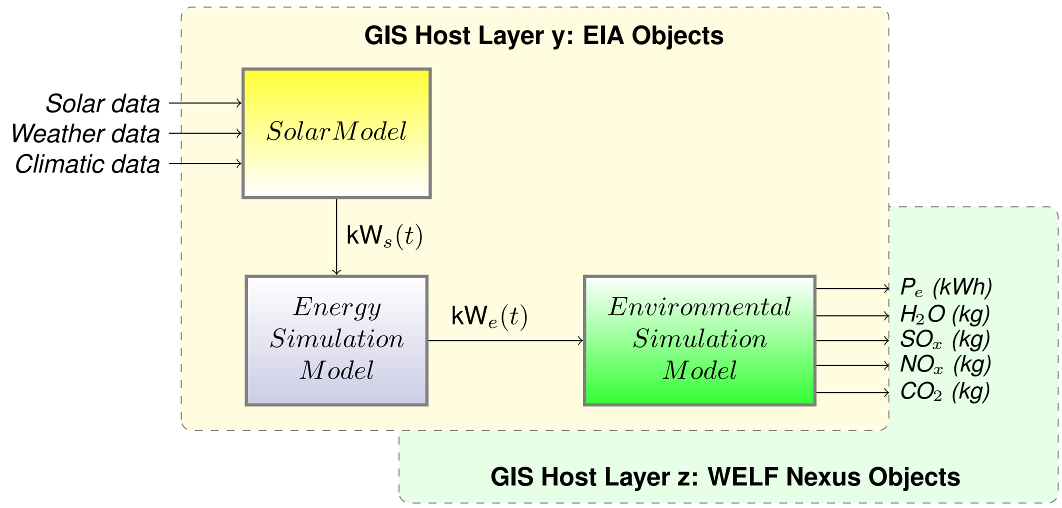


Figure 3.2: Block diagram for the *Environmental Simulation Model*, the GIS tool object model for studying the predicted environmental impact performance for planned floatovoltaic solar systems in grid-energy substitution applications.

By employing the environmental model characteristics developed by the national grid provider for the EIM model, it is possible for the *Environmental Simulation Model* in Figure 3.2 to compute the anticipated environmental impact attributes for a proposed floating solar system. In this way, the GIS toolset engages locationally-sensitive solar irradiation values and locationally-sensitive weather data sets associated with the GPS location of the selected floating solar water body (dam, irrigation pond) to determine the system's energy yield, which in turn determines the anticipated environmental impact attributes for a proposed floating solar system in terms of water preservation benefits, primary fuel/coal and coal ash waste savings, as well as avoided reductions in the emission of the substances such as SO_x, NO_x, CO_2 and aPE.

In broad terms, the logic of the proposed GIS-based model-driven simulation technique depicted in the GIS toolset host layers of Figures 3.1 and 3.2 is that the measurable attributes of the environmental-impact profile are determined as measurable EIA factors, and projected for the implementation of floating solar systems on a given farm. From Figure 3.2, it is evident that the WELF nexus parameters or attributes can be processed in the *WELF Nexus Objects* and offered as decision-supporting parameters to the user/EAP officer. The attribute parameters passed to this layer can be used as guidelines for studying and comparing various scenarios concerning sustainability (e.g. the optimisation of food production and interactions between land, energy and water resources). Such measurable nexus parameters are essential in environmental analyses for evaluating floating solar energy systems.

3.5. Experimental Procedures for GIS Toolset Demonstration

The functionality of the proposed GIS-based, decision-supporting tool that drives the energy and environmental models is demonstrated in a sequence of case-based scenario experiments. This demonstration emphasises the access to and processing of meteorological and environmental data in object-oriented simulation models embedded in a custom-designed and web-driven GIS platform - as detailed in the methodology description of this chapter. The resulting simulation results (or the results of the statistical analysis of the data) will be reported as graphs/charts or as decision metrics on the GIS tool's decision-supporting display screen. The methodological, model-driven, decision-support approach of this study engages the capabilities of the Google Maps interface to input and process the floating solar system data and parameters provided by the researcher.

Google Maps GIS interfacing will also be used to report the results in a manner that will assist decision makers in analysing the benefits and potential appropriateness of a planned floating solar system in a particular geospatial situation or context. As regards the decision-supporting functionality of the GIS-based toolset, the proposed GIS-based tool is classified as a passive decision-supporting tool. The GIS toolset facilitates the process of decision making by providing the EAP and floating solar project developer/decision maker with explicit information about the energy yield projections and the anticipated environmental impacts for the proposed or planned floating solar system.

3.5.1. Experimental site selection

In the experimental section of this study, three sites were selected in South Africa to demonstrate the operation of the proposed desktop GIS toolset from an environmental practitioner's perspective. The three sites are located in the Western Cape, Northern Cape and Mpumalanga provinces of South Africa. These experiments demonstrate the predictive environmental performance of hypothetically-planned floating solar systems at the selected locations in South Africa. From a GIS toolset demonstration perspective, computer-synthesised test-runs in the experimental section of this study are restricted to the following:
(a) predicting, through simulation, the energy output/environmental impact metric values (P_e, H_2O, CO_2, SO_x, NO_x, aPE, and aLP) for three hypothetically-planned, non-tracking, floating solar systems;
(b) plotting the predicted EIA metrics for each sample site as simulated time-graph plots (floatovoltaic energy/environmental model outputs over time); and
(c) enable user access to results by storing energy yield and environmental impact metric values on a topographical map of South Africa.

Once the GIS toolset reaches an operational level, at the point where its core functionality is available, it will be used to determine the environmental impact for several hypothetically-planned floating solar power systems at different geographical locations. The selected experimental demonstration sites include three fruit-/food-/juice-/wine- producing farm sites, the first site labelled "IF" around Nelspruit in Mpumalanga, the second site labelled "BF" around Bonnievale in the Western Cape, and the third site labelled

"RC" around Kakamas in the Northern Cape [1]. These three sites were further chosen because they have fruit-/food-/juice-/wine-processing facilities and are near a suitable water irrigation site, dam/pond which can possibly be applied for floating solar systems. For farms/businesses where fruit-/food-/wine-processing activities take place close to a water body (irrigation dam/pond), the electricity generated by a floating solar system can be fed directly into the farm's processing plant/factory with limited losses. Furthermore, fruit-/food-/wine-processing activities typically take place during the daytime when solar energy is available, thus offering the best opportunity for the farm's processing plant to make optimal use of the generated floating solar power during the daytime.

Because one demonstration site was selected in each of the three regions, Mpumalanga, Western Cape and Northern Cape, the experimental section will also demonstrate the toolset's operational performance for a geographical spread of sampling points. It will ensure an excellent spatiotemporal floating-solar-variation context, meaning the experimental predictions for the floating-solar-power outputs and environmental impacts will show anticipated levels of variation owing to a diversity of solar irradiation, climate, temperature and other location-specific conditions. This is because the energy-output and environmental-impact performances of floating solar system are usually dependent on a number of interconnected factors (solar irradiation, location, altitude, the panel-orientation angle, weather patterns, temperature) (Andrews *et al.*, 2014; Holmgren and Groenendyk, 2016).

3.5.2. Quantitative data collection and sampling

The first step in the evaluation methodology is for the researcher (as an environmental impact assessment practitioner) to collect data for sample test cases for arbitrary floating solar systems selected at the experimental analysis stage of this research. With the field data collected by the proposed GIS tool as a decision-supporting system, the responses serve as input parameters for the simulation model of the desktop computer. The second step in the method is to determine the potential amount of power that can be harvested from the sun and generated by each floating solar system at each farm site in the sample. The third step is to determine the environmental impact factors associated with the predicted annual energy outputs for each floating solar system from the second cycle of the computer simulation model.

In this research, the input data for the model include solar resource and meteorological data collected from the solar modelling toolset developed for the monitoring of the planning and performance phases of the solar energy systems. As mentioned earlier, the simulation model in this study uses Meteonorm and SolarGIS weather patterns and data to perform the actual synthesis of the operations of the floatovoltaic power installation (Meteonorm, 2016; SolarGIS, 2018). The tool platform can collect data from many weather stations that in their turn have collected meteorological data in various formats from these data sources. The GIS tool interface to feed the simulation software layers can accept a variety of weather data formats from various ground and satellite station sources. The data is typically available as Average Monthly Data, Standard TMY (Typical Meteorological Year) Data, TMY2 Data and Generated Hourly Weather Data (Solar Energy Lab, 2017).

[1] Acronyms IF,BF and RC serve as proxy references for commercial farms in the respective areas

3.5.3. Data processing method

The objective in the data processing and analytical phases of this research was to process the data samples collected during the quantitative data sampling and collection phase to quantify the anticipated environmental impact effects emanating from the installation of a hypothetical floating solar system for each location. Chandler and Scott (2011) state that, in the case of the data simulation analysis, research data collected can help to clarify and quantify the environmental changes. This process might involve explanations for past variations and can lead to an understanding of the mechanisms underlying any observed changes (Chandler and Scott, 2011).

Based on the environmental CMS technique described in the previous sections, the computer simulation models in the respective GIS layers could constitute a simulated environment for the collection of output data from the energy and environmental model. This data collection aspect of the study integrates the interdependent floating solar power and the environmentally-simulated systems. The CMS technique allows the geographer to perform data output sampling during the analysis of the simulation phase. By using a virtual solar power system in a farmland irrigation pond as the test environment, the EAP or geographer will be able to conduct data sampling and data analysis within a computer modelling environment that simulates the real-life implementation of a floating solar system on any farm landscape. Naturally, a farm that generates and supplies on-site energy would be less dependent on the energy from Eskom. This strategy reduces not only the amount of water used by Eskom to generate electricity but also the carbon footprint in the cases of both parties. Since the computer simulation model also computes the environmental impact parameters during the simulation process, the GIS toolset and simulation model will make it possible for the data output samples collected from the CMS model to assess the carbon footprint and the environmental impact aspects associated with this process.

3.5.4. Data analysis method

It was realised during the data processing phase of this research that the desktop CMS process could continue to play a valuable role in the decision-making-process (Kwan, 2004). The use of desktop CMS data in the predictive analysis of the floating solar system will make it possible for the environmental assessment practitioner to carry out a WELF nexus assessment to describe the various interactions between water, energy, food and land-use (the nexus parameters) (Flammini *et al.*, 2014). These metrics will enable the project owners to evaluate the technical performance of the floating solar system, within the context of the environmental aspects associated with the planned activities on their farms. An understanding of the relevant concepts that come to light during this study, as well as an analysis of the output data emanating from this research, will inform the researcher and eventually, and indirectly, through the dissemination of this information, promote environmental and economic sustainability, with the limited space on farms being effectively used and thus ensuring the productivity of the land and the space needed for crop production.

At the point where the core functionality is available, the experimental section of this study will engage the GIS-toolset at the different geographical locations in a desktop computerised environment. The goal with these experiments will be to demonstrate the predictive environmental performance of hypothetically-planned floating solar systems at the selected locations in South Africa. From the perspective of a GIS toolset demonstration, computer-synthesised test runs during the experimental section of this study will include the following experiments:

Experiment 1: Use the GIS toolset to determine the projected energy yield for the planned floating solar systems.

Experiment 2: Use the GIS toolset to determine the anticipated environmental impact benefits for the planned floating solar systems in relation to the application of the Eskom grid-substitution parameters.

Experiment 3: Use the GIS toolset in a decision-supporting analysis mode to display the energy outputs and environmental impact benefits for the planned floating solar systems in terms of the WELF nexus parameters.

In practical terms, the above experiments thus use the developed GIS tool to:
(a) conduct and display simulation predictions for the energy output/environmental impact metric values (P_e, H_2O, CO_2, SO_x, NO_x, aPE, and aLP) for three hypothetically-planned floating solar systems;
(b) determine and plot the predicted EIA metrics for each sample site as simulated time-graph plots (Floatovoltaic/Environmental model outputs over time);
(c) display the energy outputs and environmental impact benefits for the planned floating solar systems as WELF nexus parameters in a decision-supporting analytical display or portal; and
(d) make the results publicly available by publishing the results through a GIS website interface; also to plot the energy yield and environmental impact metric values on a GIS map for South Africa.
In terms of the assimilation of the results, the proposed methodology and GIS-based tool will contribute to the process of decision making by providing the EAP and the floating solar project developer/decision maker with explicit information about the energy-yield projections and the anticipated environmental impacts of the proposed floating solar system.

3.6. Summary

This chapter describes the research methodology to develop and test a geographical tool that would help clarify and quantify the environmental impacts associated with floating solar systems. The research methodology proposed in this chapter supports the EIA process within the fields of Physical Geography and Environmental Management. It proposes the integration of computer modelling and simulation models as software objects onto a GIS platform that models the dynamics of the floating solar system and the environmental impacts associated with the implementation of these systems. The governing philosophy behind the proposed method is that the GIS toolset defines a modelled synthesised environment for floating solar analysis in a simulated environment on an integrated GIS platform. During a simulated analytical phase, and within a computer modelling environment, this tool will allow the environmental assessment practitioner to simultaneously perform data output sampling and EIA analyses. It thus performs an EIA analysis within a computer modelling and simulation environment. It virtually simulates the real-life implementation of a floating solar system at any agricultural setting, within the borders of the South African EGIS database and system. The use of technical and environmental data in the integrated computerised energy and environmental software model described in this chapter supports most phases and aspects of environmental decision-making (Paegelow and Camacho-Olmedo, 2008). With the given contextual fieldwork parameters provided, the environmental simulation model processes the data for the analysis and evaluation of measurable environmental impact factors that could result from the roll-out of floating solar systems at any farm site in South Africa.

4. Results and Discussion

4.1. Introduction

By following the geographical systems methodology described in the previous chapter, the GIS tool named *EIAcloudGIS* was developed to conduct environmental analyses and environmental impact assessments in preparation for the installation of any proposed floating solar renewable power system in South Africa. This chapter introduces the *EIAcloudGIS* toolset with the online desktop/web interface and conducts experiments with the toolset at fruit farms located in three different provinces in South Africa. These experiments aim to determine the extent to which any particular floating solar configuration in one or more of the agricultural areas in South Africa can meet the desired energy yield in respect of due-diligence and environmental qualification criteria.

4.2. GIS Tool and User Interface

The custom-designed online GIS tool, named ***EIAcloudGIS***, was made available as an interactive cloud-based application tool, enabling the environmental impact practitioner to select and plan the chosen site and floating solar abstraction through a "Google Maps" dialogue interface. The *EIAcloudGIS* toolset was developed with the aim of ensuring an easily accessible and relatively simple interactive user interface for EIA practitioners to access and select geographical sites for the planned installation of floating solar systems. This would prove useful for future impact studies. The GIS web user interface (WUI) and data downloads are available on the world wide web (www). This *EIAcloudGIS* tool functions as an application that runs on any personal digital assistant (PDA), iPad, mobile phone, laptop or desktop computer.

The online *EIAcloudGIS* tool interface is portrayed in Figure 4.1. To prepare for the data collection process of the experimental phase of this study, the user engaged with the *EIAcloudGIS* tool dialogue interface to select the location and to create a digital terrain model of the proposed floating solar system. This interactive cartographic Google Maps interface runs as a real-time decision-supporting system (exhibited in Figure 4.1) and can be used to create thematic site maps for the farms in a way that represent real-world floating solar systems as abstract objects in the GIS platform tool layers. The *EIAcloudGIS* tool subsequently determines the anticipated environmental impact of a computer simulation analysis for any chosen location. The experimental analytical output dataset is accessible to any user, but is generally accessed by the practitioner through a secure username and password. The tool is able to output energy yield characteristics and environmental profile

***EIAcloudGIS* Decision Support Tool Display Screen**

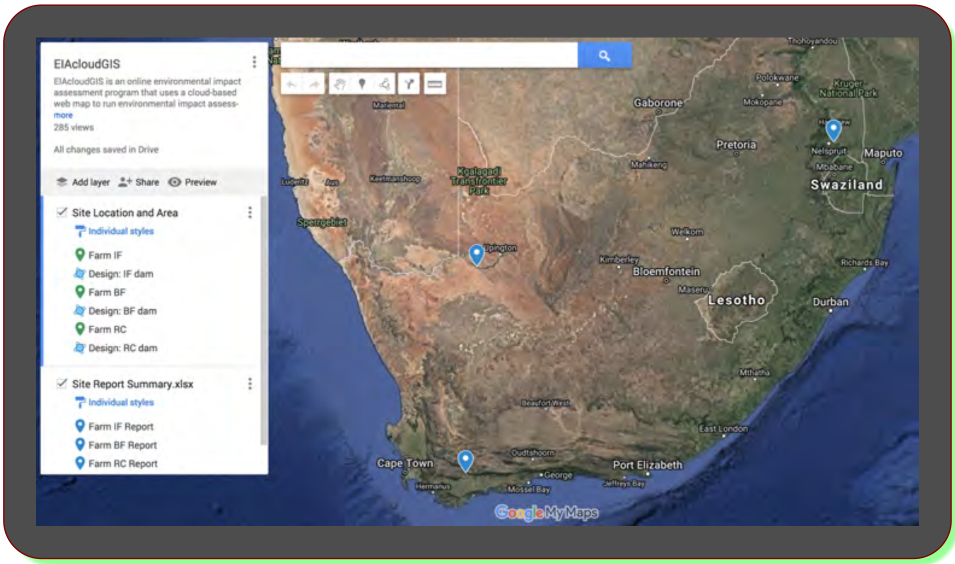


Figure 4.1: User dialogue interface for the geographical analysis toolset *EIAcloudGIS*, available online to support floating solar EIA processes in South Africa.

characteristics that are required to generate pre-installation EIA reports and due-diligence analyses for planned floating solar systems on farming sites in South Africa.

To use the tool, the impact practitioner starts off by accessing the *EIAcloudGIS* application portal on the application website. The application offers a clickable cartographic dialogue interface to define the geographical parameters for the proposed floating solar system (an abstract geometric object resembling a polygon shape). The user accesses the online website to navigate the site location, site characterisation, and to establish the solar design through graphical computer-aided design functionality. Once the suitable location of the floating solar site has been identified, the user draws and names the abstract floating solar representation as a representative polygon accordingly (geo-fencing the floating solar layout). The polygon GPS location and sizing parameters are subsequently engaged to calculate and assess the contextual energy production yield and the environmental impact profile for the planned floating solar system. To achieve this, the GIS tool interface uses a Google Geocoding API GIS for the web-based GIS application interface that operates as a basic computer-aided design tool. This API facilitates user dialogue that enables the environmental assessment practitioner to interactively build, create and embed graphical objects on thematic Google maps as drawings and pop-up labels (computer-aided design CAD phase). The GIS tool thus offers basic CAD-type functionality. This online graphical interface is used to render a floating solar overlay by drawing the outlay of the proposed floating solar system as CAD-type geodesic polygon shapes (layout markers, areas and text labels) on Google satellite maps. By running the floating solar model simulation at the end of the floating solar design layout, the *EIAcloudGIS* tool computes the geodesic polygon area for the floating solar representation from the geospatial Google map parameters and saves the SketchUp polygon drawing of the floating solar design layout on Google maps as a Keyhole Markup Language (.KML) file.

By using the *EIAcloudGIS* geoprocessing tool in the study's data collection plan, the data collection and experimental results for any planned floating solar system can be determined for any South African site selected on the map. The tool uses the site, solar system area and site-specific meteorological data (solar irradiation data and historical weather data patterns) as configuration parameters to simulate and predict the energy generating capacity and environmental impact profile for the proposed floating solar system. It also projects graphs and figures on online topographic or satellite maps, and generates reports in reporting formats required for the experiments conducted in this study. The environmental assessment practitioner can thus create a customised satellite or topographical map with built-in floating solar location markers. He/She can also save and view the graphs for the floating solar energy yield profiles with the environmental profile parameters for any selected site (as a downloadable Portable Document Format or .pdf file).

The *EIAcloudGIS* tool reports the energy yield characteristics and environmental impact characteristics on a Google map overlay. This overlay reports on the simulation-predicted solar energy yield or energy output (P_e), as well as the environmental impact profile metrics (H_2O, CO_2, SO_2, NO_x, aPE, and aLP) for any selected experimental floating solar system and site. The predicted EIA metrics for each sample site are plotted as simulated time-graph plots (floatovoltaic energy and environmental model outputs over time). Furthermore, the *EIAcloudGIS* tool provides summaries of the annual aggregated energy yield and environmental impact profile metric on a South African Google Maps GIS interface. The GIS tool uses location-linked overlay Info-Windows (latitude/longitude pin-marked waypoints icon pop-ups) on the web-driven geographical map interface to display the report summaries for each waypoint-marked floating solar site. For those sites on the map where full energy and environmental impact assessment report graphs are available, the environmental assessment practitioner can view or download the full energy and environmental impact reports by clicking on the report-link for the selected floating solar system.

The reader should note that the aim with using the GIS toolset in the present study experiments is to assist EIA processes for floating solar project approvals in absolute terms (to help practitioner complete EIA scorecard for each site). To use the tool for test-case site comparisons, the user must take cognisance of the fact that the energy production/environmental offset performances of floating solar systems in different test-case scenarios are dependent on several of inter-connected factors (solar panel/array size, solar panel type, solar irradiation, location, altitude, sunrise, sunset, panel-orientation angle, cloud cover, weather patterns, ambient temperature). Floating solar system performances can therefore only be compared with the GIS toolset if all of these factors are the same, or standardised/normalised, in the simulation runs for each site.

4.3. Experimental Site Selection

For the experimental phase of this study, three sites were selected for case-study scenario analyses in South Africa. The approach and procedure were described in detail in the experimental description methodology in Section 3.5. Three planned floating solar farm sites in the region were selected for experimentation with the *EIAcloudGIS* tool (see Section 1.7). The tool proved invaluable in that it engaged the geographical detail of these sites to determine the energy yield and environmental profile characteristics for the planned floating solar systems. By using the data collection and processing procedures described in Section 3.5.2 and Section 3.5.3, the *EIAcloudGIS* tool was able to determine whether the desired energy yields and environmental quality attributes anticipated by the EIA practitioner could be achieved with the planned/proposed floating solar system.

As described in the section *Research Location and Scope* in the first chapter of this study (Section 1.7), the experimental site selection criteria were based on selected sites for farms or businesses where fruit-/food-/wine-processing activities take place in proximity to a solar-suitable water body (irrigation dam/pond). This means that the electricity generated by the proposed floating solar system could then be fed directly into the energy network of the farms processing plant/factory with limited losses. By choosing one demonstration site for each of the three provincial regions of Mpumalanga (MP), Western Cape (WC) and Northern Cape (NC), this research was able through the experimental section of this study (Section 4.4) to demonstrate the toolset's operational performance for a geographical spread of sampling points. This ensured that experimentation was conducted in the context of an excellent spatiotemporal floating solar variation, meaning that the experimental predictions for the floating solar power and environmental profiles would show anticipated levels of variation owing to diverse variations solar irradiation, climate, temperature and other site-specific conditions.

4.3.1. Selection of experimental case study areas

In preparation for the *experimental phase* of this study, three sites were selected for the demonstration of the *EIAcloudGIS* geographical toolset operations. Table 4.1 provides a summary of the geospatial details for each of the selected experimental sites described in the rest of this section.

Table 4.1: Experimental site characterisation summary and details.

Experimental Site Parameters			
Parameter	Mpumalanga (MP)	Western Cape (WC)	Northern Cape (NC)
Area proximity	Nelspruit	Bonnievale	Kakamas
Site label	IF	BF	RC
Floating PV area	1,355 m^2	1074 m^2	842 m^2
Latitude	-25.43152	-33.91978	-28.70510
Longitude	31.097261	20.198051	20.532577
Altitude	665 m	213 m	650 m
Time zone	GMT 2.0	GMT 2.0	GMT 2.0

The first site, labelled IF around the Nelspruit area in Mpumalanga province, was selected. This floating solar installation test site (IF) incorporates an irrigation dam on a fruit farm. One of the farm's irrigation dams was chosen for the experiment. While most fruit farms in the Nelspruit area are characterised by numerous irrigation dams, this particular site, with its irrigation dam, was chosen to represent the average fruit farm in that area. The proposed floating solar system for this site was designed as an experimental system for the *EIAcloudGIS* toolset to perform planning calculations around its expected potential environmental impacts and the potential energy expected to be generated from the site over a full year (12 months) period.

The second farming site selected for experimentation with the *EIAcloudGIS* toolset was labelled BF. The farm BF is situated in the region of Bonnievale, near Swellendam in the Western Cape, where the main fruit-farming practices centre around orchards, fruit processing and fruit packaging. Once again, one of the farm's irrigation dams was chosen as an installation site for a planned floating solar system. The third experimental farming site, labelled RC, a fruit farm, is located in the Kakamas area, near Upington in the Northern Cape. RC's main farming practices centre around the production and processing of grapes, raisins and wine. The particular site was chosen to be representative of fruit farming and processing practices in the Kakamas area, where irrigation dams, generally used to irrigate the orchards and vineyards, are close to the processing facilities. Once again, one of these irrigation dams was selected for the *EIAcloudGIS* toolset to run its computer simulation model on in order to predict the energy yield and environmental impact profile for the experimental site RC.

The ensuing experiments will engage the geospatial terrain data in Table 4.1, together with the meteorological data for each geographical location, as inputs to the *EIAcloudGIS* toolset in Section 4.2. With these inputs, the toolset was able to predict the energy yield outputs and the associated environmental impact outputs for each site according to the computer simulation model and weather data for each site and installation area. Data pertaining to the differences in the meteorological weather and solar conditions around the fruit-farm sites for the three provinces of South Africa would showcase the respective energy production capacities for the different sites with their associated environmental conditions.

With the experimental sites selected, the *EIAcloudGIS* tool was used to define and display the geospatial terrain data for the floating solar systems for each of the representative geographical site in Table 4.1. The composite satellite map in Figure 4.2 displays the spread of selected experimental sites (Section 4.3.1) that were evaluated in empirical case-studies for the respective floating solar energy production units in the three different provinces of South Africa.

***EIAcloudGIS* Toolset Map Display Screen**

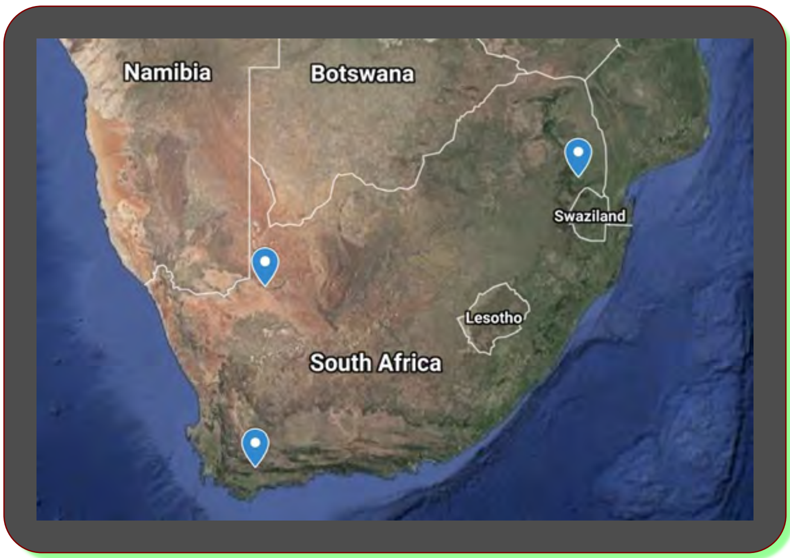


Figure 4.2: Experimental sites IF, BF and RC projected on the *EIAcloudGIS* geospatial map.

The map display in Figure 4.2 shows the planned floating solar sites prepared for site characterisation. When it comes to choosing these sites for experimental purposes, it was considered imperative for the environmental impact comparisons between the respective locations that there should preferably be a fair amount of spatial diversity. As such, the selected sites resemble three locations around South Africa and serve to display differences in solar irradiation, weather patterns, energy and environmental inputs and outputs.

The range of selected experimental sites could then be used to demonstrate the *EIA-cloudGIS* tool functionality for determining the anticipated environmental impacts for planned floating solar systems at different locations in South Africa. The next section provides a more detailed profile on the floating solar system characteristics for the marked sites on the composite satellite map of Figure 4.2, for each of the sites.

4.3.2. Experimental floating solar systems for case studies

In this section, the designed and developed *EIAcloudGIS* tool was used in site characterisation mode to represent the planned floating solar geospatial layout. This tool mode involved the use of the basic CAD-type design functionality on the Google satellite map of the GIS tool to produce a floating solar system overlay. This was done by drawing the outlay of the proposed floating solar system as a series of geodesic polygon shapes (layout markers, areas and text labels). With these system layout designs completed, and the SketchUp polygon drawing of the floating solar design layout saved as .KML files, the experiments could proceed with the floating solar system simulations that emulate the operational behaviour for the representations of the designed floating solar systems at the selected site.

This is demonstrated on the terrain map of Figure 4.3, which details the site of the floating solar system, the design layout and the geographical terrain model for the designed floating solar system at the first demonstration site on the *EIAcloudGIS* tool interface. The planned floating solar system for this particular site and irrigation dam, on the farm IF near Nelspruit (MP), has an effective solar exposure covering an area of 1,355 m^2 and is located 665 metres above sea level.

To provide the reader with some indication of the solar resource radiation spread and resource availability around the Nelspruit area, Figure 4.4 provides a snapshot of the SolarGIS (2018) *solar map* for the siting of a floating solar system on the farm IF, near Nelspruit (MP). The radiation levels are favourable and point to an ideal site for harvesting solar radiation with an average annual sum around 1900 kWh/m^2.

As regards the second experimental site, the terrain map in Figure 4.5 shows the siting of the floating solar system, the design layout and the geographical terrain model for the system chosen on the farm BF, near Bonnievale (WC), on the *EIAcloudGIS* tool interface. The planned floating solar installation for site BF covers an active solar exposure area of 1074 m^2, and is located at an altitude of 213 metres above sea level.

Figure 4.6 provides a snapshot of the SolarGIS (2018) *solar map* for the siting of a floating solar system on the farm BF, near Bonnievale (WC), in order to indicate the spread and availability of solar resource radiation around the Bonnievale area. There is evidence of a lucrative source of solar energy since the harvesting potential of around 1900 kWh/m^2 in terms of average annual sum, is extremely good.

The terrain map in Figure 4.7 details the site of the floating solar system, the design layout and the geographical terrain model for the farm RC, near Kakamas (NC) on the *EIAcloudGIS* tool interface. The irrigation dam selected for the possible installation of a

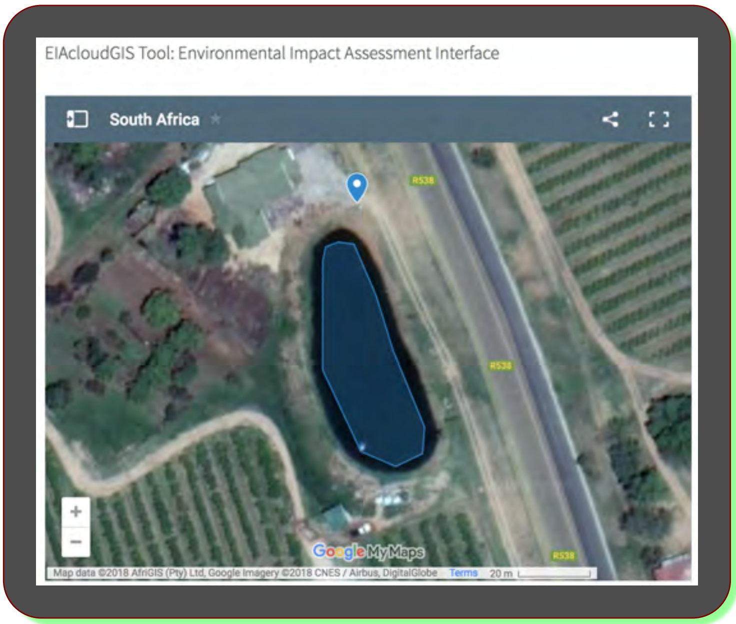


Figure 4.3: *EIAcloudGIS* tool interface, showing the siting of a floating solar system, the design layout and the satellite image for the farm IF near Nelspruit (MP).

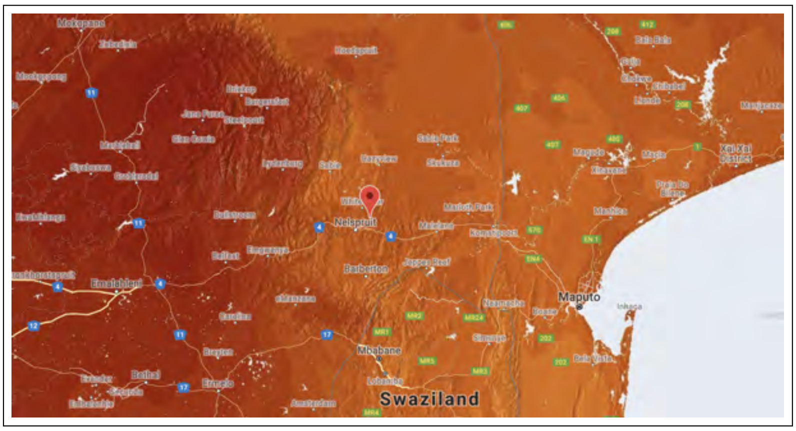


Figure 4.4: Solar map for the siting of a floating solar system on the farm IF, near Nelspruit (MP) (SolarGIS, 2018).

floating solar system at RC covers an active solar exposure area of 842 m^2, and is located at an altitude of 650 metres above sea level.

Figure 4.8 provides a snapshot of the SolarGIS (2018) *Solar Map* for the siting of a floating solar system on the farm RC, near Kakamas (NC), once again to provide the reader with an indication of the spread and availability of solar resource radiation around the Kakamas area. This area in the Northern Cape experiences an above average annual sum total of solar radiation at around 2240 kWh/^{2}. The availability of solar energy in this region is excellent and provides an exceptional harvesting potential all year round.

With the sites for each of the three provincial regions in South Africa chosen, the experimental section will now demonstrate the *EIAcloudGIS's* operational performance for

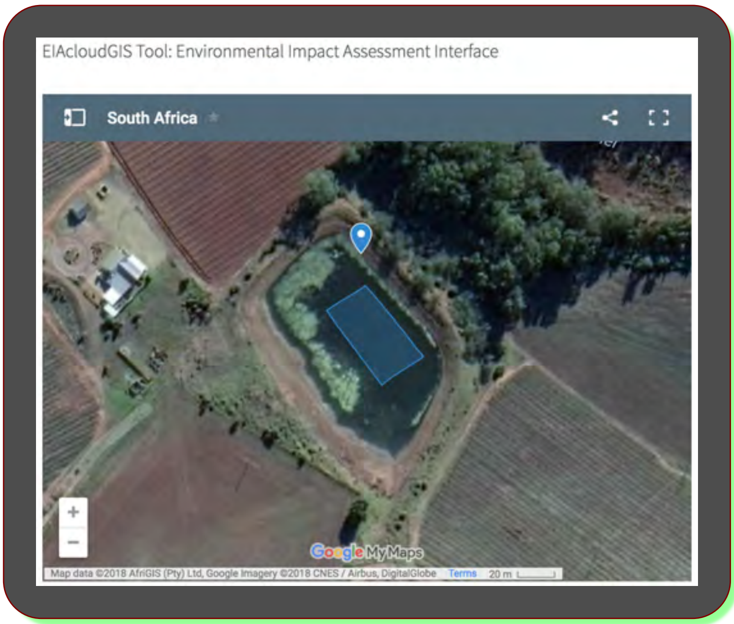


Figure 4.5: *EIAcloudGIS* tool interface, showing the siting of a floating solar system, the design layout and the satellite image for the farm BF, near Bonnievale (WC).

Figure 4.6: Solar map for the siting of a floating solar system on the farm BF, near Bonnievale (WC) (SolarGIS, 2018).

this geographical spread of sampling points. With the selected range of farming sites, the experiments in the next section are well placed to ensure an effective spatio-temporal context for floating solar variations. This approach means that the experimental predictions for the floating solar power outputs and environmental impacts will be successful in quantifying anticipated levels of variation on account of the diverse variations in terms of solar irradiation, climatic, temperature and other site-specific conditions. The newly-developed geographical-toolset *EIAcloudGIS* was used to calculate and illustrate the energy yield and environmental characterisation results for each site and to graphically present these results. This matter is discussed in the next section.

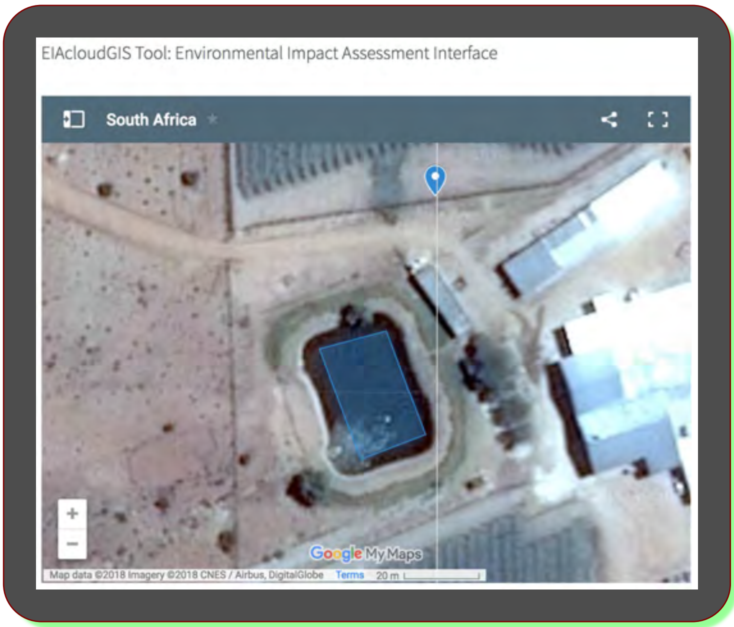


Figure 4.7: *EIAcloudGIS* tool interface, showing the site location of a floating solar system, the design layout and the satellite image for the farm RC, near Kakamas (NC).

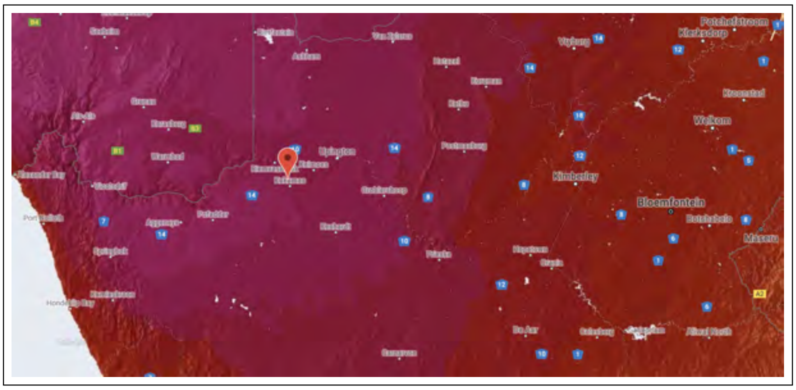


Figure 4.8: Solar map for the siting of a floating solar system for farms around the site RC, near Kakamas (NC) (SolarGIS, 2018).

4.4. Experimental Analysis and Results

While this research project is concerned with the development of a GIS-based decision-supporting tool for environmental impact assessments and due-diligence analyses of planned agricultural floating solar systems, the aim of the experiments was to demonstrate the functionality of the *EIAcloudGIS* toolset in terms of the energy yield and the environmental profiling of the solar farming applications. As such, these trial tests set out to demonstrate the production yield and environmental impact profiling results for each site in terms of the tool's ability to conduct analyses of the energy yield and the environment, and of the decision supporting methodology. Towards attaining the aim and objectives of this study, the afore-mentioned can therefore be considered as experimental analytical studies that assess the ability of the *EIAcloudGIS* tool to determine the due-diligence and environmental impact analyses of integrated floating solar energy solutions in agricultural production systems.

With the floating solar system layout designs completed, and the SketchUp polygon drawings of the floating solar designs saved as .KML files - as discussed in the previous section - the experiments in this section proceeded with system simulations and emulations that mimic the system dynamics and operational behaviours for the proposed floating solar system designs at the chosen site. The proposed experiments would thus provide information on the future anticipated energy yield capacity and environmental impact characteristics for floating solar systems on fruit- farm and -processing sites in the Mpumalanga, Western Cape and Northern Cape provinces. The reporting functionality of the *EIAcloudGIS* tool played an important role in generating valuable information required to complete due-diligence analysis and EIA approvals for the proposed floating solar systems in terms of the National Environmental Management Act, Act 107 of 1998 (S.A. Government, 1998).

4.4.1. Experiment 1: Floating solar energy yield analysis

The first experiment intended to demonstrate the energy characterisation functionality of the *EIAcloudGIS* toolset for the three experimental sites. For this energy yield analysis and experiment into quantifying its production capacity, the *EIAcloudGIS* tool employed a quantitative data-gathering methodology to perform an initial resource assessment of the floating solar site as part of an energy-profiling exercise for the farm sites defined in Section 4.3. The computational solar system behaviour models embedded in the energy layer of the *EIAcloudGIS* tool considered the photovoltaic covering and topography of the site together with other local factors (the weather and atmospheric effects) that might affect the suitability of the farming site for the proposed floating solar (floatovoltaics) project. While this experiment showcased the potential of the GIS toolset to perform energy analysis, the results enabled the environmental practitioner (or farmer) to determine the extent to which a particular floating solar design configuration would be capable of meeting any criteria in order to qualify for the desired energy production yield. Moreover, considering the technical due-diligence procedures required to mitigate technical and investment risks on a floating solar project, the reports generated by the *EIAcloudGIS* toolset provided valuable metrics for on-site assessments and information in terms of energy yield predictions to evaluate during the due-diligence processes.

4.4.1.1. Goal of experiment

The goal of the first experiment was to apply the analytical procedures of the floating solar GIS toolset to determine the projected energy yield for the planned floating solar generators at the selected fruit-farm sites labelled IF, BF and RC (sites detailed in Table 4.1). To account for the local solar irradiation and weather conditions for these sites, the *EIAcloudGIS* tool collected information regarding the historical solar, meteorological and weather conditions for each of the three agricultural floating solar systems. Regarding the methodology and the computational model defined in Section 3.4.1, the experimental energy characterisation results were determined from the computer-simulated energy model outputs and time-graph reports produced by the *EIAcloudGIS* toolset as monthly and aggregated annual energy yields. The aim was for the energy production yield results to be fed into the floating solar system feasibility analyses, so that the energy production capacity and yields could serve as decision metrics in a decision-based approach. These metrics would assist in clarifying the relationships between floating solar technology investments, the green energy economy, the environmental economy, and the conservation of the relevant natural resources on a global scale that would be essential to the mitigation of climate change.

4.4.1.2. Experimental method and procedure

As regards the experimental methodology detailed in Section 3.4, this experiment predicted the energy yield for the experimental sites under the computation modelling procedures described in Figure 3.1. The procedural steps for this methodology are set out in the basic diagram in Figure 4.9, which shows a summary of the experimental steps. The experimental steps in Figure 4.9 firstly involved the user (researcher, farmer, EAP) to engage the *EIAcloudGIS* tool web interface (Section 4.2) in order to select the relevant location for establishing a new floating solar project on the online Google Maps display screen.

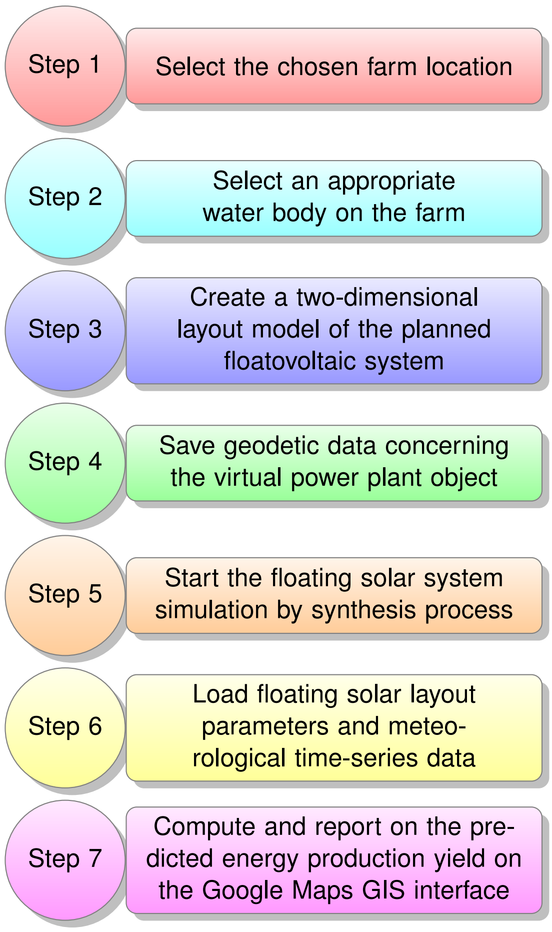


Figure 4.9: Experimental steps for determining the energy yield profile for floating solar systems in a case-based analysis scenario.

The second step in the procedure of Figure 4.9 was for the user to zoom into the chosen site and to select the appropriate water body (dam, reservoir) for the design of a floating solar system. The third step was for the user to create a two-dimensional layout model of the planned floatovoltaic system by designing a pseudo/virtual floating solar system on the water body at the selected site. The layout design for the floating solar object was created by editing a geometric polygon object as a means of describing the physical layout of the planned floating solar system for that site. Step four completed the design process for the planned floating solar layout, in which the *EIAcloudGIS* tool saved the geospatial data of the site, together with the geodetic data concerning the object details of the virtual power plant (in a Keyhole Markup Language .KML file).

The fifth step in this analytical procedure embodied the activation of the *EIAcloudGIS* tool energy simulation model to run the relevant energy simulation procedures. This conducts the environmental performance assessment for the planned floating solar system at that particular site. In the sixth step, the floatovoltaic *Energy Simulation* block in Figure 3.1 engaged the numerical Python-based simulation model in the digital simulation platform layer of the GIS toolset. In this step, the *EIAcloudGIS* tool loaded the floating solar layout parameters and meteorological time-series data in order to run the mathematical model simulation of the floating solar system in discrete time steps over a one-year time horizon (12 month window period). As part of this process, the *EIAcloudGIS* tool engaged the *Meteorological Model Object* block hosted on the GIS toolset *Meteorological Object Layer* (Figure 3.1). This solar model downloaded the site-specific meteorological time-series datasets required to perform time-series simulations in energy-yield profiling. At this stage, the user might have been be requested to insert his/her credit card details to buy the historical satellite-derived datasets for solar irradiation, cloud modulation and meteorological conditions for the selected location (around Euro 250 per site) from the prevailing online data service delivery platform (Meteonorm, 2016; SolarGIS, 2018).

With the relevant historical meteorological datasets available, the *EIAcloudGIS* tool processed the floating solar operational data in a stepwise analysis-by-synthesis process to quantify the aggregated monthly and annual energy yield values for that particular site over a full year. In the seventh and final step of the experiment detailed in Figure 4.9, the *EIAcloudGIS* tool reported the predicted energy yield quantitatively on the tool's Google Maps interface and stored the results in a GIS database. This enabled the user to subsequently engage the tool's Google Maps interface in downloading the energy yield results for the floating solar systems planned for the three farming sites in the form of a Portable Document Format (PDF) report.

4.4.1.3. Energy yield analysis case study results

In terms of steps one to five of the experimental procedures, the outcome of the case-based design process for the three fruit farms, IF, BF and RC, was completed earlier on in this chapter (Section 4.3.1). The case-based scenarios for the floating solar designs for each site are shown in Figure 4.3, Figure 4.5 and Figure 4.7 respectively. In the sixth step of the experimental procedure, the *EIAcloudGIS* tool conducted a solar resource assessment and a meteorological pattern analysis for the given sites of the floating solar systems in Figure 4.3, Figure 4.5 and Figure 4.7 respectively. For this purpose, the *EIAcloudGIS* tool used the associated meteorological site data to predict the energy outputs for planned floating solar systems for each of the three sites.

As for the the seventh step in the experimental procedure, the simulated *EIAcloudGIS* tool energy model output values (P_e) in Figure 4.10 represent the time series for the predicted energy yield profiles for the planned floatovoltaic systems in case-based scenario analyses for the respective experimental sites. The energy yield patterns for floating solar generators at the selected sits are portrayed in the site-specific profile graphs of the energy time series of Figure 4.10. In Figure 4.10, the energy-yield profile graphs, and associated temporal and seasonal variations for the experimental sites IF (Nelspruit, MP), BF (Bonnievale, WC), and RC (Kakamas, NC), are represented by the orange- (IF), pink- (BF) and blue- (RC) coloured profile time series plots respectively.

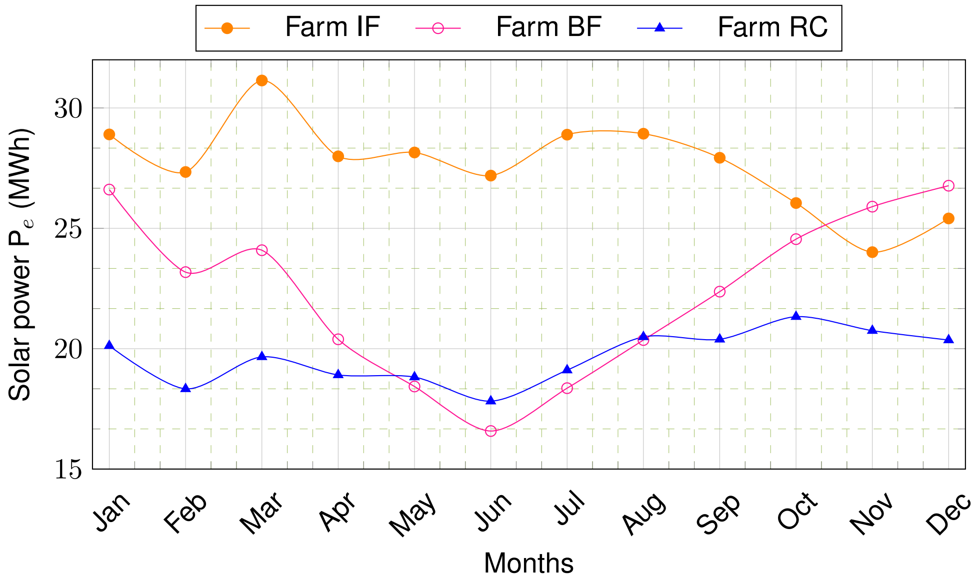


Figure 4.10: Energy yield profile plots and cumulative annual production capacity (MWh) predicted by the ElAcloudGIS tool for planned floatovoltaic systems at farming sites IF (331.9 MWh), BF (267.6 MWh) and RC (236.1 MWh).

From the time-series graphs reflecting the energy yield profiles in Figure 4.10, the *EIAcloudGIS* tool computed the total annual energy outputs for the three proposed floatovoltaic systems by summing the energy model outputs over a full year period. Through the mathematical summation of the energy yield profile in Figure 4.10, the *ElAcloudGIS* tool was able to determine the synthesised annual production capacity for each planned floating solar system to be IF (331.9 MWh), BF (267.6 MWh) and RC (236.1 MWh).

By further comparing the totals of the delivery capacity of the floating systems to the cumulative amount of annual incoming solar irradiance for each of the three floating solar sites, the *ElAcloudGIS* tool was able to determine the relative solar-to-electricity conversion efficiency for each of the planned floating solar systems. Thus, the *ElAcloudGIS* tool was able to perform a solar radiation analysis by summing the cumulative amount of annual incoming solar irradiance from the meteorological time series data files for each site. The *ElAcloudGIS* toolset determined that the annual incoming solar irradiance (MWh) for the planned floatovoltaic systems at farming locations are equal to IF (2769.08 MWh), BF (2217.4 MWh) and RC (2079.6 MWh) respectively.

The *ElAcloudGIS* tool finally engaged these annual incoming solar irradiance quantities to determine the actual predicted floatovoltaic solar-to-electricity conversion rates for each of the floating solar systems as each of the experimental sites. For the three planned floating solar sites, these efficiencies were determined through the ratios 11.9%

(331.9 MWh/2769.08 MWh) for the site IF, 12.1% (267.6 MWh/2217.4 MWh) for the site BF, and 11.4% (236.1 MWh/2079.6 MWh) for the site RC. Note that these efficiency rates for solar insolation-to-electricity conversion, also known as the theoretical performance ratios, might vary slightly among the three sites as a result of the normal variations in environmental operating conditions (e.g. moisture content, ambient air pressure, ambient temperature) for them.

4.4.1.4. Summary and conclusions for energy yield analysis experiment

The use of the developed *EIAcloudGIS* tool in this experimental energy-profiling case study demonstrates the methodological use of the tool to gain clarity in a geographical context and predictive insights into the planning of real-world systems in various spatial application domains. In this way, the *EIAcloudGIS* tool showed how its property for software modelling could draw on the growing body of geographical knowledge in its modelling and application of case-based scenarios in respect of analytical techniques for floating solar architecture. This was realised through the ability of the online GIS platform to project the energy yield, capacity and conversion efficiency for any locally-planned floating solar energy production system.

The solar power yield profile was calculated over a full year and integrated to determine the annual production capacity for the three sites. Figure 4.10 shows that the sites in the Northern Cape, Western Cape and Mpumalanga produce high potential energy yields, making solar energy a valuable natural resource to tap into. Furthermore, the figure indicates the different solar power yields in each region with good indications as to how different areas experience sun radiation on the earth's surface.

By engaging the *EIAcloudGIS* tool, the energy yield patterns for the geographically-selected site for the respective case studies could be empirically determined and graphically portrayed. Figure 4.10 plotted the time series for the energy yield profiles for the experimental sites as orange- (IF), pink- (BF) and blue- (RC) coloured energy profile traces respectively. As regards the capacity of each of the floating solar systems or their annual solar energy yields, the *EIAcloudGIS* tool quantified the annual production capacity for the planned floating solar systems as IF (331.9 MWh), BF (267.6 MWh), and RC (236.1 MWh) respectively. By relating the floating system system capacity totals IF (331.9 MWh), BF (267.6 MWh), and RC (236.1 MWh) to the annual incoming solar irradiance for each site IF (2769.08 MWh), BF (2217.4 MWh) and RC (2079.6 MWh), the *EIAcloudGIS* tool was able to quantify the relative solar-to-electricity conversion efficiency ratios for each of the sites as follows IF (11.9%), BF (12.1%) and RC (11.4%).

Important to note is that the relative variations in the magnitudes of the solar energy yield profiles and the solar-to-electric conversion efficiency for the planned floating solar systems on the farms IF, BF, and RC in Figure 4.10 differed slightly. The relative differences were firstly as a result of the relative area of solar panel coverage (the relative floating solar system layout size) and the size of the water bodies at the three farming sites. Secondly, the prevailing weather conditions and variations in cloud cover limited the intensity of the sunlight levels on the floating solar panels, thus impacting directly on the energy output levels of the three floating solar systems. As illustrated in Figure 2.4, these variations in the environmental conditions reflect directly on the site-specific weather patterns, ambient temperatures and level of cloud-cover which in turn impact directly on the resulting energy yield of the solar renewable energy systems over time.

The third consideration for the dynamic variations in the floating solar energy output profiles was found to be the seasonal nature of the availability of light. Of note are the changes in the hours of sunlight throughout the year, at least at locations that are further away from the equator. The time-varying characteristics of the solar energy yield profiles for the farms IF, BF, and RC in Figure 4.10 and the energy output envelopes for the three systems showed roughly similar seasonal time variations, which could be expected from sites that are all located in the same hemisphere. The floating solar system energy yield for the three sites could thus be seen to vary as a function of both space (location) and time (season). The time-series energy profiles in Figure 4.10 demonstrate the fact that the aggregated amount of incoming monthly solar radiation, and consequently the monthly solar energy budget for each planned floating solar system, vary from season to season among the three sites. The sites are located on different latitudes. As such, there are temporal variations in the energy output profiles mainly as a result of variations in solar illumination (NASA, 2018).

As a final comment, the reader should note that the development of the toolset was aimed at determining the direct contribution of the various systems in absolute values, with different test sites demonstrating the ability of the GIS toolset to handle site specific variations. It would be no simple task to determine, explain and justify the differences in energy-output and environmental-impact performances of floating solar systems per site in Figure 4.10, as these performances are dependent on a number of inter-connected factors (solar irradiation, location, altitude, sunrise, sunset, solar panel size, solar panel type, panel-orientation angle, cloud cover, weather patterns, ambient temperature). The GIS tool would have to isolate each aspect and re-run the simulations to determine and justify the impact of each particular factor. This would be a huge task, and would defeat the purpose of the study, which is not to compare site performances but rather to determine absolute values for energy yield and environmental profiles as required by EIA approval processes.

4.4.2. Experiment 2: Floating solar environmental impact analysis

In Experiment 2, focusing on environmental analysis and environmental profile characterisation, the environmental layer of the *EIAcloudGIS* tool model was engaged in the second cycle of processing to compute the outputs of the environmental model profile outputs. The *EIAcloudGIS* tool also employed a quantitative-data-gathering methodology to synthesise the performance-modelling procedures detailed in Section 3.4.2. In this way, the tool was able to generate assessment reports of environmental profiling as inventories of projected greenhouse gas emissions. This experiment used the same calculation process as that employed in Experiment 1 (Section 4.4.1.2) for determining these energy profiles energy production profiles in order to describe the *environmental profiles* for the three planned floating solar-power-production systems. By using the respective energy yield profiles as inputs, the environmental impact profiles could be distinguished in terms of the greenhouse gas substances falling into the specific factor categories reflecting environmental impact. Since the environmental profile of a floating solar system proved to be a linear function of the system's energy yield profile, as demonstrated in Experiment 1 (Figure 4.10), the time series for the environmental profiles for the various substances in this experiment were expected to resemble the temporal behavioural patterns and seasonal characteristics of the time-series profiles for energy yield.

4.4.2.1. Goal of experiment

In this experiment, the goal was to engage the diagnostic capabilities of the *EIAcloudGIS* tool to determine the extent to which a particular floating solar system design and configuration would be able to mitigate environmental pollution. The goal was to describe and evaluate the environmental impact profile of floating solar systems and to assess the system's ability to meet the desired environmental due-diligence qualification criteria based on Eskom's environmental pollution data model EIM (Eskom, 2017). By following the geographical methodology described in Section 3.4 of the previous chapter, the environmental analysis and environmental impact assessment for any proposed floating solar energy system offer a quantitative decision-oriented approach to understand the relationship between the environmental profile and methods to mitigate climate change. The *EIAcloudGIS* tool diagnostics were expected to provide guidelines towards quantifying the environmental impact of floating solar systems in respect of their mitigatory potential for countering climate change. The results for the experiments conducted for this research project are therefore likely to confirm that Eskom's power generation through the burning of coal is a negative driver for change in the global atmosphere and climate (Letete *et al.*, 2010), which can be mitigated mainly by substituting Eskom grid power with clean solar energy from floating installations on farms. The relevant GIS-based computer-simulated model outputs (energy yield and environmental impacts) would thus support EIA protocols in the evaluation of any proposed floating solar systems.

4.4.2.2. Experimental method and procedure

In this experiment, focusing on the description on characterisation of an environmental profile, the environmental layer of the *EIAcloudGIS* tool computed the profiling outputs of an environmental model by using the synthesised performance-modelling procedures detailed in Section 3.4.2. For this methodology, the floating solar system energy yield analysis was used to compute the environmental impacts for the selected site listed in Table 4.1. This diagnostic type of experiment analysed the environmental impacts of the experimental sites by following computational modelling procedures in the experimental model and according to the methodology detailed in Section 3.4. In this description, the computer simulation model in Figure 3.2 was custom-designed to study the essential environmental impact assessment aspects of floating solar systems. From the time-series data in respect of energy performance determined by the floatovoltaic *energy simulation model* in the previous experiment, the *EIAcloudGIS* tool engaged the *environmental simulation model* in Figure 3.2 to profile and predict the environmental impact of the floating solar system based on the time series (historical statistics) of the solar irradiation and weather patterns for each of the experimental sites. Procedurally, the *environmental simulation model* engaged the *energy simulation model* outputs (Figure 4.10) as inputs, to simulate the floating solar environmental impact profiles. In this way, the *EIAcloudGIS* tool was able to compute the environmental profile time series for the planned floatovoltaic systems on the farms IF, BF, and RC. This was done by running a parametric simulation model in discrete time steps over a one-year time horizon (12 month window period).

According to this model, the environmental characterisation of a floating solar power plant can be computed from proportional equivalence factors for the relevant greenhouse gas substances (H_20, CO_2, SO_x, NO_x, aPE) (Eskom, 2014*a*). The characterisation of the environmental profiles of floating solar power plants involves the quantification of the reduction in the concentrations of direct and indirect greenhouse gases from pollutants emitted by coal-fired power plants, especially in the case of substances such as carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_x) (nitrogen monoxide and nitrogen dioxide) and airborne particle emissions (aPE).

4.4.2.3. Environmental impact case study results

The results obtained by the *EIAcloudGIS* tool in this step in characterising floating solar plants were used to plot the potential environmental impacts from the energy model outputs for each of the selected farming sites IF, BF, and RC. The resultant list of scores for effective pollutant substances constitutes the *environmental footprint* or *environmental profile* of a floating solar system. The proportional environmental advantages of a floating solar system for water (H_20) conservation, air quality improvements (reductions in the concentrations of gases), the control of particle emissions (CO_2, SO_x, NO_x, aPE), fuel reductions (coal), and reductions in coal waste (ash) (Eskom, 2014*c*) reflect the collective impact on the environment. These avoided substance emissions and environmental impact savings contribute to the green initiative and carbon reduction in the agricultural sector.

In the context of this experiment, the time-series plots in Figure 4.11 reflect the mitigating effects of the proposed floating solar systems for the farms IF, BF and RC respectively on CO_2 concentrations and on climate change. The *EIAcloudGIS* tool was used to simulate the predicted outputs according to the reduction in CO_2 (kg/ton) concentration. In the Eskom EIM model, the environmental impact of CO_2 concentrations for a floating solar system in a grid substitution application is a function of the energy model output (model defined in Chapter 3). Figure 4.11 indicates the results by demonstrating the predicted reductions in CO_2 (kg/tons) concentrations for each site on a monthly basis. The monthly levels of reduction in the CO_2 concentrations are plotted in tons, while the annual cumulative total reduction in CO_2 concentrations were found to be equal to IF (328.6 tons), BF (264.9 tons) and RC (233.7 tons) respectively per year.

The results in Figure 4.11 should be viewed against the backdrop of Figure 1.1, where CO_2 is shown to be one of the major greenhouse gasses associated with the generation of energy and global-scale atmospheric CO_2 gas concentrations recently exceeded the benchmark of 400 parts per million (ppm) (Harris and Roach, 2018). In this context, the relevant time-series plots in Figure 4.11 reflect the proposed value in respect of the environmental impact of planned floating solar systems in the reduction of the carbon footprint for each of the three sites. It shows that floating solar systems provide a valuable controlled method for mitigating and compensating for unavoidable impacts of air pollutants radiated by coal fired power stations, especially by providing environmental offset benefits such as CO_2 reductions (Figure 4.11). This result is of great significance as atmospheric CO_2 levels keep rising on account of the process of coal-based power generation, causing negative externalities with a broad impact on the local environment (EPA, 2018).

While NERSA and Eskom are in the process of developing a framework for energy wheeling by privately owned generators (Eskom, 2011), the estimated CO_2 equivalence factors (depicted in Figure 4.11) offer valuable opportunities for floating solar project owners. In the NERSA framework, floating solar system owners would be considered non-Eskom Generators (NEG), meaning they will be allowed to participate in energy wheeling within the boundaries of the South African Eskom distribution network. Energy wheeling may cre-

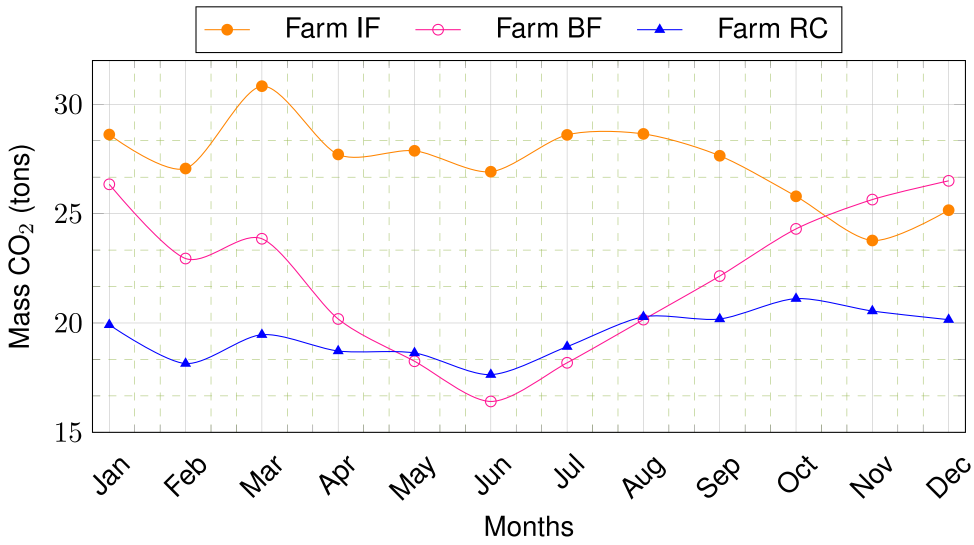


Figure 4.11: Environmental profiles, as CO_2 emissions (in tons) avoided, for planned floating solar systems at the farm sites IF (328.6 tons), BF (264.9 tons), and RC (233.7 tons).

ate additional long-term revenue opportunities for floating solar owners such as potential carbon credit trading and off-farm energy trading benefits.

As mentioned in Chapter 1, one of the objectives of the study is concerned with the interest of EIA practitioners in the environmental impact of floatovoltaic systems, and how the power generated from these systems on farms would be used as a substitute for the power from Eskom grid. Eskom power generation relies on the burning of coal. As such, it consumes large amounts of water (H_2O) in the cooling processes (Letete *et al.*, 2010). Figure 4.12 confirms that water consumption can be significantly reduced annually through the generation of electricity from floatovoltaic systems, and thus once again also reduce the impact of farm activities on the environment.

The time-series trend lines in Figure 4.12 present the predicted water savings (H_2O preserved) for proposed floatovoltaic systems in an Eskom grid substitution model (EIM defined in Chapter 3). The pink and blue time-series traces in Figure 4.12 show the individual environmental H_2O impacts for planned floating solar systems on the farms IF, BF, and RC respectively. Since the conservation of water (H_2O) resources and reductions in the carbon footprint in the Eskom grid-substitution applications are both functions of floating solar power production, the temporal profile patterns for both the CO_2 and H_2O impacts in Figures 4.11 and 4.12 show a strong correlation with the energy profiles in Figure 4.10.

In Eskom grid substitution applications, floating solar systems are set to replace water-cooled coal-fire generated electric power (Eskom, 2014*a*). In this context, the impacts emanating from the conservation of the national water resource through photovoltaic-type floating solar systems are a critical aspect of environmental profiling in the case of floating solar products. The environmental profiles in Figure 4.12 highlight the value of floating solar systems in that a significant volume of water can be conserved by applying this valuable form of technology. This factor in itself is based on the use of a clean energy source, as a substitute for Eskom grid power (water-cooled, coal-fired power generation) in the production of energy. Together, the environmental impact contributions of floatovoltaic systems in respect of reducing the carbon footprint CO_2 and in conserving water can thus play a

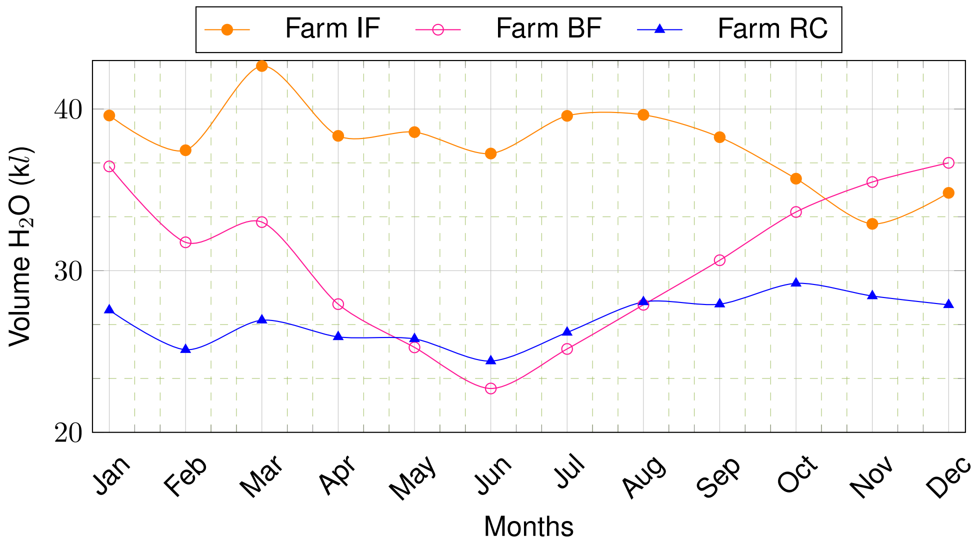


Figure 4.12: Environmental profiles, as water conserved (in kl), for planned floating solar systems at the farm sites IF (454.7 kl), BF (366.5 kl), and RC (366.5 kl) respectively.

significant role in the conservation of resources and the mitigation of climate change.

As regards the consumption of coal fuel in power generation, the *EIAcloudGIS* tool further predicted the environmental impact for planned floating solar systems as reductions in coal fuel consumption for each farm site on a monthly basis. These calculations are based on the requirements for calculating the NCV and CEF factors for the South African grid EIM model described in Section 3.4.2 (Eskom, 2014*c*). The time-series trend lines shown in Figure 4.13 depict the experimental profiling results for the predicted reduction in coal usage (kg/tons) as a result of the installation of the proposed floatovoltaic systems to substitute the Eskom grid on the farming sites labelled IF, BF, and RC respectively.

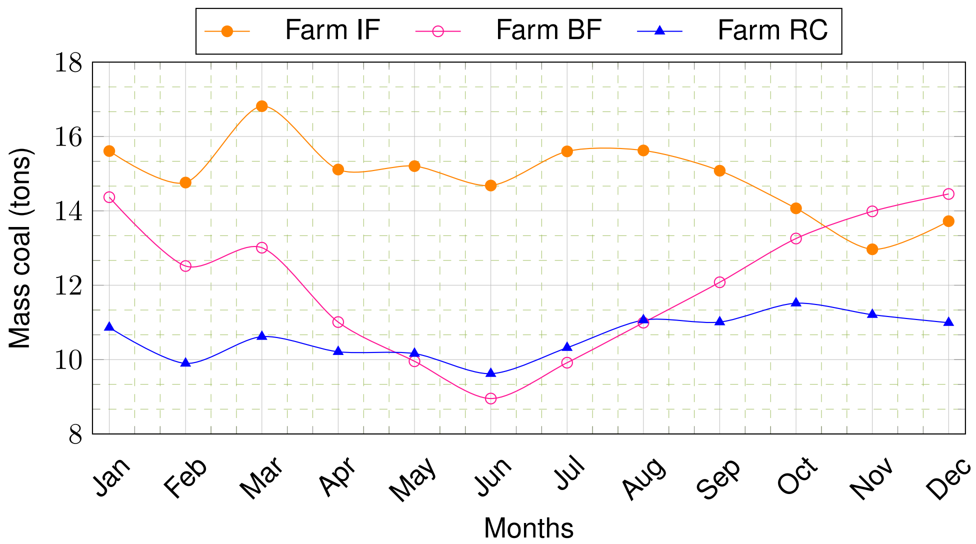


Figure 4.13: Environmental profiles, as coal-fuel savings (in tons), for planned floating solar systems on the farm sites IF (179.2 tons), BF (144.4 tons), and RC (127.4 tons) respectively.

The environmental model for the substitution of the Eskom grid power implied that coal fuel savings computed in Figure 4.13, together with coal ash waste reduction, are essential aspects of the environmental profile as coal fuel savings have long-term ecological benefits for coal mining. Coal ash, on the other hand, constitutes a waste product from coal-based power generation, which means that a decrease in waste ash offers a positive impact on the national air quality and waste environment. The *EIAcloudGIS* tool predicted reduction in the coal ash concentrations as a function of the ash substance equivalence parameter for the Eskom environmental model (Eskom, 2014*a*). The time-series results for coal ash waste reduction emanating from floating solar systems, shown in Figure 4.14, depicting the reduction in coal ash waste (in tons) as environmental impact benefits for the proposed floatovoltaic systems on the farming sites IF, BF, and RC.

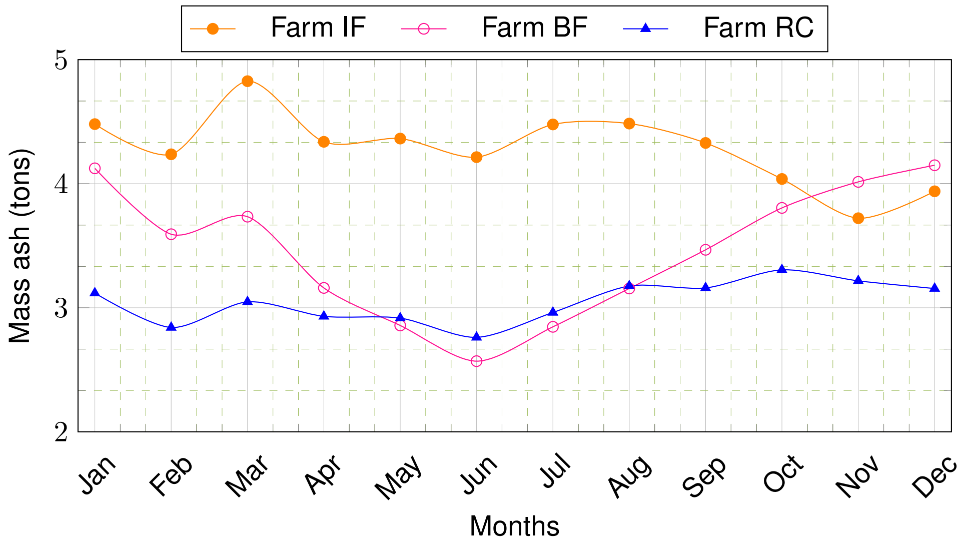


Figure 4.14: Environmental profiles, as avoided waste coal ash (in tons), for planned floating solar systems on the farm sites IF (51.4 tons), BF (41.4 tons), and RC (36.5 tons).

Improvements in air quality through mitigation by floating solar systems could be expected to reduce human exposure to gaseous SO_x (SO_2 in particular), with an important co-benefit floating solar systems being a reduction in the formation of particulate sulphur pollutants (sulphate particles) in the air (EPA, 2018). The predicted reduction in the SO_x (kg) concentrations was also determined for the SO_x substance equivalence factor defined in the *EIAcloudGIS* tool (Eskom, 2014*c*). The results for the experiment on the environmental profiling of floating solar systems for SO_x (kg) are shown in the time-series graphs in Figure 4.15. It shows the reduction in the concentration of SO_x as environmental impact benefits associated with the proposed floatovoltaic systems on the farming sites IF, BF, and RC respectively.

The results presented in Figure 4.15 highlight the fact that environmental control interventions such as the installation of farm-based floating solar systems could play a significant role in reducing atmospheric SO_2 concentrations. Sulphur dioxide (SO_2) and other sulphur oxides(SO_x) result from the burning of fossil fuels and materials containing sulphur, as in the case of the combustion of fuels in coal-fired power generation plants (EPA, 2018). Sulphur dioxide (SO_2), as one of the sulphur oxide SO_x gas groups, is generally regarded as

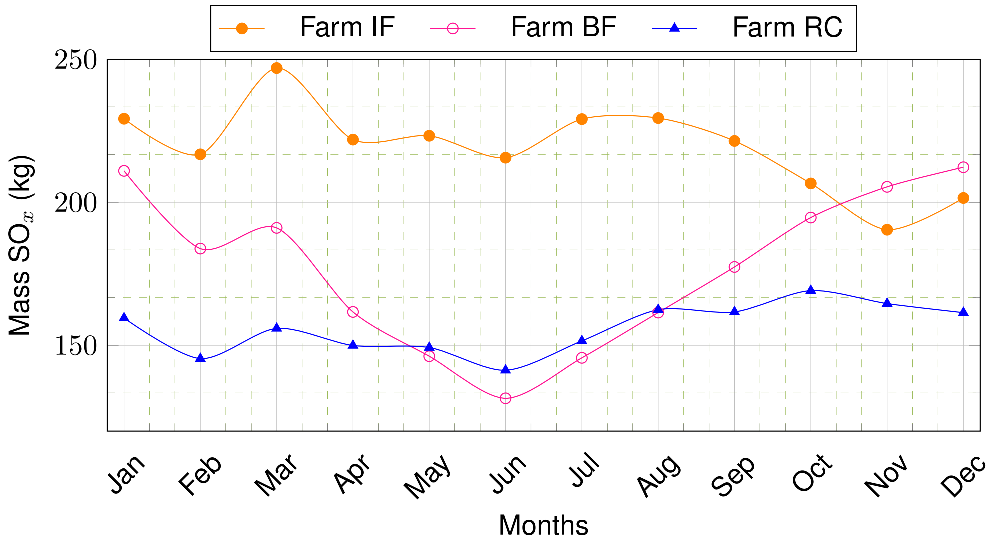


Figure 4.15: Environmental profiles, as avoided SO_x emissions (kg), for planned floating solar systems at the farm sites IF (2632.19 kg), BF (2121.94 kg), and RC (1872.1 kg).

a leading indicator for gaseous sulphur oxides as it often leads to the formation of many of the other sulphur oxides (SO_x) (Satein, 2009). Higher concentrations of SO_x in the atmosphere generally affect both human health and the environment. Gaseous SO_x generally harms plants and trees as it damages foliage and diminishes plant and fruit growth.

Apart from gases like the sulphur oxides (SO_x), nitrogen oxides (NO_x) also contribute to the formation of smog, haziness in the air and acid rain. NO_x enters the atmosphere primarily as a result of the burning of carbon-based fuels (such as coal, diesel or related petroleum). Since NO_x also interacts with oxygen (O), water (H_2O) and other reactants in the atmosphere to form acid rain, NO_x can harm sensitive ecosystems such as farmland and water bodies (EPA, 2018). This results in the environmental problem of acidification, which emanates from the exposure of rivers, streams and soil to anthropogenic air pollutants such as SO_x and NO_x, that are released during the power generation process. NO_x is also harmful to the environment and humans owing to its effects on the body's respiratory system when inhaled (EPA, 2018).

When considering the potential of floating solar systems to heal the environment, the time-series values for predicting reductions in the NO_x footprint levels in Figure 4.16 highlight the environmental benefits of this intervention to mitigate climate change. The predicted time-series plots for a reduction in NO_x (kg) concentrations in the profile graphs of Figure 4.16 reflect the environmental impact benefits associated with the proposed floatovoltaic systems on the farm sites labelled IF, BF and RC respectively. The *EIAcloudGIS* tool predicted the reduction in the NO_x (kg) concentrations for the NO_x substance equivalence factor according to the Eskom environmental model (Eskom, 2014*a*).

In so far as the value of floating solar systems is concerned, this technology would help to reduce the release of NO_x into the atmosphere since it generally reacts with many other substances in the air to form *particulate matter* and *ozone*. Reductions in the concentration levels of NO_x in the atmosphere, indicated in the time-series graphs of Figure 4.16, can therefore be considered to be the most valuable environmental impact benefit.

Another environmental benefit of floating solar systems is the reduction in pollution from

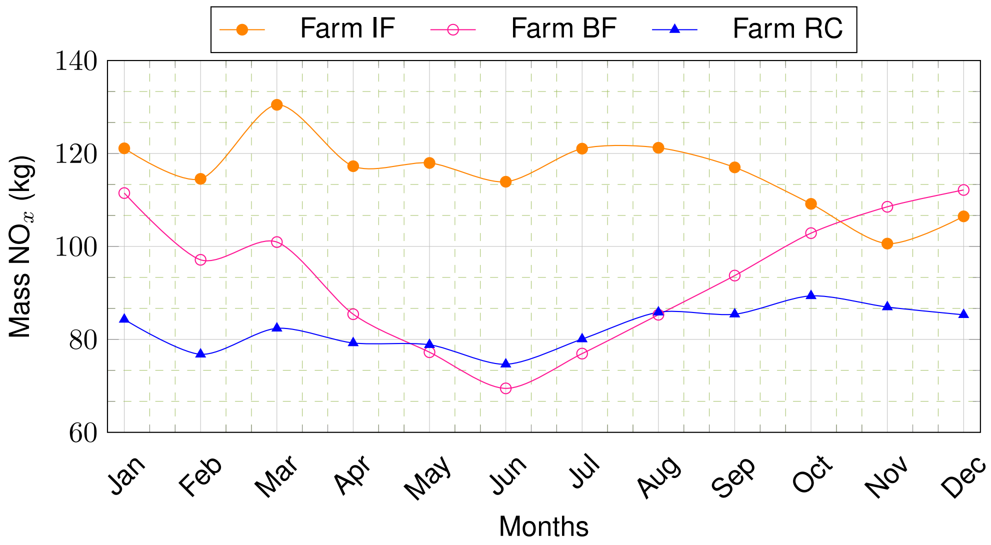


Figure 4.16: Environmental profiles, as avoided NO_x emissions (kg), for planned floating solar systems at the farm sites IF (1390.78 kg), BF (1121.18 kg), and RC (989.12 kg).

airborne particulates, the chemical composition of these airborne particulates resulting from the combustion of carbon products such as the burning of coal and reactions with other gases in the atmosphere. The time-series graphs in Figure 4.17 depict the results of the predicted reduction in the concentrations of particulate emissions (kg) as environmental impact benefits for proposed floatovoltaic systems on the farm sites labelled IF, BF, and RC respectively. On the evaluation and interpretation of the profiles for atmospheric and environmental pollution for the emitted particulates, the predicted reduction in the concentrations of particulate emissions (kg) were determined by the *EIAcloudGIS* tool for particulate equivalences according to the Eskom environmental model (Eskom, 2014*c*).

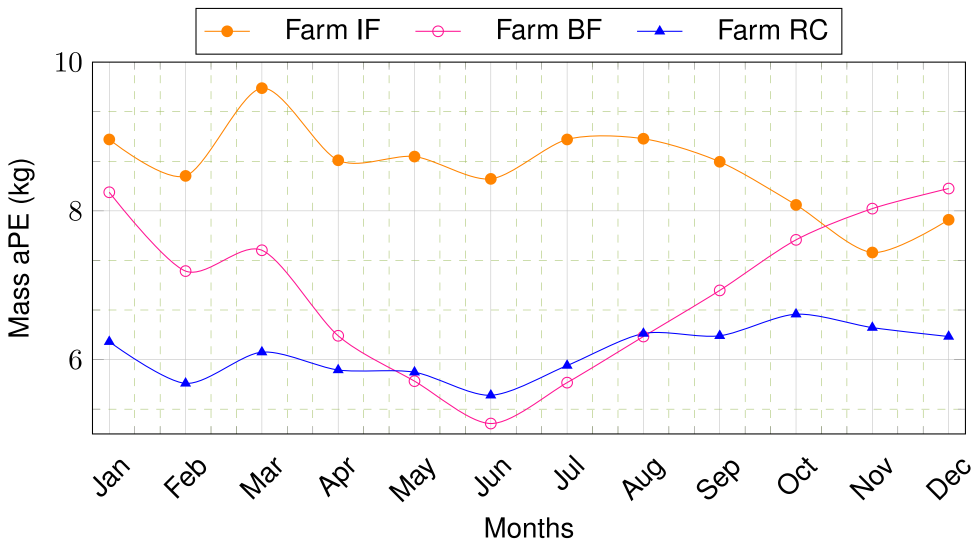


Figure 4.17: Environmental profiles, as avoided aPE emissions (kg), for planned floating solar systems at the farm sites IF (102.9 kg), BF (82.95 kg), and RC (73.18 kg) respectively.

In terms of the results shown in Figure 4.17, a floating solar system improves public health, as well as visibility; furthermore, it reduces emissions of inhalable particles and the generation and dispersion of airborne particulates. This is especially beneficial to humans since high concentrations of particulate matter are generally responsible for health problems as the particulates enter the mouth and nose. Particulate emissions (aPE) become even more hazardous when they are deposited in the respiratory tracts of animals and humans (especially particles with a mean aerodynamic diameter of 100 microns or less) (Satein, 2009).

Together with aPE emissions, excessive concentrations of NO_x, SO_x in the atmosphere further contribute to nutrient pollution in irrigation waters. As such, floating solar technology can help to play a direct role in narrowing the range of negative environmental effects on irrigation waters. Furthermore, the problem of acidification adversely impacts on aquatic and terrestrial animals and plants, thus disturbing the food chain. The fact that it increases the mobilisation and leaching behaviour of heavy metals in the soil is the main reason for this (Satein, 2009).

4.4.2.4. Summary and conclusions for environmental impact analysis experiment

According to the methodology of this experiment, the floating solar analysis tool was used to simulate real-life systems in software simulation concepts to analyse the due-diligence attributes of complex environmental systems. The *EIAcloudGIS* tool performed time-series environmental profiling analyses to determine the predicted environmental impact benefits for proposed floating solar systems at three experimental site (detailed in Section 4.3). The methodology engaged the *EIAcloudGIS* tool to process the prediction results for the input energy yields determined by the GIS toolset in Experiment 1. The tool employed a quantitative-data-gathering methodology to synthesise performance-modelling procedures in order to generate environmental profiling assessment reports on inventories of the projected greenhouse gas emission presented in the time-series graphs in Figures 4.11 to 4.17. These results reflect the environmental profiles for planned floating solar systems as Eskom grid-substitution emission factors (substance equivalence factors) for the farm locations IF near Nelspruit, BF near Bonnievale, and RC near Kakamas.

The *EIAcloudGIS* tool reported the environmental profiling analyses for the floating solar systems as greenhouse gas reductions (CO_2, SO_x, NO_x, aPE) for the respective sites in the time series-traces of Figures 4.11 to 4.17 respectively. The predicted impact profiles in Figures 4.11 to 4.17 characterise the environmental impacts for floating solar systems in terms of most gases that serve to increase global warming. These greenhouse gases are detrimental to the environment as they absorb infrared waves radiated from the earth's surface and the lower layers of the earth's atmosphere which get trapped and emitted back towards the surface of the planet and, as such, warm the earth's atmosphere. Furthermore, the individual greenhouse gases profiled by the *EIAcloudGIS* tool contribute to global warming through the chemical transformations and reactions with other chemical compounds in the atmosphere, thus affecting the absorptive properties of the earth's atmosphere (e.g. effecting cloud formation) or influencing the atmospheric lifetime of other greenhouse gases in the atmosphere (Satein, 2009).

The *EIAcloudGIS* tool's environmental profiling methodology defines a specific approach in applying quantitative methods to capture a system's environmental impact in quantifiable terms. In this experiment, the parametric computer simulation model illustrated in Figure 3.2

was used to investigate and determine essential environmental impact aspects of planned floating solar systems. The GIS-tool model and its associated methodology operated as a quantitative-data-gathering technique that was able to determine the amount of energy that would be generated by a floating solar system. The time-simulated energy yield data served as an input into the *environmental simulation model* to produce the environmental impact analysis output profile trajectories in Figures 4.11 to 4.17. Since the environmental profile of a floating solar system is known to be a function of the system's energy yield profile (Figure 4.10), the environmental profiles for the various substances (CO_2, SO_x, NO_x, aPE in Figures 4.11 to 4.17) indeed reflect the same temporal seasonal characteristics and profile behavioural patterns as those observed in the system's energy analyses.

The analyses of the environmental characteristics conducted in this case-based experiment could be valuable in the assessment process in that they determine the extent to which a particular floating solar configuration could meet any desired environmental qualification or due-diligence criteria. This methodology included assessment scenarios of the infrastructure to evaluate the environmental impact characteristics of planned floating solar systems. The ability and efficiency of the *EIAcloudGIS* tool to assist the environmental impact practitioner in gauging the effect of planned floating solar systems on the environmental profile and on reductions in greenhouse gases (CO_2, SO_x, NO_x, aPE) is portrayed in Figures 4.11 to 4.17. These experimental results on the impacts of floating solar systems would be valuable in environmental product declarations and in documenting the certification of sites (Redón Santafé *et al.*, 2014).

The time-series-based environmental profiling exercise demonstrates how the online *EIAcloudGIS* application provides an essential tool for evaluating the architecture and configuration of a planned floating solar system. The results of this environmental profiling exercise could assist the impact practitioner in developing due-diligence reports for the proposed floating solar system on the site before the system is installed on the farm's irrigation ponds or dams. Such essential environmental studies include the undertaking of an EIA process. In the standard EIA study protocol and approach, the environmental impact practitioner would assess the annual environmental impacts associated with the proposed project as part of an investigation into compliance with the Environmental Impact Assessment Regulations (2014), and read with Section 24 (5) of the National Environmental Management Act (NEMA Act No 107 of 1998) (as amended) (S.A. Government, 1998). With the EIA information at hand, an application for an Integrated Environmental Authorisation (IEA) could then be lodged with the Department of Environmental Affairs. This process is usually undertaken as a means to ultimately allow the competent authorities (the Department of Environmental Affairs) to make informed decisions about authorising and permitting solar energy projects.

In the next experiment, the *EIAcloudGIS* tool applied the energy yield predictions and environmental impact analyses in a scientifically-driven, business-decision-supporting mode, thus aiding the impact practitioner by determining the energy outputs and environmental impact benefits for the planned floating solar systems as WELF nexus parameters.

4.4.3. Experiment 3: Floating solar decision support analysis

Decision-making in the field of environmental management calls for quantitative research methods to help make informed environmental due-diligence decisions about a proposed new development based on reliable predictions of the dynamics of a floating solar ecosystem and the impacts of the planned floating solar project. While Experiments 1 and 2 had already determined the respective energy yield profiles/capacities and the results of the environmental impact analyses for planned floating solar systems for the selected case-study sites, Experiment 3 allowed for the processing of these results to establish an evaluative decision-supporting mechanism. Computer models embedded in the *EIAcloudGIS* tool layers, therefore, employed the data collected through the quantitative methodology process to convert the floating solar energy yield and environmental impact profiles into decision metrics suitable to the process of due-diligence analysis and decision support. In one of these steps, the *EIAcloudGIS* toolset processed the findings in respect of the WELF nexus parameters and plotted the results in a suitable format for the user to analyse. By converting the energy yield and environmental profile characterisation for planned floating solar systems into WELF nexus parameters, the assessment proved to be suitable for viewing and interpretation on a decision-supporting analytics portal. Such decision metrics are especially valuable in the EIA processing stages of a project, where decisions around the implementation of a planned floating solar system may form part of a solar farming expansion or a sustainable development project.

4.4.3.1. Goal of experiment

The goal of this experiment was to use the *EIAcloudGIS* toolset in a decision-supporting analysis mode to quantify and display the energy yield and environmental impact benefits for planned floating solar systems as WELF nexus parameters. In this decision-supporting experiment, the *EIAcloudGIS* toolset processed and presented the projected energy yield and environmental impacts as WELF nexus parameters for the proposed floating solar systems at the three sites of Section 4.3. The experimental results, particularly for the Water-Energy-Land aspects of WEL(F), could assist EIA practitioners to study projected environmental due-diligence analyses based on computer-simulated model outputs for energy yield and environmental profiles in a format suitable for interpretation on a geoinformatics type of display screen. In this way, the results of the experiments support the EIA process for the proposed floating solar systems at the farm sites labelled IF, BF, and RC respectively. Furthermore, the *EIAcloudGIS* toolset projections could assist the practitioner in developing scientifically-based EIA reports for a proposed onsite floating solar systems long before the installation of the system.

4.4.3.2. Experimental method and procedure

The method used in this decision-supporting analysis exploited the energy and environmental characterisation capabilities of the *EIAcloudGIS* tool to develop decision metrics from the predicted energy and environmental profiles for the proposed floating solar systems. Once again, this experiment used the parameters for the same floating solar system designs and layouts as for Experiment 1 (Section 4.4.1.2).

Section 3.4.2 describes the steps for converting energy and environmental profiles into decision-ready WELF nexus parameters, ready to project these values on a decision-supporting systems display. The *EIAcloudGIS* toolset implements the Eskom grid substitution model (Eskom, 2014*a*) in order to determine the environmental impact parameters in custom-designing an environmental impact software model based on the WELF nexus. This *environmental simulation model* in the EIA GIS object layer shown in Figure 3.2 engages a computer-modelled systems approach that includes a set of energy and environmental output parameters in order to model the WELF nexus (Simonovi, 2012). The *EIAcloudGIS* tool finally displays the land, energy and water conservation aspects as WELF nexus parameters in the decision-supporting portal display.

4.4.3.3. Decision support analysis case study results

This experiment is designed to use the *EIAcloudGIS* tool to profile the energy and environmental characteristics of a floating solar power plant as decision metrics. In this way, the proposed methodology and GIS-based tool proved to be invaluable aids in the decision-making process in that they provided the EAP and the floating solar project developer/decision maker with explicit information about the energy yield projections and the anticipated environmental impacts for the proposed floating solar system.

The resultant *environmental profiles* of the floating solar systems for each of the sites are presented in the decision support portal, in particular the dashboard display given in Figure 4.18. Each of the colour bars in the environmental profiles depicted in Figure 4.18 reflect the respective annual environmental impact scores emanating from substituting the Eskom grid energy with energy from the proposed floatovoltaic systems. The *EIAcloudGIS* tool simulation model outputs the projected water savings, coal savings, reduced coal ash content, as well as the SO_2, NO_x, CO_2 and aPE reductions relative to the displacement of Eskom grid energy. The graphs in Figure 4.18 enabled the EIA practitioner to make a comparative analysis of the relative environmental impacts of the planned floating solar systems at the three sites IF, BF and RC respectively.

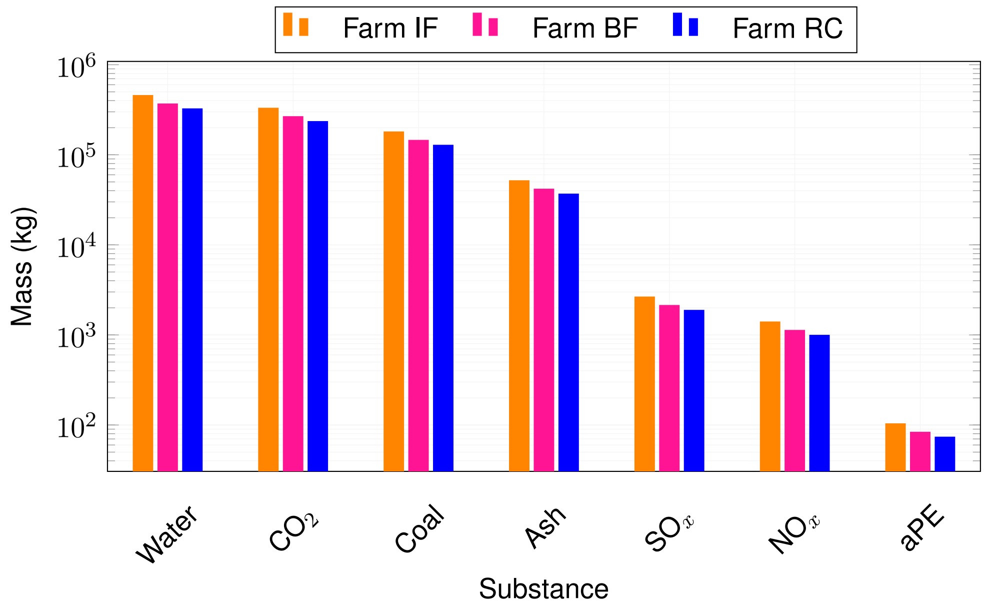


Figure 4.18: *EIAcloudGIS* tool decision support dashboard, showing the *Environmental Profiles* for floating solar systems at the farms IF, BF and RC (on a base-10 log scale).

According to the Eskom model, the environmental characterisation of a solar power plant is computed as proportional equivalence factors for pollutant substances (H_20, CO_2,

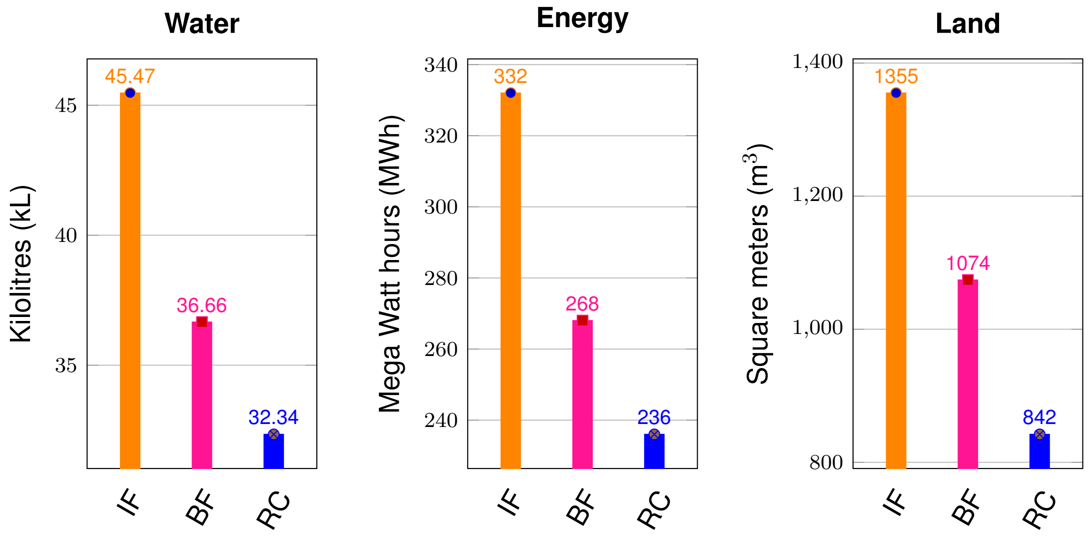
SO_x, NO_x, aPE) (Eskom, 2014*a*). The substance factors in the results of Figure 4.18 show the chemometrics for the carbon footprint analysis and environmental impact equivalents for the Eskom grid power replaced by energy from the proposed floatovoltaic system at each of the three selected site locations. In terms of a logarithmic scale, this figure shows the EIA values computed per the latest Eskom environmental model configuration and parameters as described in the research design methodology (Section 3.3) of this study. This list of effective pollutant substance scores in Figure 4.18 constitutes the *environmental footprint* or *environmental profile* of the planned floating solar systems for the respective farm site cases. Furthermore, the *EIAcloudGIS* tool reported on future anticipated environmental impact factors for the three experimental sites in the Mpumalanga, Western Cape and Northern Cape provinces, all of which contributed essential and valuable information to approve EIAs for floating solar systems under the National Environmental Management Act, Act 107 of 1998, as amended (S.A. Government, 1998).

Comparisons of the predicted environmental impacts for the three floating solar locations brought to light the fact that the environmental impact of a floating solar system with a more significant sun-harvesting surface area (site IF) has a more substantial effect on the carbon footprint of the farm. These results allowed the EIA practitioner to make a comparative analysis between the relative environmental impacts of the respective floating solar systems at the three sites and ways in which a floating solar system could mitigate the effects of climate change at both the local and national levels.

The results of this research have demonstrated that the *EIAcloudGIS* tool methodology and the analysis of the respective research sites can be successfully used to meet all the research objectives and to find answers to the research questions. Both the energy and environmental impact results recorded in Figures 4.10 and 4.18 could assist the environmental impact practitioner in evaluating opportunities for the use of floating solar systems on farm sites. Furthermore, the results in Figures 4.10 and 4.18 reflect the energy and environmental profiles of the respective floating solar systems. The environmental impact results reflect the way in which floating solar power systems can make a positive contribution to sustainable farming, and include the impact of a floating solar system on the carbon footprints of the respective farms.

The *EIAcloudGIS* tool's decision-supporting analysis in Figure 4.19 reports on the energy production capacity (P_e) of the floating solar energy systems on the farm sites, and the water conservation (H_2O) and agricultural land-use saving benefits (aLP in m^2) to the area in terms of food production. The decision-supporting dashboard display Figure 4.19 depicts the annual environmental benefits determined by the *EIAcloudGIS* tool as the WEL(F) nexus parameters, namely (a) aLP or agricultural land preserved; (b) P_e or grid energy preserved, and (c) H_2O or water preserved for the three selected fruit farms.

The decision-support dashboard depicts the environmental profiles in Figure 4.19 to provide the EAP with an indication of the agricultural land-use (fruit-/food-production) benefits aLP of a floating solar system as WELF nexus parameters (Ringler *et al.*, 2013). The dashboard display essentially illustrates the fact that by installing water-based floating solar systems on the irrigation ponds on fruit farms, several square metres of fertile agricultural land could then be set aside for fruit/food production. One can further infer from Figure 4.19 that floating solar technology reduces the tendency to uproot existing orchards to set up land-based photovoltaic solar systems. The benefits associated with agricultural land-use (aLP), water preservation (H_2O) and grid energy substitution (P_e) in floating solar systems could thus undoubtedly make a positive contribution to the sustainability aspects of fruit and



(a) Water preservation (b) Energy preservation (c) Land preservation

Figure 4.19: *EIAcloudGIS* tool decision support dashboard, showing the *WEL(F) nexus environmental profiles* as decision scorecard metrics to help assess the annual yielding capacities and environmental impacts/offsets for floating solar at farms IF, BF, and RC.

wine farming in South Africa.

4.4.3.4. Summary and conclusions for decision support analysis experiment

The experiment demonstrated how the *EIAcloudGIS* tool was able to draw from the growing body of international experience in applying scenario-based solar architecture analysis techniques to support environmental due-diligence analyses. These techniques are valuable considering that the online GIS platform can determine profiling analyses through scientific projections of the energy and environmental characteristics for planned floating solar energy production systems. The delivered *EIAcloudGIS* tool outputs proved to be most valuable in decision support where floating solar due-diligence analyses could be applied to the interpretation of the profiling results. Such an approach enables the farmer or environmental impact practitioner to make informed decisions by combining energy production yields and environmental impact factors as decision metrics to support decision-based approaches. The *EIAcloudGIS* tool thus assists the farmer or environmental impact practitioner to better understand the relationship between the green energy economy, environmental economics, and the natural world, it being essential to the mitigation of climate change.

This research, governed by the geographical methodology described in Section 3.5, conducted associated energy production analyses and environmental impact assessments to test the feasibility of implementing the proposed floating solar systems. The experiment described in this section was conducted to determine the extent to which a particular floating solar configuration could meet any future defined or desired environmental due-diligence or environmental qualification criteria for the selected sites listed in Table 4.1. The present research/experiment demonstrates how the *EIAcloudGIS* tool supports the goals of the South African National Development Plan concerning renewable energy and sustainable rural agricultural development (National Planning Commission, 2012).

The experimental results portrayed in Figure 4.18 and Figure 4.19 prove how the *EIAcloudGIS* tool can offer a quantitative decision-based approach to understanding the relationship between the environmental economy and the use of natural resources essential to the mitigation of climate change. While environmental issues are of fundamental importance in this context (Harris and Roach, 2018), the experimental impact analysis and environmental profile scenarios for the floating solar systems at the selected locations reflect an updated perspective on the benefits associated with environmental floating solar systems. In this regard, the results are valuable in clarifying the potential for floating solar systems to mitigate climate change.

In terms of the *EIAcloudGIS* tool's decision-supporting display board, Figure 4.19 plotted the energy production capacity (P_e in kW) for the planned floatovoltaic systems on the fruit-farm sites IF, BF and RC respectively, and water preservation (litres H_2O) and agricultural land-use savings (aLP in m^2) benefits to the area in terms of food production. By re-running the experiments with different floating solar system configuration parameters, impact practitioners would be able to obtain results similar to those displayed in Figure 4.19 from which they would be able to gauge the impact of a specific change or event on the system's environmental profile.

Concerning the aims and objectives of this research, valuable conclusions could be drawn when comparing the decision metrics in terms of the energy yield of floatovoltaic systems and the environmental benefits for the fruit farm sites as WELF nexus parameters. Figure 4.19 shows that the WELF nexus concept offers valuable measuring tool to study sustainability scenarios in the agricultural sector for the optimisation of food production, land-, energy- and water-resource interactions (Hoff, 2011; Ringler *et al.*, 2013). The *EIAcloudGIS* tool's decision-supporting procedures champion the integration of the WELF nexus parameters into a scorecard for decision-making on the environmental impacts of a GIS-based floating solar system. From an agricultural due-diligence and an environmental-scoping perspective, the interactive *EIAcloudGIS* tool offers a WELF nexus decision scorecard display that has proved to be valuable in geographical and environmental-scoping exercises. The *EIAcloudGIS* tool's decision-supporting display is beneficial in studying space optimisation opportunities and water preservation benefits for floating solar energy systems as part of the environmental management plans for floating solar power plants at agricultural settlements (Peuthert, 2010; Sahu *et al.*, 2015).

From an environmental impact perspective, the WELF nexus parameter "Water" and its impacts in terms of conservation on each of the selected farms in Table 4.1 are of great importance. The *EIAcloudGIS* tool's prediction of Eskom's water consumption levels and its methods to generate the same amount of electricity as floating solar (Figure 4.12) systems demonstrates the flaws in the argument that the cost of coal-based power generation is low: this, while the cost of water makes coal-based power generation extremely expensive in the long run (De Villiers and de Wit, 2010). Noticeably, the conservation of water that is effected through floating solar systems (as one of the WELF nexus components Figure 4.19) supports the argument for environmental cost benefits.

Comparative results for the conservation of water through the planned floating solar system installations at the three selected sites show that these coal-free power plants can conserve a significant amount of water. They show potential annual water savings of on average approximately 400 Kilolitres of water per year per site (see Figure 4.19). The water conservation scoring values in Figure 4.19 represent only the indirect water conservation component of floating solar, namely the Eskom cooling water conserved during coal-based power generation. In the present *EIAcloudGIS* tool model, the results in Figure 4.19 does not compute the amount of water evaporation reduction as a result of the shadowing effects of a floating solar system on the local irrigation pond. Floating solar system water evaporation aspects required further research, especially since estimates show that localised water evaporation reduction improvements of 70% can be achieved with certain floating solar system configurations (SPG Solar, 2010).

As regards the problem statement and aims/objectives of this research, the goal to incorporate WELF nexus parameters into the development of a future integrated GIS-based environmental scorecard was met. The space optimisation and water conservation opportunities offered by floating solar energy systems can be described more effectively as WELF nexus parameters.

4.5. EIAcloudGIS System: Online Access to Results

As regards the requirements defined in Section 3.5.4, the experiments described in this chapter have demonstrated the value in using the GIS toolset in terms of its ability to:
(a) conduct and display simulation predictions for the energy output/environmental impact metric values (P_e, H_2O, CO_2, SO_2, NO_x, aPE, and aLP) for three hypothetically-planned, non-tracking, floating solar systems;
(b) determine and plot the predicted EIA metrics for each sample site as simulated time-graph plots (Floatovoltaic/Environmental model outputs over time);
(c) display the energy outputs and environmental impacts for the floating solar systems as WELF nexus parameters in a decision-supporting analytical display or portal; and
(d) store the energy yield and environmental impact metric values on a GIS map and enable user access by clicking on localities shown on a South African map.

Concerning the objectives of this study, the final outstanding reporting factor to be demonstrated by the *EIAcloudGIS* toolset is the aspects listed under items (c) and (d) above. For these resulting maps and projections, the full suite of features of the GIS-based toolset proved to be a great value in facilitating the process of decision making in that it provided the EAP and the floating solar project developer/decision maker with explicit information about the energy yield and environmental impact projections for the proposed floating solar system. The decision-supporting feature of the *EIAcloudGIS* tool used the GIS interface together with the data access functionality to demonstrate the "Decision Support Tool Display Screen" projected in the GIS map of Figure 4.20.

The georeferenced site map in Figure 4.20 displays the spread of geo-tagged experimental sites as different floating solar energy production sites on farms in three of the provinces of South Africa. Since the objective of developing the *EIAcloudGIS* tool in this experiment was to improve the EIA process for practitioners, it is only logical that the tool should make the experimental results available to the public by publishing the energy and environmental profiles on the internet. This is done by embedding the geo-tagged results in the dedicated EIAcloudGIS website. Concerning the articulation of outcomes online, the *EIAcloudGIS* tool feeds the geo-tagged results and data to the user through the EIA-cloudGIS webpage.

***EIAcloudGIS* Tool Display Screen**

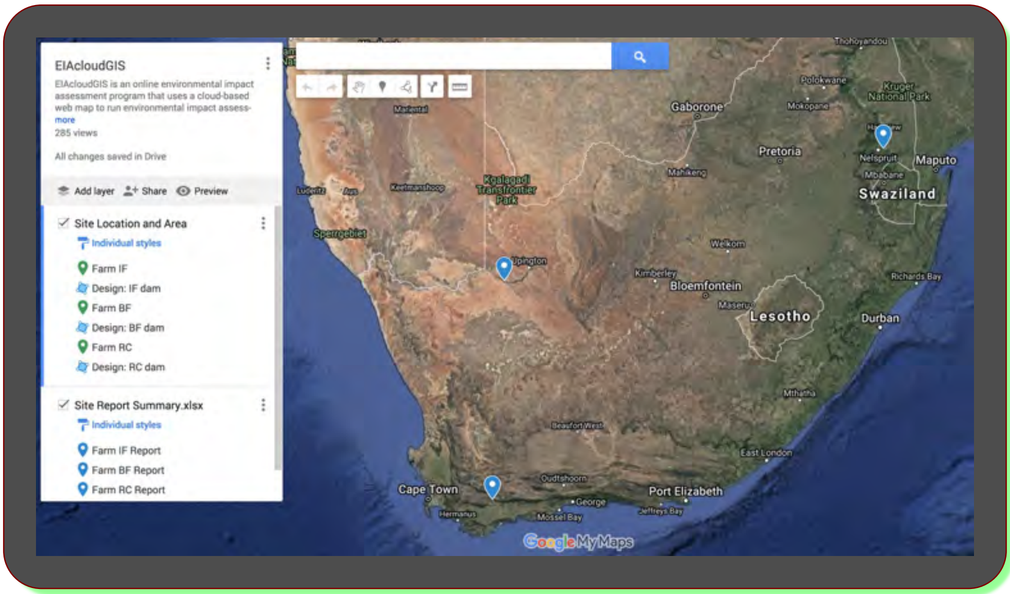


Figure 4.20: Waypoint clickable *EIAcloudGIS* display map projecting the predicted decision impacts for planned floating solar systems at the farms IF, BF, and RC.

Figure 4.21 shows how the impact parameters (P_e, H_2O, CO_2, SO_2, NO_x, aPE, and aLP) are displayed in the waypoint clickable *EIAcloudGIS* tool display map. The aggregated floating solar profile parameters calculated by *EIAcloudGIS* toolset simulations are then saved in an online GIS database for transfer and use in floating solar EIA scorecard reports.

The *EIAcloudGIS* tool web interface and data downloads are available at the *EIAcloudGIS* tool application website. The *EIAcloudGIS* tool interface illustrated in Figure 4.20 allows the EAP to access (view and save) the detailed EIA reports for the energy output (in kW and kWh) and environmental impact metric values (P_e, H_2O, CO_2, SO_2, NO_x, aPE, and aLP). These reports are available by clicking on any of the sites (waypoint markers displayed on the map) representing the experimental floating solar system sites on a Google Maps interface.

4.6. Summary

In this chapter, an analysis of the environmental impact of the three proposed floating solar systems was conducted in several case-based scenario experiments. The experiments engaged the custom designed *EIAcloudGIS* toolset developed in this study. The tool used a computer simulation model in a web-based application to conduct three real-world analytical experiments. The energy of the *EIAcloudGIS* toolset and its environmental model layers incorporated software for floating solar modelling as part of the proposed methodology to determine the extent to which a floating solar system can meet specific environmental impact criteria for qualifying as the desired energy production unit for the future.

In the experimental section of this study, sites in South Africa were selected to demonstrate the operation of the proposed desktop GIS toolset from the perspective of an environmental impact practitioner. The goal with these experiments was to demonstrate the

***EIAcloudGIS* Tool Display Screen**

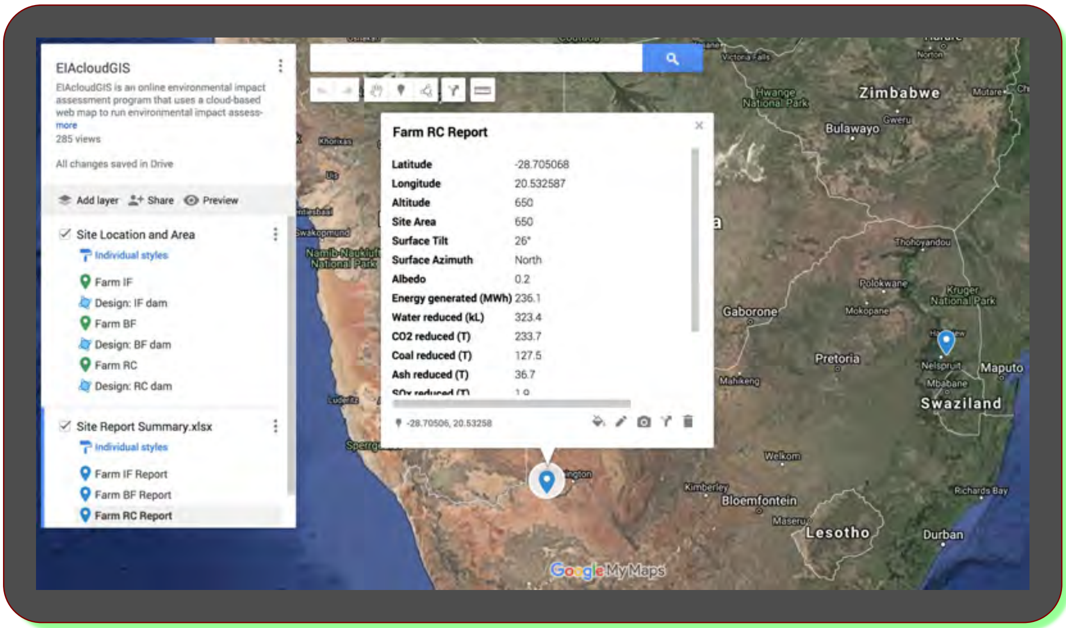


Figure 4.21: Example of *EIAcloudGIS* display map, projecting and reporting the predicted decision-supporting metrics for a planned floating solar system at farm site RC.

predictive environmental performance of hypothetically-planned floating solar systems at the selected locations in South Africa. In this procedure, the developed GIS toolset was able to display the simulation predictions for the energy output metric values (P_e) for the three hypothetically-planned floating solar systems and saving the results on a GIS-based map of South Africa to enable user access.

Each experimental scenario demonstrated how the *EIAcloudGIS* toolset and its embedded software simulation concept layers could provide guidance for the analysis of complex nonlinear energy and associated environmental systems to assess and report on technical and environmental due-diligence attributes. Experiments with the energy and environmental simulation models in the *EIAcloudGIS* toolset offered decision-supporting metrics to fundamentally clarify the environmental impacts for locally-proposed agricultural floating solar installations.

The experimental results achieved with the developed *EIAcloudGIS* toolset not only provided valuable decision-supporting metrics to evaluate anticipated environmental impact factors for future planned floating solar systems in South Africa, but also generated the essential information required for completing the official documentation for gaining environmental approval on the installation of floating solar systems in respect of the National Environmental Management Act (Act 107 of 1998, as amended) (S.A. Government, 1998).

5. Conclusion and Recommendations

5.1. Summary and Synthesis of Main Findings

A research need has been identified in the field of sustainable development, in particular, a knowledge gap in the field of environmental analyses associated with floating solar technology defined in the Problem Statement (Section 1.3) of this dissertation. From a geographical perspective, novel research needed to fill the knowledge gap in determining the comprehensive set of environmental offsets and impacts of floating solar technology before system installation. This gap has limited the ability of decision-makers (land-owners, policy-makers, practitioners) from making decisions around the implementation of new floating solar (water-based) solar renewable systems, or to compare the benefits to that of traditional land-based solar renewable energy systems.

This dissertation describes the development of a GIS toolset for floating solar PV systems to calculate the energy generated and avoided environmental impacts of the PV systems relative to electricity supplied on the national grid in South Africa. This study classifies itself as a computerised simulation research method, wherein the main research activity is the development of a GIS toolset to evaluate the environmental impacts and energy generation potential of floating solar systems. The toolset comprises a solar model, an energy simulation model, and an environmental simulation model. The study succeeded in developing a digital GIS-based computer simulation model for floating solar systems capable of predicting the anticipated energy yield for floating solar systems, calculating the environmental offsets achieved by substituting coal-fired generation by floating solar panels, determining the environmental impact and land-use preservation benefits of any floating solar system, and relating the above metrics to water-energy-land-food nexus parameters suitable for user project viability analysis and decision support. Three case studies of farms in the Northern Cape, Western Cape and Mpumalanga Lowveld were used to demonstrate the capabilities of the GIS toolset.

Geospatial issues and challenges generally motivate GIS-based planning and modelling for infrastructural development for floating solar energy in the renewable energy discourse. There are significant challenges and future research avenues for technical and environmental modelling in the new sustainable energy transformation process (da Silva and Branco, 2018; Resch *et al.*, 2014; Sharp Corporation, 2008). The present dissertation and geographical research have made it possible to digitally implement a custom-designed energy and environmental impact assessment approach and methodology to assess and evaluate the eco-efficiency improvement potential of floating solar technology in South Africa. This implementation process involved the conceptualisation, designing and development of a software GIS-based decision-supporting tool to assist environmental impact practitioners and landscape architects to perform guideline environmental scoping and environmental due-diligence analyses for planned floating solar systems in the agricultural sector.

The lack of environmental scoping and characterisation research in respect of floating solar technology in Africa inspired the development of the *EIAcloudGIS* tool for the theoretical characterisation of energy and the environmental profiling of floating solar systems in the South African context (Prinsloo, 2017*a*). The implemented GIS tool acts as a virtual advisor to assess and quantify the environmental-impact profile characteristics for floating solar systems in order to study the value of its environmental implications. The tool supports impact and due-diligence studies, assisting farmers and practitioners who require quantitative evidence of environmental profiles for any planned floating solar system on any water body in the country. The primary rationale for this study thus centres around the engagement of geographical knowledge in a virtual computer-advising application that operates as a dedicated desktop/online GIS toolset to support the planning, design and implementation phases of the floating solar system as an emerging renewable energy technology concept for the agricultural sector.

To achieve this goal, this study employs the capabilities of GIS computer technology to simulate the energy operation of a floating solar system, from which to determine the required environmental impact factors. Apart from predicting the anticipated energy yield, environmental impact and land-use preservation benefits of floating solar systems, the tool can calculate the environmental offsets achieved through the reduction in impacts resulting from substituting coal-fired generation by floating solar panels. In this way, the GIS-based toolset can determine the extent to which a floating solar system's environmental offset can achieve a conservation outcome for the impacted environmental matter. Since this digital GIS toolset can determine the extent to which an environmental impact and conservation outcome is achieved by a particular floating solar system, the system parameters can be selected, designed and managed to maintain the viability of the prescribed environmental matter.

The *EIAcloudGIS* geographical toolset used in this research project implemented environmental models as layered computer software in the context a GIS platform, thus creating an enabling environment for studying environmental impacts associated with floating solar energy technology. The experimental part of the dissertation demonstrated the operation of the custom-designed *EIAcloudGIS* interface and toolset in terms of solar resource assessments and forecasting, energy yield analyses and environmental impact profile assessments. The tool generated geo-tagged reports on the projected energy yield and environmental impact profiles for three hypothetically-planned floating solar systems at three fruit farms tagged as IF (Mpumalanga -Nelspruit, GPS [-25.4315281171, 31.0972611105], BF (Western Cape, Bonnivale, GPS [-33.9197836647, 20.1980516088], and RC (Northern Cape, Kakamas, GPS [-28.7051089519, 20.5325777026]) respectively (defined in the *Experimental Site Selection* in Section 4.3). The selected farming sites each have a fruit-/food-/wine-processing facility near the selected water body (irrigation dam/pond), from where the electricity generated by a floating solar system can feed into the farm's processing plant/factory. Another benefit is that a floating solar power system operates during the daytime when solar energy is available, thus offering the best opportunity for any fruit-/food-/juice-/wine-processing facility on the farm/processing plant to make optimal use of the floating solar generated power during the daytime.

Figure 4.3, Figure 4.5 and Figure 4.7 show the floating solar system site locations, design layouts and geographical terrain models for these farms. The floating solar *EIAcloudGIS* toolset experiments documented the predicted energy yield and environmental impact profiling aspects for planned floating solar system at any GPS location in South Africa. In Experiment 1, the tool employed a quantitative-data-gathering methodology to synthesise the energy performance-modelling procedures detailed in Section 3.4.1. In terms of the experimental results on the systems capacity, or the annual solar energy yield, the *EIAcloudGIS* tool quantified the projected annual production capacity for the planned floating solar systems at the sites as IF (331.9 MWh), BF (267.6 MWh), and RC (236.1 MWh) respectively. By comparing the floating system delivery capacity totals to the cumulative amount of annual incoming solar irradiance for each of the three floating solar sites, the *EIAcloudGIS* tool was able to quantify the solar-to-electric conversion efficiency ratios for the sites as IF (11.9%), BF (12.1%), and RC (11.4%) respectively. Variations in these theoretical performance ratios (electricity conversion efficiency ratios) were found to be accountable to the expected variations in the environmental conditions (moisture content, ambient air pressure, ambient temperature) for the three planned floating solar system sites.

The *EIAcloudGIS* tool used in this research also operated as a type of environmental floating solar power profiler: It used the energy/power yield profile results depicted in Figure 4.10 to perform environmental profiling assessments in an equivalencies analysis of Eskom grid replacement greenhouse gases. In Experiment 2, it determined the predicted environmental impact benefits for the proposed floating solar system at the three sites (tagged IF, BF and RC). In this experiment, the tool employed a quantitative-data-gathering methodology to synthesise the environmental performance-modelling procedures detailed in Section 3.4.2 to generate environmental profiling assessment reports as inventories of projected greenhouse gas emissions. Experimental results for the farm sites IF, BF and RC were presented as monthly time-series graph reports of the proportional greenhouse gas equivalencies depicted in Figures 4.11 to 4.17. The aggregated *environmental profiles* for the respective planned floating solar products in the composite footprint profile of Figure 4.18 shows the inventories of the projected greenhouse gas emissions in relation to the equivalence factors for various greenhouse substances. The environmental footprint presented in Figure 4.18 was used to gauge the impact of the planned floating solar system in the form of an environmental profile and including the chemo-metric elements (chemical substances CO_2, SO_x, NO_x, aPE) associated with the reduction in the concentrations of the greenhouse gases.

The *EIAcloudGIS* simulation tool projected the water savings, coal savings, reduced coal ash content, as well as avoided emissions of SO_2, NO_x, CO_2 and aPE in the decision-supporting metric displays of Figures 4.18 and 4.19, also available in the GIS maps of Figures 4.20 and 4.21. The geo-tagged reporting graphs in the projections in Figures 4.18 and 4.19 enabled the EIA practitioner to make comparative analyses about the relative environmental impacts for the planned floating solar systems at the three sites IF, BF and RC. The *EIAcloudGIS* tool's decision-supporting metrics display Figure 4.20 assisted the environmental impact practitioner to gauge the impact of floating solar systems in terms of the environmental profile and of the reduction in the concentrations of greenhouse gas emissions (CO_2, SO_x, NO_x, aPE). Together with the metrics in Figures 4.18 to 4.19, the map-projected results Figure 4.20 were also plotted to aid in the assimilation of the results. Collectively, the results confirmed that the installation of water-based floating solar systems on the irrigation ponds of fruit farms provide positive environmental impact benefits while conserving several square metres of fertile agricultural land for fruit-/food-production activities.

The present research project has demonstrated how the proposed GIS toolset supports the body of geographical knowledge in the fields of Energy and Environmental Geography. The development of the *EIAcloudGIS* toolset contributed to the solving of analytical problems and challenges around energy and environmental sustainability in the planning of newly-envisaged floating solar installations on fruit farms in South Africa. The experiments further showed how this study and toolset succeeded in using present-day theoretical frameworks provided by the Environmental Geography and Energy Geography disciplines to solve a real-world problem. The tool virtually supports the NEMA EIA processes in that it formulates and develops GIS-based computer simulation models. This approach proved to be beneficial in that it also simplified and semi-automated certain aspects of environmental impact analysis for newly-envisioned and planned floating solar installations in South Africa.

The results demonstrated how the functionality of the *EIAcloudGIS* tool for calculating power generation saves time since it standardises the object-level design process for the sophisticated high-level analysis of the energy capacity of floating solar systems. It enables various agricultural and professional users to use the same online platform and seamlessly share information concerning floating solar projects. Furthermore, the design of system and the editing facilities of the *EIAcloudGIS* tool offer a facility for modelling the floating solar system scheme in reasonable detail. Furthermore, the tool's reporting mode assists users (farmers, developers or EAP's) in developing site survey proposals, in presenting accurate hourly power generation data reports and energy calculations to clients, and also in offering the client presentations on design optimisation.

In conclusion, the experiments collectively demonstrated the capacity of the implemented *EIAcloudGIS* computer application and GIS-toolset. In particular, it was possible, by integrating the computational modelling techniques onto a custom-designed GIS platform, to quantitatively evaluate the performances of the floating solar system. In terms of the *EIAcloudGIS* tools capacity to assimilate the results, its outputs are most valuable for evaluating floating solar systems and due-diligence analytical processes essential assessing the mitigatory contribution of floating solar technology to impact upon climate change. Details of the energy production capacity and yields of floating solar systems can be incorporated together with environmental profiling characteristics to serve as decision-supporting metrics in a decision-based approach that could contribute to an understanding of the relationship between the green energy economy and the conservation of the relevant natural resources.

5.2. Revisiting the Aims and Objectives

The experimental results show that the aims and objectives of the research study concerning the development of a proposed *EIAcloudGIS* toolset and a computer application were attained. Furthermore, the results show that the study succeeded in its goal to develop a GIS-based geographical tool as a decision-supporting aid for due-diligence evaluations of projects geared to integrated water-based floating solar energy solutions in local agricultural production systems.

This research aimed at developing a dedicated GIS toolset to determine the environmental feasibility regarding the use of floating solar systems in the South African agricultural sector. The research objectives of this study included the following:

1. to develop a GIS-based toolset for predicting the energy yields of agricultural floating solar systems in South Africa.

2. to use the toolset to theoretically determine the environmental offsets and environmental impacts of agricultural floating solar systems in South Africa.
3. to demonstrate the anticipated difference in environmental impacts associated with a floating solar energy system as opposed to those relying solely on the Eskom power grid.
4. to predict the anticipated energy yield, environmental impact and land-use preservation benefits of a floating solar system as WELF nexus parameters.
5. to demonstrate the capacity of a GIS-based floating solar energy toolset in a decision-supporting application of floating solar energy.

The *research aim* was achieved in that a dedicated GIS toolset, namely *EIAcloudGIS*, was designed, developed and implemented. The *EIAcloudGIS* toolset has the functionality to determine the feasibility of using floating solar systems in agricultural applications in the South African region to determine the associated energy yields and environmental impacts. The technical details of this *EIAcloudGIS* toolset mechanism, together with the application methodologies for the operation of this toolset, were covered in Chapter 3 of this dissertation. Chapter 3 also detailed the fundamental principles and procedures around the collection of quantitative data and around sampling approaches when using the *EIAcloudGIS* toolset as the basis for scientific experimentation in respect of the defined research objectives.

The results in Experiment 1 show that objective one of the research was achieved in that the *EIAcloudGIS* toolset was able to predict the energy yields of various agricultural floating solar systems in South Africa. The energy yield analysis methodology and energy yield characterisation profiles for the three case study areas at the farm sites IF, BF, and RC were compiled and displayed as time-series graphs in Figure 4.10.

The experimental results in Experiment 2 demonstrate that the second objective was achieved successfully. The *EIAcloudGIS* toolset theoretically determined the environmental impacts for various agricultural floating solar systems in South Africa. The resultant *environmental profiles* for the planned floating solar systems are presented graphically in the environmental profile shown in Figure 4.18. These results demonstrate how the GIS tool is able to gauge the impact of various floating solar systems in terms of environmental profiles and substance emission avoidance (CO_2, SO_x, NO_x, aPE) in the time-series graphs of Figures 4.11 to 4.17.

Furthermore, on the basis of Experiments 2 and 3, the results in Figure 4.18 show that the *third research objective* was achieved. In these experiments, the *EIAcloudGIS* toolset was used to compute the anticipated difference in environmental impacts associated with a floating solar energy system as opposed to those issuing from Eskom grid. These results were determined through Eskom's grid (substitution) environmental model (Eskom, 2014*c*) by which established the Eskom greenhouse substance equivalence factors. The results in Figure 4.18 show that the emissions of several tons of CO_2, IF (328.6 tons), BF (264.9 tons) and RC (233.7 tons) can be avoided thanks to the installation of floating solar systems at the respective sites. The aggregated *environmental profiles* for the individual planned floating solar products are presented in the composite footprint profile of Figure 4.18 and depicts the projected emission reductions for all of the greenhouse gases, with emission inventories expressed as equivalence factors for the various greenhouse gas substances.

Moving on to the *fourth objective* of this research, the *EIAcloudGIS* toolset was able to theoretically predict the anticipated energy yields, environmental impacts and land-use conservation benefits of the various floating solar systems as WELF nexus parameters. The study was thus able to meet the fourth objective through Experiment 3, where the results (as displayed in Figure 4.19) determined by the *EIAcloudGIS* tool portrayed the energy production capacity (P_e in kW), water preservation (litres H_2O) and agricultural land-use saving (aLP in m^2) benefits for floatovoltaic systems. This also includes the agricultural land preservation benefits (aLP as associated food production land-preservation area) for the planned floatovoltaic systems at the fruit farming locations IF, BF, and RC. On the basis of these results Figure 4.19, and in conjunction with the *environmental profiles* for the respective planned floating solar systems in the footprint bar-chart of Figure 4.18, the environmental impact practitioner would be able to report and take decisions on the inventories of the projected greenhouse gas emissions as equivalence factors in respect of the relevant chemical substances.

The *fifth research objective* was achieved using the results of the *EIAcloudGIS* decision-supporting analysis in Figure 4.18 and Figure 4.19, which demonstrated how the GIS-based floating solar analysis results could be engaged in floating solar system decision-supporting applications. The energy yield characteristics displayed in Figure 4.10, the environmental profile decision metrics depicted in Figure 4.18, as well as the decision support dashboard display portrayed in Figure 4.19 jointly offer the environmental impact practitioner with decision opportunities through site-specific floating solar decision metrics. Specifically, the results from Experiments 1, 2 and 3 offer the following decision metrics: (a) energy yield profiles, (b) environmental profiles, (c) agricultural land preserved, (d) energy preserved, and (e) water preserved for fruit farms IF, BF, and RC.

The *EIAcloudGIS* simulation tool was also able to project the water savings, coal fuel savings, reduced coal ash content. The *EIAcloudGIS* simulation tool was able to finally project the avoided SO_2, NO_x, CO_2 and aPE emissions as decision-supporting metrics on the GIS map displays of Figures 4.20 and 4.21. Collectively, the experimental results in Figures 4.18 to 4.21 confirm the successes achieved in respect of the fifth research objective in Experiment 3.

5.3. Limitations of the Study

There are certain limitations of the study that came to light when the characteristics of the design methodology that could impact on the outcomes and interpretation of the findings by the *EIAcloudGIS* tool used in this research were considered. One of the first limitations of the study was found to be the accuracy of the pseudo-CAD-type GIS design that represents computer abstractions of the floating solar system architecture. While the GIS tool offers a basic CAD-type of functionality to render a floating solar outlay for a proposed floating solar system (geodesic polygon shapes), differences between the dimensions and technical layout characteristics of such a design are to be expected. The physical sizes and efficiencies of the floating solar system panels may further vary from manufacturer-to-manufacturer, which could impact on the energy yields of the planned system. The *EIAcloudGIS* tool also makes very rough assumptions about losses suffered in respect of the efficiency of the equipment as a result of the degradation of the equipment, as well as about systems losses on account of dust collecting on and the soiling of the solar panels. Moreover, the use of wiring, cable connection configurations, and the placement of electrical conversion equipment could be expected to further impact upon the energy yield profile of the floating solar system design. These aspects could be addressed in future research and tool module developments.

In the present study experiments, the GIS toolset is used to support EIA processes for floating solar project approvals in absolute terms (to help practitioner complete EIA score-card for each site, not necessarily for site performance comparison purposes). If the goal is to use the tool in different test-case site comparisons, then several factors must be standardised/normalised in the simulation runs for each test site. This is because floating solar energy production/environmental offset performances in different test-case scenarios are dependent on several of inter-connected factors (solar panel/array size, solar panel type, solar irradiation, location, altitude, sunrise, sunset, panel-orientation angle, cloud cover, weather patterns, ambient temperature). Future development versions of the GIS toolset would consider allowing for at least solar unit area normalisation to enable more logical site performance comparisons.

Since the development of the GIS toolset focused on assisting the EIA processes for floating solar in absolute terms, the tool was not necessarily developed for comparing the energy production/greenhouse gas contributions of floating solar to that of land-based solar systems. It would be of great value to extend the future capabilities of the GIS toolset to enable comparisons of water/land-based solar systems. This aspect may also be included as an option in future tool feature extensions.

One assumption of the study is that farming-and fruit-processing activities would fully absorb all the power generated by the planned floating solar system. In the real world, as part of the energy and environmental profiling process, the demand-side profile of a farm/processing facility must match the supply side profile of the floating solar system. The energy model of the future could possibly be extended to include demand-side management using self-organising smart-grid technology in farm-based micro-grid energy distribution models (Gomez-Lorente *et al.*, 2017). However, from a geographical perspective, these technicalities would significantly complicate the energy and environmental profiling processes. It would call for finely-detailed energy demand estimation from available farm-specific data sources combined with supply/demand matching optimisation, which in turn involves complicated electronic processing in smart-grid or smart-microgrid energy management structures (Eger *et al.*, 2013; Mazzola *et al.*, 2017). The incorporation of these aspects in the *EIAcloudGIS* toolset would significantly complicate the computational modelling aspects of the GIS tool.

Despite the assumptions and variations mentioned earlier, the *EIAcloudGIS* toolset still provides a relatively good assessment of the energy yield and environmental impact profiles for a floating system of suitable size for farming irrigation ponds or dams. Such estimates are sufficient for the purpose because the aim of the research was for the *EIAcloudGIS* toolset to provide strategic energy and environmental profiling guidelines in terms of strategic energy yields and environmental profiling to enable project owners and environmental impact practitioners to make fundamental decisions concerning the implementation of projects and comparisons between preliminary design configurations. In this context, the *EIAcloudGIS* tool averts the much more expensive process of engaging a range of professional experts in cumbersome procedures associated with the traditional assessment of a clean energy impact analysis in the early stages of the planning phase.

5.4. Conclusion and recommendations for future research

On a future envisaged EIA-reporting platform, expanded GIS platform functionality could operate as an extension to the current *EIAcloudGIS* toolset. *EIAcloudGIS* toolset-reporting formats and satellite maps could thus be further customised to be more suitable for investment and for supporting EIA process concerning planned floating solar investment decisions, incentive/subsidy applications, environmental approval applications, comparisons in respect of ecological suitability, due-diligence analyses or environmental sustainability studies.

In the future, the proposed GIS toolset and its associated geographical simulation objects will be extended to function as a more intelligent tool to deal with environmental-impact analyses specifically geared to floating solar systems. Within the context of this agriculturally-based application of floating solar technology, this custom-designed and -developed *EIAcloudGIS* geographical toolset will prepare for the ultimate goal of this research, namely the development of electronic environmental and financial scorecards on a geoinformatics decision-supporting platform. These scorecard goals for a diagnostic system will be pursued in a future study on the development of processes in respect of environmental impact and due-diligence analyses related to floating solar system installations in South Africa. With these computerised assessment scorecards that are based on information technology, the *EIAcloudGIS* toolset intends to provide further impetus to decision-making in respect of floating solar technology to enhance the digital customer experience in a cloud-based environment.

The development of an extended electronic scorecard module focusing on the environment and finances, and a decision-supporting system for a supportive environment offered by the *EIAcloudGIS* toolset constitutes another aspect of the directions for future research. The predictive floating solar analytics/parameters determined through the *EIAcloudGIS* toolset simulations of this study (P_e, H_2O, CO_2, SO_2, NO_x, aPE, and aLP) should be extended to generate more advanced electronic scorecard reports in respect of floating solar technology. Such a toolset feature could use computer-based, deductive reasoning processes with sustainability indicators to interpret the profiling results for each site in order to reach logical conclusions from the environmental impact figures predicted by the GIS-toolset of the present study. Such geoinformatics-type, decision-supporting analyses and reporting could be incorporated into the *EIAcloudGIS* toolset to assist with the assimilation of results and decision support around the requirements for EIA legislation, legislative carbon taxation requirements/implications, and the anticipated economic impacts of the planned system.

With the specific primary *EIAcloudGIS* toolset functions established, a future direction for research would also be to continue with the further development of geoinformatics to raise the awareness among farmers in South Africa of the floating solar technology domain. The predictive analytical profiling of the existing desktop GIS toolset for floating solar systems will be enriched by further processing to offer results in a digital storytelling-type of format on a display portal. The sampled simulation output data projected on the portal could be used in a GIS-based automated decision-supporting system in support of the decision-making activities of farming enterprises (Sprague and Watson, 1986). In such an extended GIS-based decision-supporting application, the quantitative outputs of the *EIAcloudGIS* tool could be extended to support decision-making processes concerning floating energy technology from a multi-decision-supporting perspective, involving a combination of energy, environmental, and economic perspectives.

From an accounting and business management perspective, the present GIS-based toolset should finally be extended to include techno-economic valuations of water-mounted photovoltaic systems. Economic valuations would be the most valuable in performing financial viability and due-diligence analyses as part of the preparatory work for clinching potential floating solar financing deals. The *EIAcloudGIS* toolset could thus be extended to model the economic aspects of power generation in floating solar systems. Economic cost-benefit analyses of floating solar power generation could engage computer science and management information systems principles on a more intelligent geoinformatics platform. The extended smart tool will be able to guide developers in the field of floating solar projects and project investors to make decisions about energy yields and the environmental and economic impacts of floating solar systems, and to determine those benefits that could not otherwise be specified in advance. One application prospect would be for the *EIAcloudGIS* analysis to predict the sensitivity of the planned installation to solar electricity prices, inflation rates, and how the viability of the system responds to changes in the income/eco-tax rates, the price of carbon credits, and the prevailing interest rate on equipment loans. With these capacities, arithmetic operations and instruction sets embedded in the *EIAcloudGIS* toolset layers would contribute to the project appraisal processes through a range of empirically-determined due-diligence decision metrics crucial to financial investment decisions.

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List of References

Akorede, M., Hizam, H. and Pouresmaeil, E. (2010). Distributed energy resources and benefits to the environment. *Renewable and Sustainable Energy Reviews*, vol. 14, no. 2, pp. 724–734.

Alwitt, P., De Maio, J., Moore, M., Bogart, R., Westbrook, S. and Thompson, D. (2012). A floating support structure for a solar panel array. In: *U.S. Patent Journal, Patent No. U.S. 20120279557 A1, SPG Solar Incorporated, United States Patent and Trademark Office*, 8, pp. 1–15. U.S. Patent Office.

Andrews, R.W., Stein, J.S., Hansen, C. and Riley, D. (2014). Introduction to the Open Source PV LIB for Python Photovoltaic System Modelling Package. *2014 IEEE 40th Photovoltaic Specialist Conference, PVSC 2014*, vol. 2, no. 1, pp. 170–174.

Ayash, M. (2014). Research Methodologies in Computer Science and Information Systems. *Computer Science*, vol. 2014, pp. 1–6.

Benson, D., Gain, A. and Rouillard, J. (2015). Water Governance in a Comparative Perspective: From IWRM to a Nexus Approach? *Water Alternatives*, vol. 8, no. 1, pp. 756–773.

Blignaut, A. (2017). South Africa's draft carbon tax legislation and carbon offset regulations: How will it work? *Blue North Carbon Tax Review*, vol. 1, pp. 1–3.

Blue North (2017). Development of Sustainability Self-Assessment Tools. *Performance Assessment and Monitoring*, vol. 1, pp. 1–3.

Bonkaney, A., Madougou, S. and Adamou, R. (2017). Impacts of Cloud Cover and Dust on the Performance of Photovoltaic Module in Niamey. *Journal of Renewable Energy*, vol. 1, no. 2, pp. 1–8.

Broome, J. and Warner, K. (2008). Agro-environmental partnerships facilitate sustainable winegrape production and assessment. *California Agriculture*, vol. 62, no. 4, pp. 133–141.

Burns, N. and Grove, S. (2005). *The Practice of Research: Conduct, Critique and Utilization*. 5th edn. Elsevier Science Publishers, Saint Louis, U.S.A.

Cape-Ducluzeau, L. and van der Westhuizen, C. (2015). Strategic Environmental Assessment for Renewable Energy in South Africa: Renewable Energy Development Zones (REDZs). *Annual Conference of the International Association for Impact Assessment, Florence, 20-23 April, Vancouver*, vol. 1.3, pp. 1–10.

Casillas, C. and Kammen, D. (2012). The challenge of making reliable carbon abatement estimates: the case of diesel microgrids. *Sapiens*, vol. 5, no. 1, pp. 1–22.

Cebecauer, T. and Suri, M. (2015). Typical Meteorological Year Data: SolarGIS Approach. *Energy Procedia*, vol. 69, pp. 1958–1969.

Chandler, R. and Scott, M. (2011). *Statistical Methods for Trend Detection and Analysis in the Environmental Sciences*. 1st edn. John Wiley and Sons, Oxford, England. ISBN 978-0-470-01543-8.

Chang, Y., Li, G., Yao, Y., Zhang, L. and Yu, C. (2016). Quantifying the Water-Energy-Food Nexus: Current Status and Trends. *Energies*, vol. 9, no. 65, pp. 1–17.

Choi, Y. (2014). A study on power generation analysis of floating PV systems considering environmental impact. *International Journal of Software Engineering and its Applications*, vol. 8, no. 1, pp. 75–84.

Choi, Y.K., Lee, N.H. and Kim, K.J. (2013). Empirical Research on the Efficiency of Floating PV Systems compared with Overland PV Systems. *Proceedings of the International Conference on Circuits, Control, Communication, Electricity, Electronics, Energy, System, Signal and Simulation, CES-CUBE 2013*, vol. 25, pp. 284–289.

Connor, P. (2015). Liquid Solar Array. *Project Report, SunEngy Pty Ltd, Sydney, Australia*, vol. 2, pp. 1–37.

Cossio, M.L.T. (2012). Research Ethics Checklist. *University of Edinburgh*, vol. 1, no. 3, pp. 1–5.

da Silva, G.D.P. and Branco, D.A.C. (2018). Is floating photovoltaic better than conventional photovoltaic: Assessing environmental impacts environmental impacts. *Impact Assessment and Project Appraisal*, vol. 1, no. 2, pp. 1–11.

De Villiers, S. and de Wit, M. (2010). H2O-CO2-energy equations for South Africa: Present status, future scenarios and proposed solutions. *Published by Africa Earth Observatory Network (AEON), University of Cape Town, Rondebosch, Cape Town*, vol. 1, pp. 1–49.

DEA (2018). Maps and graphics: Environmental geographic information systems (EGIS). *Department of Environmental Affairs of South Africa*, vol. 1, pp. 1–20.

Deambi, S. (2016). *Photovoltaic System Design: Procedures, Tools and Applications*. 1st edn. CRC Press, Taylor and Francis Group, Boca Raton, Florida, USA.

Department of Environmental Affairs (2015). Discussion Document on Environmental Offsets. Tech. Rep. 6, Department of Environmental Affairs, Pretoria.

Derman, B.B. (2013). Contesting climate injustice during COP17. *South African Journal on Human Rights, Climate change justice, narratives, rights and the poor*, vol. 29, no. 1, pp. 170–179.

Dickinson, B. (2011). *Is a Floating Solar Energy Plant a Smart Idea?* Available at: http://www.zdnet.com/article/is-a-floating-solar-energy-plant, [Accessed: 5 May 2017].

Dierauf, T., Growitz, A., Kurtz, S. and Hansen, C. (2013). Weather-Corrected Performance Ratio. *NREL National Laboratory of the U.S. Department of Energy*, vol. 2, pp. 1–16.

DOE (2015). Carbon Farming Initiative (CFI): Mapping Guidelines. *Department of Environment, Australian Government*, vol. 1, pp. 1–27.

Donatelli, M. (2008). Integrated Modelling Frameworks for Environmental Assessment and Decision Support: How modeling extends the scientific method at the base of research. In: A.J. Jakeman, A.A. Voinov, A.E. Rizzoli, S.C. (ed.), *Developments in Integrated Environmental Assessment, Environmental Modelling, Software and Decision Support*, pp. 101–118. Elsevier Science Publishers, London, U.K.

Duffie, J. and Beckman, W. (2013). *Solar engineering of thermal processes*. John Wiley and Sons, London, UK.

Eger, K., Goetz, J., Sauerwein, R., Frank, R., Boëda, D., de Cerio, I.M.D., Artych, R., Leukokilos, E., Nikolaou, N. and Besson, L. (2013). Microgrid Functional Architecture Description. *Participatory report by Siemens AG, Grenoble INP, Iberdrola S.A., Orange Labs, Synelixis, Thales*, vol. 1, pp. 1–169.

El Chaar, L., Lamont, L. and El Zein, N. (2011). Review of photovoltaic technologies. *Renewable and Sustainable Energy Reviews*, vol. 15, no. 5, pp. 2165–2175. ISSN 13640321.

Engelbrecht, D., Biswas, W., Pritchard, D. and Ahmad, W. (2015). A new tool for calculating the carbon footprint of Western Australian farms. *The Grain Industry Association of Western Australia (GIWA)*, vol. 1, pp. 1–4.

Enthought (2017). Python Distribution and Integrated Analysis Environment: Python Package with a Graphical Package Manager. *Enthought Canopy, Proven Scientific Python Distribution plus Integrated Analysis Environment*, vol. 1, pp. 1–7.

EPA (2018). *Overview of Most Prominent Greenhouse Gases*. Available at: https://19january2017snapshot.epa.gov/ghgemissions/overview-greenhouse-gases_.html [Accessed 1 June 2018].

Eskom (2011). Wheeling/offset of energy: The Eskom approach. *Eskom non-Eskom Generator (NEG) Model*, vol. 1, no. 3, pp. 1–18.

Eskom (2014*a*). Climate change factors as modelled in the Eskom 2012 Annual Integrated Report. *Eskom IDM Project Evaluation Committee EsCo-Model Template*, vol. 1, pp. 1–21.

Eskom (2014*b*). Environmental implications of using or saving electricity. *Integrated Results Presentation, Eskom Holdings Limited, Johannesburg, South Africa*, vol. 1, pp. 1–3.

Eskom (2014*c*). Environmental implications of using or saving electricity. *Integrated Results Presentation, Eskom Holdings Limited, Johannesburg, South Africa*, vol. 1, pp. 1–5.

Eskom (2017). Eskom Integrated Report, 2017. *Eskom Annual Report*, vol. 1, no. 3, pp. 1–68.

ESRI (2010). GIS Best Practices: GIS for Renewable Energy. *ESRI, 380 New York Street Redlands, CA 92373-8100 USA*, vol. 1, no. 1, pp. 1–46.

ESRI (2017). GIS Use in Map, Chart and Data Production. *ESRI Environmental Systems Research Institute, MAPS Community*, vol. 1, pp. 1–44.

European Commission (2008). Reform of the European Union wine market. *European Commission, Agriculture and Rural Development: Adopted by the Council of Ministers in April 2008, EC Regulation 479/2008 and 555/2008*, vol. 1, pp. 1–2.

Evaluation, T., Project, U.N.E. and Economy, G. (2017). Evaluation of the UN Environment Project on Green Growth Knowledge Platform. *United National Environmental Programme*, vol. 1, no. 1, pp. 1–148.

Filik, U., Filik, T. and Gerek, O. (2018). A Hysteresis Model for Fixed and Sun Tracking Solar PV Power Generation Systems. *Energies*, vol. 11, no. 603, pp. 1–15.

Fischlin, A. (1990). Interactive Modeling and Simulation of Environmental Systems on Workstations. *Systems Ecology Group, Institute of Terrestrial Ecology, Department of Environmental Sciences, Swiss Federal Institute of Technology, Zurich (ETHZ). ETH-Zentrum, CH-8092 Zurich, Switzerland*, vol. 1, no. 5, pp. 1–18.

Flammini, A., Puri, M., Pluschke, L. and Dubois, O. (2014). *Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative*. Climate, Energy and Tenure Division (NRC). Food and Agriculture Organization of the United Nations, Rome, Italy. ISBN 978-92-5-108487-8.

Flint, D. and Golicic, S. (2009). Searching for competitive advantage through sustainability: a qualitative study in the New Zealand wine industry. *International Journal of Physical Distribution and Logistics Management*, vol. 39, no. 10, pp. 841–860.

Foran, T. (2015). Node and Regime: Interdisciplinary Analysis of the Water-Energy-Food Nexus in the Mekong Region. *Water Alternatives*, vol. 8, no. 1, pp. 655–674.

Frenkiel, F. and Goodall, D. (1978). *Simulation Modelling of Environmental Problems*. 1st edn. John Wiley and Sons, London, U.K. ISBN 0471991800.

Ge, J., Sutherland, L.A., Polhill, J.G., Matthews, K., Miller, D. and Wardell-Johnson, D. (2017). Exploring factors affecting on-farm renewable energy adoption in Scotland using large-scale microdata. *Energy Policy*, vol. 107, no. 4, pp. 548–560.

GeoModel Solar (2017). *GeoModel Solar Launches New Generation Online Tools for Solar Site Prospecting and Bankable Photovoltaic Yield Assessment*. Available at: http://geomodelsolar.eu [2017, May 13].

Gilman, P. (2018). SAM Photovoltaic Model Technical Reference Update. *National Renewable Energy Laboratory, NREL P-6A20-64102*, vol. 3, no. 1, pp. 1–93.

Gomez-Lorente, D., Rabaza, O., Aznar-Dols, F. and Mercado-Vargas, M. (2017). Economic and

Environmental Study of Wineries powered by grid-connected Photovoltaic Systems in Spain. *Energies*, vol. 10, no. 2, pp. 222–231.

Government Gazette (2010). Sector Guidelines for Environmental Impact Assessment Regulations. *Department of Environmental Affairs, National Environmental Management Act, 1998 (Act N0.107 Of 1998 (as amended), Publication of Implementation Guidelines*, vol. 6, no. 33, pp. 1–148.

Government Gazette (2014). Environmental Impact Assessment Regulations. *Department of Environmental Affairs, National Environmental Management Act, 1998 (Act No. 107 of 1998)*, vol. 1, no. 12, pp. 1–288.

Graser, A. and Olaya, V. (2015). Processing: a python framework for the seamless integration of geoprocessing tools in QGIS. *ISPRS International Journal of Geo-Information*, vol. 4, no. 4, pp. 2219–2245.

Gueymard, C.A. and Myers, D.R. (2008). Validation and ranking methodologies for solar radiation models. In: Gueymard, C.A. (ed.), *Modeling Solar Radiation at the Earth's Surface: Recent Advances*, 1st edn, chap. 20, pp. 479–509. Springer Link Publsihers, New York. ISBN 9783540774549.

Gurupira, T. and Rix, A.J. (2016). Photovoltaic System Modelling using PVLib-Python. *Fourth South African Solar Energy Conference, SASEC 2016, University of Stellenbosch, South Africa*, vol. 1, no. 1, pp. 1–10.

Harris, J.M. and Roach, B. (2018). *Environmental and Natural Resource Economics: A Contemporary Approach*. Routledge Publications, New York.

Harrison, J. (1999). The Concept of Simulation in Organizational Research. *University of Texas at Dallas*, vol. 1, pp. 1–26.

Herman, R., Gaunt, C. and Tait, L. (2015). On the adequacy of electricity reliability indices in South Africa. *Proceedings of the South African Universities Power Engineering Conference, Johannesburg, 28-30 January 2015*, vol. 1, pp. 1–12.

Hernandez, R., Easter, S., Murphy-Mariscald, M., Maestree, F., Tavassolib, M., Allend, E., Barrows, C., Belnapg, J., Ochoa-Huesoh, R., Ravia, S. and Allend, M. (2014). Environmental impacts of utility-scale solar energy. *Renewable and Sustainable Energy Reviews*, vol. 29, no. 2, pp. 766–779.

Ho, C.J., Chou, W. and Lai, C. (2015). Thermal and electrical performance of a water-surface floating PV integrated with a water-saturated MEPCM layer. *Energy Conversion and Management*, vol. 89, pp. 862–872. ISSN 0196-8904.

Hoff, H. (2011). Understanding the Nexus. *Bonn 2011 Conference on the water, energy and food security nexus. Stockholm Environment Institute, Stockholm*, vol. 1.2, pp. 1–18.

Holcomb Research Institute (1976). Environmental modeling and decision making: the United States experience. *Report by the Holcomb Research Institute, Butler University for the Scientific Committee on Problems of the Environment*, vol. 1, pp. 1–152.

Holmgren, W.F., Andrews, R.W., Lorenzo, A.T. and Stein, J.S. (2015). PVLIB Python 2015. *IEEE 42nd Photovoltaic Specialist Conference, PVSC 2015*, vol. 1, pp. 1–5.

Holmgren, W.F. and Groenendyk, D.G. (2016). An Open Source Solar Power Forecasting Tool Using PVLIB-Python. *43rd IEEE Photovoltaic Specialists Conference*, vol. 1, pp. 1–5.

IPCC (2014). Climate Change 2014: Synthesis Report Summary for Policymakers. *Intergovernmental Panel on Climate Change*, vol. 1, no. 1, pp. 1–256.

Jakhrani, A.Q., Samo, S.R., Kamboh, S.A., Labadin, J. and Rigit, A.R.H. (2014). An improved mathematical model for computing power output of solar photovoltaic modules. *International Journal of Photo-energy*, vol. 2014, pp. 1–9. ISSN 1687529X.

James, K. and Shachar, O. (2015). Carbon Footprint Master-class Slides. *Global Carbon Exchange (Africa), Environmental Impact Analysis Specialists*, vol. 2, pp. 1–50.

Khaiter, P. and Erechtchoukova, M. (2007). From Complex to Simple in Environmental Simulation Modelling. *The Atkinson Faculty of Liberal and Professional Studies, York University, Canada*, pp. 2069–2075.

Kothari, C. (2004). *Research Methodology: Methods and Techniques*. 2nd edn. New Age International Publishers, New Delhi.

Kurian, M. (2017). The water-energy-food nexus: Trade-offs, thresholds and transdisciplinary approaches to sustainable development. *Environmental Science and Policy*, vol. 68, no. 1, pp. 97–106.

Kwan, M.P. (2004). GIS Methods in Time-Geographic Research: GEO-Computation and GEO-Visualization. *Swedish Society for Anthropology and Geography*, vol. 86, no. 4, pp. 267–280.

Lee, Y.G., Joo, H.J. and Yoon, S.J. (2014). Design and installation of floating type photovoltaic energy generation system using FRP members. *Solar Energy*, vol. 108, pp. 13–27. ISSN 0038092X.

Letete, T., Guma, M. and Marquard, A. (2010). Carbon accounting for South Africa. *In T. Letete (1st ed.). Information on climate change in South Africa: greenhouse gas emissions and mitigation options. Cape Town: University of Cape Town.*, pp. 1–9.

Lew, D., Miller, N., Clark, K., Jordan, G. and Gao, Z. (2010). Impact of high Solar Penetration in the Western Interconnection. *National Renewable Energy Laboratory, NREL Contract No. DE-AC36-08GO28308, Task No. SM101610, Technical Report NREL/TP-5500-49667, December 2010*, vol. 1, pp. 1–10.

Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. *Progress in Planning*, vol. 62, no. 1, pp. 3–65.

Mañé-Estrada, A. (2006). European energy security: towards the creation of the geo-energy space. *Energy Policy*, vol. 34, no. 18, pp. 3773–3786.

Mather, B. and Yuan, G. (2017). On the Sunny Side: Integrating Solar Energy at Increasing Rates. *IEEE Power and Energy Magazine*, vol. 15, no. 2, pp. 14–18.

Mazzola, S., Vergara, C., Astolfi, M., Li, V., Perez-Arriaga, I. and Macchi, E. (2017). Assessing the value of forecast-based dispatch in the operation of off-grid rural microgrids. *Renewable Energy*, vol. 108, pp. 116–125.

Meteonorm (2016). *Meteonorm: Irradiation data for every place on Earth*. Available at: http://www.meteonorm.com/downloads [Accessed 2 May 2017].

Ministry of Finance (2015). Draft carbon tax bill. *National Assembly (proposed section 77)*, vol. 1, pp. 1–43.

Moradi, H., Abtahi, A. and Messenger, R. (2016). Annual performance comparison between tracking and fixed photovoltaic arrays. *IEEE 43rd Photovoltaic Specialists Conference (PVSC)*, vol. 1, no. 1, pp. 1–12.

Movellan, J. (2013). Running out of Precious Land? Floating Solar PV Systems may be a Solution. *Renewable Energy World*, pp. 1–3.

NASA (2018). *Climate and the Earth's Energy Budget*. Available at: https://earthobservatory.nasa.gov/Features/EnergyBalance/page3.php [Accessed 1 June 2018].

National Planning Commission (2012). National Development Plan 2030. *National Development Plan and Programme of Action*, vol. 1, no. 2, pp. 1–489.

NERSA (2017). National Energy Regulator of South Africa. In: *NERSA regulatory authority established in terms of Section 3 of the National Energy Regulator Act, 2004 (Act No. 40 of 2004)*, pp. 1–5. Available at: http://www.nersa.org.za/ [2016, June 2].

Noel, Castree, D.D., Liverman, D. and Bruce Rhoads (2009). *A Companion to Environmental Geography*. 1st edn. Wiley Online Library, London, U.K. ISBN 9781444305722.

Nowak, L.I. and Washburn, J.H. (2002). Building Brand Equity: Consumer Reactions to Proactive

Environmental Policies by the Winery. *International Journal of Wine Marketing*, vol. 14, no. 3, pp. 5–19.

Ntombela, S.M. (2019). A general equilibrium analysis of the effects of carbon tax policy on South Africa's agricultural industries. *Doctor of Philosophy in Agricultural Economics, University of Pretoria*, pp. 1–125.

Paegelow, M. and Camacho-Olmedo, M.T. (2008). *Modelling Environmental Dynamics: Advances in Geomatic Solutions*. 1st edn. Springer-Verlag, Berlin Heidelberg. ISBN 978-3-540-68498-5.

Pather, V. (2004). Eskom and Water. *Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference*, vol. 1, pp. 659–664.

Patton, T., Almer, L., Hartman, H. and Smith, K. (2013). An overview of potential environmental, cultural, and socioeconomic impacts and mitigation measures for utility-scale solar energy development. *Environmental Science Division, Argonne National Laboratory, Contract ANL/EVS/R-13/5*, vol. 2, no. 1, pp. 1–118.

Pentland, W. (2011). Napa Winery Pioneers: Solar Floatovoltaics. *Forbes Business*, vol. 2011, no. 8, pp. 1–3.

Peuthert, A. (2010). *Spray Irrigation with Cyanobacterial Toxin Contaminated Water: A Potential Risk for Plants Used in Agriculture, Using Medicago Sativa L. as a Model Plant*. 1st edn. Berlin Dissertation Press. ISBN 9-783-86624492-4.

Portney, K.E., Hannibal, B., Goldsmith, C., McGee, P., Liu, X. and Vedlitz, A. (2017). Awareness of the Food-Energy-Water Nexus and Public Policy Support in the United States: Public Attitudes among the American People. *Environment and Behavior*, vol. 5, pp. 1–9.

Pringle, A.M., Handler, R.M. and Pearce, J.M. (2017). Aquavoltaics: Synergies for dual use of water area for solar photovoltaic electricity generation and aquaculture. *Renewable and Sustainable Energy Reviews*, vol. 80, no. 5, pp. 572–584.

Prinsloo, F. (2017*a*). *Environmental Impact and Assessment for Floating Solar Systems on Wine Farms in the Western Cape Wine Region*. Bachelor of Science (Honours) Dissertation, University of South Africa.

Prinsloo, F. (2017*b*). Proposal for the development of a GIS-based decision support tool for environmental impact assessment and due-diligence analyses of planned agricultural floating solar systems. *Master of Science Proposal, UNISA*, vol. 1, no. 2, pp. 1–43.

Prinsloo, F. and Lombard, A. (2015*a*). Die Omgewingsimpak van Drywende Sonkragstelsels in die Wynbedryf. *Suid-Afrikaanse Tydskrif vir Natuurwetenskap en Tegnologie*, vol. 35, no. 1, pp. 4173–4180.

Prinsloo, F. and Lombard, A. (2015*b*). Environmental Impact Factors in Floating Solar Systems: Lessons for the South African Wine Industry. *Academy of Sciences, Student Symposium in Natural Sciences 2015, at the University of the Free State, South Africa*, vol. 1, pp. 1–15.

Prinsloo, F. and Lombard, A. (2015*c*). Floating Solar Systems in Sustainable Viticulture and Oenology: Environmental Solutions in Support of Water-Energy-Food-Land-use Nexus Goals: Geoinformatics, Physical Geography Environmental Impact Assessment. *International Winery 2015 Conference, Stias Centre, Stellenbosch, South Africa*, vol. 1, pp. 1–66.

QGIS, D. (2015). QGIS Geographic Information System. *Open Source Geospatial Foundation Project.*, vol. 1, no. 2, pp. 1–10.

Redón Santafé, M., Torregrosa Soler, J.B., Sánchez Romero, F.J., Ferrer Gisbert, P.S., Ferrán Gozálvez, J.J. and Ferrer Gisbert, C.M. (2014). Theoretical and experimental analysis of a floating photovoltaic cover for water irrigation reservoirs. *Energy*, vol. 67, no. 1, pp. 246–255.

Remund, J. (2015). Accuracy of Meteonorm 7.1. *MeteoTest, Fabrikstrasse 14, Bern, Switzerland*, vol. 1, pp. 1–33.

Republic of South Africa (2019). Act No. 15 of 2019: Carbon Tax Act, 2019. *Government Gazette*, vol. 52, no. 42483, pp. 1–65.

Resch, B., Sagl, G., Törnros, T., Bachmaier, A., Eggers, J.-B., Herkel, S., Narmsara, S. and Gündra, H. (2014). GIS-Based Planning and Modeling for Renewable Energy: Challenges and Future Research Avenues. *ISPRS International Journal of Geo-Information*, vol. 3, no. 2, pp. 662–692. ISSN 2220-9964.

Ringler, C., Bhaduri, A. and Lawford, R. (2013). The nexus across water, energy, land and food (WELF): Potential for improved resource use efficiency. *Current Opinion in Environmental Sustainability*, vol. 5, no. 6, pp. 617–624. ISSN 1877-3435.

Rosa-Clot, M., Tina, G.M. and Nizetic, S. (2017). Floating photovoltaic plants and wastewater basins: An Australian project. *Energy Procedia*, vol. 134, no. 10, pp. 664–674. ISSN 18766102.

Royal Haskoning DHV (2015). Environmental Impact Assessment Study for the proposed Concentrated Solar Power Plant on the farm Sanddraai 391, Northern Cape. *Environmental Scoping Report for SolAfrica Energy (Pty) Ltd*, vol. 1, pp. 1–116.

S.A. Government (1998). National Environmental Management Act (NEMA). *Government Gazette of the Republic of South Africa*, vol. 401, no. 19519, pp. 1–37.

Sahu, Y., Shahabuddin, M. and Agrawal, P. (2015). Floating solar photovoltaic system an emerging technology. *National Seminar on the Prospects and Challenges of the Electrical Power Industry in India*, vol. 2, pp. 219–227.

Satein, H. (2009). Chemical Relationships between Greenhouse Gases and Air Pollutants in Biomass Energy Production. *Oregon Toxics Alliance*, vol. 1, no. 1, pp. 1 – 5.

Seaflex (2017). *Solar energy solutions based on floating platforms*. Available at: http://www.seaflex.net/applications/floating-solar-panels/ [2017, June 2].

Sharp Corporation (2008). U.S. vineyard uses space-saving floatovoltaics. *Renewable Energy Focus*, vol. 9, no. 4, pp. 64–65. ISSN 17550084.

Sholarin, E.A. and Awange, J.L. (2016). Environmental Project Management: Geospatial in Support of EIA, SEA, and SA. In: *Environmental Science and Engineering*, 1st edn, pp. 263–293. Springer Link Publishers, London, UK.

Simonovi, S.P. (2012). A Systems Approach to Modelling Water-Energy-Food Nexus. *Department of Civil and Environmental Engineering The University of Western Ontario London, Ontario, Canada*, vol. 1, pp. 1–29.

Singh, G. (2013). Solar power generation by PV (photovoltaic) technology: a review. *Review Article Energy*, vol. 53, pp. 1–13.

Sirieix, L. and Remaud, H. (2010). *Consumer perceptions of eco-friendly vs. conventional wines in Australia*. Doctoral Dissertation, University of Auckland.

Smith, J., Rogers, B., Taylor, J., Roark, J., Neenan, B., Mimnagh, T. and Takayesu, E. (2017). Time and Location: What Matters most when valuing Distributed Energy Resources (DER). *IEEE Power and Energy Magazine*, vol. 15, no. 2, pp. 29–39.

Smyth, M. (2011). Solar Winery Design and Operation. In: Smyth, M. (ed.), *Solar Energy in the Winemaking Industry*, 1st edn, chap. 7, pp. 357–454. Springer London, London. ISBN 978-0-85729-844-7.

Solar Energy Lab (2017). *Weather Data: Monthly Average Data, Standard TMY (Typical Meteorological Year), TMY2 Data and Generated Hourly Weather Files*. Available at: http://sel.me.wisc.edu/trnsys/weather/weather.htm [Accessed 2 May 2017].

SolarGIS (2018). Satellite-derived Solar Radiation and Meteorological Data. *High-resolution meteorological database, SolarGIS Database version 1.8, GeoModel Solar*, vol. 1, no. 8, pp. 1–12.

Spalding-Fecher, R. (2011). What is the carbon emission factor for the South African electricity grid? *Journal of Energy in Southern Africa*, vol. 22, no. 4, pp. 1–7.

SPG Solar (2010). Floatovoltaics Solar Power System. *SPG Solar Inc. Floatovoltaics, Overview and*

SPG Solar Statement of Qualifications, vol. 1, pp. 1–19.

Sprague, R.H. and Watson, H.J. (1986). *Decision support systems: putting theory into practice*. 2nd edn. Englewood Clifts, N.J., Prentice Hall. ISBN 0-13-197286-3.

Stein, J.S., Holmgren, W.F., Forbess, J. and Hansen, C.W. (2017). PVLIB: Open source photovoltaic performance modeling functions for Matlab and Python. *Conference Record of the IEEE Photovoltaic Specialists Conference*, vol. 11, no. 1, pp. 3425–3430. ISSN 01608371.

Suri, M., Cebecauer, T. and Skoczek, A. (2014). Cloud Cover Impact on Photovoltaic Power Production in South Africa. *Southern African Solar Energy Conference SASEC2014*, vol. 1, no. 2, p. 8.

Teodoro, A.C. (2018). Open Source GIS Tools: Two Environmental Applications. In: *GIS - An Overview of Applications*, pp. 1–229. Bentham Science Publishers, London, U.K.

Terrapon-Pfaff, J., Ortiz, W., Dienst, C. and Gröne, M.C. (2018). Energising the WEF nexus to enhance sustainable development at local level. *Journal of Environmental Management*, vol. 223, no. June, pp. 409–416. ISSN 10958630.

Tina, G.M., Cazzaniga, R., Rosa-Clot, M. and Rosa-Clot, P. (2018). Geographic and Technical Floating Photovoltaic Potential. *International Scientific Journal on Thermal Energy Science*, vol. 2, no. 8, pp. 1–12.

Trapani, K. and Santafe, M. (2015). A review of floating photovoltaic installations: 2007-2013. *Progress in Photovoltaics: Research and Applications, Wiley Publications*, vol. 23, no. 4, pp. 524–532. ISSN 10627995.

Unisa (2007). Policy on research ethics. *Research Department, University of South Africa*, vol. 1, pp. 1–26.

University of Wisconsin-Madison, T.D.G. (2009). *TrnSys 17: Transient System Simulation program: Volume 4, Mathematical Reference*. 1st edn. Solar Energy Laboratory, University of Wisconsin, Madison, U.S.A.

Urbaniec, K., Mikulcic, H., Rosen, M. and Duic, N. (2017). A Holistic Approach to Sustainable Development of Energy, Water and Environmental Systems. *Journal of Cleaner Production*, vol. 155, no. 1, pp. 1–11.

Van de Ven, J. (2016). Roles and application of carbon pricing in design of projects for the Green Economy Transition. *European Bank for Reconstruction and Development*, vol. 2, no. 1, pp. 1–6.

Van Niekerk, J., Brent, A. and Musango, J. (2015). Agricultural Sector Implications of a Green Economy Transition in the Western Cape Province of South Africa. *International Association for Management of Technology, IAMOT 2015 Conference Proceedings*, vol. 1, pp. 591–610.

van Niekerk, W. (2010). Solar Energy Technology Roadmap of South Africa (SETRSA). *Department of Science and Technology South Africa*, vol. 1, no. 1, pp. 1–106.

VinIntell (2012). Future scenarios for the South African Wine Industry: Impact of climate change. *VinIntell Newsletter*, vol. 12, no. 1, pp. 1–9.

Virginia Tech (2017). Introduction to Distributed Generation. *Distributed Generation Education Modules*, vol. 1, pp. 1–10.

Vos, P. and Shults, L. (2015). Learning about Simulations as a Research Approach LaSiRA. *Mathematics Education Research Group Agder (MERGA), Department of Mathematical Sciences*, vol. 1, pp. 1–3.

Votteler, R. and Brent, A. (2016). A literature review on the potential of renewable electricity sources for mining operations in South Africa. *Journal of Energy in Southern Africa*, vol. 27, no. 2, pp. 1–12.

Wainwright, J. and Mulligan, M. (2012). *Environmental Modelling Finding Simplicity in Complexity*. John Wiley and Sons. ISBN 0471496170.

Wang-Helmreich, H. and Kreibich, N. (2019). The potential impacts of a domestic offset component in a carbon tax on mitigation of national emissions. *Renewable and Sustainable Energy Reviews*, vol. 101, no. 3, pp. 453–460.

Winkler, H. and Marquard, A. (2015). Comments on the Proposed Carbon Tax. *Energy Research Centre (ERC), University of Cape Town*, vol. 1, pp. 1–11.

WRI (2004). A Corporate Accounting and Reporting Standard. *World Business Council for Sustainable Development (WBCSD), World Resources Institute (WRI), Greenhouse Gas Protocol*, vol. 1, pp. 1–116.

WWF & SABMiller (2014). Water-Food-Energy Nexus- Insights into resilient development. *Report on resources and events relating to the Water Energy Food nexus*, vol. 2, no. 1, pp. 1–55.

Yang, J., Sun, Y. and Xu, Y. (2013). Modeling impact of environmental factors on photovoltaic array performance. *International Journal of Energy and Environment*, vol. 4, no. 6, pp. 955–968.

Zhang, C., Chen, X., Li, Y., Ding, W. and Fu, G. (2018). Water-energy-food nexus: Concepts, questions and methodologies. *Journal of Cleaner Production*, vol. 195, pp. 625–639. ISSN 09596526.

Zoeclein, B. (2008). Sustainable Winery Expansion, New World Wine Maker. *Enology Lecture Notes 141, Enology Grape Chemistry Group, Virginia Polytechnic Institute and State University*, pp. 1–13.

Appendices