A FRAMEWORK FOR THE MANAGEMENT OF ENVIRONMENTAL INFORMATION IN HIGHER EDUCATION INSTITUTIONS

BLESSING TAPIWA JONAMU

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Department of Computing Sciences

A Framework for the Management of Environmental Information in Higher Education Institutions

Blessing T. Jonamu

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Supervisor: *Prof A.P. Calitz*

Co-Supervisor: *Dr B. Scholtz*

DECLARATION

I, Blessing Jonamu (209080561), hereby declare that the dissertation for Students qualification to be awarded is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

Blessing Tapiwa Jonamu

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Summary

Higher Education Institutions (HEIs) are not immune to the global environment problems. An increasing awareness of the environmental responsibilities of HEIs has led researchers to investigate the role of environmental information and Environmental Management Information Systems (EMISs) in HEIs. EMISs play a major role in environmental management and environmental decision making in HEIs. Internationally, an increasing number of HEIs are embracing the concept of 'sustainable HEIs' by undertaking green campus initiatives.

HEIs often use diverse information systems, some of which are manual systems, proven to be inefficient and this gives rise to redundant and inconsistent databases which result in non-compliance with regulations, confusion and lack of co-ordinated effort. There is therefore need for an integrated, comprehensive software system and framework which can assist with the efficient management of environmental information at South African HEIs. This study fills a gap in the field of environmental sustainability at HEIs as the evaluation of existing sustainability programs has shown common weakness such as: Failure to effectively set baselines, flaws in data acquisition and management and missing documentation. The aim of this study is to propose a framework for Environmental Information Management (EIM) in HEIs. The framework includes guidelines related to the components of the framework which can also be used to perform a gap analysis to facilitate the improved design of effective and efficient EIM processes and data stores.

The Design Science Research (DSR) methodology is the research methodology used in the development of the two artifacts of this study namely: The EIM framework for HEIs and an EMIS prototype to serve as proof of concept. Problem identification and motivation was the first activity of the DSR which was done through a rigorous literature review and an investigation and evaluation of extant systems. This resulted in the design of an initial EIM framework for HEIs.

Nelson Mandela Metropolitan University (NMMU) was the HEI used as the case study. The EIM framework was applied at NMMU and this enabled the researcher to understand the current As-Is EIM processes at NMMU and this resulted in clear objectives of a solution. The

EMIS prototype (data warehouse) was then designed and implemented based on the theoretical framework. Three sets of evaluations were done to determine the acceptance of the EIM framework for HEIs and the performance of the EMIS prototype. The EIM framework was generally positively accepted and minor suggestions were made. An updated version of the EIM framework was proposed and evaluated. The experimental evaluation results showed that the EMIS prototype was efficient and effective. The contribution of this study is an EIM framework for HEIs and an implementation of an EMIS (EnviroDW) at NMMU that could be utilised by other HEIs.

Keywords: Environmental Information Management, HEIs, Environmental Management Information Systems, EIM Framework.

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List of Abbreviations

AASHE	Advancement of Sustainability in Higher Education
AISLE	Adaptive Intelligent Service Layer for Environmental information management
DSR	Design Science Research
DW	Data Warehouse
DHET	Department of Higher Education and Training
DEMS	Dynamic Environmental Management System
EIM	Environmental Information Management
EIS	Environmental Information System
EISs	Environmental Information Systems
EMIS	Environmental Management Information System
EMS	Environmental Management Systems
EPA	Environmental Protection Agency
EPD	Environmental Performance Dashboards
ETL	Extract, Transform and Load
GIS	Geographical Information System
GRI	Green Reporting Initiative
HEI	Higher Education Institution
HEIs	Higher Education Institutions
ISO	International Standardisation Organisation
JCBMS	Johnson Control Building Management System
NMMU	Nelson Mandela Metropolitan University
NGO	Non-Government Organisations
ODS	Operational Data Store

PMS	Performance Management System
STARS	Sustainability Tracking, Assessment & Rating System
STORM	Sustainable Online Reporting Model

Chapter 1: Introduction

1.1 Background

Higher Education Institutions (HEIs) are not immune to global environment problems (Velazquez, et al., 2006) and there has been an increasing awareness of the environmental impact and environmental responsibilities of HEIs (Bagnoli & Snyder, 2007; Disterheft, et al., 2012). With this increasing awareness came the realisation that HEIs should take commendable action to ensure that their environmental impact is at a minimum (Jain & Pant, 2010). Sustainability involves meeting economic, environmental and social needs (UN, 1987). Environmental sustainability in higher education is a topic that has been gaining interest in recent years (Alshuwaikhat & Abubakar, 2008). The large number of research publications, published, international conferences held and declarations made in the last four decades are proof of the growing phenomenon (Wright, 2002; Lozano, et al., 2013).

Environmental Protection Agencies (EPAs), HEI stakeholders and Non-Government Organisations (NGOs) are putting pressure on HEIs to act towards environmental sustainability. For example, in 2000 the EPA in the United States of America (U.S.A.) issued an enforcement alert which states that the agency was now holding HEIs to the same standards as industries so as to "create a safe haven for human health and the environment" (Savely, et al., 2007, p. 660). Furthermore, the United Nations Educational, Scientific and Cultural Organisation (UNESCO) proclaimed the Decade of Education for Sustainability Development 2005-2014 (UNESCO, 2010).

Internationally, the combination of environmental awareness of HEIs and pressure from external and internal bodies has resulted in an increasing number of HEIs that are embracing the concept of sustainability in higher education by undertaking green campus initiatives (Beringer, 2007; Disterheft, et al., 2012). Sustainability means the use, development and protection of resources at a rate that meets today's needs and the needs of future generations (UN, 1987). The most predominant initiative to enhance sustainability in HEI is the implementation of an Environmental Management System (EMS) at these institutions (Jones, et al., 2011; Disterheft, et al., 2012). The ISO 14001 standard specified by the International

Standardisation Organisation (ISO) defines an EMS as "*the part of an overall management system that includes organisational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing, and maintaining the environmental policies*" (ISO, 2004, p. 2).

It is evident therefore that an EMS is not a computer system, but rather a management model or approach. Computer systems which support environmental management by automating the management of environmental information are classified as Environmental Information Systems (EISs). EISs are further divided into different categories. Environmental Management Information System (EMIS) is a category of EISs that is developed to assist with the monitoring and measurement of environmental information within an organisation (ISESS, 2000).

Although environmental sustainability in higher education and EMSs has gained interest, the concept has been particularly prominent in Europe, the United States, Asia, Australia, Canada and South America, however it has had limited penetration into African institutions (Velazquez, et al., 2006; Disterheft, et al., 2012). Sammalisto and Arvidsson (2005) identify that government directives to force HEIs to manage their environmental impact could be a key factor as to why HEIs are implementing EMSs to achieve environmental sustainability. Hence the lack of strong regulations placed on the African institutions by African governments or NGOs might be one reason why African HEIs are lagging behind or it is possible that African institutions are simply not publicising their initiatives. In South Africa, the Department of Higher Education and Training (DHET) has recently published a government notice that states the regulations for reporting by public HEIs starting in the year 2015 (DHET, 2014). The slow penetration of sustainability in African HEIs could also be due to several other factors such as lack of data access as well as lack of communication and information (Velazquez, et al., 2005).

Sustainability in higher education and environmental management has many dimensions but the management of environmental information is one factor in achieving environmental sustainability in HEIs (Bero, et al., 2012). There is a need for communication and flow of environmental information across the HEIs (Franz-Balsen & Heinrichs, 2007; Jones, et al., 2011). A key factor to achieving environmental sustainability in higher education and in an effective EMS is the availability of a centralised reporting function (Herremans & Allwright, 2000).

An EMIS is one category of EIS and it attempts to simplify and automate environmental management tasks such as the obtaining, processing, accessing and reporting of relevant environmental information within an organisation (El-Gayar & Fritz, 2006). An EMIS also encapsulates tasks such as cost accounting, auditing and environmental compliance. The development of an EMIS has been identified as a necessary precondition to the development of an effective EMS and if an EMIS exists but is ineffective this will reduce the effectiveness of the EMS (Stuart, 2000). El-Gayar and Fritz (2006) indicate that an EMIS forms the backbone of any organisation's environmental management efforts by supporting the organisation's EMS and by meeting the reporting needs of stakeholders.

An EMS is a framework that provides a set of guidelines to guide environmental sustainability efforts in an organisation. Miles and Huberman (1994) define a framework as a graphic or written or visual explanation of the main items to be studied, that is key factors, concepts or variables and the presumed relationships among them. A framework can also be defined as "the structure of a particular system" or "a set of beliefs, ideas, or rules that is used as the basis for making judgements or decisions" (Oxford University Press, 2014). Although environmental information management is a prerequisite to environmental sustainability efforts in HEIs, there is a limited number of formal guidance in establishing integrated, effective and efficient environmental information management processes that are tailored for HEIs. Therefore, there is a need of a framework for the management of environmental information at HEIs to help understand environmental information and guide management efforts at HEIs.

1.2 Problem Relevance

HEIs have followed industry and have started to develop or adopt environmental programmes and systems (Bero, et al., 2012). However, most EMISs are not tailored for HEIs and pioneers in this domain are still experimenting to find the most effective system to use, hence manual systems are still used at some HEIs (Savely, et al., 2007; Bero, et al., 2012). The Nelson Mandela Metropolitan University (NMMU) in South Africa is no exception.

The As-Is state is a state in which things are currently in and this state is usually undesirable. The To-Be state is a desirable state in which things should be in. In order to understand the As-Is state and in turn the problem relevance, preliminary interviews were done with staff from the Technical Services Department at NMMU. The Technical Services Department is responsible for the management of electricity and water data at NMMU. Findings from these preliminary interviews indicated that the As-Is processes within HEIs are supported by diverse and often manual information systems (Barnardo, 2013; Ducie, 2013; Syce, 2013). These processes are inefficient and enable the creation of redundant, disparate and inconsistent databases, spreadsheets and other electronic documentations. This affects compliance with regulations and results in duplication of work, lack of co-ordinated effort and poor decision making with regard to achieving environmental sustainability at the HEI.

1.3 The Problem Statement

The management of environmental information has been identified as a key factor in achieving environmental sustainability in higher education. Watson, et al. (2010) discuss how information systems take the central role in supporting sustainable practices. Furthermore, the study of Watson, et al. (2010) highlights how academics in HEIs need to take action and not be bystanders as the world faces possible environmental crises issues. However, there is limited formal guidance or frameworks available for HEIs which can assist them with managing their environmental information (Simkins & Nolan, 2004; Bero, et al., 2012). Environmental information sources in South African HEIs can be found in several disparate systems but they are often manually created.

Therefore the problem statement for this research study is as follows:

There is no integrated management of environmental information within HEIs. This leads to a lack of effective and efficient reporting of environmental information.

1.4 The Thesis Statement

An EMIS can be a powerful support tool that can provide a service for data centralisation, automation of data collection and integration of legacy and heterogeneous systems at HEIs

(El-Gayar & Fritz, 2006). Consequently, a thesis statement was formulated to address the problem statement:

An integrated environmental information management framework for HEIs can lead to effective and efficient reporting of environmental information.

This study fills a gap in the field of environmental sustainability at HEIs since the evaluation of existing sustainability programmes has shown that common weaknesses include failures to effectively set baselines; there are flaws in data acquisition; and there is also missing documentation (Savely, et al., 2007; Bero, et al., 2012). This study will provide a framework which will provide guidance with regard to how environmental information can be managed in the context of a South African HEI. This will also include an evaluation of existing EMISs that could be suitable for HEIs in order to determine the best-practice processes for management of environmental information in industry and education. The study will also propose a best practice To-Be process for the management of environmental information and as proof of concept will develop a prototype of a sub-system to support a subset of the proposed To-Be processes. A best-practice process is a process that has proven superior results over any other.

1.5 Research Objectives

The Main Research Objective (RO_M) of the study is:

To propose and develop a framework that supports the effective and efficient management of environmental information in HEIs.

The research objective will be achieved by addressing the following secondary objectives:

RO1: Determine the types of IT solutions that are used in Environmental Management in organisations and in HEIs.

RO2a: Identify the components of a framework for Environmental Information Management in HEIs.

RO2b: Design a framework for Environmental Information Management in HEIs.

RO3: Analyse the As-Is processes and data stores at NMMU which are related to Environmental Information Management.

RO4: Propose the To-Be processes and data stores for the management of environmental information at NMMU.

RO5: Develop and implement an EMIS prototype for NMMU.

RO6: Conduct an evaluation of the proposed framework which will include an evaluation of the prototype as proof of concept.

1.6 Research Questions

Mindful of the purpose of the research and its objectives the following main research question will be asked:

Main Research Question (RQ_M):

What are the components of a framework that supports the effective and efficient management of environmental information at HEIs?

Secondary Research Questions

Several secondary research questions (Table 1.1) need to be asked in order to successfully answer the main research question. Each research question requires an appropriate strategy that can be used to answer the question.

Table 1.1: Secondary Research Questions

Research questions		Research Strategy	Chapter
RQ_1	*What types of IT solutions are used to aid Environmental Information Management efforts in organisations and HEIs?*	Literature Study	Chapter 3
RQ_2	*How can a framework for environmental information management at HEIs be designed?*	Literature Study Investigation of extant systems	Chapter 3
RQ_3	*What are the As-Is processes and data stores at NMMU which are related to environmental information?*	Literature Study	Chapter 4
RQ_4	*What are the To-Be processes and data stores for the management of environmental information at NMMU?*	Surveys Interviews Document studies	Chapter 4
RQ_5	*How can a prototype for the sub-system of an EMIS be designed as proof of concept?*	Literature Study	Chapter 5
RQ_6	*What methods can be used for the evaluation of the artifacts (framework and prototype)?*	Analytical evaluation	Chapter 6
RQ_7	*Are the artifacts acceptable and usable by the stakeholders?*	Evaluation	Chapter 7

1.7 Scope and Envisioned Contribution

The study will focus on the design of a framework for the management of environmental information at an HEI. The framework will include guidelines that should be taken into consideration when making an effort to maintain environmental sustainability and the management of the environmental information. Based on the framework, an EMIS will be designed and a prototype for a sub-system of the EMIS will be developed to serve as proof of concept. The study will be done by focusing on one South African HEI, the Nelson Mandela Metropolitan University (NMMU). NMMU is used as a case study because the institution requested assistance in the management of its environmental information.

1.8 Limitations of the Study

There are many aspects to environmental impact namely: water usage, electricity usage, carbon footprint, chemicals and hazardous waste and land and air pollution (GRI, 2013). In an attempt to show a proof of concept, the sub-system prototype scope will be limited to two environmental aspects, water usage and electricity usage. However the prototype will be scalable.

1.9 Ethical Consideration

In this study, staff from NMMU were required to participate in the initial gathering of the requirements for the study and the evaluation of the prototype. The NMMU research ethics and policies will be adhered to throughout this research study. Participation will be voluntary and participants will be given consent forms and they will be well informed of the aim and scope of the study. Results of the study will be made available to the participants if they wish to access them. Ethical clearance was approved by the Nelson Mandela Metropolitan University (NNMU) Human Research Ethics Clearance Committee (REC-H) (Appendix A). The ethics clearance number for this study is H13-SCI-CSS-23.

1.10 Research Methodology and Dissertation Structure

This study follows a Design Science Research (DSR) methodology (Hevner, et al., 2004). The DSR methodology consists of six activities which will be adhered to in this study. These activities are: problem identification and motivation, objectives of a solution, design and development, demonstration, evaluation and communication. To effectively apply the design science research, some of the activities will be combined. In each of the activities, different and highly suitable strategies will be used.

Preliminary interviews and a literature study will be done in order to identify and understand the problem. After which, a combination of a literature review, surveys and interviews will be used to effectively determine what is expected of the solution. An analysis of extant systems will then be performed to investigate common components and features of an EMIS. Insights gained from this investigation will be used in designing a system tailored for HEI. The design will then be implemented. The prototype will be evaluated to determine if it has achieved the goals set out for it in this research.

This dissertation consists of seven chapters. Each chapter attempts to meet a research objective by answering the questions posed in Table 1.1. The structure of the dissertation also follows the design science research process (Figure 1.1) with each chapter focusing on the different activities of design science. The structure of the dissertation with the various strategies and research question/s which the chapter addresses are visually depicted in Figure 1.2.

Chapter 1 (Introduction) is concerned with the first activity of the design science research methodology which relates to the identification and motivation of the problem. The chapter provides background information on EMISs with regard to their use in business organisations and highlights the importance and motivation of this research and its intended direction. The outline of the research is discussed in terms of the research objectives and the research questions posed to meet these objectives.

Chapter 2 (Research Design) discusses the research paradigm that is employed in this study. The chapter further illustrates how the research will be conducted by discussing the research methodology, the research strategies and the research activities in the DSR methodology.

Chapter 3 (Environmental Information Management) explores the problem identification and motivation activity in more detail and provides a literature review of the field of environmental management research and the Information Technology (IT) solutions used to assist in the management of environmental information. The chapter looks at the extent to which IT solutions are important for environmental information management and the adoption of these solutions in industry and in education. It also investigates existing problems related to EIM proposed in solutions and literature in order to determine the components of a framework for the management of environmental information at an HEI.

Chapter 4 (GAP Analysis of EIM at NMMU) analyses results of the surveys done at NMMU and from them an outline of the requirements of the solution to the explicated problem to be investigated are compiled. The survey results also show the current As-Is state of environmental information processes and data stores at NMMU. The theoretical framework is used to design, the desired To-Be processes for NMMU.

Chapter 5 (An EMIS for NMMU) describes the design and implementation of the EMIS sub-system based on the proposed framework. The EMIS sub-system prototype will serve as a proof of concept of the framework.

Chapter 6 (EIM Framework and Data Warehouse Evaluation) discusses the evaluation plan of the EIM framework and the implemented EMIS sub-system. The results of the evaluation will be presented and any amendments suggested in the evaluation will be made to both the framework and the prototype sub-system.

Chapter 7 (Recommendations and Conclusions) concludes the dissertation by evaluating the achievements and results of the research. The theoretical and practical contributions are discussed and followed the limitations of the study and future research.

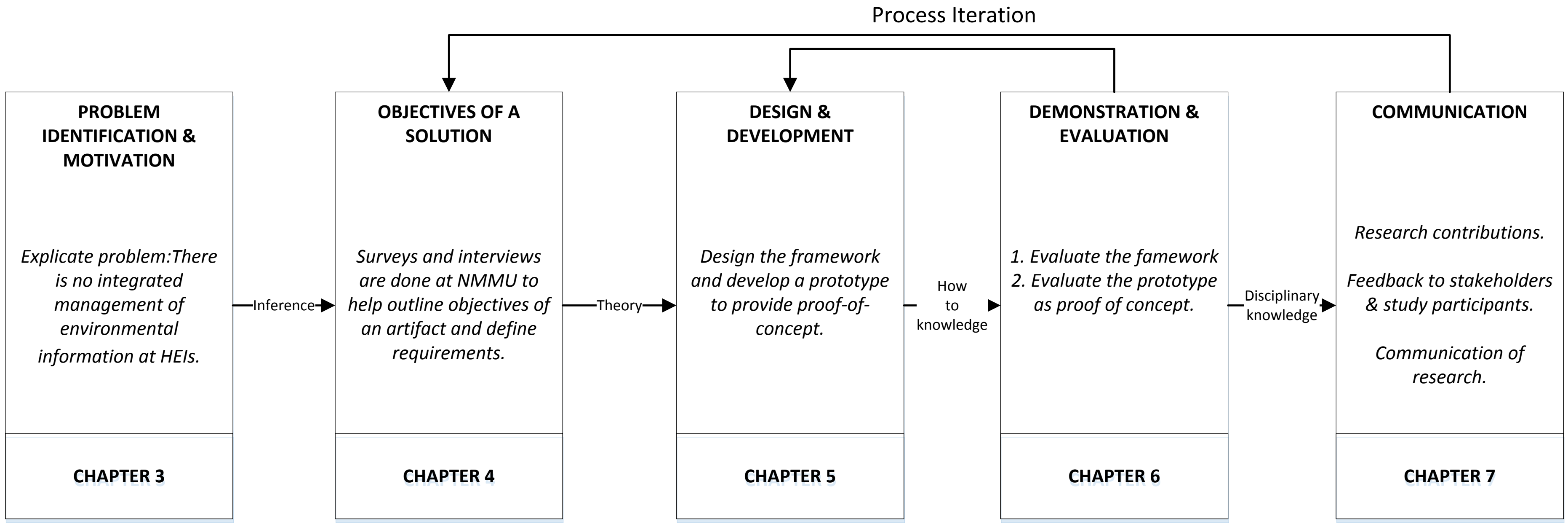


Figure 1.1: The Design Science Research Activities with Corresponding Chapters

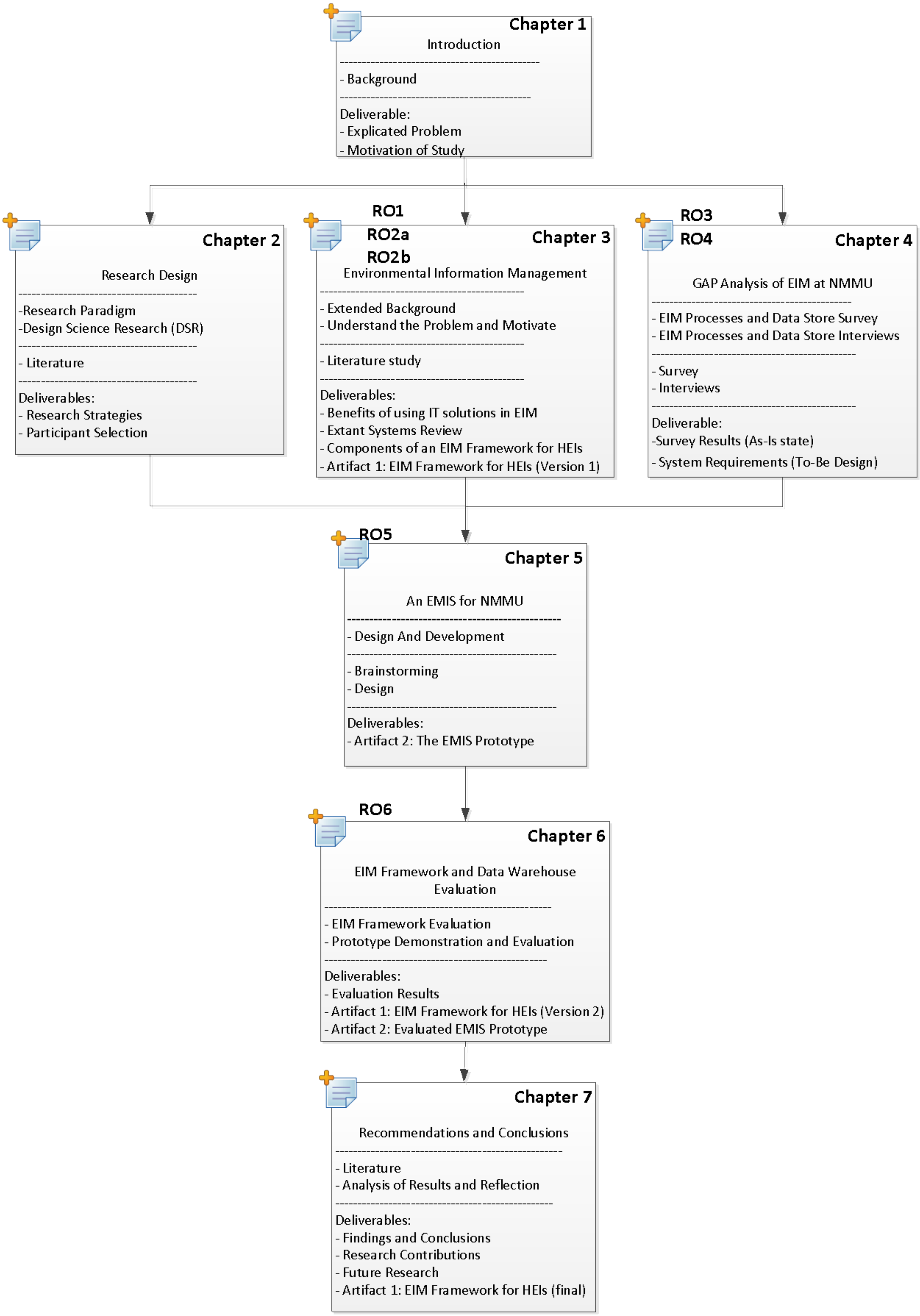


Figure 1.2: Chapter Layout

Chapter 2: Research Design

2.1 Introduction

The research compiled in this dissertation and analysis of the results derived from the research will be dependent on the manner in which the research is undertaken. The way the research is conducted is affected by the characteristics of the research design. The research onion proposed by Saunders, et al. (2009) gives an overview of the research process (Figure 2.1). This research onion illustrates that there are several possibilities for designing research and these relate to the philosophy, approach, strategy, choice, time horizon and data collection and analysis techniques. To achieve the objectives of this research in an effective manner the research will be undertaken in a structured manner with proper consideration for the research paradigm approaches (Section 2.2); strategies, time horizons and finally data collection methods to be adopted by the researcher. A systematic approach will be used to apply the chosen methodology to help answer and solve the researcher's problem (Section 2.3). Section 2.4 will present a summary of the chapter.

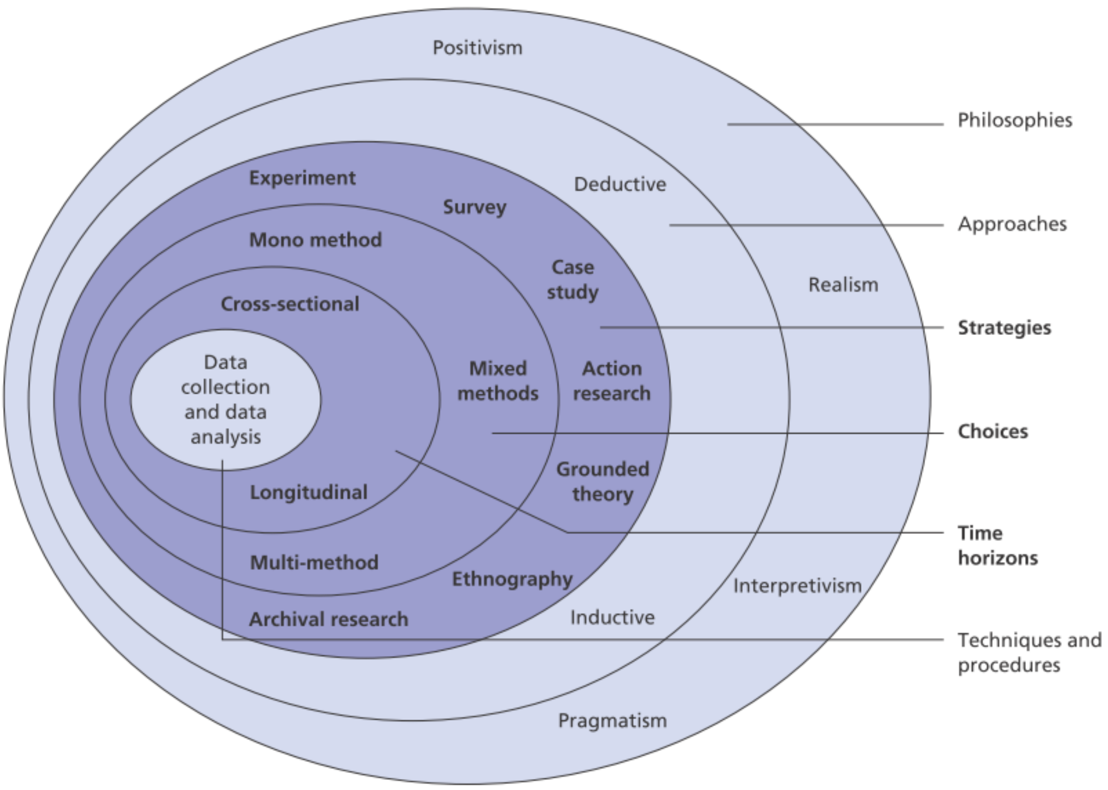


Figure 2.1: The Research 'Onion' (Saunders, et al., 2009)

2.2 Motivation for Selected Research Methodology

In order to choose the most appropriate research philosophy, approach and strategies to use in research, the researcher needs to understand the aim of the research. This research aims to address the problem of inefficiency in the management of environmental information at HEIs by producing, as a solution, a framework which includes an EMIS that will assist with efficiently manage environmental information. With this aim in mind, literature suggests that positivism and interpretivism are the two philosophies that are used in Information Systems Research (ISR) which eliminates the philosophies, pragmatism and realism (Johannesson & Perjons, 2012). The philosophies, positivism and interpretivism will be applied in this study where necessary within the chosen research methodology.

When choosing a research methodology to adopt, it is important that the domain of the research, the methodologies used, particularly in that domain, and the aim of the research be considered. This study focuses on the Information Systems (IS) and systems development domains. Investigations into the IS and systems development disciplines revealed a variety of methodologies which are appropriate depending on the different aspects of the research and philosophical position of the researcher.

The range of IS research studies requires various approaches, each with its advantages and disadvantages depending on the research focus and application domain. Empirical approaches include case studies, surveys, laboratory and field experiments, various types of simulation and forecasting, as well as action research and ethnographic studies. Design Science Research (DSR) is one of the emerging IS research methodologies that borders between system development methodologies and research methodologies.

The main aim of implementing any form of IS, is to increasing an organisation's effectiveness and efficiency (Hevner, et al., 2004; March & Storey, 2008). The capabilities and performance of the IS determines how useful the system is to the organisation. Design science has its roots in engineering and is regarded as a technical science seeking utility (Purao, 2002; Hevner & March, 2003; Winter, 2008). "Design science seeks to create innovations, or artifacts, that embody the ideas, practices, technical capabilities, and products required to efficiently accomplish the analysis, design, implementation, and use of information systems" (Hevner & March, 2003, p. 111). Action research is another research methodology that can be used when an IS is developed and evaluated in a social context. Methodologies such as surveys, laboratory and field experiments, simulation and forecasting are methodologies that are employed in similar cases.

DSR includes three inherent research cycles which are the relevance cycle, the design cycle and the rigor cycle (Figure 2.2). The relevance cycle connects the context environment of the research project to the activities of design science. The design cycle iterates between the core activities of building and evaluating the design artifacts and processes of the project. The rigor cycle connects the knowledge base (literature) experience, expertise scientific theories and methods with the activities of design science.

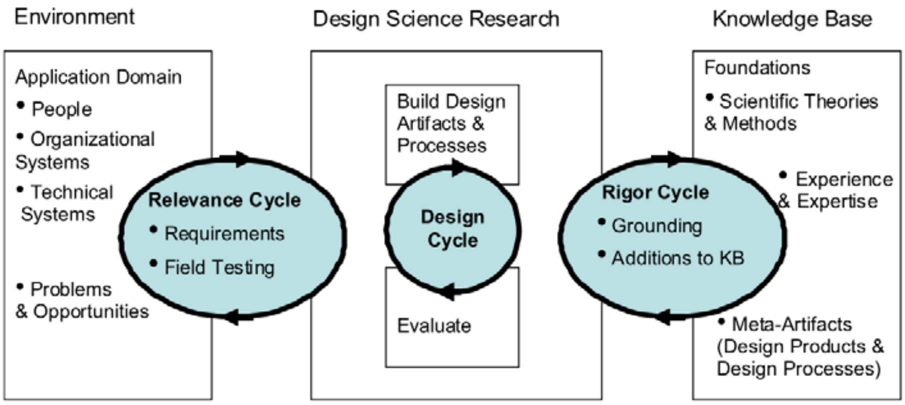


Figure 2.2: Design Science Research Cycles (Hevner, 2007)

DSR provides a holistic approach to problem solving by means of artifacts (Hevner, et al., 2004). This study's main aim is to produce two artifacts: the first artifact is a framework for environmental information management and the second is a prototype of a sub-system of the proposed EMIS to serve as proof of concept. Taking this main aim into consideration, the design science paradigm will be employed. DSR will focus the study on developing artifacts that will increase an organisation's effectiveness and efficiency. The iterations between designing, development and evaluation will ensure that the artifacts address and satisfy the stakeholder's requirements.

2.3 Application of Research Methodology

This dissertation follows the DSR methodology which provides a detailed process for performing design science research (Peffers, et al., 2006; Johannesson & Perjons, 2012). The DSR consists of six activities which were adopted for this study in order to address the main research question. The activities are: Problem identification and motivation (Section 2.3.1), Objectives of a solution (Section 2.3.2), Design and development (Section 2.3.3), Demonstration and evaluation (Section 2.3.4) and Communication (Section 2.3.5). The demonstration and evaluation activities have been combined in this study.

Johannesson and Perjons (2012) discuss the Design Science Method (DSM), which is similar to the DSR (Peffers, et al., 2006). The nature of the activities are similar, but in some instances the names are slightly different. However, the concepts are the same. The names of the activities used in this study are the ones used by Johannesson and Perjons (2012) and are: Problem identification and motivation, objectives of a solution, design and development, demonstration, evaluation and communication. In each activity of the DSR, there is an input that is then processed by means of research strategies and methods and facts taken from the knowledge base. Each activity then produces output which then becomes input for another activity. The DSR seems to suggest a waterfall-like approach to design science, however, this is not the case as the design cycle is done between the design and development and the evaluation of the artifact. The rigor cycle and the relevance cycle are also continually done as relevancy and the contribution of knowledge seem to change everytime the artifact is evaluated and amended.

2.3.1 Problem Identification and Motivation

During the problem identification stage, an initial problem needs to be addressed (Figure 2.3). In an attempt to determine the underlying problems and fully comprehend the problem, research methods such as interviews and document studies can be used. The researcher also looks at literature and previous research/extant systems in order to gain some knowledge in the problem domain. The result is then a well explained and understood problem and clear motivation is provided for undertaking the research.

In an attempt to get the initial understanding of the problem, preliminary interviews with stakeholders will be conducted at NMMU. Interviews will allow the researcher to understand the problem in an interactive way and to ask follow up questions which would be limited if a survey is used. The limitation of using interviews can be the bias of the interviewee's towards their own interests and perspectives. This will be mitigated by having interviews with a variety of stakeholders and by doing document studies to ensure that the documents are in agreement with what interviewees say. Documented studies can also expand on the problem and show underlying problems that interviewees are not willing to disclose. Furthermore, an analysis of the interviews and a careful rigorous investigation into the literature will be done in order to show that the problem is worthwhile addressing.

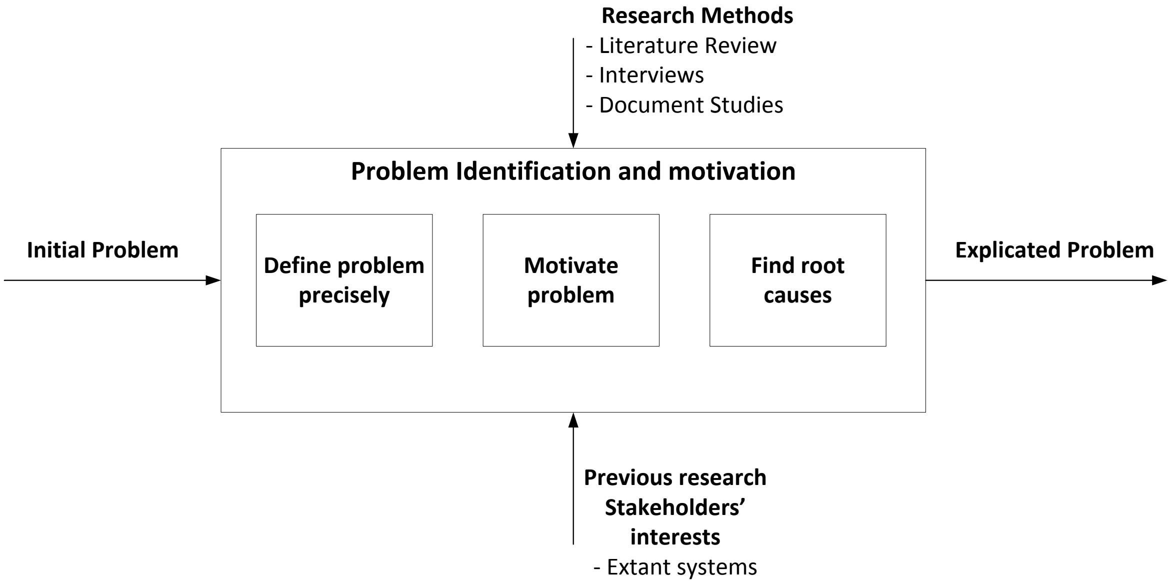


Figure 2.3: Explicate Problem (Adapted from Johannesson & Perjons, 2012)

2.3.2 Objectives of a Solution

It is vital to know what is expected of the solution. Figure 2.4 shows a diagrammatic view of how the objectives of a solution should be outlined. Hence an investigation will be done in an attempt to outline the objectives for a solution to the explicated problem. This also means determining the requirements of the artifact. Several methods will be used for identifying the requirements. Surveys will be used as a tool to gather the requirements, and will consist of two phases. The first phase attempts to identify the green initiative projects that are currently being undertaken at NMMU. These will be analysed to determine their relevance to this study and to identify stakeholders who can provide more details regarding the As-Is situation of these projects.

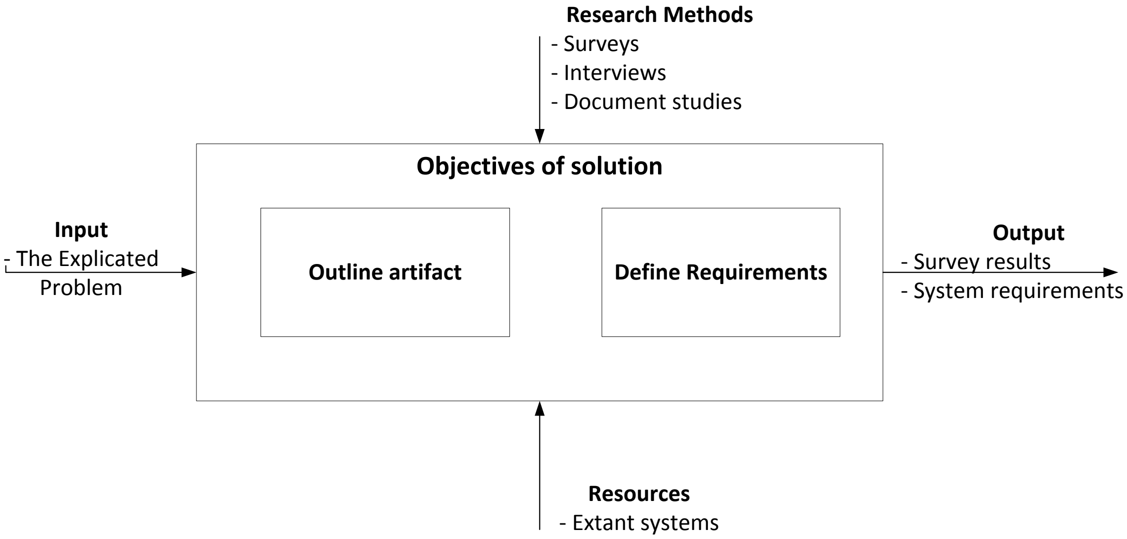


Figure 2.4: Objectives of Solution (Adapted from Johannesson & Perjons, 2012)

Surveys can often provide superficial results as stakeholders may not be prepared to spend time and effort to provide detailed descriptions. To counter this, interviews and document studies will be used to complement the surveys. The analysis of key documents such as the electricity readings could show the researcher information that may have been overlooked in the survey. This will ensure that the information obtained, closely describes the real problem. A literature review will be performed to investigate existing solutions and best practice with regard to environmental information management in HEIs. The desired To-Be situation will then be identified from the best-practice solutions and from this the design of the proposed solution can be derived. Existing systems will be analysed and evaluated and the results from this investigation will be used to design a framework for environmental information management for HEIs.

2.3.3 Design and Development

In the design and development stage, the framework (artifact) will be designed and created according to the requirements gathered in the previous stage. In turn, an application will be developed to serve as a proof of concept. Figure 2.5 shows the two sub-activities:

1. Generate.
2. Search and select.

These activities will be mainly used in designing the prototype rather than the framework. A number of possible designs will be generated and then the researcher will analyse and evaluate the possible solutions and select one.

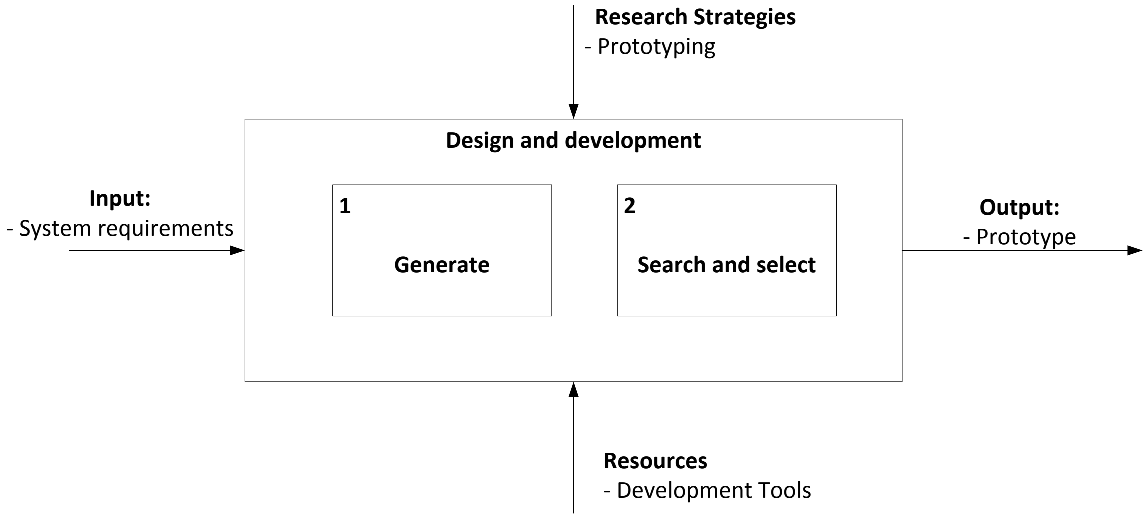


Figure 2.5: Design and Development (Adapted from Johannesson & Perjons, 2012)

2.3.4 Demonstration and Evaluation

Demonstration and evaluation activities are usually separated in the DSR methodology but in this study they will be combined and done concurrently (Figure 2.6). The EMIS sub-system prototype will be used in a real-life case study as a proof of concept thereby proving the feasibility of the framework. The demonstration will show that the artifact can solve the research problem. At this stage the application is evaluated against how well it fulfils the requirements and to what extent it can solve, or alleviate, the practical problem that motivated the research.

Table 2.1 shows some methods that could be used for evaluating artifacts. The aim of this study is to design and develop an efficient and effective artifact; therefore the analytical evaluation method will be used in an attempt to obtain feedback associated with the design of the framework. Static analysis and architecture analysis are the two analytical evaluation methods that will be used since they address the two aspects of the framework which need to be evaluated. The controlled experimental evaluation method will be used to evaluate the EMIS prototype. Problems that are uncovered with the prototype will be amended. Iteration between designing, development and evaluation will be done until all problems are amended and the framework and prototype satisfy all the requirements.

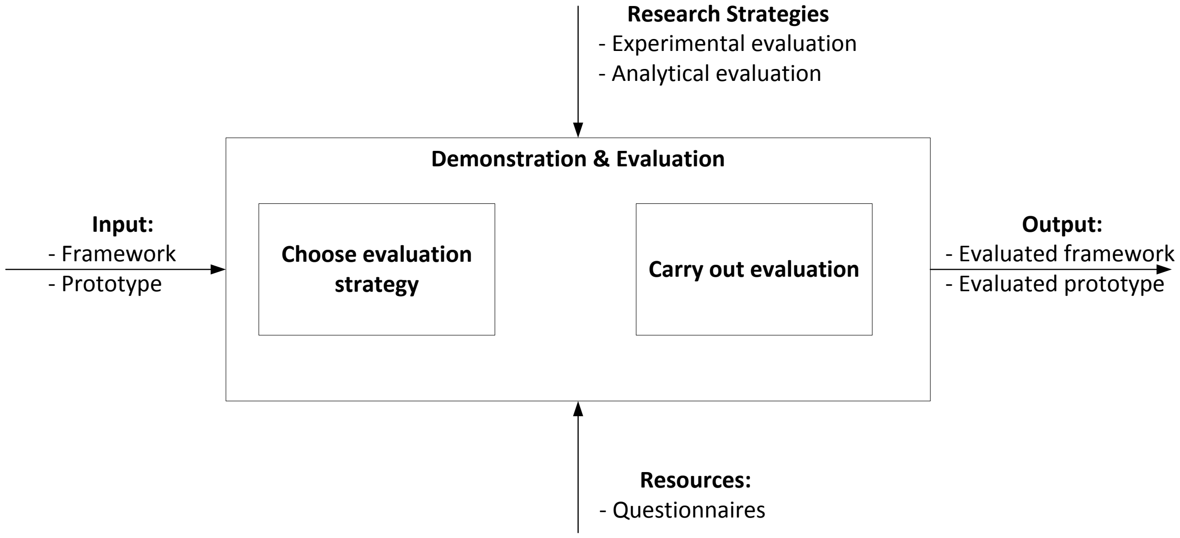


Figure 2.6: Demonstration and Evaluation (Adapted from Johannesson & Perjons, 2012)

Table 2.1: Evaluation Methods (Hevner, et al., 2004)

Evaluation Methods	Description
Observational	Case Study: Study artifact in depth in business environment.
	Field Study: Monitor use of artifact in multiple projects.
Analytical	Static Analysis: Examine structure of artifact for static qualities (e.g., complexity).
	Architecture Analysis: Study fit of artifact into technical IS architecture.
	Optimisation: Demonstrate inherent optimal properties of artifact or provide optimality bounds on artifact behaviour.
	Dynamic Analysis: Study artifact in use for dynamic qualities (e.g., performance).
Experimental	Controlled Experiment: Study artifact in controlled environment for qualities (e.g., usability).
	Simulation: Execute artifact with artificial data.
Testing	Functional (Black Box) Testing: Execute artifact interfaces to discover failures and identify defects.
	Structural (White Box) Testing: Perform coverage testing of some metric (e.g., execution paths) in the artifact implementation.
Descriptive	Informed Argument: Use information from the knowledge base (e.g., relevant research) to build a convincing argument for the artifact's utility.
	Scenarios: Construct detailed scenarios around the artifact to demonstrate its utility.

2.3.5 Communication

The communication activity is about the communication of research. In this study, the researcher will communicate the research in the form of presentations and journal article publications. Feedback to participants will be given on request to participants. Feedback from the publications made and presentations done can help focus the study and improve the quality of the research.

2.4 Summary

Design science focuses the research on creating the artifact, which in this study is the framework for management of environmental information systems. Furthermore, as proof of concept, a prototype sub-system will be developed and rigorously evaluated and amended to ensure that it addresses the explicated problem that motivates the research. Figure 2.7 shows the study flow of this research according to the cycles of the DSR.

The study flow of this research study conforms to the DSR research cycles. In the relevance cycle, preliminary interviews will be done to understand and motivate the research this is complemented by a literature review. The researcher will also seek ethics approval at this stage. The design cycle, consists of five undertakings that will be done iteratively. A survey will be done to determine the individuals to interview will be followed by the interviews. Document studies will be used to complement the interviews and during the design and development activity, the researcher will continuously refer back to document studies and will do more interviews in an attempt to better understand the As-Is state at NMMU, user's requirements and expectations.

An evaluation will be done and this will result in further design and development to improve the artifacts. As part of the rigor cycle, knowledge from (literature) experience, expertise scientific theories and methods will continuously be applied in the design science activities of this research which will result in the theoretical and practical contribution of the artifacts implemented in this research study.

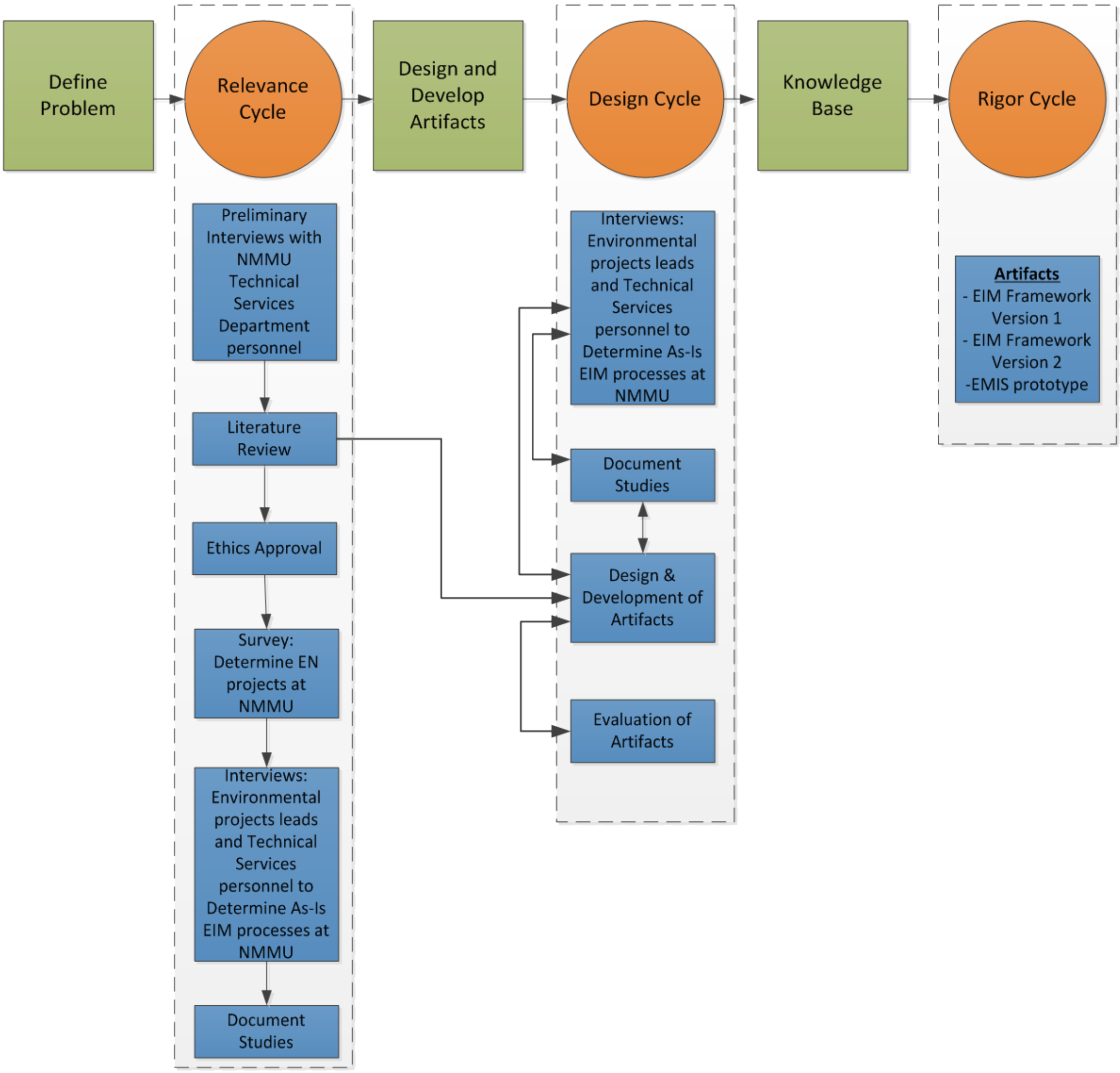


Figure 2.7: Study Flow of this Research Conforming to DSR

The next chapter describes the first activity of the DSR and attempts to understand the problem domain by investigating literature, past research and extant systems. The chapter reveals common IT solutions that are used in environmental information management and further reveals the common components of these IT solutions. An initial framework for the management of environmental information is the key deliverable presented in Chapter 3.

Chapter 3: Environmental Information Management

3.1 Introduction

HEIs now have the responsibility to increase sustainability awareness by educating internal and external society of their environmental impact and involve stakeholders in their sustainability efforts (Velazquez, et al., 2006). Institutions need to reduce their environmental impact and research innovative ways to reduce this impact, for example, by reducing energy and water consumption. The two research questions that this chapter addresses are:

RQ_1: What types of IT solutions are used to aid Environmental Information Management efforts in organisations and HEIs?

RQ_2: How can a framework for environmental information management at HEIs be designed?

This chapter is the continuation of the problem identification and motivation activity of the DSR methodology. Chapter 1 introduced the initial problem, whilst this chapter will continue and motivate the research further by reviewing literature, performing document studies and analysing extant systems (Figure 3.1). This activity forms part of the relevance cycle of DSR (Figure 2.7)

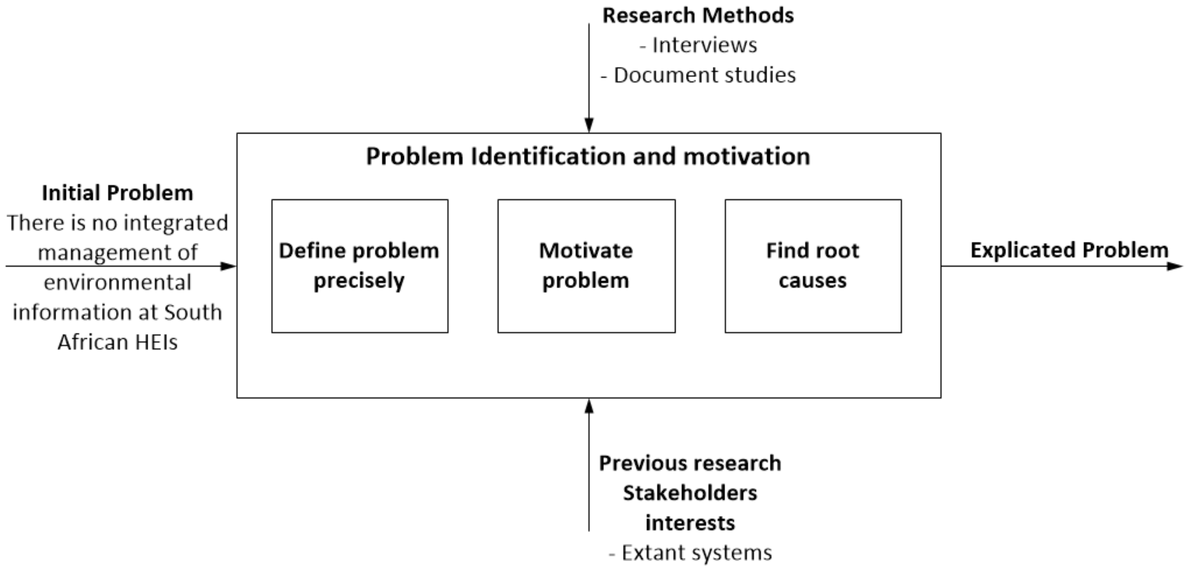


Figure 3.1: Implementation of the Problem Identification and Motivation Activity

A layout of Chapter 3 and the research objectives and deliverables achieved from this chapter are shown in Figure 3.2. Environmental Management Systems (EMSs) have been implemented in companies globally on a large scale and several HEIs have started to follow this trend (Section 3.2). HEIs are now implementing EMSs as one of the tools to use to manage their environmental efforts and achieve environmental sustainability at institutions (Disterheft, et al., 2012). The management of environmental information facilitates and improves environmental management (El-Gayar & Fritz, 2006).

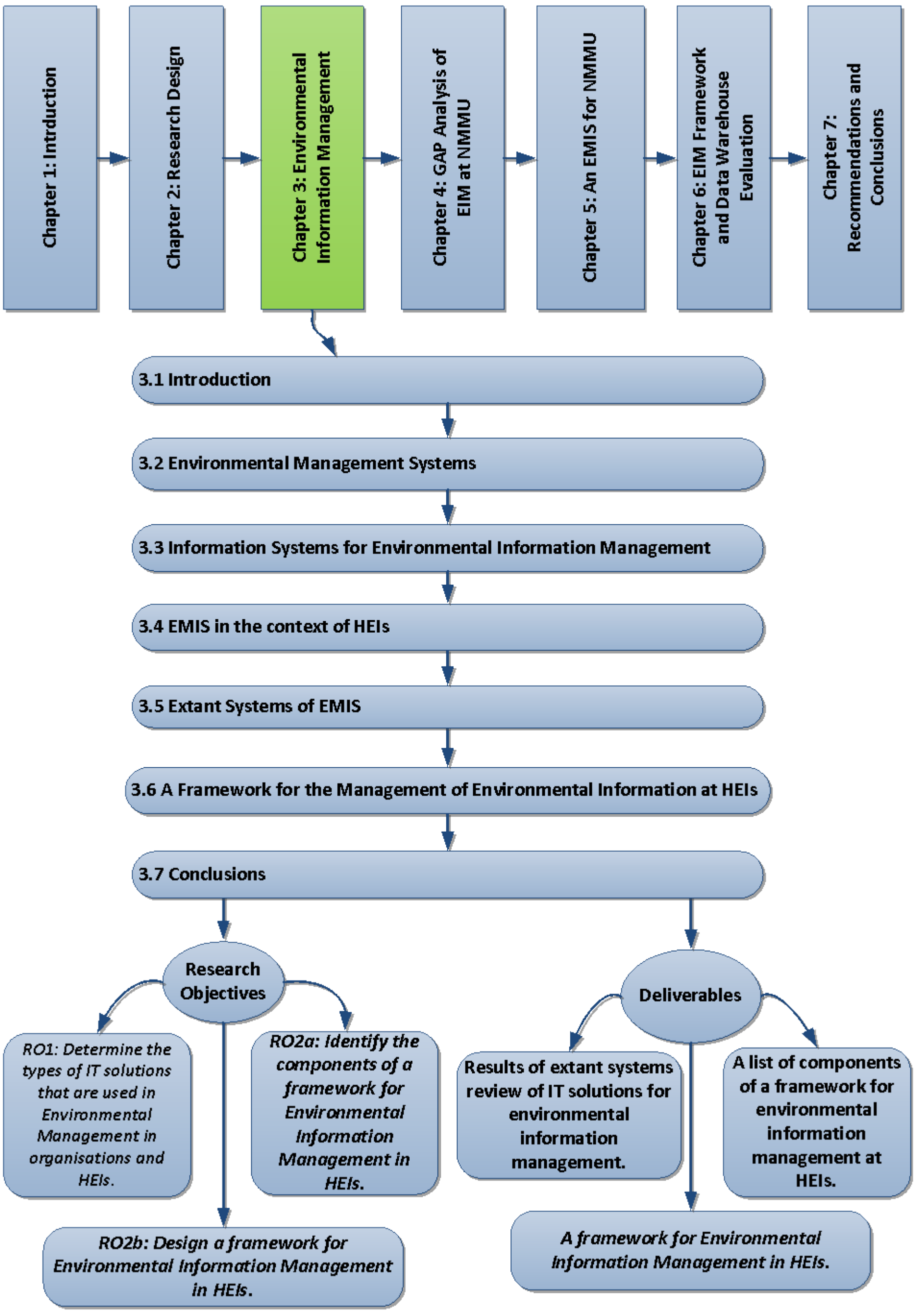


Figure 3.2: Chapter 3 Layout and Deliverables

Several IS have been proposed for automated management of environmental information (Section 3.3). Environmental Management Information Systems (EMISs) are a class of EIS that can be used to manage environmental information at an HEI (Section 3.4). An investigation into previous research and future system implementations can help to identify the key requirements and elements of an EMIS (Section 3.5). A framework for the management of environmental information at an institution can be designed with several key elements (Section 3.6). This framework highlights the key components associated with the management of environmental information in HEIs. Conclusions can be made based on the literature review (Section 3.7).

3.2 Environmental Management Systems (EMS)

An EMS is defined as a set of management tools and principles designed to aid an organisation to incorporate environmental concerns into its daily business activities (Speshock, 2010). An EMS has also been described as a tool that assists organisations to improve their corporate image, comply with regulations, minimise legal and financial risk, reduce operating costs, improve operational efficiency by efficiently managing resources and improving staff moral and the work environment (Savely, et al., 2007).

An EMS is not a computer application or system but rather a part of a management system that consists of planning activities, processes, procedures and resources for developing and maintenance of environmental policies within an organisation (ISO, 2004). The EMS process follows a Plan-Do-Check-Act (PDCA) cycle to continuously improve environmental performance (Figure 3.3). This means that all the EMS practices and processes generally originated from the PDCA cycle.

The implementation of an EMS at an organisation has numerous benefits. Speshock (2010) lists some of the benefits of implementing an EMS:

1. Improvements in overall environmental performance and compliance;
2. increased efficiency and potential cost savings when managing environmental obligations;
3. more effective targeting of scarce environmental management resources;
4. enhanced public posture with outside stakeholders; and

5. an integrated effort across the entire organisation.

Figure 3.3: The 'Plan-Do-Check-Act' Cycle (Bagnoli & Snyder, 2007)

There is a number of EMS standards of which the two most popular are the International Standards Organisation (ISO) 14001 and the European Eco-management and Audit System (EMAS). These standards provide sound frameworks to help organisations develop and maintain processes for environmental management. The ISO 14001 is similar to the EMAS with minor differences. The EMAS tends to extend on the ISO 14001 and provides more rigorous certification criteria.

3.2.1 The ISO 14001

The ISO 14001 conforms to the PDCA cycle (Figure 3.4). The planning (P) phase is the stage in which an organisation needs to establish its objectives and processes necessary to deliver results in accordance with the organisation's environmental policy. In the Do (D) phase the organisation then implements these established processes. In the Checking (C) phase, the organisation must monitor and measure its performance against the environmental policy and goals and report on their performance. The organisation then takes action to continually improve the performance of the EMS in the Acting (A) phase.

The five components in the ISO 14001 EMS model can be sub-divided into 18 elements of the ISO 14001 (Figure 3.4). Organisations, including HEIs, can be certified by these standards. However, most organisations may comply with these standards but do not seek certification due to the fact that certification is costly.

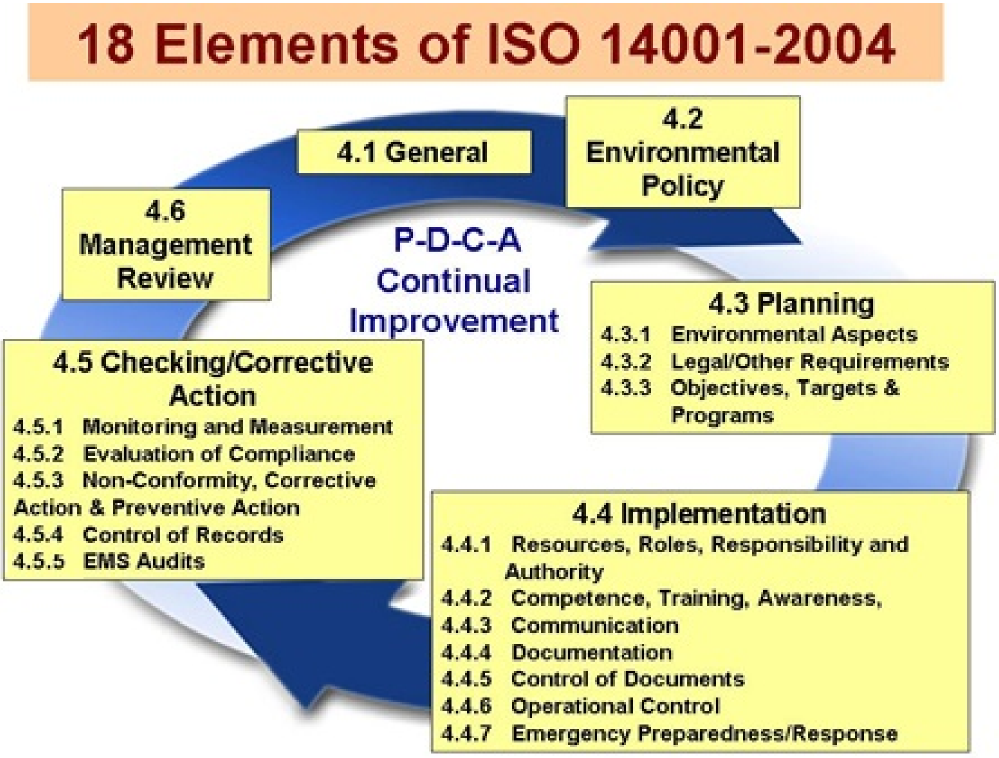


Figure 3.4: The ISO 14001 EMS Model with the 18 Elements of ISO 14001 (ISO, 2004)

3.2.2 EMS in the context of HEI

The advent of EMSs at HEIs has been due to a number of factors which are (Delakowitz & Hoffman, 2000):

1. *Compliance with government and NGO directives*: Directives from governments and NGOs have pressured HEIs into managing their environmental impact.
2. *Social responsibility for the preservation and protection of the natural environment*: Some HEIs are co-located with natural reserves and it is the duty of the community to

protect the animals and the reserve. Also resources, such as energy, are scarce in Africa and need to be used and managed responsibly.

3. *Stakeholders*: Students, faculty and staff, management and board are increasingly becoming concerned with the environmental impact of their institutions. Future students are also included.
4. *Image and prestige*: Future students are now selecting an HEI based on a number of factors. Future students and employees consider the educational quality, flexibility and applicability of an institution and an HEI that has innovative environmental management, demonstrates a voluntary continuous process of learning, development and adaptability has an advantage.
5. *Competitive advantage for clients*: Clients in this case are students and employees.

EMS was originally designed for industry (Hens, et al., 2009) and the two main standards (ISO 14001 and EMAS) in use were not designed with HEIs in mind, therefore there is limited formal guidance or frameworks for HEIs which adopt them (Simkins & Nolan, 2004). HEIs function differently from industry and have different organisational structures (Jones, et al., 2011). The structure of a HEI consists of four dimensions, namely education, research, operations and external community when compared with industry structures which are focused primarily on profit (Cortese, 2003). Hence, it is imperative that EMSs be tailored to meet the specific educational needs of HEIs.

A significant number of models have been proposed and developed for environmental impact management and EMSs in HEIs (Velazquez, et al., 2005; Disterheft, et al., 2012). Research at HEIs that are pioneering the implementation of EMSs has taken strides towards adapting EMSs for HEIs. EcoCampus is an EMS and award scheme tailored for HEIs in the United Kingdom (EcoCampus, 2013). The scheme enables HEIs to systematically identify, evaluate, manage and improve their environmental performance and practices. For example, the University of Osnabruck, Germany, proposes the Osnabruck Environmental Management Model for HEIs based on the EMAS guideline and the University of South Carolina, U.S.A. has also outlined a plan to develop a state-wide higher education EMS (Savely, et al., 2007).

The Sustainability Tracking, Assessment & Rating System (STARS) is another voluntary, self-reporting framework for recognising and gauging sustainability performances for an HEI

(AASHE, 2012). The framework was proposed and is maintained by the Association for the Advancement of Sustainability in Higher Education (AASHE). STARS allows for a comprehensive understanding of all sustainability sectors in higher education and it also offers incentives for HEIs to have a STARS rating. A survey done by Kamal and Asmuss (2013) showed that STARS was identified as the most effective tool for assessing and tracking sustainability in an HEI.

STARS has four categories which are interwoven into the five dimensions of an HEI (Figure 3.5). Each category has credits that must be acquired in order for an institution to become certified. The environmental credits are highlighted in Figure 3.5 as these are the focus of the study. Appendix I shows STARS 1.2 Table of Credits highlighting the Research, Education and Operations categories. These are shown together with the maximum possible points that an institute can obtain from each category.

Some HEIs have made internal decisions to obtain certifications mostly from ISO 14001 or EMAS and some have implemented variations of ISO 14001 and EMAS (Rashed, et al., 2008; Disterheft, et al., 2012; Bagnoli & Snyder, 2007; Speshock, 2010). Research at HEIs has also managed to identify some of the key environmental indicators (sustainability metrics) at an HEI. Research done by Bero, et al. (2012) which focused on the challenges in the development of an EMS on the modern HEI campus highlighted the environmental indicators that were relevant to the Northern Arizona University. A closer investigation of the environmental indicators shows that most of the indicators are relevant to any HEI. Table 3.1 compares the environmental indicators implemented at three American HEIs. The STARS 1.2 Table of Credits also shows the environmental indicators at HEIs in comparison with the GRI standard and the environmental indicators of STARS.

Analysis of three HEIs (Northern Arizona University, Indiana University and the University of Maryland) shows the common and different environmental indicators at the HEIs (Table 3.1). Bero, et al. (2012) lists the environmental indicators for Northern Arizona University (NAU). A study by Velazquez, et al. (2006) attempts to list general environmental attributes in HEIs; these environmental indicators are also tabulated in Table 3.1. The resources category shows four environmental indicators and of the four, at least three are recognised at these HEIs. This shows that these three indicators are essential indicators for any HEI.

Transportation and communication show that HEIs have currently shifted to measuring and monitoring various attributes in this sector when compared with the year 2006 in which no environmental indicator was monitored as was highlighted by Velazquez, et al. (2006). For the transportation and communication category each university recognises at least three of the seven indicators.

Table 3.1 further highlights that HEIs are also focusing on reducing their waste generation and they are doing their due diligence by involving, educating and leading their community's environmental sustainability activities. All HEIs recognise at least three of the four environmental indicators in the education programmes category.

3.3 Information Systems for Environmental Information Management

The International Symposium on Environmental Software Systems (ISESS) describes Environmental Information System (EIS) as being the overall encompassing term for all systems relating to the automation of environmental information (ISESS, 2000). These systems include one or more of the following functions:

- Monitoring;
- data storage and access;
- disaster description and response;
- environmental impact reporting;
- state of the environmental reporting;
- planning; and
- simulation modelling and decision making.

Environmental management is multifaceted; however most aspects, if not all, tightly depend on the availability and accessibility of correct and current information (Frysinger, 2001). Hence, environmental management requires environmental information management. Organisation stakeholders need access to environmental information to evaluate and access the environmental dimension of organisational decisions, both at a managerial level and at a strategic level (El-Gayar & Fritz, 2006).

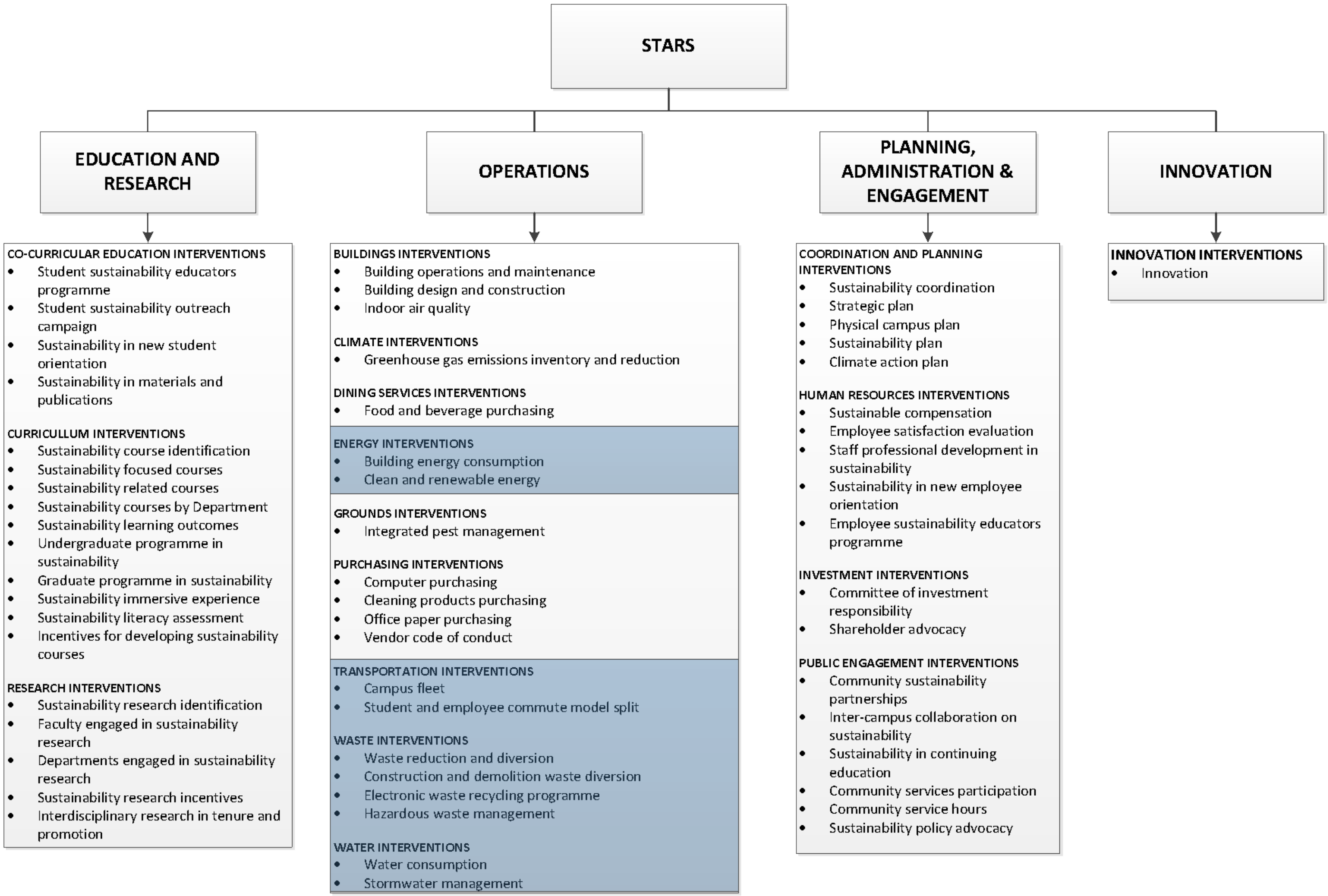


Figure 3.5: The Categories of STARS (Adapted from AASHE, 2012)

Table 3.1: Environmental Factors at HEIs

Environmental Indicator	Universities/HEIs				Standards	
	General HEIs Indicators	NAU	Indiana Univesity (2014)	Maryland (2013)	**STARS**	**GRI**
Utilities usage/ Resources						
Energy consumption	✓	✓	✓	✓	✓	✓
Renewable energy	✓	✓	✓	✓	✓	✓
Water consumption	✓	✓	✓	✓	✓	✓
Reclaimed water		✓			✓	✓
Transportation and commuting						
Air travel				✓		
Shuttle/bus Ridership				✓	✓	
Campus vehicle fleet fuel use		✓	✓	✓	✓	
Parking spaces		✓	✓	✓		
Bike racks			✓	✓		
Faculty, staff and student commuting		✓	✓		✓	
Greenhouse gas emissions				✓	✓	✓
Waste generation						
Solid waste	✓	✓	✓		✓	
Hazardous waste		✓			✓	
Air emissions	✓	✓	✓	✓	✓	
Electronic waste			✓		✓	
Recycling	✓	✓	✓		✓	
Educational Programs						
Environmentally related programs to study	✓	✓	✓	✓	✓	
On-campus programs	✓	✓	✓	✓	✓	
Outreach programs	✓	✓	✓	✓	✓	
Related research projects	✓	✓	✓		✓	
Grounds/natural heritage						
Compositing	✓		✓			
Pruning/cutting wastes		✓				
Pesticide/herbicide, fertilizer use		✓			✓	
Tree planting			✓			
Purchasing/food services						
Environmentally certified vendors		✓		✓	✓	
Locally grown foods	✓	✓	✓	✓		
Organic foods	✓	✓		✓		
Recycled paper and materials		✓			✓	
Disposable products		✓				
Janitorial products		✓		✓	✓	

The IT department needs to be involved in the planning phase by having an IS that can gather environmental data and be used to establish a baseline from which top management can work to create environmental sustainability goals and objectives (Figure 3.6). Environmental sustainability initiatives are centred around two continually repeated cycles namely: *data collection*, in which environmental performance data is collected and archived, and *assessment*, where the archived data is analysed and used for decision making and reporting purposes.

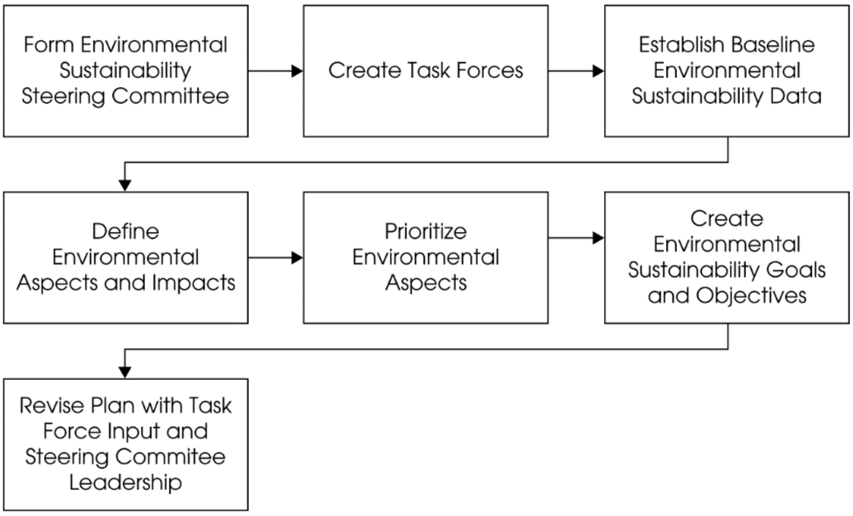


Figure 3.6: Planning Stage Process Flow with IT Department (Speshock, 2010)

Organisations must exhaust and use IT resources to convert the raw environmental data into meaningful and useful information which can be used to draw meaningful conclusions and with the help of some environmental management tools and techniques, and real-time information, recommendations for decisions can be provided by the tools (Speshock, 2010). Therefore it is difficult to conceive an effective and well-integrated EMS which does not stand upon an EIS.

3.3.1 Components of Environmental Information Systems

Attempts to categorise the different EISs that are in existence have proven to be unsuccessful and this has been the same for environmental information (Haklay, 2001). The definition of environmental information according to the Aarhus convention (UNECE, 1998) leaves the reader wondering; *What kind of information is not Environmental Information?* as described by Haklay (2001). This vagueness or broadness is due to the multi-disciplinary nature of the environmental domain as it ranges from fields like agriculture, climate, chemistry and marine, for example, soil acidity, to industry and transport.

The complexities of EISs depend on various key factors that Denzer (2005) calls the components of an EIS, which are:

1. Environmental information: Environmental information is unique and complex as it is characterised as heterogeneous, spatial and time dependent;
2. Complex software tools and algorithms: An EIS can consist of tools from any domain of IT. These tools include databases, real-time acquisition systems, meta information systems, networks, GIS, artificial intelligence, expert systems and remote sensing technology;
3. Complex data management systems due to the variety of autonomous data providers and customers;
4. The absence of real data and metadata standards for many domains;
5. Complexity of tool integration: Different tools have to be combined into one holistic solution for end users, where the tools may use different algorithmic and/or data management strategies.

The four main interconnected building blocks or components of an EIS according to Denzer (2005) are: Models, Geographical Information System (GIS), Decision Support System (DSS) and Data Management (Figure 3.7). Denzer (2005) goes on to argue that a typical EIS consists of at least two of these main building blocks. It is important to note that this approach looks at EISs from a *software development* perspective which is of importance to this study.

The GIS and DSS components in the Denzer (2005) model tend to overlap. A DSS is a tool that uses Artificial Intelligence (AI) to analyse the information and a GIS is a system that stores, analyses and displays geo-referenced environmental information (Lukasheh, et al., 2001; Denzer, 2005). Hence, if the system includes data analysis then it is classified as a DSS; however if a geographical component is added (for example electricity used at a certain location) and location information is required then it becomes a GIS. Retrieving data for a specific location can also be classified as analysis hence the distinction between DSS and GIS is not clear as there are potential overlaps. Moreover, in many cases the term EIS is used to describe a GIS and vice-versa (Haklay, 1999). However, any form of EIS needs a data management component.

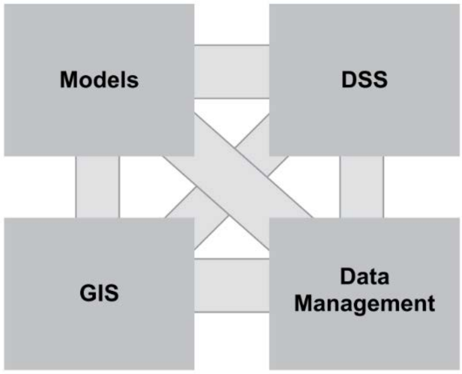


Figure 3.7: Main Building Blocks of EIS (Denzer, 2005)

Environmental Software and Services (ESS) designed a generic EIS framework called the ECOSIM Information System Framework (Figure 3.8). The middle layer of the framework shows four components of an EIS namely: a Database (DB), GIS, models and an Expert System (ES). The DB and GIS form part of the IS whereas models and ES form part of the analytical system. The Graphical User Interface (GUI) is a presentation layer that provides information to users in different formats and perspectives. The data and information pre-processing layer is where the data is cleaned, validated, and aggregated in preparation for use in the IS and/or analytical system. These components are in agreement with Denzer's components with the minor differences being the ES and the DSS.

The components approach used by Denzer (2005) and ESS (2002) provides a holistic view of the structure of an EIS by incorporating the structure, definition, and relationship between data elements, as well as processes and procedures by which this data is collected, created, modified, used and destroyed (Frysinger, 2001).

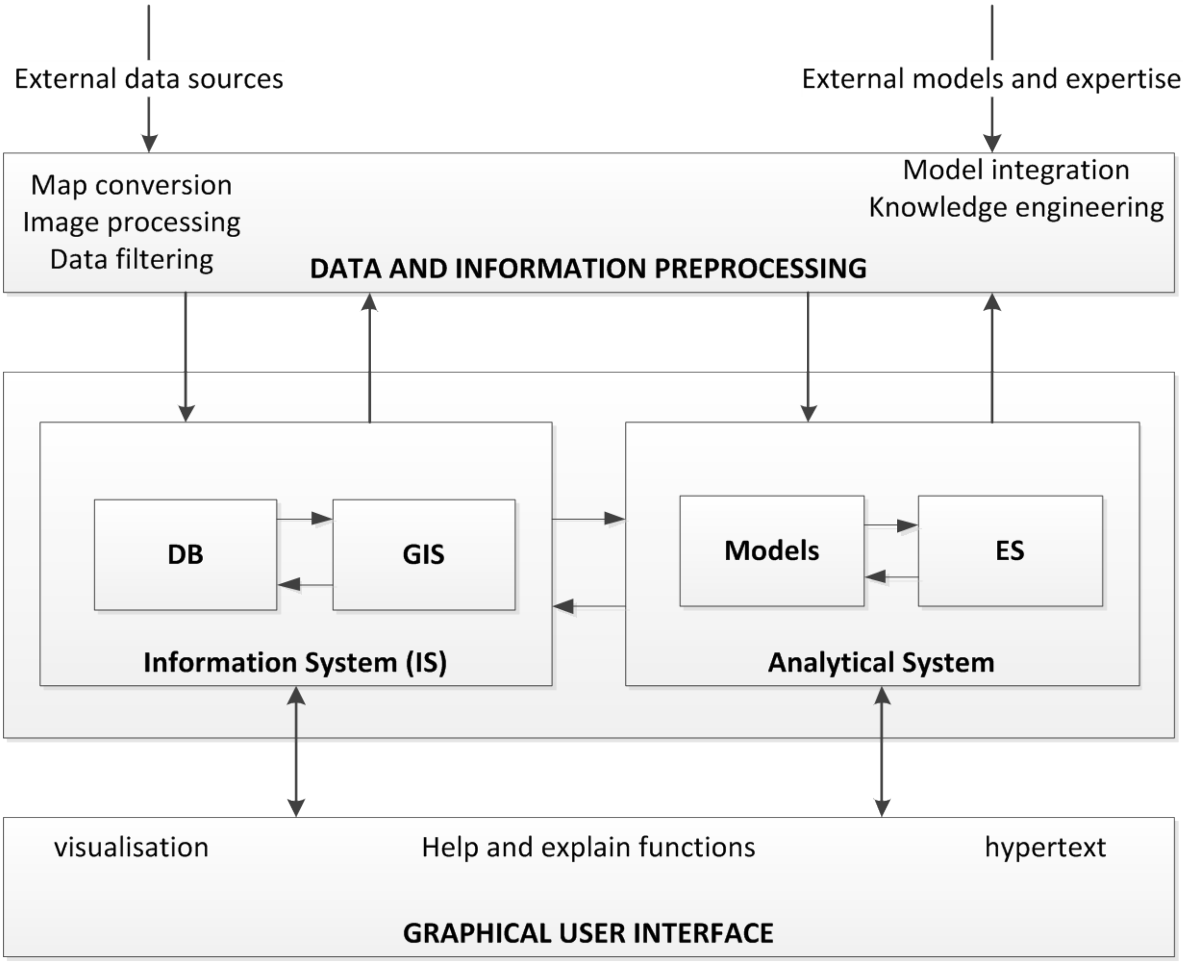


Figure 3.8: The ECOSIM Information System Framework (ESS, 2002)

The Environmental Decision Support System (EDSS) is another example of an EIS and provides aggregation, ad-hoc querying, and modelling of environmental data and processes (El-Gayar & Fritz, 2006). It facilitates strategies of business process re-engineering, technological innovation, process improvement and workflow optimisation.

3.3.2 Environmental Management Information Systems (EMISs)

There is a number of competing and complementary definitions for EMIS. Gunther (1998) describes an EMIS as a system that manages environmental information within an organisation while Gilbert (1999) defines it as the use of technology to manage Environmental Health and Safety data for record keeping and reporting purposes. An EMIS is, broadly speaking, computer-technology to support an EMS (Moore & Bordeleau, 2001). The computer-technology is mainly concerned with the efficient collection of environmental performance data to directly support performance measurement and process improvement. Other authors (Turner & Greco, 2003; Athanasiadis, 2006; Burke & Gaughran, 2006; Speshock, 2010) use the term Environmental Information Management System (EIMS), which from its definition, is similar to an EMIS and the terms can therefore be used interchangeably. Speshock (2010) defines an EIMS as a system used to store, manage, verify, protect, retrieve and archive the organisation's environmental information. For the purpose of this study the term EMIS will be used with the definition of Speshock (2010).

A stand-alone EMIS is usually a simple report generator with basic database functionality to record environmental information and generate reports satisfying an organisation's compliance requirements (El-Gayar & Fritz, 2006). Serving as basic data repositories and report generators, EMISs enhance the environmental management capabilities and support an implemented EMS. Although EMISs evolved as standalone systems, industries soon realised the benefits and the need of integration with other systems. Industries realised that an EMIS can help save both operational costs and time for organisations. El-Gayar and Fritz (2006) discuss case studies from major multinational companies which show a reduction in time for environmental information gathering and reporting after implementing an EMIS.

The implementation of an EMIS has been identified as a necessary precondition to the development of an effective EMS. In addition, it has been noted that an ineffective EMIS reduces the effectiveness of the EMS (Stuart, 2000). El-Gayar and Fritz (2006) argue that EMISs stand as the backbone of any organisation's environmental management efforts by supporting the organisation's EMS and by meeting the reporting needs of stakeholders. EMIS data is consumed by higher strategic levels in order to assess the effectiveness of, and in turn, to modify, as necessary, the EMS that guides operations. EMISs can exist as support systems for an organisation-wide EMS or as support for specific environmental management functions such as waste management or environmental health and safety. However, there is a lack of literature in the field of EMISs.

3.3.3 Components of EMIS

Studies (Giesen, et al., 2009; Al-Ta'ee, et al., 2013) have investigated and identified the key components of an EMIS (Figure 3.9 and Figure 3.10).

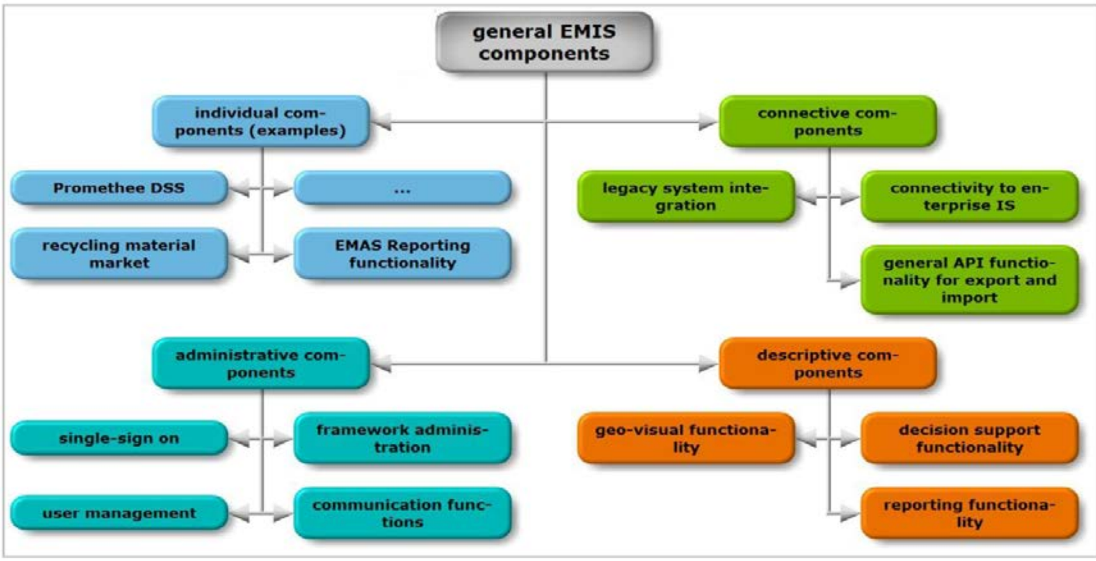


Figure 3.9: General Components of a System Based EMIS (Giesen, et al., 2009)

Although the components identified by Giesen, et al. (2009) and Al-Ta'ee, et al. (2013) appear very different, there are several commonalities. The model of Giesen, et al. (2009) has the geo-visual functionality and the decision support system which corresponds to the map tools and the analysis tools of the Al-Ta'ee, et al. (2013) model respectively. Figure 3.10 tends to be a higher level representation of the components of an EMIS while the Giesen, et al. (2009) model divides the components further and provides more detail.

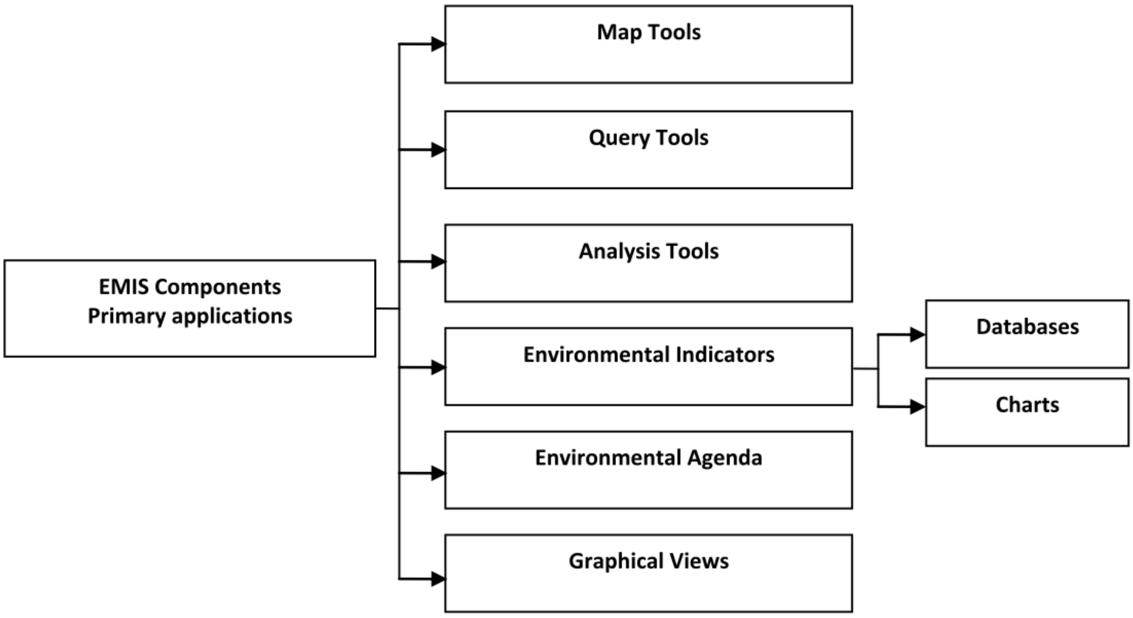


Figure 3.10: The Major Components of EMIS (Al-Ta'ee, et al., 2013)

Su, et al. (2013) propose a seven layer architecture for a system for environmental monitoring and management (Figure 3.11). The sensor layer collects data from environmental sensors, the data is then transported through the transport layer to the acquisition layer. All the data is then stored in a storage layer. The data layer filters and normalises the raw data. Data is then analysed in the application layer and is then produced for information distribution through the presentation layer (Su, et al., 2013). These seven layers map to the components described by Giesen, et al. (2009) and Al-Ta'ee, et al. (2013).

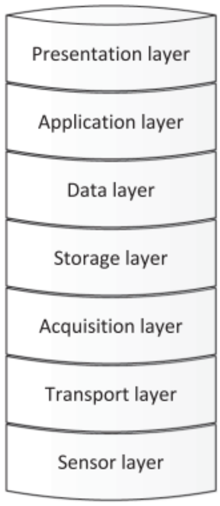


Figure 3.11: Seven-layer Model for an Environmental Monitoring and Management System (Su, et al., 2013)

An analysis of several studies (Al-Ta'ee, El-Omari, & Ghwanmeh, 2013; Alshuwaikhat & Abubakar, 2008; Disterheft, da Silva Caeiro, Ramos, & de Miranda Azeiteiro, 2012; El-Gayar & Fritz, 2006; Frysinger, 2001; Giesen, Farzad, & Marx-Gómez, 2009; ISESS, 2000; Su, Shao, Vause, & Tang, 2013) of EMIS reveal four commonly identified types of components of an EMIS, namely:

- Data collection (data cleaning, validation, integration and normalisation);
- centralised data storage and access;
- data processing (aggregation, simulation, modelling of data and decision support); and
- monitoring and reporting (ad-hoc querying).

Data collection within an EMIS includes the integration of legacy and heterogeneous systems and the data collection mechanisms vary depending on the legacy systems or the lack of legacy systems. Data collection includes the mechanisms that are used for data acquisition and data pre-processing which include data cleaning, validation, integration and normalisation. Some EMISs are also developed to cater for document management (Al-Ta'ee, et al., 2013). In environmental efforts, documents such as environmental policies must be stored in a safe and secure environment.

Organisations need to process environmental data into useful information which can be used to draw meaningful conclusions (Speshock, 2010). Data processing involves complex algorithms that provide aggregation, ad hoc querying and modelling of environmental data and processes (El-Gayar and Fritz, 2006). Some EMISs have complex data processing that offers the capability to analyse, simulate and provide decision support. These capabilities are useful and make an EMIS valuable to the top management of any organisation. Table 3.2 shows the how the components of Giesen, et al. (2009), Al-Ta'ee, et al. (2013) and Su, et al. (2013) conform to the four commonly identified types of components of an EMIS.

Table 3.2: Comparison of EMIS Components

Component Type	Giesen, et al. (2009)	Al-Ta'ee, et al. (2013)	Su, et al. (2013)
Data collection	• Legacy system integration • Connectivity to enterprise IS (ERP system) • General API functionality for import		• Sensor layer • Transport layer • Acquisition layer
Centralised data storage and access	• General API functionality for export	• Databases	• Storage layer • Data layer
Data processing	• Decision support functionality	• Analysis/analytical tools	• Application layer
Monitoring and reporting	• Geo-visual functionality • Reporting functionality (EMAS)	• Map tools • Query tools • Charts • Graphical views	• Presentation layer

EMISs generally have three design options that organisations must consider in choosing an appropriate solution to implement. The context of the EMIS is almost as important as the type of EMIS itself. The EMIS design options are as follows (Moore & Bordeleau, 2001):

1. *Meta-information System*: Reference information is available in the location of environmental and business data available in the organisation.
2. *Virtual Database System:* Users access and update information via a uniform and standardised web or client-server interface.
3. *Central Database System or Data Warehousing Approach*: Required environmental data are collected by the various information systems of the company and centralised in the data warehouse so that the data can be easily accessed on demand.

Table 3.3 shows the common components of an EMIS conforming to the four types of components of an EMIS. Moore and Bordeleau (2001) highlighted that the data warehousing approach is a common approach that is used in the developement of an EMIS hence some of the components are derived from data warehousing literature. Data warehousing technology encompases architectures, algorithms, and tools for bringing together selected data from multiple databases or other information sources into a single repository called a data warehouse (Widom, 1995). A data warehouse is suitable for direct querying and analysis (Widom, 1995).

An operational data store (ODS) is a database designed to integrate current valued subject oriented, volatile and up-to-date data from multiple sources such as IS or sensor networks (Inmon, 1999). An ODS is usually designed to contain low level or atomic (indivisible) data (such as transactions). The ODS provides input to the data warehouse by storing transactional data that is necessary to create information (Inmon, 1999). For example, an ODS can store indivisible data such as meter readings which is data needed by the data warehouse to calculate usages. ODS involves multiple data sources therefore this process includes data cleaning and validation. The first step in the generation of a data warehouse is the Extraction, Tranformation and Loading (ETL) of data from various sources. Similar to the data collection component, the data warehouse's ETL process involves data cleaning, validation and integration. Therefore, the data warehouse, ETL and ODS can be added as components of EMISs.

Data warehousing also includes data aggregation which provides information that can be used for analysis and decision support. A data warehouse is designed in such a manner that it can facilitate ad hoc querying of information which allows for monitoring and reporting. This shows that a data warehouse also provides functioanilty that falls in the data processing category and monitoring and reporting category.

Table 3.3: Components of an EMIS

Component Type	Description	Components
Data collection	Data collection within an EMIS includes the integration of data sources such as legacy and heterogeneous systems and databases. Data collection includes the mechanisms that are used for data acquisition and data pre-processing which include data cleaning, validation, integration and normalisation (ESS, 2002; Denzer, 2005; Disterheft, et al., 2012).	• Extract, Transform and Load (ETL) (Inmon, 1999) • Quality assurance (data validation and verification) (ESS, 2002; Inmon, 1999)
Centralised data storage and access	Data from various sources is stored in a central database so that it can easily be accessed on demand (Moore & Bordeleau, 2001).	• Operational Data Store (ODS) (Inmon, 1999) • Data Layer/Data warehouse (Moore & Bordeleau, 2001; Su, et al., 2013)
Data processing	Data processing involves complex algorithms that provide data aggregation, analysis, simulation, modelling and decision support (El-Gayar & Fritz, 2006).	• Analysis/analytical tools (Al-Ta'ee, et al., 2013)
Monitoring and reporting	Involves the ad hoc querying of EN data (Al-Ta'ee, et al., 2013).	• Presentation layer (Su, et al., 2013)

3.4 EMIS in the context of HEIs

According to Velazquez, et al. (2006), a HEI is considered to be a sustainable institution if the institution addresses, involves and promotes the minimisation of negative environmental, economic, social and health impact of daily activities involved in the functioning of the institution. Sustainable HEIs have influence to the extent that they help, regional or global societies to transition to sustainable livelihood. Until recently, there was a common understanding that sustainability in higher education has four dimensions; namely: education, research, operations and community engagement/external community (Cortese, 2003). Governance has been identified as the central fifth dimension (Figure 3.12).

The adoption of EMISs as tools to support environmental efforts has been found to be most prominent in industries that have a significant impact on the environment. Such industries include pharmaceuticals, oil, hazardous chemicals, automotive, utilities, primary metals and semiconductors industries. In contrast to many industrial contexts, HEIs face a range of unique challenges (Bagnoli & Snyder, 2007; Alshuwaikhat & Abubakar, 2008; Bero, et al., 2012), namely:

- An extremely diverse community of faculty, students, staff, and support personnel, all with differing priorities, modes of engagement, and supervisory models;
- a broad range of institutional activities and facilities including offices, laboratories, machines, classrooms, dining halls, and dormitories;
- broad distribution across a range of buildings and facilities of differing design and age, potentially dispersed over a large area; and
- relatively limited financial and personnel resources for developing, implementing, and sustaining an effective EMS.

The complex structure of HEIs requires that EMISs be tailored for HEIs (Figure 3.12). The implementation of an EMIS in HEIs has many benefits. The ultimate benefit is the reduction in the environmental footprint of the institution in that there is a reduction in water usage, an improvement in energy efficiency and a reduction in pollution. These are benefits of having environmental information readily available so that through the analysis of the information, decisions can be made by top management that will result in the optimal use of resources such as energy and water and accordingly enhance the financial management of the HEI (Jones, et al., 2011).

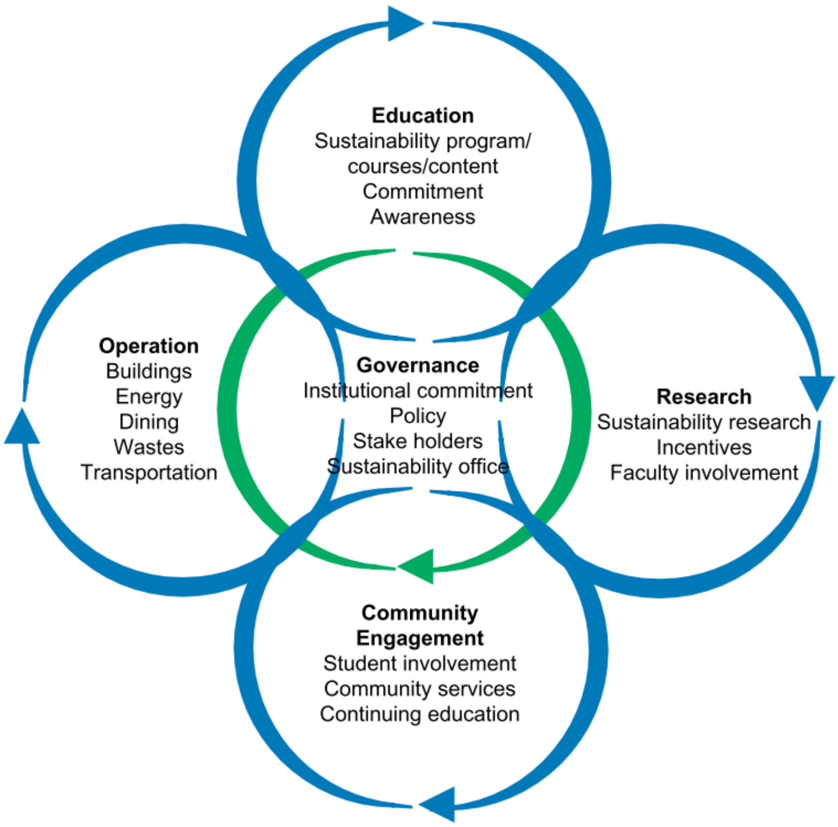


Figure 3.12: General Practice of Higher Education (Kamal & Asmuss, 2013)

Other benefits of an EMIS in HEIs are that the system can allow HEIs to do objective tracking, analysis of root causes of problems, areas requiring corrective action, improvement in emergency response time, improve performance and increase efficiency (Savely, et al., 2007). For example, management can be alerted about anomalies in resource (water) usage, the problem of a burst pipe can be noted and immediate action can be taken to rectify the problem.

Environmental information from an EMIS can also be publicised to students, staff and external stakeholders. Publicising environmental information to the HEI's community can raise the environmental awareness of students and staff at the institution and they can take action to reduce their contribution to the negative environmental impact of the institution. Results can also be communicated between departments to keep momentum, get credit for improvements or cost saving/avoidance and celebrate accomplishments.

3.5 Extant Systems of EMIS

It will be advantageous to investigate several studies of past, current and possible future implementations of EMISs and EISs to help understand the requirements, limitations and challenges of the proposed solution (Athanasiadis, 2006; El-Gayar & Fritz, 2006; Solabach, et al., 2010; Bero, et al., 2012), thre EMISs will be discussed in the following sub-sections.

3.5.1 STORM

The Sustainable Online Reporting Model (STORM) is a web-based EMIS that is used mainly for sustainability reporting (Solabach, et al., 2010). Sustainability reporting efforts are tightly associated with EMISs just as much as environmental management efforts are. Sustainability reporting requires that environmental information is retrieved from the various information sources and EMISs serve this particular purpose in sustainability reporting efforts (Solabach, et al., 2010). One other key role that EMISs play in sustainability reporting is the verification of the environmental information to be published. STORM seeks to address such issues. STORM can retrieve data for reporting from legacy information systems and other databases or sensor networks (Figure 3.13).

STORM has built-in standards which are the Global Reporting Initiative (GRI) and EMAS to define environmental indicators and it can be edited to represent the particular organisation's schema. The system has different functions and interfaces for different roles namely, administration, editor, and public user or reader. STORM is a well-integrated sustainability report-oriented system.

The limitations of STORM are:

1. STORM is focused on sustainability reporting. Although, sustainability reporting is being introduced in HEIs and is also advisable, it is an emerging field, one that requires that the data acquisition and management processes are well established and effective (Lozano, 2006; Fonseca, et al., 2011). The main focus of this study is not on sustainability reporting, but rather on data acquisition and management in the early stages of sustainability management, which will allow for baselining and eventually

progress to sustainability reporting at a much later stage. Hence, STORM will not serve the purposes or address the issues for which this study was motivated.

2. STORM is designed for an organisation that has databases in place and more advanced technology such as sensor networks (Solabach, et al., 2010). Initial research highlights that manual processes are currently used and that there is a lack of comprehensive databases and sensor networks. Therefore, STORM will not be able to address the issues in HEIs, which mainly use manual processes that motivated this research.

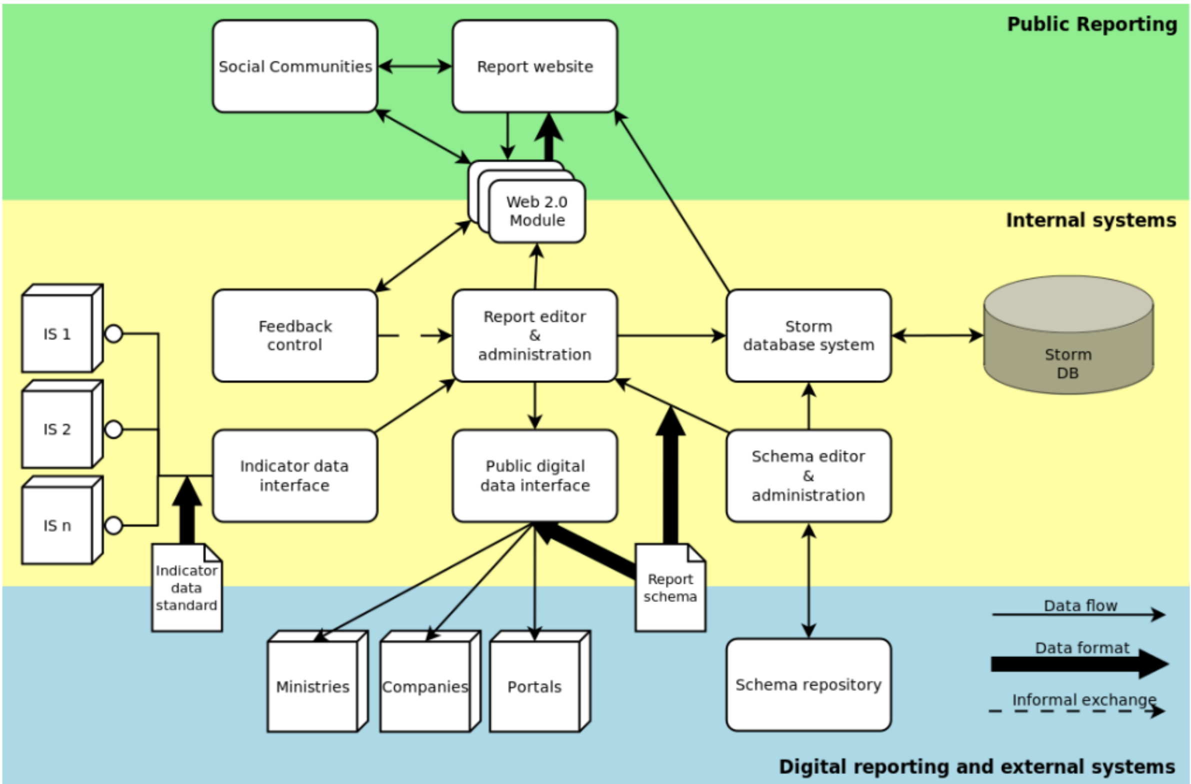


Figure 3.13: Reference Architecture for STORM (Solabach, et al., 2010)

3.5.2 AISLE

Environmental data is generally raw, noisy or incomplete, vary in formats, and is often hidden in legacy systems, reports, or other non-reusable forms. In such situations, an EMIS must be implemented to retrieve relevant environmental information from several data sources, which are typically in different physical locations and diverse implementations. The Adaptive Intelligent Service Layer for Environmental information management (AISLE), is one such service-oriented EMIS that mediates between environmental data providers and actual end user applications that require pre-processed environmental information (Athanasiadis, 2006).

The AISLE platform is situated between the data pool and the end-user applications (Figure 3.14). The main objectives of AISLE are to extend the capabilities of legacy systems and also to supply high quality data to end-user applications. AISLE pulls data from a sensor network, FTP or HTTP files and databases. This data usually inherits the critical properties of environmental data such as low reliability, redundancy and poor semantics. To most end-user applications the data is usually incomplete and/or incompatible (Athanasiadis, 2006). AISLE handles these environmental data uncertainties and communicates the data with end-user applications.

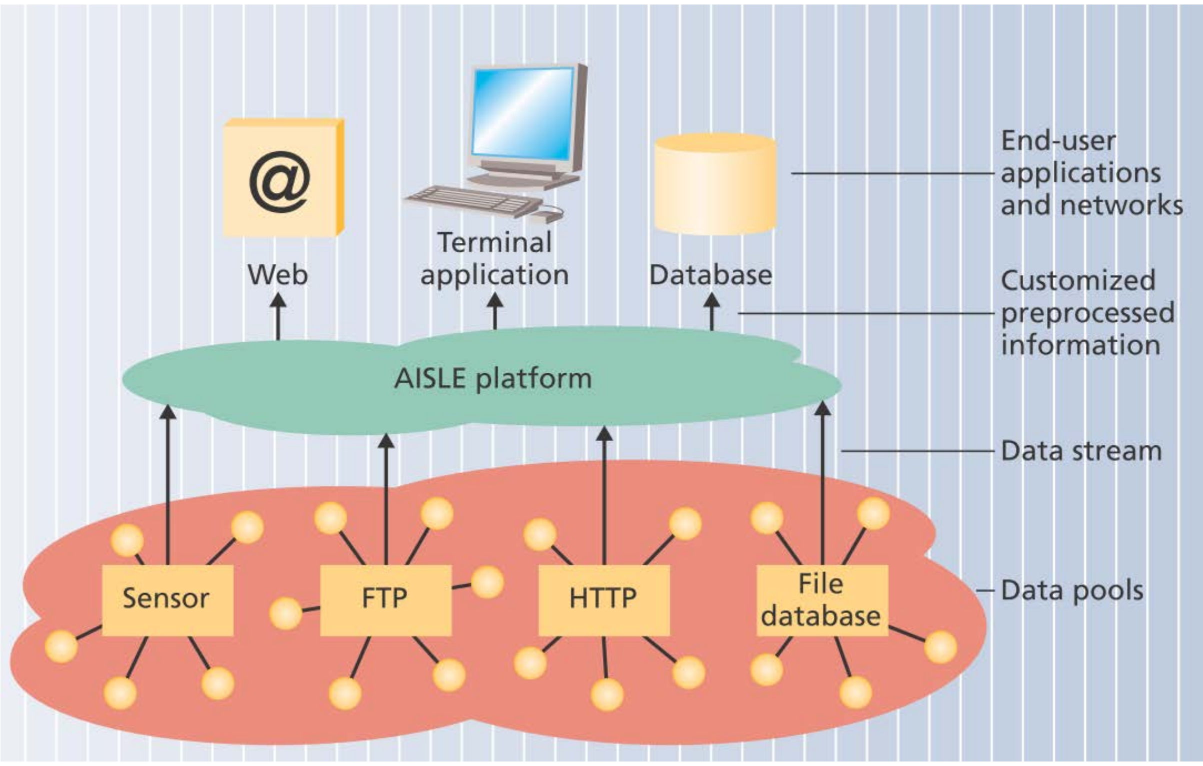


Figure 3.14: The AISLE Operational Environment (Athanasiadis, 2006)

AISLE provides an extensive set of services or components, namely (Athanasiadis, 2006):

- Data gathering and validation;
- substitution or estimation of missing and/or erroneous measurements;

- data management and pre-processing; such as data cleaning, normalisation, integration, and validation capability;
- system extensibility and adaptation, add or remove data pools or end-user applications; and
- information propagation receives data from sensor networks, databases and files and provides it all to end-user applications.

AISLE has three layers which are called clusters of services (Figure 3.15). The first layer called the *contribution services cluster* is responsible for data collection, validation and handling of missing or erroneous measurements. The *management services cluster* focuses on data management and integration. The *distribution services cluster* provides the appropriate interfaces to end-user applications.

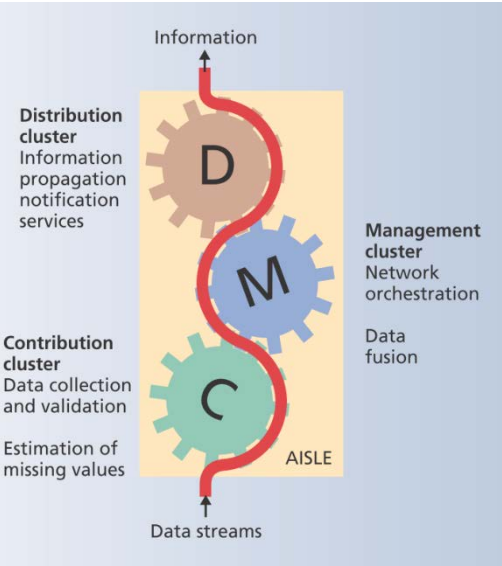


Figure 3.15: AISLE's Three Cooperative Clusters (Athanasiadis, 2006)

The main limitations of AISLE are that the data gathering process is not comprehensive enough to cater for manually gathered data. Initial research highlighted that HEIs lack advanced network sensors and that they rely heavily on manual processes rather than smart network sensors. Therefore AISLE may not be able to fully address the set of issues in HEIs.

3.5.3 The Dynamic Environmental Management System (DEMS)

Bero, et al. (2012) discuss a number of systems such as the lucid dashboard (http://www.luciddesigngroup.com/products.php) which provides a real-time view of electricity, water, gas, and other resource usage in fully-instrumented buildings and the Pulse Energy's Energy Management Software (www.pulseenergy.com). These systems focus on displayed automated sensor data and do not cover the full range of a campus's environmental indicators (for example waste, transportation, carbon emission). Development of automated EMS systems for large institutions is significantly complicated by profound heterogeneity in campus infrastructure, management policies, and limited data accessibility; legacy data is often incomplete or inaccurate (Bero, et al., 2012).

The Dynamic Environmental Management System (DEMS) which was developed for the Northern Arizona University was designed with specific aims. The aims were (Bero, et al., 2012):

1. Provide a robust infrastructure for implementing a comprehensive sustainability programme monitoring a full range of campus resource usage;
2. support not only automated, sensor-based collection of data, but also streamline distributed 'at the source' manual entry key environmental data;
3. provide for a wide range of facilities, including older facilities with only old-fashioned manual resource measurement devices;
4. provide sophisticated analytic tools and displays to allow campus administrators to juxtapose usage data for various resources on a timeline with specific usage-reduction initiatives to determine the overall effect of these measures;
5. provide support for associating resource usage not only with buildings, but also with campus units and the types of activities that various spaces are used for; and
6. support public awareness and outreach by allowing access to simplified aggregated data summaries of system data for public display.

The DEMS was developed by two distinct collaborative sub-teams (Bero, et al., 2012). The first team was a data acquisition team, which was responsible for exposing campus infrastructure, negotiating access to data sources (human and automated), and entering both legacy and incoming data into the evolving system. The second team was a software development team, which focused on developing the sophisticated web-based interface, analytic and visualisation tools, and relational database that comprise the DEMS system. The data acquisition team compiled the environmental indicators at the Northern Arizona University (Table 3.1). However, only a subset of the indicators was used in the implementation of the prototype. The subset was chosen based on the level of overall environmental impact, availability of data, and ease of data collection.

The DEMS has three different types of modules implemented, namely real-time data, manually collected data and spatial types. The design and implementation of the DEMS is based on a relational database. This is advantageous as it allows data to be viewed from any number of analytic perspectives. For example, resource usage can be displayed by a building, or it can be viewed or analysed by an organisational (administrative or academic) unit, or by space utilisation (for example classrooms, offices labs). For DEMS to support these analyses, logical entities including buildings, spaces, organisational units, and usage categories were built into the core system data model. Data collected also included a building photo, historical information, type of heating and cooling system, available bicycle parking, and any special sustainability features of the building.

Data acquisition for DEMS proved to be extremely difficult (Bero, et al., 2012). The challenges experienced in the data acquisition process were:

1. Ever-increasing complexity and heterogeneity in campus infrastructure, widely varying quality of legacy datasets, and differences in data collection procedures (frequency, units, accuracy).
2. No one person could provide a complete overview of power, water, reclaimed water and gas as a distributed network to manage. These were created over time.
3. Meters associated with individual buildings were exceptions. More commonly, sub-loops in the distribution grid or groups of buildings shared meters; fine-grained utility data were only available for specific buildings or parts of buildings where distinct entities (e.g. food services in student unions) were separately billed.
4. Where records of historical resource usage existed, they often varied in granularity (monthly, annually) and completeness (gaps in the record).

5. Automated utility metring systems available in many newer buildings had been disabled due to budget constraints and lack of trained personnel to configure and maintain them.

However, the DEMS managed to address some of the problems encountered such as the group meter for buildings. The DEMS has apportionment modifiers that algorithmically apportion meter utility usage to arbitrary buildings and spaces within a metered loop. Water consumption was more complex, as the type of building also affected the usage. For example, student residences can be expected to use more water that offices or classrooms. Also the apportionment was more complex in that reclaimed water is used for flushing toilets and for irrigation purposes on some campuses.

The DEMS was driven by four key principles:

1. ***Universal access:*** To avoid expense and remove the limitations associated with developing various operating systems for specialised clients, such as a computer on different campuses, a web-based DEMS was designed. Security features were put in place such that an individual can only be granted access to a specific section of the system.
2. ***Extensibility:*** Due to the large number of environmental indicators, a modular system was developed such that a new indicator could be easily added.
3. ***Distributed data entry:*** The system should be able to allow distributed point of entry of data e.g. manually, automatically from smart meters, databases, legacy systems etc.
4. ***Timely, dynamic data analysis:*** The system should be able to allow individuals to see data as it is entered and it should provide powerful analysis and visualisation tools.

The two layer architecture of the DEMS allows for a realistic and comprehensive data gathering process (Figure 3.16). The DEMS takes into account the complexity of HEIs and the technology level that HEIs have. Organisations that have a big impact on the environment may be willing to invest in advanced technology such as smart meters but not all HEIs are willing and able to invest in such technology.

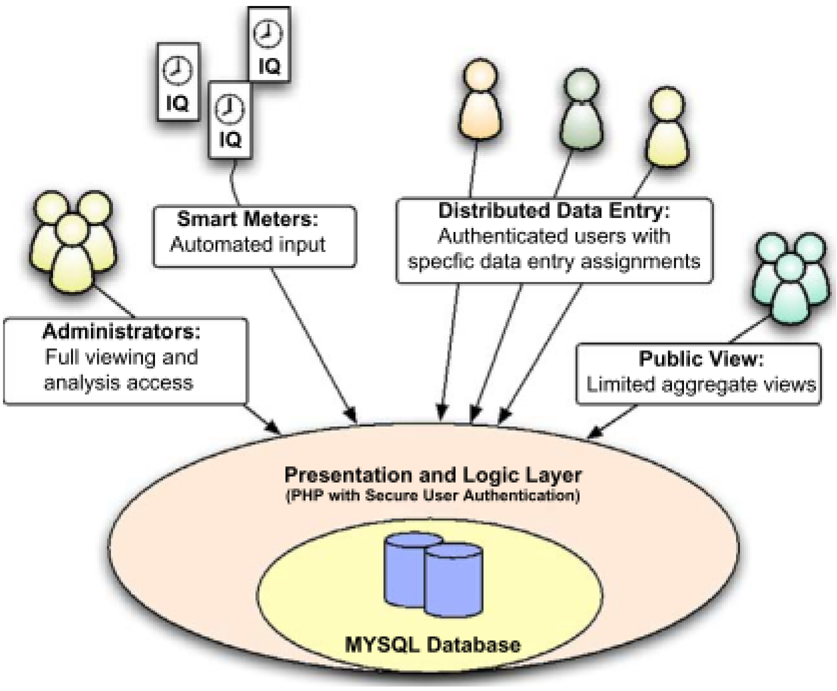


Figure 3.16: Two-layer Architecture of DEMS (Bero, et al., 2012)

Figure 3.17 shows a more detailed two layer architecture with the focus on the internal structure of the system. The major elements of the DEMS schema are the DEMS database and the web interface. The database structure highlights the packages and structure of the packages. The three packages shown are; the campus infrastructure, the resource usage and the DEMS system data. The campus infrastructure basically highlights the various organisational units and the physical spaces used, as well as the building, and the resource usage highlights how the resources are used, linked to the infrastructure. The web interface pulls the data from the DEMS and presents the data to the various organisation stakeholders.

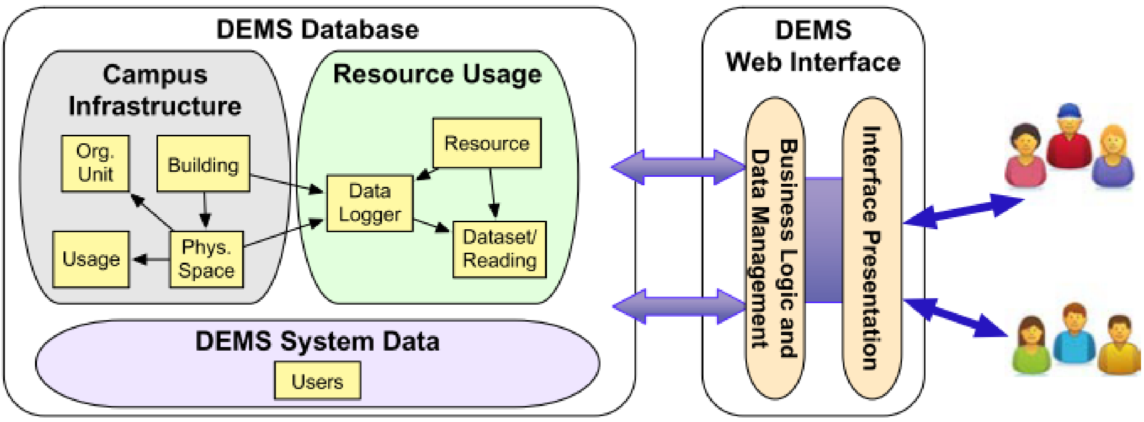


Figure 3.17: The Main Elements of the DEMS Schema (Bero, et al., 2012)

3.5.4 Comparison of EMIS

EMIS can consist of four common components which are data collection, centralised data storage and access, data processing and reporting (Section 3.3.3). A comparison of extant systems based on the common components of EMIS highlights the common features and differences in the extant systems (Table 3.4). All three systems (STORM, AISLE and DEMS) have data collection capabilities which include pulling data from various sources. However, the level of capability within the data collection component also varies. The AISLE system focuses on providing high quality data hence it performs extensive data pre-processing as data is collected. The DEMS has the capability of distributed manual entry of data.

All three extant systems have a central database in which they store data. However, STORM and DEMS do not allow for access to this raw data but AISLE can provide access to the data to third party end-user applications which then process the data to provide valuable information. This shows the different objectives for which these systems were developed. AISLE is developed with the main aim of providing high quality data to third party applications whereas STORM and DEMS process and use the data themselves. Hence AISLE does not consist of the other two common components of an EMIS.

The data processing component consists of complex algorithms that provide EMIS with powerful tools for EIM. STORM only processes information for reporting purposes which show a high-level view of the environmental status of an organisation in a common standard such as GRI or EMAS. The DEMS is one such EMIS that offers analytical and visualisation tools which can be used for decision making. The DEMS also has a presentation layer which consists of a web interface that is used to show aggregated summaries of environmental data to HEI stakeholders. Moore and Bordeleau (2001) propose a data warehouse approach for EMIS. Data warehousing technology offers the capability to retrieve data from various sources and then perform data cleaning, validation, normalisation, aggregation and offers ad-hoc querying and reporting. To an extent, this agrees with Moore and Bordeleau's (2001) data warehouse approach since the approach has similar components as those of an EMIS (Table 3.4).

Table 3.4: Comparison of Extant Systems (Based on Common Components)

Component Type	Extant Systems		
	STORM	**AISLE**	**DEMS**
Data collection	Retrieves data from legacy information systems and other databases or sensor networks. Performs data verification or validation.	AISLE pulls data from a sensor network, FTP or HTTP files and even databases. AISLE performs: • data cleaning; • normalisation; and • validation.	DEMS allows for • automated collection of data from databases and files; • sensor-based collection of data; and • distributed 'at the source' manual entry environmental data collection.
Centralised data storage and access	The ***STORM DB*** provides a central database were it stores the data it receives from the different pools.	AISLE receives data from sensor networks, databases and files and integrates it. AISLE can provide data to third party end-user applications.	Has a central MySQL database to store collected data.
Data processing	STORM processes the data to provide GRI or EMAS reports.		DEMS provides powerful analysis and visualisation tools.
Monitoring & Reporting	STORM has a public reporting component that has a website to report environmental information. Provides GRI or EMAS reports.		DEMS has a web interface which pulls the data from the DEMS and provides aggregated data summaries for public display.

Based on the evaluation of these tools three additional components of EMIS were identified and added to the set of components resulting in a set of ten components of EMIS. The three additional components are:

1. Sensor networks/Sensor-based collection (Bero, et al., 2012).
2. Distributed data entry (Bero, et al., 2012).
3. Legacy systems (Giesen, et al., 2009; Solabach, et al., 2010).

Athanasiadis (2006) divides the components and features of a EMIS into three clusters of services, namely: contribution services cluster, management services cluster and distribution services cluster (Table 3.5). Based on the definition of these clusters, the four common components of an EMIS can be grouped into these clusters. Data collection and centralised data storage falls under the contribution services cluster while data processing, monitoring and reporting falls under the managerial services cluster. Access to data and presentation of data falls under the distribution services cluster.

The contribution services cluster is responsible for data collection (Athanasiadis, 2006). Data collection involves integration of data sources such as legacy and heterogeneous systems and databases. In addition, data collection includes the mechanisms that are used for data acquisition and data pre-processing which includes data cleaning, validation, integration, normalisation and handling of missing or erroneous measurements. Hence, three components of an EMIS can be identified under this cluster, namely: Sensor networks and Legacy systems, quality assurance (data cleaning and validation) and Central Operational Data Store (CODS). Bero et al. (2012) proposed a fourth component which is distributed data entry (Table 3.5).

Table 3.5: Components of an EMIS Classified into Clusters of Services

Cluster	Component	References
Contribution Services Cluster	Operational Data Store (ODS)	Herremans and Allwright, (2000); Inmon, (1999)
	Distributed data entry	Bero et al. (2012)
	Sensor networks	Giesen, et al. (2009); Bero et al. (2012)
	Legacy systems	Giesen, et al. (2009); Bero et al. (2012)
	Quality assurance (data validation and verification)	Athanasiadis (2006)
Management Services Cluster	Analytical tools	Simkins and Nolan (2004); Bero et al. (2012); Al-Ta’ee, et al. (2013); Su, et al. (2013)
	Data Layer: Data Warehouse (DW)	Bero et al. (2012); Su, et al. (2013)
	Extract, Transform and Load (ETL)	Widom, (1995); Bero et al. (2012); Giesen, et al. (2009)
	Monitoring	Herremans and Allwright, (2000); Disterheft et al. (2012); Bero et al. (2012)
	Reporting	Herremans and Allwright, (2000); Disterheft et al. (2012); Bero et al. (2012)
Distribution Services Cluster	Presentation layer	Athanasiadis (2006); Franz-Balsen and Heinrichs (2007); Jones et al. (2011); Bero et al. (2012); Su, et al. (2013)

The management services cluster focuses on data processing, management, integration, monitoring and reporting. Data processing involves complex algorithms that provide data aggregation, analysis, simulation, modelling and decision support. Monitoring and reporting involves the ad-hoc querying of data which is also a type of processing of data. Hence, the ETL process of a DW, the database structure of the DW, analytical tools, monitoring tools and reporting tools are the components in the managerial service cluster of an EMIS.

The distribution services cluster involves the distribution of data to third party end-user applications, the distribution of aggregated data summaries or reported information for public display or access for administrators. Hence, a presentation layer is a component of the distribution services cluster.

3.6 A Framework for the Management of Environmental Information at HEIs

The Performance Management System (PMS) framework for HEIs proposed by Muntean, et al. (2010) uses data warehousing technology. A PMS can be identified as the process of quantifying action which leads to organisational efficiency, competitiveness and growth (Ohemeng, 2011). The PMS uses data warehousing technology to manage data from various pools of data and to display meaningful information by means of a performance dashboard. A performance dashboard is an application that allows stakeholders to measure, monitor and manage organisation performance more effectively (Muntean, et al., 2010).

The PMS framework uses data warehousing technology to Extract, Transform and Load (ETL) data. The ETL processes allow for data aggregation, normalisation and integration. Data is extracted from various sources and is stored in the database of the data warehouse which is in the data layer. The reporting layer allows users to access and query data. In addition, the reporting layer allows for ad hoc querying and standard report generating from the university portal and is valuable for managerial decision making (Muntean, et al., 2010).

The analytical layer is a useful tool for management in decision making and strategising. This layer allows for advanced functionality such as data mining, forecasting, decision support and data visualisation (Lih Ong, et al., 2011). The monitoring layer is for monitoring and management of performance. Tools that are available in this layer include dashboards and scorecards (Muntean, et al., 2010). The university portal which is also a presentation layer is the hub of all the university IT applications and services needed by students, administrators, faculty and staff.

The PMS framework can be applied to the domain of environmental sustainability performance management and EIM. Components of the PMS agree with the components of an EMIS (Table 3.5). The PMS framework conforms to the three clusters of an EMIS, however, a fourth cluster can be identified from the EMS framework recommended by the

ISO 14001 (ISO, 2004). The fourth cluster which is called the sustainability strategy cluster incorporates the iterative planning and management review components of the ISO 140001 standard for environmental impact management. Martin (1998) suggests adding a gap analysis component to the sustainability strategy cluster. The resulting extended framework is an EIM Framework for HEIs (Figure 3.18) and it is iterative in nature, similar to ISO 14001. Table 3.6 shows four clusters and twelve components of an EIM framework for HEIs.

Table 3.6: Components of an EIM Framework for HEIs

Category	Components	References
Sustainability Strategy Cluster	Management Review	Martin (1998); ISO (2004); Simkins and Nolan (2004)
	Planning	Martin (1998); ISO (2004); Simkins and Nolan (2004)
	Gap Analysis	Martin (1998)
Contribution Services Cluster	Operational Data Store (ODS) : operational database "EnviroDB"	Herremans and Allwright (2000); Muntean, et al. (2010); Bero, et al. (2012)
	Distributed data entry	Bero, et al. (2012)
	Sensor networks	Bero, et al. (2012)
	Legacy systems	Giesen, et al. (2009); Bero et al. (2012)
	Quality assurance (data validation and verification)	Athanasiadis (2006)
Management Services Cluster	Monitoring Layer	Muntean, et al. (2010); Bero, et al. (2012)
	Analytical Layer	Simkins and Nolan (2004); Muntean, et al. (2010); Bero, et al. (2012)
	Reporting Layer	Herremans and Allwright (2000); Muntean, et al. (2010); Disterheft, et al. (2012);
	Data Layer (Data Warehouse - EnviroDW)	Muntean, et al. (2010); Bero, et al. (2012)
	Extract, Transform and Load (ETL)	Muntean, et al. (2010); Bero, et al. (2012)
Distribution Services Cluster	University portal and presentation layer	Franz-Balsen and Heinrichs (2007); Muntean, et al. (2010) Jones, et al. (2011); Bero, et al. (2012) Athanasiadis (2006)

An initial gap analysis needs to be done to determine the current state of EIM processes after which a plan for improvement is made. In the planning stage of the framework, environmental indicators are identified and prioritised. The design of an architecture for EIM is the third stage and here reports can be generated for stakeholders so that they can check progress and to see if they have or will achieve their environmental sustainability goals. This phase can therefore provide guidance for designing the desired To-Be information stores and processes for EIM and reporting in an HEI. In the last phase of the proposed EIM Framework for HEIs, the stakeholders will have a chance to do a management review in order to assess their performance, improve their goals, set new ones and even add or remove environmental indicators, thereafter the cycle can begin again. Analysis of literature shows that the architecture of an EMIS is similar to that of the PMS (Gunther, et al., 2004; Yang, et al., 2012). Table 3.7 shows the best practice guidelines which can be used in conjunction with the EIM Framework to establish EIM practices within a HEI.

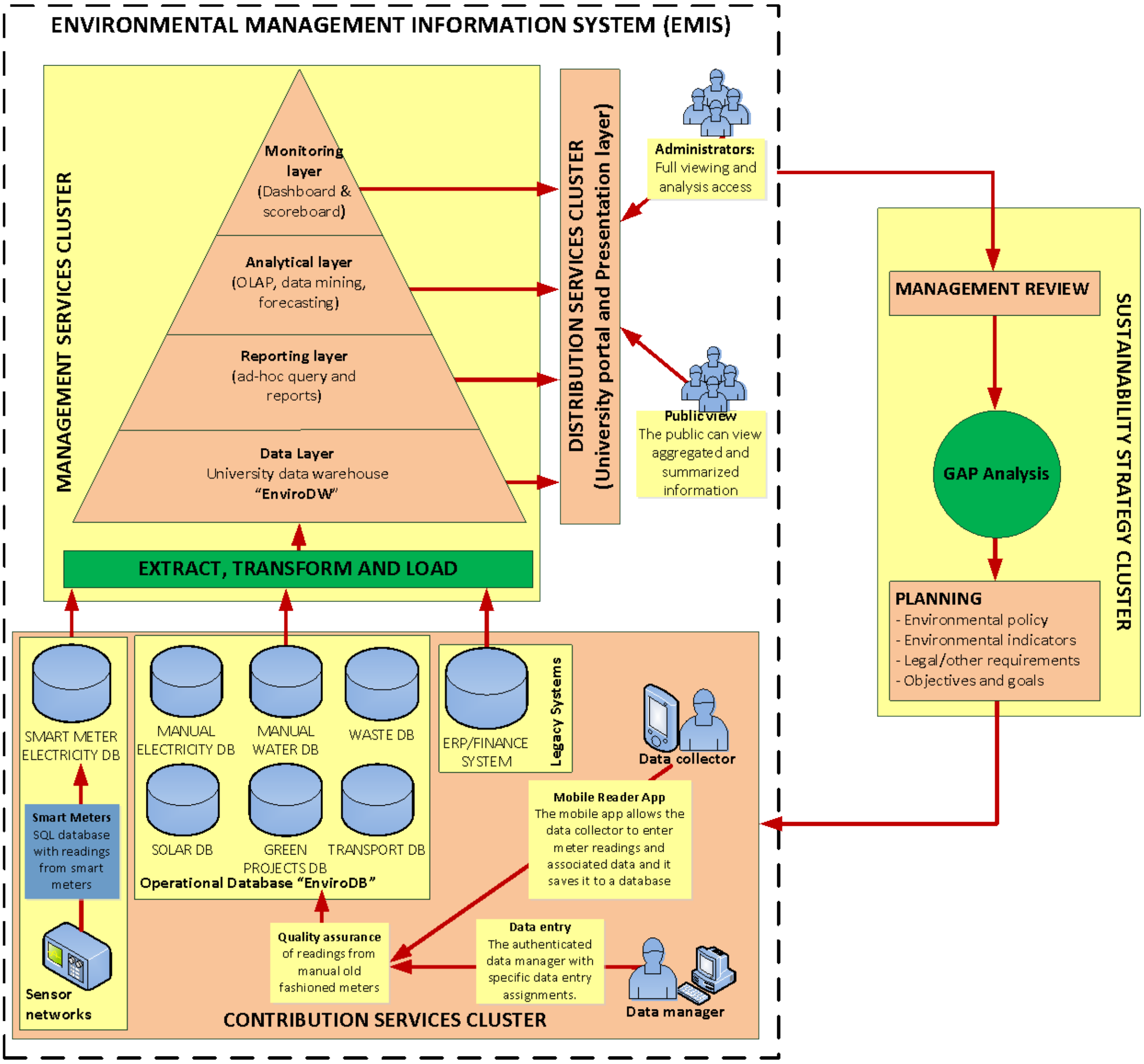


Figure 3.18: An EIM Framework for HEIs (Version 1)

Table 3.7: Guidelines for Components of EIM Framework for HEIs

No.	Guidelines	
Sustainability Strategy Cluster		
G1	A gap analysis can be used to identify areas for improvement in environmental information management processes.	Martin (1998)
G2	Top management support is important for the success of EIM efforts in HEIs.	Martin (1998); ISO (2004); Simkins and Nolan (2004)
G3	Environmental indicators for HEIs must be identified and prioritised at a strategic level.	Martin (1998); ISO (2004); Simkins and Nolan (2004)
G4	EIM efforts need to be aligned with strategic goals of the HEI.	Martin (1998); ISO (2004); Simkins and Nolan (2004)
Contribution Services Cluster		
G5	There is need for centralised storage of environmental information in an HEI.	Herremans and Allwright (2000); Bero, et al. (2012)
G6	HEIs need a computerised process for capturing environmental data (e.g. water and electricity meter readings).	Bero, et al. (2012)
G7	HEIs need to automate environmental data collection processes where possible (e.g. sensor based collection; smart meters).	Bero, et al. (2012)
G8	It is important that HEIs perform quality assurance (data validation and verification) on environmental data collected.	Athanasiadis (2006)
Management Services Cluster		
G9	Environmental sustainability reporting should be automated wherever possible.	Herremans and Allwright (2000); Disterheft, et al. (2012)
G10	Data analytics and monitoring of EIM should be provided.	Simkins and Nolan (2004); Bero, et al. (2012)
G11	Simplified aggregated data summaries of EIM must be available.	Bero, et al. (2012)
G12	Data processing should be provided (Ad-hoc querying, modelling of data and decision support).	Bero, et al. (2012)
G13	There should be support for allocating resource usage to buildings and campus facilities such as sports grounds and departments.	Bero, et al. (2012)
Distribution Services Cluster		
G14	There should be support for public awareness and outreach by allowing access to simplified aggregated data summaries of system data for access by HEI stakeholders (student, staff, board members, management, government bodies, etc.).	Franz-Balsen and Heinrichs (2007); Jones, et al. (2011); Bero, et al. (2012)
G15	Third party applications should be granted access to environmental information where possible.	Athanasiadis (2006); Bero, et al. (2012)

3.7 Conclusions

The topic of sustainability in higher education has gained momentum over the last few years and this has resulted in HEIs (Alshuwaikhat & Abubakar, 2008). HEIs have taken the proactive approach by investing into research and implementation of an EMS and investigations into the role of environmental information and Environmental Information Management Systems (EMISs). EMSs ensure that environmental concerns are taken into account in the management decisions of the institution, as well as in decisions regarding the curriculum (Hens, et al., 2009) and EMISs in turn, simplify and automate environmental management tasks such as the obtaining, processing, accessing and reporting of relevant environmental information within an organisation (El-Gayar & Fritz, 2006).

The first research question: *RQ_1: What types of IT solutions are used to aid Environmental Information Management efforts in organisations and HEIs?* is addressed in this chapter as the chapter highlights EMIS as IT solutions that play a major role in environmental management and environmental decision making in HEIs. The management of environmental information is identified as a key factor in reducing the environmental impact of a HEI and achieving environmental sustainability. At present, HEIs have no existing integrated, comprehensive software systems which can assist with the efficient measurement and management of environmental information, impact and performance. This spread of diverse non-integrated systems gives rise to redundant and inconsistent databases which result in non-compliance with regulations, confusion and lack of co-ordinated effort.

Literature reveals that an EMIS consists of four common types of components which are data collection, centralised data storage and access, data processing and reporting. An investigation into extant systems showed that systems are generally created with particular objectives and at the moment none has been created to cater for the collection of data from various sources that include manual data from distributed sources and providing access of this data to third party applications.

The research question: RQ_2: *How can a framework for environmental information management at HEIs be designed?* has also been addressed. The question is addressed in two parts: identifying the components of an EIM framework for HEIs and designing the EIM framework for HEIs. The components of a framework for the management of environmental information at HEIs are categorised into four distinct clusters, namely: the sustainability strategy cluster, the contribution services cluster, the management services cluster and the distribution services cluster (Figure 3.18). Table 3.6 lists the components of the EIM framework for HEIs.

The chapter then provides an initial design of the proposed EIM framework and component guidelines for the management of environmental information at a HEI. The framework shows that top management has to decide on the environmental indicators that their environmental information management efforts should focus on. An EMIS can then be put in place and with the use of an analysis tool, management can view the data from different perspectives and also create reports. The EMIS would also be able to provide the HEI stakeholder access to aggregated summaries of the institution’s environmental data.

In the next chapter, the objectives of the solution to the explicated problem are highlighted. Nelson Mandela Metropolitan University (NMMU) is presented as the case study of the research and an analysis of the current data management practices is done. The chapter further describes desired environmental management practices for NMMU. This clearly shows the gap that has to be closed between the current practices and the desired practices.

Chapter 4: GAP Analysis of EIM at NMMU

4.1 Introduction

Chapter 3 highlighted the importance of managing environmental information in order to achieve environmental sustainability in HEIs. Furthermore, the analysis and synthesis of studies related to environmental management at HEIs resulted in an initial design of a framework for the management of environmental information at HEIs (Figure 3.18). An investigation into current and future systems identified some of the components used to manage environmental information and several guidelines were identified.

Two research questions will be addressed in this chapter, namely:

RQ_3: What are the As-Is processes and data stores at NMMU which are related to environmental information?

RQ_4: What are the To-Be processes and data stores for the management of environmental information at NMMU?

This chapter focuses on the second activity of DSR which is outlining the objectives of the solution. These objectives are identified through the application of the framework for EIM and the related guidelines proposed in Chapter 3. Research methods such as surveys, interviews, document studies, extant systems analysis were also used (Figure 4.1). As-Is processes related to the data acquisition processes and information stores at Nelson Mandela Metropolitan University (NMMU) are analysed in an attempt to outline the objectives of the solution.

As-Is processes refer to the existing state of things, that is, the processes which depict the way that things are currently done (Harmon, 2007). The As-Is processes describe and formulate the current problem that needs to be addressed. Understanding and defining As-Is processes is the first step to performing a gap analysis (Figure 4.3). The next step would be to design the desired processes which are known as the To-Be processes. The To-Be processes depict how things will be done in the future. The EIM framework for HEIs (Figure 3.18) can provide guidance for migrating from existing As-Is to the desired To-Be EIM processes in HEIs.

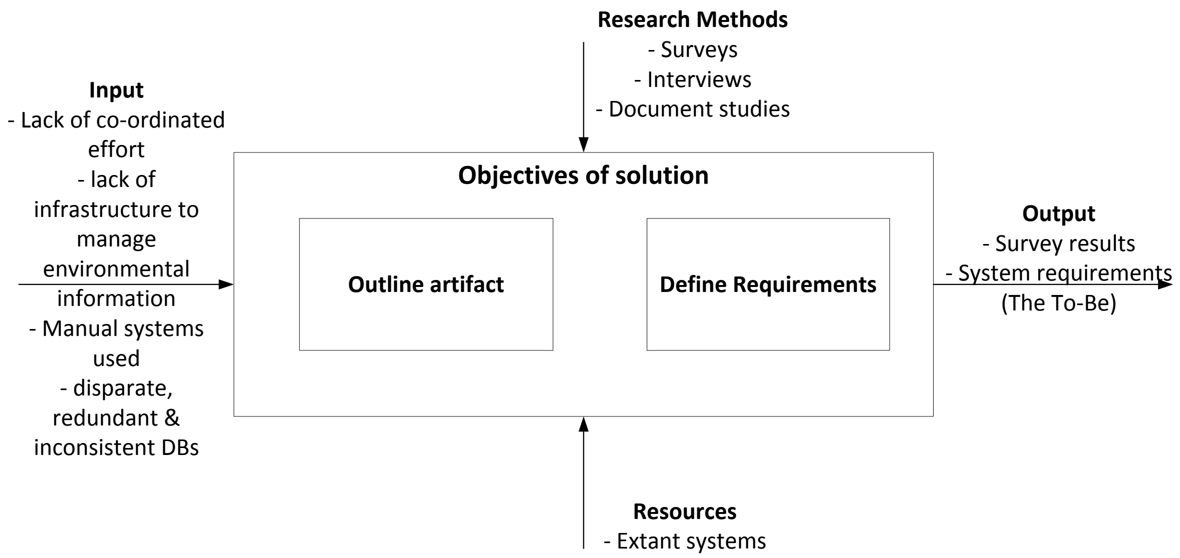


Figure 4.1: Implementation of the Objectives of the Solution Activity

A gap model can be used as the method of determining the requirements or desired To-Be situation (Section 4.2). The Nelson Mandela Metropolitan University (NMMU) is used as a case study and a gap analysis performed for this case study (Section 4.3). The combination of interviews, document studies and literature helped to determine a list of environmental indicators at NMMU (Section 4.4). These interviews helped determine the target users and their expectations of the system (Section 4.5). These interviews also revealed the As-Is processes followed by NMMU to manage its environmental information (Section 4.6). The EIM framework is applied at NMMU in order to analyse the current As-Is processes and to design the desired To-Be processes for the case study (Section 4.7). The To-Be processes (Section 4.8) will be derived from literature and from the functionality of the extant systems that were analysed (Section 3.5). The chapter layout is shown in Figure 4.2 which includes the research objectives and deliverables.

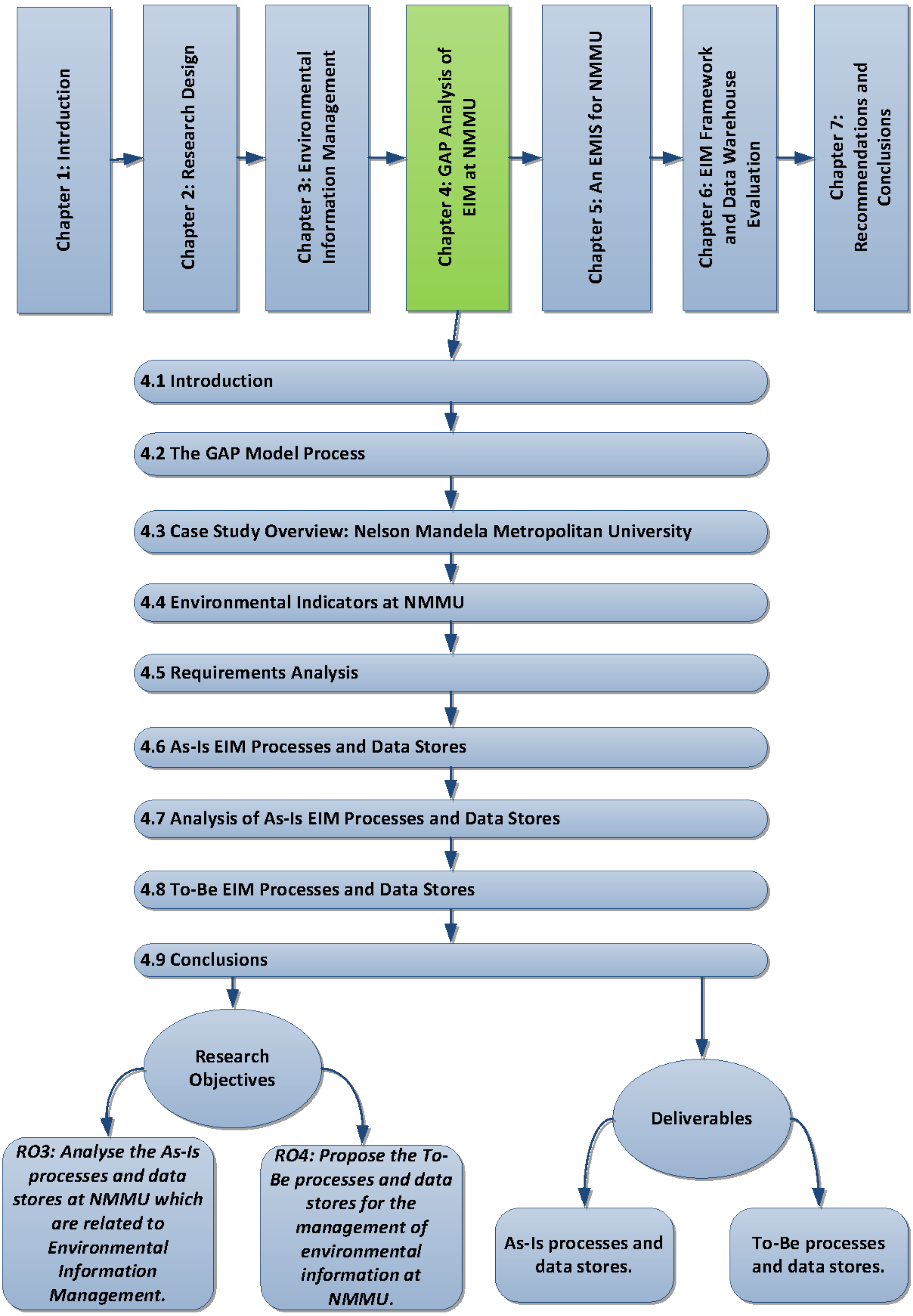


Figure 4.2: Chapter 4 Layout and Deliverables

4.2 The Gap Model Process

A gap analysis model (Figure 4.3) is a tool that allows for comparison of the current state and the desired state. A gap model is defined by Harmon (2007) as the transition process from the current state (As-Is state) to the desired state (To-Be state). The As-Is state is a detailed description of the situation as it presently stands.

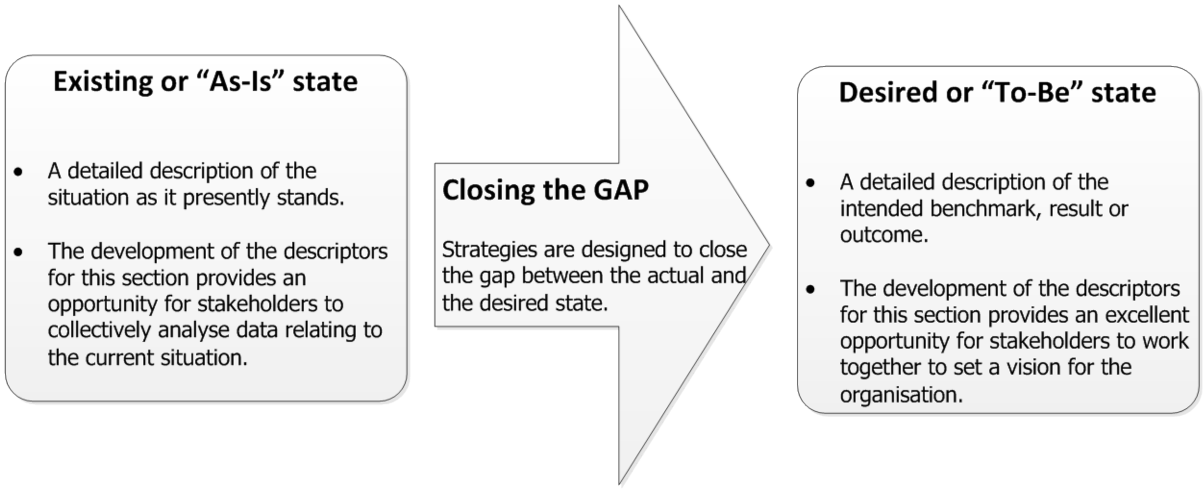


Figure 4.3: Gap Model Process (Harmon, 2007)

The desired To-Be state is the improved state. The To-Be state is a detailed description of the intended benchmark, result or outcome. This description can then be used to identify the system objectives and requirements. The gap model firstly seeks to understand comprehensively the current state as a detailed description is required. Analysing the current As-Is state can reveal improvement opportunities. The gap model shows the strategies which stakeholders will use to move from the current undesired state to the desired state.

4.3 Case Study Overview: Nelson Mandela Metropolitan University (NMMU)

NMMU is the largest higher education institution in the Eastern and Southern Cape, with a total of approximately 27 000 students enrolled at six different campuses, namely: South Campus, North Campus, Second Avenue Campus, Bird Street Campus, Missionvale Campus and George Campus. Five of the campuses are located in the Nelson Mandela Metropole, and one in the city of George. One of NMMU's Vision 2020 objectives is the management of environmental impact at the institution (NMMU, 2010).

The merits of implementing an EMS at an HEI are emphasised by management at NMMU. NMMU has started with the implementation of its own EMS. NMMU makes use of the Sustainability Tracking, Assessment & Rating System (STARS) which has allowed them to identify and establish their goals and the different environmental aspects, amongst other things. The university has also established a steering committee (The NMMU Sustainability Management group) which is responsible for coordinating sustainability efforts at NMMU. This committee is chaired by one of the Deputy-Vice Chancellors. Furthermore, administration at NMMU has helped initiate student task groups, such as the Green Campus Initiative (GRI).

Preliminary interviews with selected university staff members indicated that environmental management processes within the university are supported by diverse and mostly manual systems (Barnardo, 2013; Ducie, 2013). This confirms the study of Bero, et al. (2012) which reported similar problems at HEIs. NMMU can therefore benefit from an EMIS aimed at managing all environmental information at the university. This study will implement the EIM framework for HEIs (Figure 3.18) at NMMU and special attention will be given to the design and development of a proof-of-concept EMIS prototype for NMMU.

4.4 Environmental Indicators at NMMU

The Green Reporting Initiative (GRI) is the most popular standard for establishing the environmental indicators in industry (GRI, 2013). Industrial organisations usually have a main focus which determines their environmental indicators, for example pharmaceutical companies would have their environmental indicators focused on hazardous waste. HEIs are diverse in nature and environmental indicators associated with HEIs are therefore also diverse as highlighted by STARS. Studies and initiatives by some HEIs revealed common environmental indicators in HEIs and these were used as a base for environmental indicators in HEIs (Table 4.1).

The analysis of the interviews conducted helped to generate a list of environmental indicators at NMMU and because NMMU uses the STARS system, the environmental indicators also link to STARS (Table 4.1). Environmental indicators at NMMU are similar to the environmental indicators from other HEIs which were identified in Section 3.2.2 (Table 4.1).

Table 4.1: Environmental Indicators at HEIs Including NMMU

Environmental Indicator	Universities/HEIs					Standard
	General HEIs indicators	NAU	Indiana Univesity (2014)	Maryland (2013)	**NMMU**	**STARS**
Utilities usage/ Resources						
Energy consumption	✓	✓	✓	✓	✓	✓
Renewable energy	✓	✓	✓	✓	✓	✓
Water consumption	✓	✓	✓	✓	✓	✓
Reclaimed water		✓			✓	✓
Transportation and commuting						
Air travel				✓	✓	●
Shuttle/bus Ridership				✓	✓	✓
Campus vehicle fleet fuel use		✓	✓	✓	✓	✓
Parking spaces		✓	✓	✓		
Bike racks			✓	✓		
Faculty, staff and student commuting		✓	✓		✓	✓
Greenhouse gas emissions				✓	✓	✓
Waste generation						
Solid waste	✓	✓	✓		✓	✓
Hazardous waste		✓			✓	✓
Air emissions	✓	✓	✓	✓	✓	✓
Electronic waste			✓		✓	✓
Recycling	✓	✓	✓		✓	✓
Educational Programs						
Environmentally related programs to study	✓	✓	✓	✓	✓	✓
On-campus programs	✓	✓	✓	✓	✓	✓
Outreach programs	✓	✓	✓	✓	✓	✓
Related research projects	✓	✓	✓		✓	✓
Grounds/natural heritage						
Compositing	✓		✓		✓	●
Pruning/cutting wastes		✓				
Pesticide/herbicide, fertilizer use		✓			✓	✓
Tree planting			✓			
Purchasing/food services						
Environmentally certified vendors		✓		✓	●	✓
Locally grown foods	✓	✓	✓	✓		
Organic foods	✓	✓		✓		
Recycled paper and materials		✓			●	✓
Disposable products		✓				
Janitorial products		✓		✓	✓	✓

A black circle (●) indicates that the environmental indicator is either at NMMU but not recognised by the STARS system or vice versa. Only four of these environmental indicators are identified (Table 4.1). High priority environmental indicators are classified as those indicators that have a high environmental impact. These indicators are utilised to measure the concerns of an institution. The following is a list of high priority environmental concerns at NMMU as highlighted in NMMU's report (NMMU, 2009) and by researchers at NMMU (Fabricius & Du Preez, 2009; Lillah & Viviers, 2010):

- Energy efficiency, conservation, management, monitoring and reporting;
- the use of renewable energy;
- water conservation and management;
- protecting the environment; and
- vehicle fleet management (working towards a "green fleet").

The scarcity of electricity in developing communities such as those in Sub-Saharan Africa is a major problem since 75% of households do not have access to basic lighting. This is the case for a significant number of African countries and African universities are not immune to this issue (Podmore, et al., 2011). South African HEIs therefore need to address these areas of sustainability as a top priority. It is evident that energy/electricity is among the environmental indicators with the highest priority at NMMU (Fabricius & Du Preez, 2009; NMMU, 2009). Hence, energy needs to be used sparingly and managed correctly.

Ferguson and Maxwell (2010) highlight that developing countries in particular need to manage their water resources carefully. Water conservation and management is one of the indicators that was discussed in NMMU's '*Greening*' report (Lillah & Viviers, 2010) and therefore is one of the environmental indicators with the highest priority at NMMU. One of the interviews highlighted that Port Elizabeth, the region in which NMMU is located, is experiencing water shortages due to changing rainfall patterns and it is imperative that systems be put in place to ensure that water is used sparingly and is managed well. This confirms the focus of this study on energy and water management.

Fabricius and du Preez (2009) and Lillah and Viviers (2010) confirm NMMU's report of 2009 (NMMU, 2009). NMMU values natural heritage and because NMMU is co-located with a game reserve, NMMU protects and is responsible for the management of the game reserve. NMMU also places management of the vehicle fleet which is a major contributor to carbon emissions as a high priority. Waste management has also been highlighted as a priority. This indicator has seen student bodies such as the Green Campus Initiative taking initiatives by installing recycle bins across campuses, especially in the residences.

4.5 Objectives of the Solution

The first step in analysing requirements for a system is to identify the target users of the solution system (the EMIS). The target users for the proposed EMIS were identified as:

1. The NMMU ICT department;
2. the NMMU Technical Services department;
3. the NMMU top management;
4. other NMMU stakeholders; and
5. third party applications.

The business objectives of the solution were identified as follows:

1. To ensure that resources are used effectively and optimally;
2. to reduce the institution's carbon footprint; and
3. to provide a central repository of environmental information.

Feedback from the target users showed that the main goal is to provide a central repository of environmental information and that an EMIS should be able to answer questions such as:

1. What is the monthly usage of electricity for a cost centre (or location) over a year (or a specified time period such as a semester)?
2. Which cost centre (or location) uses the most electricity over a year?
3. Which cost centre (or location) uses the least electricity over a year?
4. What is the average electricity usage for a cost centre (or location) over a year?
5. What is the total electricity usage for a cost centre (or location) over a year?

A cost centre is an entity that is originally referred to as either a department (for example, Computing Sciences) or a service unit (for example, street lights or an external entity to the university such as a shop). The solution should also be able to compare the resource usages between two or more cost centres or locations. The main business fields are electricity usage and water usage which are the two environmental indicators that the university has set as the top priorities. For the effectiveness of the solution it is important for resource usage data to be viewed with the following perspectives:

1. Cost centre or department;
2. location; and
3. meter.

In an attempt to understand and describe the current processes that are involved in the management of environmental information at NMMU, a two-phased approach was utilised. The first phase was to conduct a survey aimed at determining the various administrative and non-administrative projects that affect or influence the university's environmental indicators (Table 4.1). The second phase was to conduct interviews with selected managers or project leaders on projects or administrative service units which are in alignment with the major environmental indicators at NMMU.

The survey was sent out as an email to all the university staff members (Appendix B). Fifty six people responded and out of the 56 responses, six responses listed environmentally related projects and the other 50 responses confirmed that the participants were not aware of any environmental projects. A list of projects and of the contact people involved was generated from the survey (Appendix C). To counter the low number of responses and to have a holistic view of all contributors to the major environmental indicators, the contacts at the service units that handle electricity, water and waste management data for the purpose of paying the bills and generating environmental reports were added to the list of contacts. Each of the contacts was then interviewed. These interviews allowed the researcher to gain a deeper insight into the processes involved in the management of environmental information (Appendix D, Appendix E).

4.6 As-Is EIM Processes and Data Stores

The following sections discuss electricity (Section 4.6.1), renewable energy (Section 4.6.2), municipal electricity and solar energy at NMMU (Section 4.6.3), water (Section 4.6.4), transport and commuting (Section 4.6.5), waste management (Section 4.6.6) and educational programmes (green projects) (Section 4.6.7) which are the major environmental contributors at NMMU.

4.6.1 Electricity Usage Processes

Electricity is one of the big contributors to NMMU's environmental footprint. Hence, the management of this environmental aspect is very important. Electricity can be divided into two categories which are municipal electricity and renewable electricity. To determine the data collection and data stores of municipal electricity at NMMU, interviews had to be conducted with the personnel from the Technical Services department of NMMU. This department is in charge of the collection of electricity consumption data on all five campuses. Interviews revealed that the department collects the data for the management of the institute's electricity consumption validates and quality assures the data. The Financial Department can then pay the account and environmental reports can be produced.

Management of the institute's electricity consumption includes maintaining a steady supply of electricity such that the university does not exceed the target amount of electricity (Kilo Volt Amps – KVA) that the municipality sets for the institution. The management of the institution's electricity consumption also includes the intelligent management and distribution of the load on the grid. For example, the university ensures that geysers are off early in the morning when most other equipment is switched on.

The electricity data acquisition and management processes can be sub-divided into two types of processes: the manual processes and the automated processes. Since 2009, NMMU's Technical Services Department has been gradually moving to an automated electricity data acquisition and management process (NMMU, 2009). The institution has been gradually replacing manual meters with Johnson Control Building Management System (JCBMS) smart meters. Hence some buildings are monitored by the JCBMS smart meters and others still have the manual meters. Appendix H shows the list of buildings that currently have the JCBMS smart meters. The manual process is used for older meters whereas the new smart meters are able to support an automated process. The processes are shown using an Event-driven Process Chain (EPC) diagram (Figure 4.4). EPC is a modelling language that can be used to business processes and workflows (ARIS, 2015). The manual process is as follows:

1. On the first Monday of each month, an electrician collects meter readings from each meter and records the readings manually, by hand on paper (Appendix F). It takes the electrician generally two days to read all manual university meters. At NMMU, not all buildings have meters exclusively allocated to them and in these cases the technical department can use estimates based on percentages to allocate usage to a specific location or cost centre. For example, the residents on the South Campus are given an estimated 6% of the total South Campus consumption. Furthermore a group of locations (buildings) may share a single meter and there is no apportionment that is done to the individual buildings.
2. The handwritten document is then given to the responsible personnel at the Technical Services Department. A duplicate handwritten copy is then made of the electrician's handwritten copy and they are both filed at the Technical Services Department. It is during this duplication process that validation, verification and quality assurance are done by manual inspection. Validation, verification and quality assurance are done by considering past trends.
3. The responsible personnel then captures consolidated data such as the usage for academic buildings, the usage of residences, and the usage by service units that generate revenue (such as the cafes) into an Excel file (Appendix G). These consumption figures are grouped together into what are called 'electricity accounts' and stored in Excel Files. For example, the consumption and cost of consumption for academic buildings is under one electrical account called academic buildings. These electrical accounts are then reconciled with the municipality's electricity accounts.
4. The total consumption value which is obtained internally from each campus is then compared to the municipal total reading per campus which the municipality obtains from each campus's sub-station reading. If there is a significant difference between the internally obtained figures and the external municipal figures, the municipality is then asked to give a detailed explanation of how they arrived at its consumption figures.

5. The Excel file of electricity accounts can be used for one of or both of the following purposes:
    a. Sent to the financial department for accounting and bill payment purposes.
    b. Used to generate reports and graphs for reporting purposes.

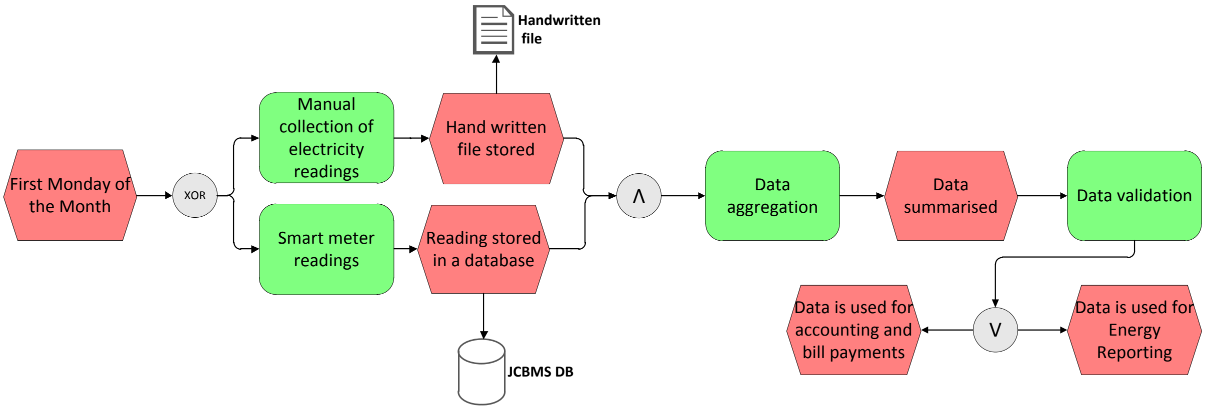


Figure 4.4: EPC Diagram of the As-Is Process for Electricity Usage at NMMU

The JCBMS smart meters provide real-time data to the JCBMS. The JCBMS provides the Technical Services Department with capabilities that include: load management, switching electrical equipment on/off and alerts on extremely high use of energy. Figure 4.5 shows an example of some of the capabilities that the JCBMS has, such as the ability to show the current electricity usage, the peak usage and the voltages. The JCBMS also has the capability to show how each building is performing. Figure 4.6 shows the status (On/Off, temperature and so on) of the air conditioning in all the buildings with air conditioning at South Campus and allows control of the air conditioners.

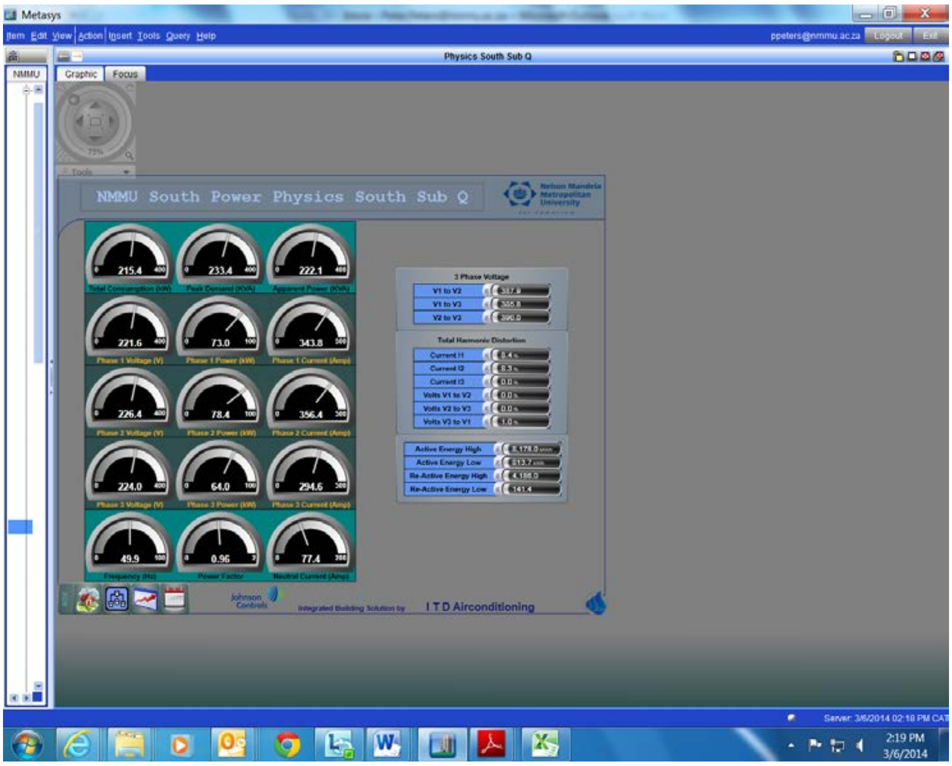


Figure 4.5: NMMU Physics Building's Electricity Usage Dashboard of the JCBMS

The JCBMS has a SQL database in which it stores all the data for the specific buildings in which the JCBMS smart meters are installed. The summarised automated process for electricity usage (Figure 4.4) is as follows:

1. Either a pulse requesting data is sent to the smart meters at a regular time interval or the user requests that data be pulled at a specific moment that they need to use the data.
2. Data is then sent to the JCBMS.
3. The system then relays the data to be stored in a database on a NMMU's server.
4. On the request of the user (Technical Services personnel) data can be pulled from the NMMU server database and can be used for one of or both of the following purposes:
    a. Sent to the financial department for bill payment purposes.
    b. Used to generate reports and graphs for reporting purposes.

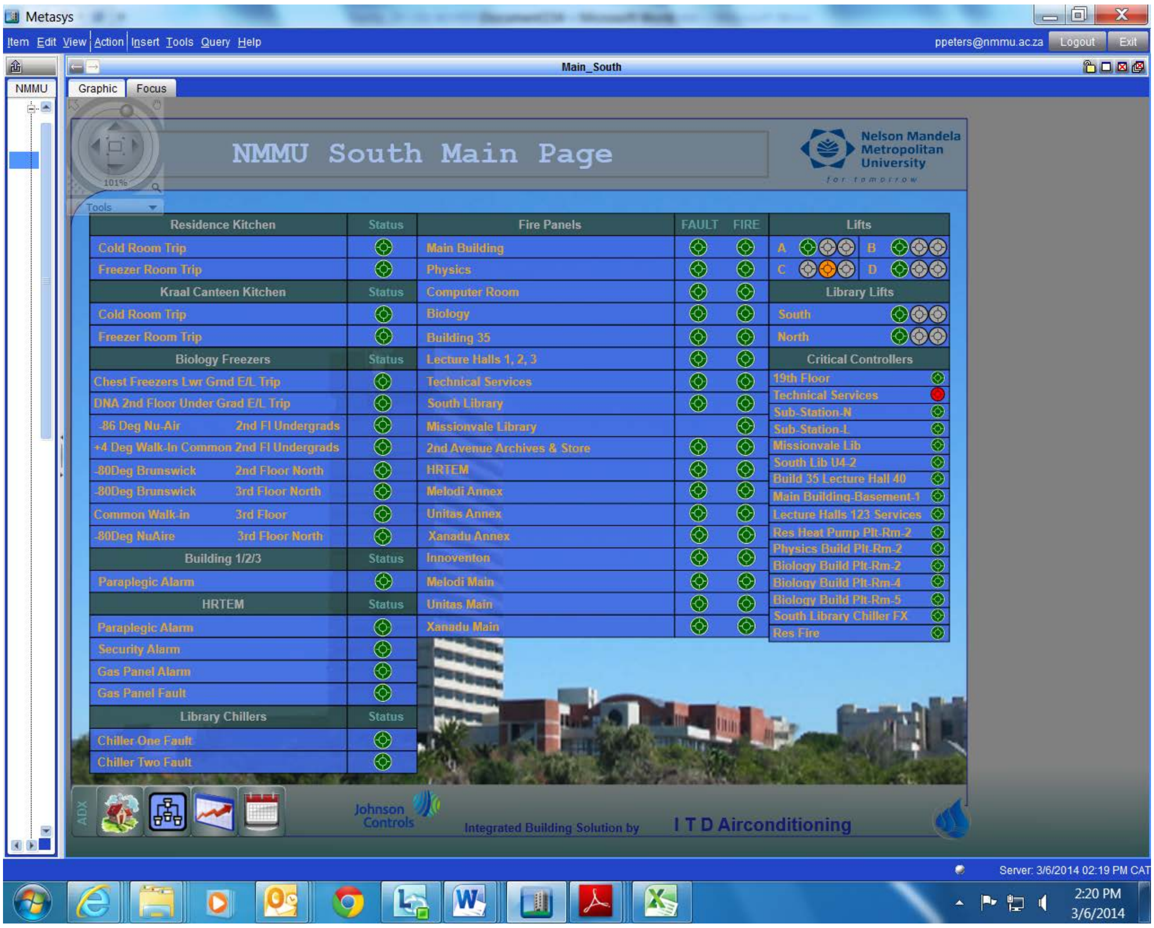


Figure 4.6: NMMU South Campus Air Conditioning Main Page for JCBMS

4.6.2 Renewable Energy (Solar Energy) Processes

The Physics Department at NMMU is currently in charge of the Centre of Energy Research (CER). One of the projects at CER is a solar project known as the 'Embedded Generation' project. In the project, two independent systems generate electricity. The two systems utilise different technologies. One consists of a series of solar panels which are used to harvest or generate renewable energy. The renewable energy generated is then channelled into the university energy grid. This injection of renewable energy into the university grid has obvious effects such as the reduction of the municipal electricity used which in turn reduces the university's carbon footprint and reduces the operating costs of the university.

Manual and automated processes are both used for measuring and capturing data of the renewable energy generated at the solar facility. Diverse data and scientific data are collected by the Physics Department. The data includes solar radiance, temperature and electricity generated. The data collected is mainly used for ongoing research and student projects. One solar generation system is over a year old and the other system is more than a year and a half old.

The manual process for acquiring the solar generation data is as follows (Figure 4.7):

a) A data logger continuously collects data from the solar system and temporarily stores the data in the solar panel station.
b) Periodically (generally on a weekly basis or as required) a student assistant manually downloads renewable energy data from the solar panel station onto a hard-drive. However, the renewable energy data can be stored for up to two months in the solar panel station.
c) The data from the hard-drive is then uploaded onto Dropbox as a text file.
d) Data from Dropbox can also be used for other purposes such as presentation or documentation. When this is done usually data validation is also done.
e) Validation has been by inspection for some period but now, a Matlab application has been developed to detect anomalies in the data.
f) The data is used for research for purposes.

The automated system for acquiring the solar generation data (Figure 4.7):

a) The automated system has a package that collects the measured data every ten minutes to a Comma Separated Value (CSV) file on a dedicated computer.
b) Data from the CSV file can also be used for other purposes such as presentation or documentation. When this is done usually data validation is also done.
c) Validation has been by inspection for some time but now, a Matlab application has been developed to detect anomalies.
d) The data is used for research for purposes.

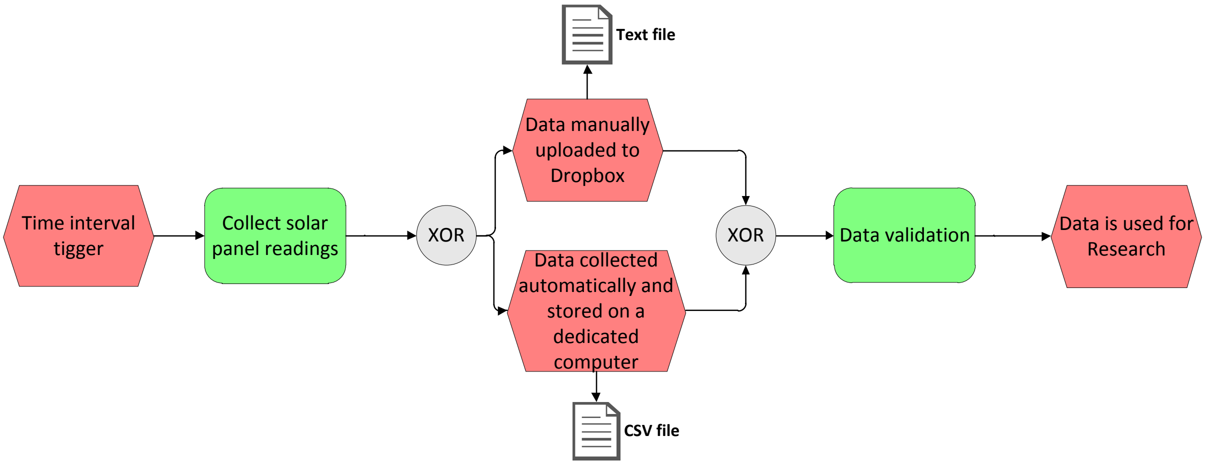


Figure 4.7: EPC Diagram of the As-Is Process for Solar Energy at NMMU

4.6.3 Municipal Electricity and Renewable Energy Data Stores at NMMU

Electricity data at NMMU consists of municipality electricity usage and the solar generated energy (Table 4.2). A large percentage of the electricity readings are still collected manually at NMMU and these files are stored as handwritten hardcopies. Automated electricity usage and solar generated energy has the data stored in electronic formats as shown in Table 4.2. Unfortunately, at present, there is no information regarding the allocation or usage of this renewable energy.

Table 4.2: As-Is Electricity Data Stores at NMMU

Electricity usage		
Manually Collected	Type of File	Handwritten, Hardcopy
	Location	Technical Services Department (North Campus)
	Attributes	Year, Month, Date collected, Campus, Building/Location/Service unit, Meter number, Meter Reading, Electricity Usage
From smart meters	Type of File	SQL database
	Location	Technical Services department (North Campus)
	Attributes	Timestamp, Campus, Meter Reading
Energy generation		
Renewable energy (solar)	Type of File	Comma Separated Value (CSV), Text (.txt)
	Location	Physics Department
	Attributes	Unknown

4.6.4 Water

Water is a resource that has to be used sparingly and optimally, particularly in an African context (Jonker, 2007). Furthermore, Port Elizabeth is a region that has had and is expected to have water shortages until 2019. This emphasises the need to manage water sparingly at NMMU and other African institutions. There are two different types of water that are used at NMMU namely: potable water which is municipality water and non-potable water which is reclaimed water, harvested rain water and borehole water. Interviews with key stakeholders highlighted that NMMU uses potable water particularly for irrigation purposes (Storm, 2014). However, the water that is used for irrigation contains between 50-70% non-potable water and the rest is potable water.

The sources of non-potable water are the Cape Recife sewage plantation, the boreholes and rain water harvesting that is done on some campuses. Potable water is easily measured but no records exist for the use of borehole water and rain harvested water. However, the use of non-potable Cape Recife water is recorded. Even though there are no meters to measure the consumption of the Cape Recife water, by knowing the number of irrigation heads that were on and how long they were on for and as the rate at which they release water is known (for example 2 Kilo-litres per hour) the amount of Cape Recife water consumed can be calvulated. These calculations produce a close representation of the actual non-potable Cape Recife water used.

Management of the institute's water consumption included installing 'fail-safes' that allow for early detection of water leakages. Hence, potable water was recorded more frequently over the previous years; however, lack of personnel has resulted in currently less frequent recording of water meter readings. The process to retrieve and manage water usage data is a manual process and is as follows (Figure 4.8):

1. Once each month, an internal plumber (the plumber on the staff of the institute) collects meter readings from each meter and records the readings manually (by hand) on paper. The internal plumber does this over a period of two weeks. The municipality also collects the readings for specific campuses in the first week of a month and then the other campuses in the second week of a month. The internal plumber follows the municipality routine such that the university's readings are close to the municipal readings for ease of verification. Each campus has a global meter which measures the water usage of an entire campus. However, some buildings have their own meters. The number of water meters is significantly larger than the number of electricity meters. Some buildings do not have meters and the Technical Services Department uses estimates based on percentages to allocate usage to a specific building or service unit. For example, the Sports Department is given an estimated 20% of the total usage. This estimation is based on data from previous years where it was noticed that the Sports Department accounted for approximately 20% of the university's usage.
2. The handwritten document is then given to the responsible personnel at the Technical Services Department (Table 4.3). A duplicate handwritten copy is then made of the plumber's handwritten hardcopy and they are both filed at the Technical Services Department.
3. It is during this duplication process that validation and verification is done by manual inspection. The validation is done by considering past trends and the previous month's consumption.
4. The responsible personnel at the Technical Services Department captures consolidated data such as the usage for academic building, the usage of residences and the usage by service units that generate revenue, such as the cafes, to an Excel file.

The consumption figures for each campus, which are called the 'water account' are filed separately in different Excel files.

5. The total water usage, which is obtained internally at each campus, is then compared to the municipal total reading per campus, which the municipality obtains from each campus's main meter reading. This is the verification process. If there is a significant difference between the internally obtained figures and the municipal figures, the municipality is then asked to provide a detailed explanation of how they arrived at their consumption figures.
6. The Excel file of accounts can be used for one of or both of the following purposes:
    a. Sent to the financial department for bill payment purposes.
    b. Used to generate reports and graphs for reporting purposes.

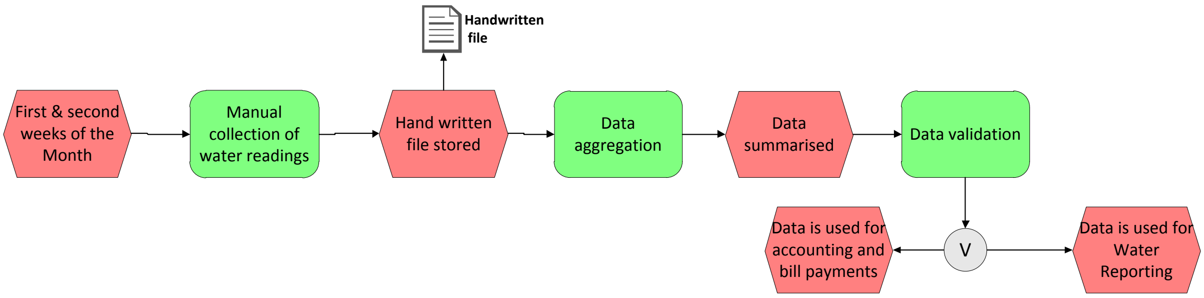


Figure 4.8: EPC Diagram of the As-Is Process for Water Usage at NMMU

Table 4.3: As-Is Water Data Stores at NMMU

Water usage		
Non-potable	Type of File	Handwritten, Hardcopy
	Location	Technical Services department (North Campus)
	Attributes	Month, Week, Date collected, Campus, Building/Location/Service unit, Meter type, Meter number, Meter Reading

4.6.5 Transportation and Commuting

Transportation and commuting costs can be classified into four categories, however, Table 4.4 only shows three categories because currently at NMMU student/staff private vehicles/public transport is not monitored or recorded. The four transportation and commuting categories are:

1. *Student/staff private vehicles/public transport*: Currently, no record is kept of the student or staff private vehicles or public transport vehicles that enter or leave the various campuses.
2. *NMMU campus service and utility vehicles*: NMMU keeps a record of the fuel usage of campus service and utility vehicles and this is specifically done for the Finance Department that keeps track of the costs.
3. *Shuttle services*: NMMU outsources the shuttle services and does not have the specifications of the vehicles, for example, fuel usage, but information such as the number of vehicles used is available and any extra information could to be obtained from the service provider.
4. *Staff/Student travel*: Staff and student travel should be considered because NMMU staff and/or students and even guests can travel to numerous places to do NMMU official business. The types of travel include land and air. Staff members and students can hire vehicles or use their own private vehicles to do NMMU official business. In this case, the university reimburses the costs of fuel usage. This fuel can be added to NMMU's fuel usage which adds to the institution's carbon footprint. Traveling by air also contributes to the institutions carbon footprint and websites such as (http://calculator.carbonfootprint.com) can be used to calculate an individual's carbon footprint. The details of the trip are documented by the different departments as well as by NMMU's Finance Department. These details are recorded for financial purposes only and currently the environmental impact is not measured or reported on.

Table 4.4: As-Is Transportation and Commuting Data Stores at NMMU

Transportation and commuting		
Campus utility vehicles	Type of File	Unknown
	Location	Vehicle management department
	Attributes	Fuel consumption per month, Cost of fuel per month, Number of vehicles
Shuttle services	Type of File	Unknown
	Location	Vehicle management department
	Attributes	Cost of service, Number of shuttles
Staff/Student travel	Type of File	ITS
	Location	Finance department, individual departments
	Attributes	Financial Cost

4.6.6 Waste Management

Unlike electricity and water usage which to some extent is apportioned between locations and cost centres in a straight forward manner, waste management varied greatly in information availability, quality and completeness. NMMU outsources waste management services to an external company. The service provider could not provide the actual weekly or monthly details of waste generation per campus and could not apportion it to buildings. However, the company collects waste from all the campuses and the waste is weighed at the land fill sites or by waste buyers or at recycling sites.

Table 4.5: As-Is Waste Management Data Stores at NMMU

Transportation and commuting		
General waste	Type of File	Unknown
	Location	Finance department, Service provider
	Attributes	Date of collection, location (campus only), weight/volume
PC's	Type of File	Unknown
	Location	Finance department, Service provider
	Attributes	Date of collection, location (campus only), units

Details of the data stores for waste are the same for general waste, cardboard, glass, office paper, newspaper, Polyethylene terephthalate (PET) bottles, cans, metal, garden by-product for compost and broken consumables. Personal Computers (PCs) and wooden pallets are different because they are measured in units instead of weight or volume. Hence only general waste and PCs are highlighted as they are representative of the data stores (Table 4.5). The service provider could only provide estimates of monthly averages as shown in Appendix J.

4.6.7 Educational Programmes

Educational programmes which relate to environmental sustainability are sometimes referred to as '*green projects*'. These projects in HEIs can be classified under the following categories: environmental study programmes, outreach programmes, student initiatives, environmentally related research projects and on-campus programmes (Table 4.6). Some initiatives can be classified in more than one category. For example, the same initiatives can be classified as student initiatives and also as outreach programmes.

Environmental study programmes: These include the modules that are studied as part of a degree or can be an environmentally related degree. For example, the Department of Computing Sciences at NMMU has an Environmental Management Information Systems module which is an elective at honours level. An environmentally related degree would include a degree such as Bachelor of Technology: Nature Conservation which is an environmental degree in its entirety. These are well documented and recorded in Portable Document Format (PDF) or in Microsoft Word documents.

Outreach programmes: Outreach programmes are environmentally related projects that are done by university stakeholders helping the outside community. These may be well documented or not depending on the department or organisation that handles the programme.

Student initiatives: Student bodies or initiatives can have a significant influence on other students. For example, the Green Campus Initiative (GCI) is a student initiative that focuses on raising environmental awareness amongst students. It does this by actively involving members in environmentally related campaigns such as the beach clean-up campaign they inaugurated in 2013 and that in which the environmental bins were installed at the student residences.

Environmentally related research projects: Some universities have environmentally related research projects being undertaken at their facilities. This research can be research being done as part of a degree or research being done by NMMU personnel, that is, academics. For example, the NMMU Department of Computing Sciences has a research project that is focused on counting the number of cars that enter the campus and those that leave. This will allow NMMU to have a baseline of the contribution to its carbon footprint. In an attempt to reduce the carbon footprint at NMMU, a pilot project was initiated in which some lecturers were given scooters to commute between the South and North Campuses which are two closely located campuses. In addition, NMMU is currently conducting research to determine the viability of the 'e-Bike' project. This project will allow students/staff to sign out an e-bike with their student card and then sign the bike in later at any other docking station at any campus. These docking stations will charge the batteries of the bikes using renewable energy sources such as wind and solar energy. There are various other environmental related projects at NMMU (Appendix C) and it is the researcher's opinion that there are many other projects. This data is documented by each department that is responsible for the project.

On-campus programmes: On-campus programmes are environmentally related projects that are facilitated by the university administration.

Table 4.6: As-Is Educational Programmes (Green Projects) Data Stores at NMMU

Green projects		
Environmental study programmes	Type of File	PDF, Hardcopy, Word (Documents)
	Location	Departments
	Attributes	Name, Code, Lecturer, Department, Description, Pre-requisites, Credits, Semester, Duration
Outreach programmes	Type of File	PDF, Word
	Location	Currently no central shared location
	Attributes	Name, Community, Description
Student initiatives	Type of File	Unknown
	Location	Initiative organisations
	Attributes	Name, Team Leader, Team members, Description
Environmentally related research projects	Type of File	PDF, Hardcopy, Word (Documents)
	Location	Departments
	Attributes	Name, Researcher, Supervisor, Department, Description, Date
On-campus programmes	Type of File	PDF, Hardcopy, Word (Documents)
	Location	Departments
	Attributes	Name, Team Leader, Team members, Description

4.7 Analysis of As-Is EIM Resource Usage Processes and Data Stores (Electricity and Water)

Figure 4.9 shows the summary of the As-Is processes and data stores related to resource usage at NMMU. The data store describes the type of file or storage the data is in. The processes for green initiative projects are numerous and not documented, for this reason they are not highlighted in Figure 4.9. After gathering all the information on the current processes and data stores that are implemented at NMMU (the As-Is), and comparing it to the fifteen guidelines identified for EIM in HEIs (Table 4.7) it was clear that there was a need for improvement as 55% of EIM processes at NMMU have no or very little support (Table 4.8). A score of 0 to 5 was applied based on the level of support where 0 represented No Support and 5 represented full support. The level of support was based on the interviews and document studies.

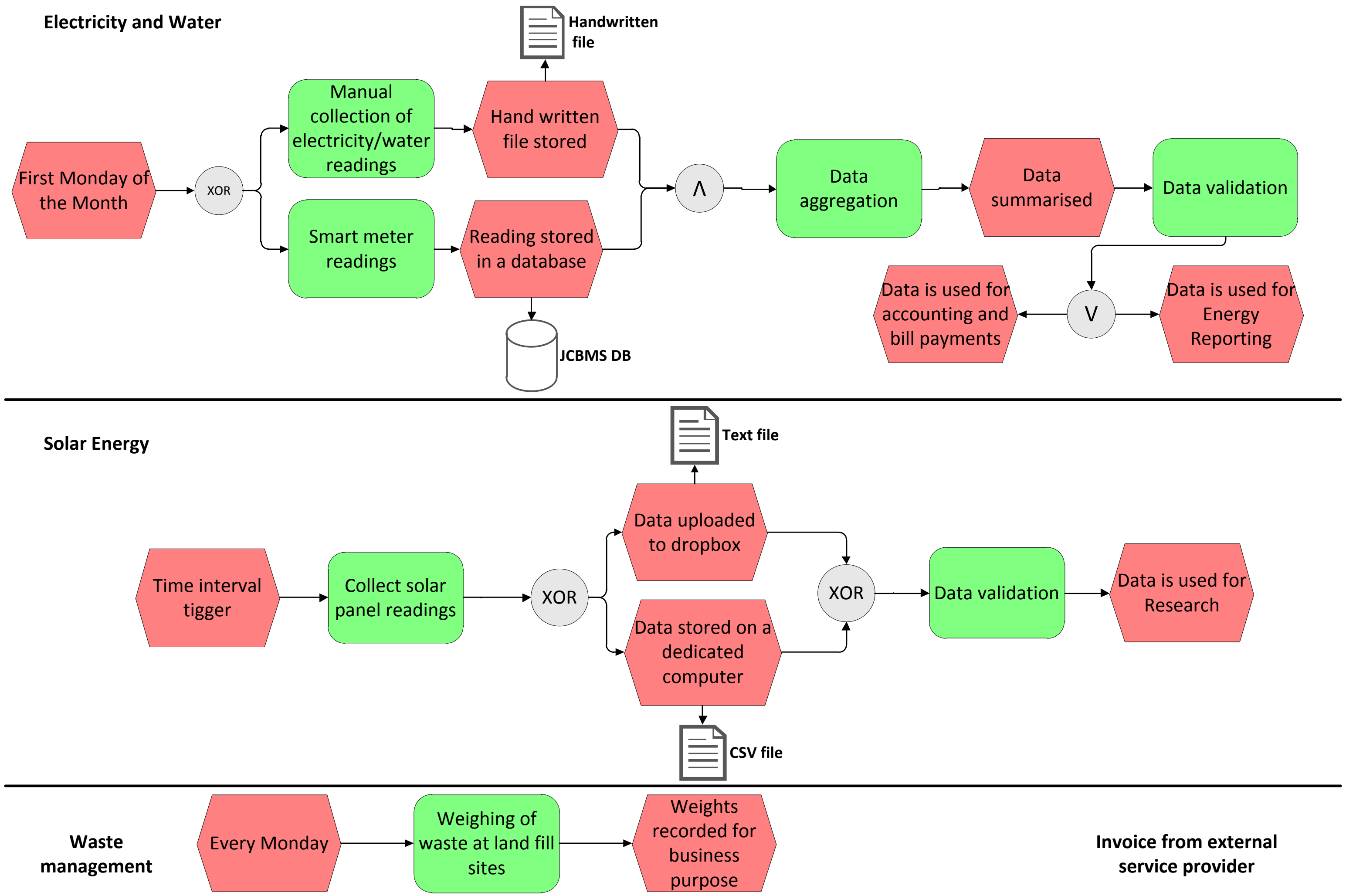


Figure 4.9: As-Is Processes and Data Stores for Resource Usage at NMMU

Table 4.7: Comparison of NMMU's EIM Processes to the Guidelines of EIM at HEIs

No.	Guidelines	NMMU					
		No Support				Full Support	
		0	1	2	3	4	5
Sustainability Strategy Cluster							
G1	A gap analysis can be used to identify areas for improvement in environmental information management processes.		✓				
G2	Top management support is important for the success of EIM efforts in HEIs.			✓			
G3	Environmental indicators for HEIs must be identified and prioritised at a strategic level.					✓	
G4	EIM efforts need to be aligned with strategic goals of the HEI.				✓		
Contribution Services Cluster							
G5	There is need for centralised storage of environmental information and support for legacy systems in an HEI.		✓				
G6	HEIs need a computerised process for capturing environmental data (e.g. water and electricity meter readings).	✓					
G7	HEIs need to automate environmental data collection processes where possible (e.g. sensor based collection; smart meters).			✓			
G8	It is important that HEIs perform quality assurance (data validation and verification) on environmental data collected.		✓				
Management Services Cluster							
G9	Environmental sustainability reporting should be automated wherever possible.		✓				
G10	Data analytics and monitoring of EIM should be provided.		✓				
G11	Simplified aggregated data summaries of EIM must be available.				✓		
G12	Data processing should be provided (Ad-hoc querying, modelling of data and decision support).			✓			
G13	There should be support for allocating resource usage to buildings and campus facilities such as sports grounds and departments.		✓				
Distribution Services Cluster							
G14	There should be support for public awareness and outreach by allowing access to simplified aggregated data summaries of system data for access by HEI stakeholders (student, staff, board members, management, government bodies, etc.).	✓					
G15	Third party applications should be granted access to environmental information where possible.	✓					

Table 4.8: Comparison of EIM Processes at NMMU with the EIM Guidelines for HEIs

Level of Support	Number	Percentage
No Support	3	18,8
Very Little Support	6	37,5
Little Support	3	18,8
Moderate Support	2	12,5
Above Average Support	2	12,5
Full Support	0	0

The guidelines receiving the most support are at a strategic level (G1-G4). The support level decreases in the other clusters. This confirms studies (Savely, et al., 2007; Bero, et al., 2012) that show that diverse and manual systems are still evident in HEIs. The contribution services cluster forms the foundation of an EMIS because data processing and distribution can only happen after the data is collected and stored. NMMU significantly lacks support for contribution services as 75% of them have no or very little support.

Table 4.7 shows that NMMU needs to support legacy systems and have centralised storage for environmental information (G5). Also data capturing processes are not computerised as suggested by guideline G6, hence, the existing data capturing processes are cumbersome, time consuming and prone to human error. Distributed data entry must be implemented at NMMU to eliminate these cumbersome processes. Data verification and validation (G8) is also done manually which makes it prone to human errors and time consuming, therefore, this processes must be automated as suggested by guideline G7.

Table 4.7 also reveals that management services have little support. There is a lack of support for environmental sustainability reporting (G9) at NMMU, however, NMMU needs to fully comply with guideline (G9) since the South African Department of Higher Education and Training (DHET) issued a mandate that states that HEIs in South Africa should start reporting in the year 2015. NMMU has little support for EIM monitoring, aggregated data availability and data processing. These need to be improved as suggested by guidelines (G10-G12). The current situation at NMMU is such that meters associated with individual buildings are exceptions. More commonly, groups of buildings share meters which makes it difficult if not impossible to allocate resource usage to a building or a department as suggested by guideline (G13).

There is no support for distribution services at NMMU. Interviews revealed that distribution of environmental information is only in the departments that handle the environmental information and top management. Environmental information is not made available to HEI stakeholders such as students, staff, government bodies as well as third party applications. There is need for improvement and compliance with guidelines (G14 and G15) at NMMU.

Adhering to the EIM guidelines for HEIs is key to improvement of NMMU's environmental sustainability status. Table 4.7 highlights the level of support for EIM processes and components at NMMU. Table 4.7 also highlights the gaps in EIM processes and data stores at NMMU and these can be used to design the To-Be EIM processes and data stores for NMMU.

4.8 To-Be EIM Processes and Data Stores

It is evident from the analysis of the As-Is processes that NMMU lacks support for contribution services, management services and distribution services. Based on the EIM guidelines for HEIs, the following sections propose To-Be EIM processes and data stores for electricity, renewable energy, water and waste management (Section 4.8.1), transport and commuting (Section 4.8.2) and educational programmes (green projects) (Section 4.8.3) at NMMU.

4.8.1 Electricity, Renewable Energy, Water and Waste

As-Is processes highlight the duplication of effort when electricity data readings are copied from one handwritten file to another handwritten file. This process is cumbersome and prone to errors. One of the interviews with the Technical Services Department personnel indicated that reading the electrician's handwriting can sometimes be difficult which can result in erroneous data (Barnardo, 2013). The necessary improvement that has to be done here is to have the data stored and managed electronically as this adds numerous benefits such as, easy sharing of data between departments and fewer errors.

Historical electricity data will be first captured into a Microsoft Excel file. An operational database should be created to allow for direct entry of data (Figure 4.10). The desired processes allow for the automated collection of data from smart meters (G7), but implementation of a Mobile Meter Reader application on a mobile device will improve the collection processes over manual meters. This Mobile Meter Reader app allows for capturing of data from manual meters, thereby eliminating any manual entry of environmental data (G6). The data is saved on a mobile device and with the push of the button the data can be submitted to a central operational database (G5).

The automated process in which electricity data is collected from the JCBMS smart meters is efficient but inadequate as the database is not comprehensive enough to include necessary data attributes such as the name of the building and meter number (G13). This renders the information collected in the current database not usable. The service provider of the JCBMS should allow the system to feed detailed data into the database. A centralised solution should be able to query and pull data from the database when requested.

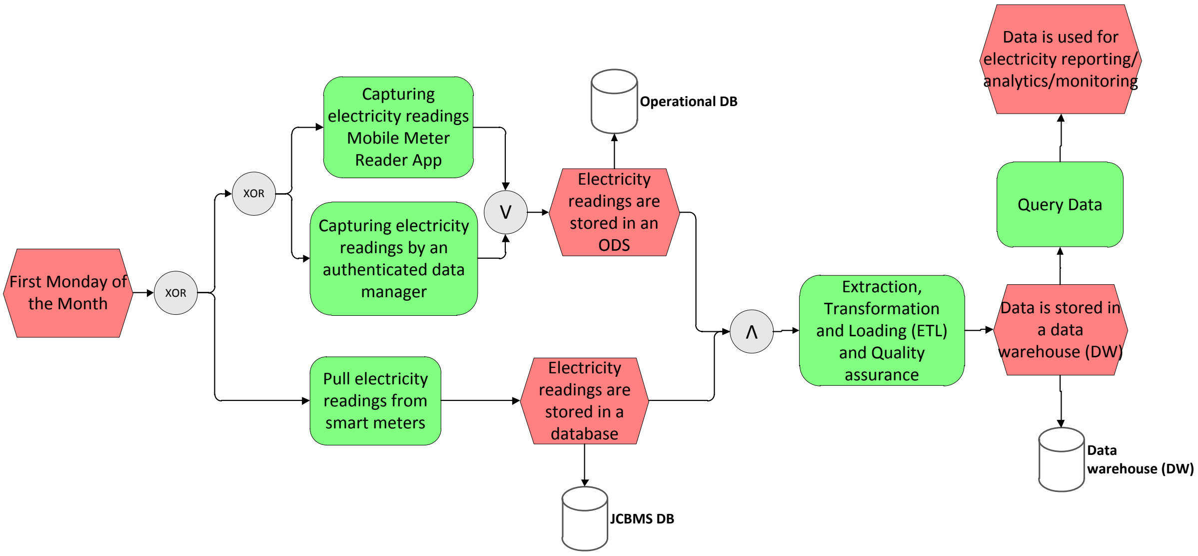


Figure 4.10: EPC Diagram of the To-Be Electricity Usage Data Management Processes at NMMU

The As-Is processes reveal that the only form of energy generated at NMMU is solar energy. The solar generated energy is channelled into NMMU's energy grid such that the energy is consumed together with municipal electricity. This structure makes it impossible to track the usage of the energy generated. However, energy generated is measured by the Physics Department. The two solar systems are used to generate solar energy and store data of generated electricity in CSV files and text files. Sensor networks should be used to automate the data collection process (G7) (Figure 4.11).

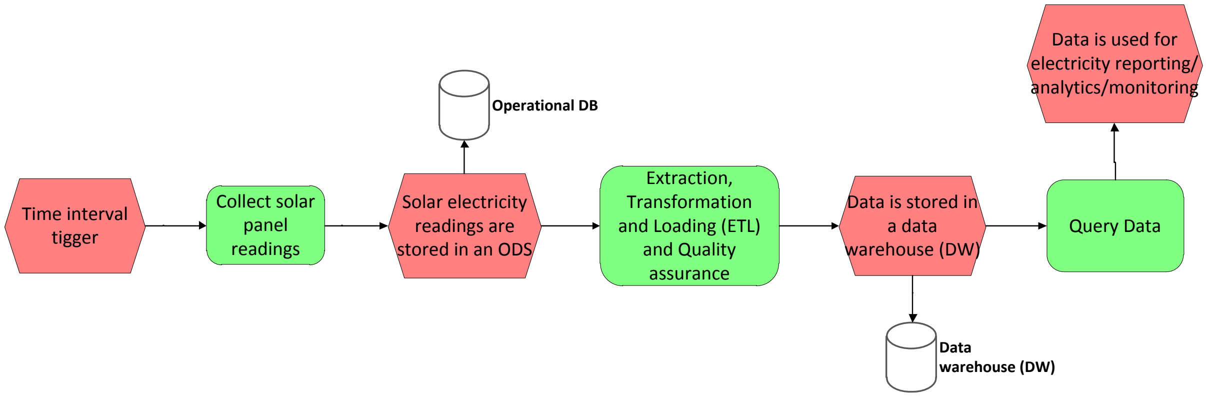


Figure 4.11: EPC Diagram of the To-Be Solar Energy Data Management Processes at NMMU

The current process of water data acquisition is similar to the current electricity data acquisition process. The process also includes copying a handwritten file and creating a second handwritten file. The suggested To-Be process will also eliminate duplication of procedures and will also introduce the use of an electronic data capturing system (G6) (Figure 4.12).

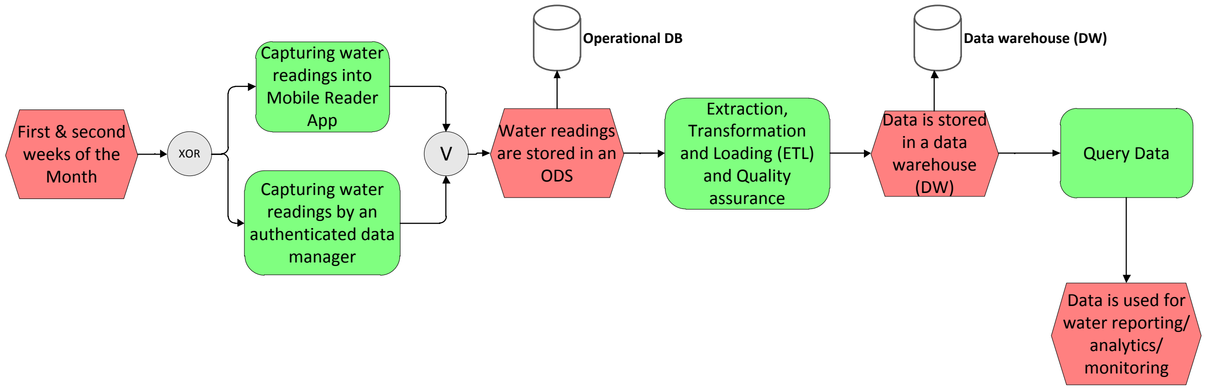


Figure 4.12: EPC Diagram of the To-Be Water Data Management Processes at NMMU

The current waste management processes are manual and prone to errors. A new system is required which will allow users to capture data as they collect the waste (G6) (Figure 4.13). This will allow for the apportionment of the environmental impact of the waste to the different campuses, buildings and services units. The data must be comprehensive and detailed so that management can determine trends in waste management at the university. This will allow for better decision making in terms of reducing the university's environmental impact. The attributes that must be measured and stored include: *Date* *collected, Campus, Building/ Location/Service unit, Type of waste and Volume/Weight*. Figure 4.13 shows the To-Be process for waste management. Figure 4.14 shows the To-Be logical data model for electricity, renewable energy, water and waste management.

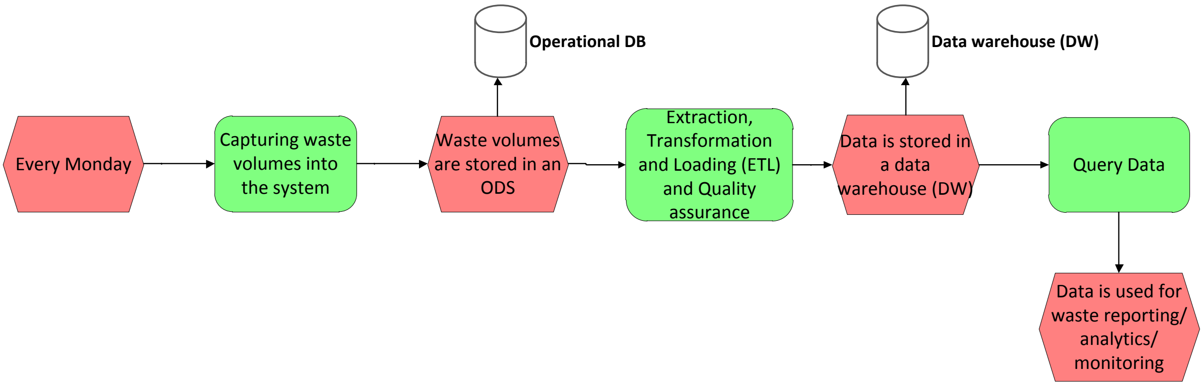


Figure 4.13: EPC Diagram of the To-Be Waste Data Management Processes at NMMU

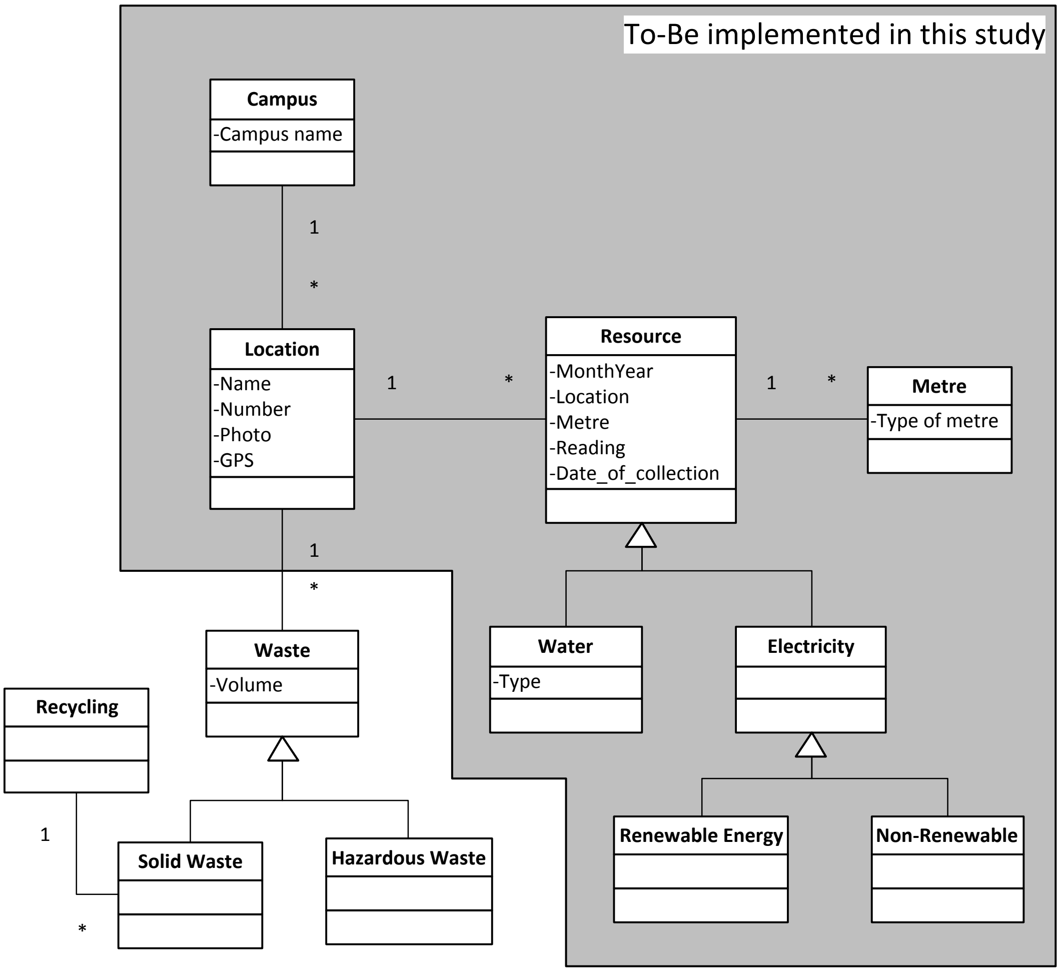


Figure 4.14: To-Be Data Model for Electricity, Water and Waste at NMMU

4.8.2 Transportation and Commuting

Currently the transportation management system at NMMU is not comprehensive because it does not take into account student and staff commuting. The suggested To-Be data model for transportation and commuting takes all aspects of this category into account (Figure 4.15).

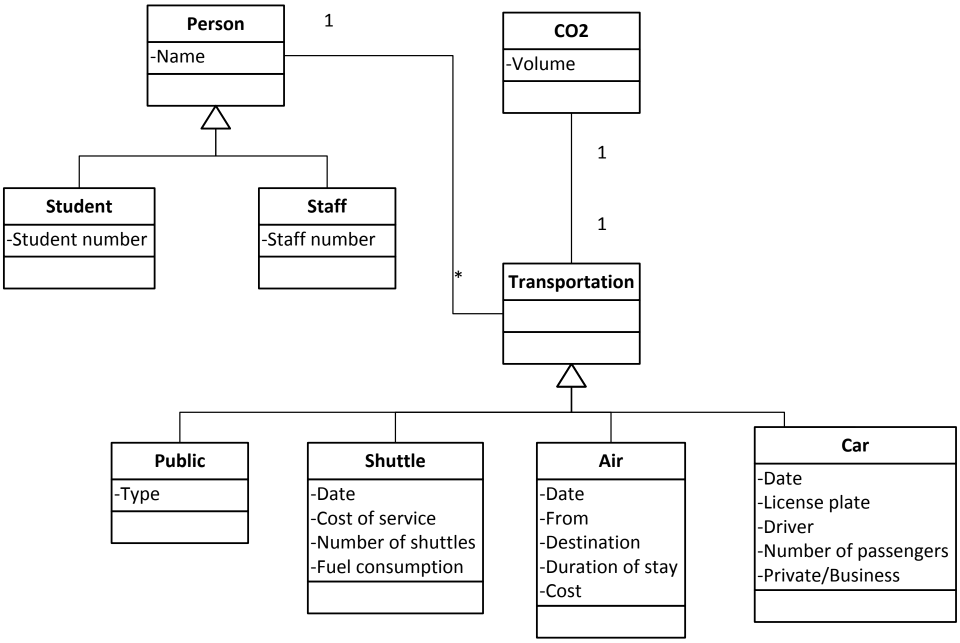


Figure 4.15: To-Be Data Model for Transportation at NMMU

4.8.3 Educational Programmes

Educational programmes (green projects) are currently recorded at the various departments that facilitate them. However, there is not a central location where this data is collected. Although these programmes are collected and are in electronic formats they are not in any database. They are generally stored as pdf or word documents. This results in a lack of collaboration or well-coordinated effort. Figure 4.16 shows the To-Be logical data model for educational programmes.

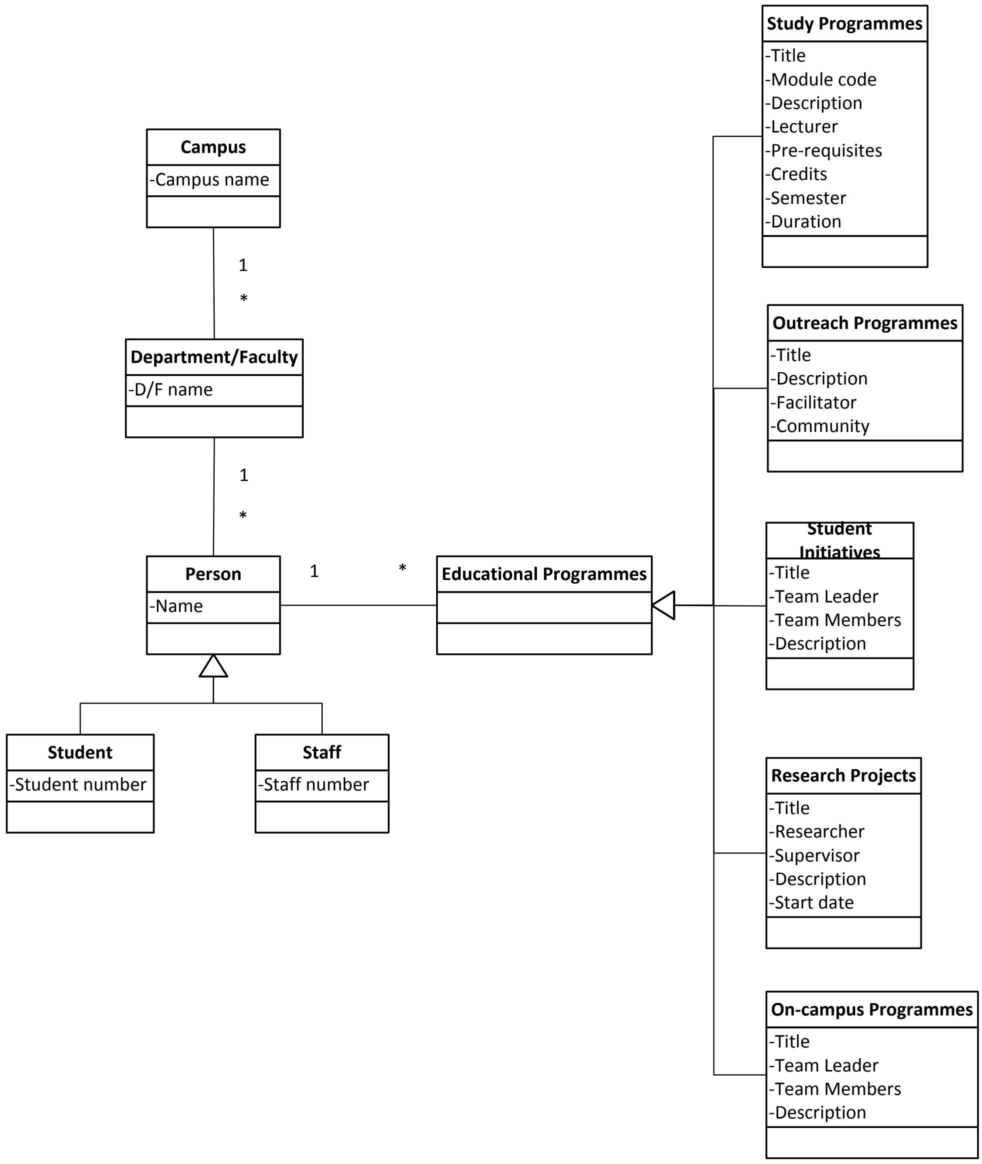


Figure 4.16: To-Be Data Model for Educational Programmes

4.8.4 Summary

Figure 4.17 shows the desired To-Be processes of the electricity, renewable energy, water and waste management environmental indicators.

Figure 4.17: To-Be Processes of the Environmental Indicators at NMMU

Electricity, renewable energy, water and waste management are the environmental indicators given top priority at NMMU and therefore the main focus of this study. The proposed To-Be approach will allow for distributed data entry whereby each data managers or data collectors use the mobile reader application or a website to capture data into the operational data store (ODS). Data should then be extracted from the ODS and transformed and loaded into the data warehouse (DW). The ETL process should also include data quality assurance. Data should then be available for querying, reporting, analysis, monitoring and distributing. The To-Be processes comply with the EIM guideline for HEIs (Table 3.7). Figure 4.18 illustrates the suggested desired data model for the daily operations at NMMU.

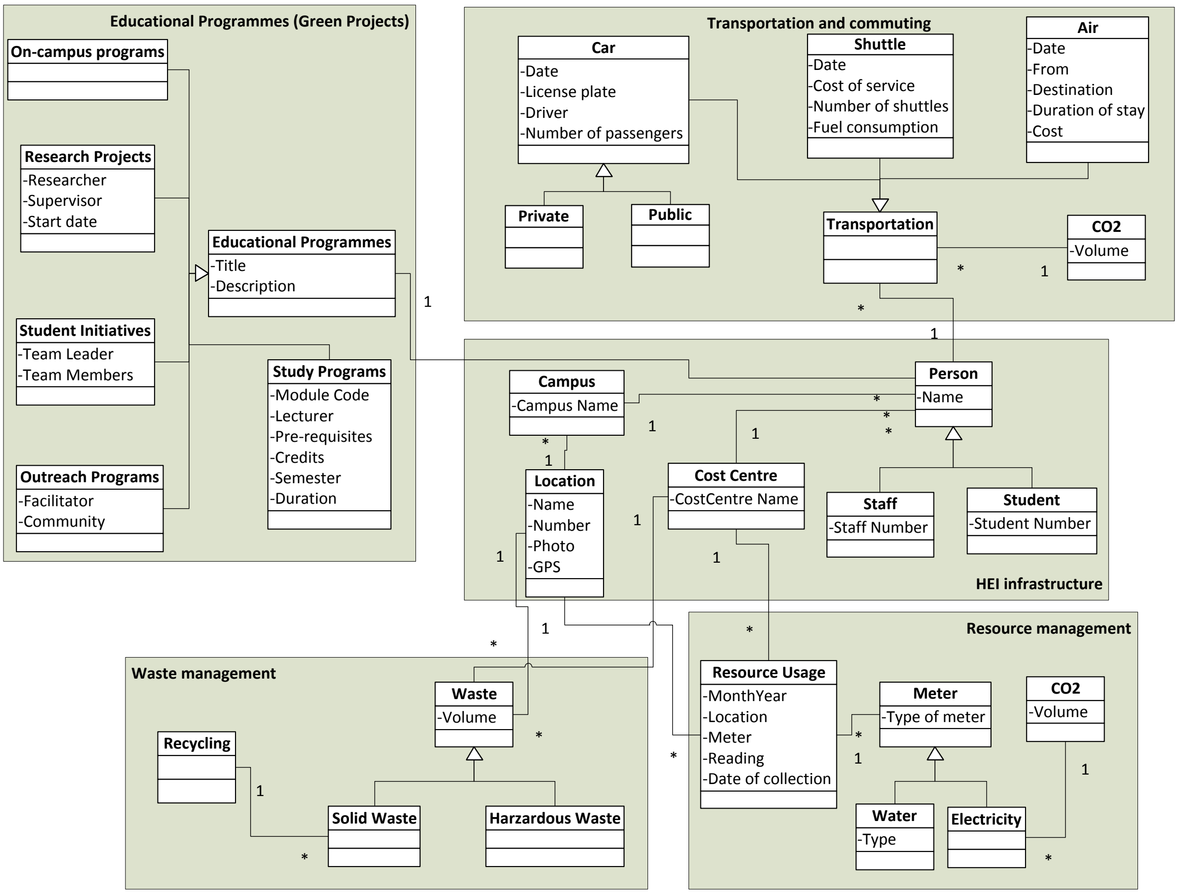


Figure 4.18: To-Be Data Model of all Environmental Information at NMMU

4.9 Conclusions

The main purpose of this chapter was to apply the EIM framework for HEIs (Figure 3.18) and the guidelines (Table 3.7) to the NMMU. The first objective that this chapter had to achieve was: *RO3: Analyse the As-Is processes and data stores at NMMU which are related* *to Environmental Information Management.* The objective was achieved through interviews and document studies. Interviews exposed the ever-increasing complexity in campus infrastructure and showed the varying quality of datasets and the differences in the data collection procedures. The procedures can vary in frequency, units and accuracy depending on the department responsible for the data and the purpose they collect the data for.

Collection of data on resources (water and electricity) is more efficient than that of all the other environmental data that is collected at NMMU. In some cases, the data is fine-grained getting to the level of buildings. However, not all buildings have meters assigned to them individually. Some buildings share a meter and some just have usages estimated for them. This makes apportionment of the usage difficult and to some extent impossible, as in the case for waste management. Where records of historical resource usage exist, the data varies in formatting and completeness. In addition, it was found that manual processes are currently used at NMMU and it is rare to find easily uploadable spread sheets or complete databases.

The second objective of this chapter "*RO4: Propose the To-Be processes and data stores for the management of environmental information at NMMU.*" This objective was achieved as a result of the analysis of the current As-Is processes as compared to the EIM guidelines and framework for HEIs. This resulted in the design of To-Be processes that include building an operational database and a data warehouse that can query data from existing complete databases. The deliverables of the chapter are the objectives of the solution. The objectives of the solution were highlighted as: Computerisation and automation of the electricity and water data acquisition, centralised storage of electricity and water data, integration with legacy systems and cater for future datasets, support for electricity and water allocation to buildings and departments, support for ad-hoc querying and provide data distribution services.

Research from this chapter was communicated through the publication of a peer reviewed conference paper at the International Development Informatics Association (IDIA) Conference of 2014 (IDIA, 2014) (Appendix M). The next chapter details the design and implementation of the solution based on the objectives highlighted in this chapter.

Chapter 5: An EMIS for NMMU

5.1 Introduction

Chapter 4 describes the current As-Is situation at NMMU and the proposed To-Be processes and the data stores. In chapter 4, the EIM framework was applied at NMMU in order to analyse the current As-Is processes and to design the desired To-Be processes for the case study. The analysis of the As-Is processes and data stores and the design of the To-Be processes produced the objectives of the solution. The objectives of the solution (system requirements) were highlighted as: Computerisation and automation of the electricity and water data acquisition, centralised storage of electricity and water data, integration with legacy systems and cater for future datasets, support for electricity and water allocation to buildings and departments, support for ad-hoc querying and provide data distribution services.

This chapter describes the design and development activity of the DSR methodology (Figure 5.1) of one of the two artifacts of this study, namely an EMIS sub-system prototype that is based on objectives of the solution that were produced as a result of the application of the EIM framework at NMMU (Section 4.5). This activity is part of the design cycle of the DSR methodology.

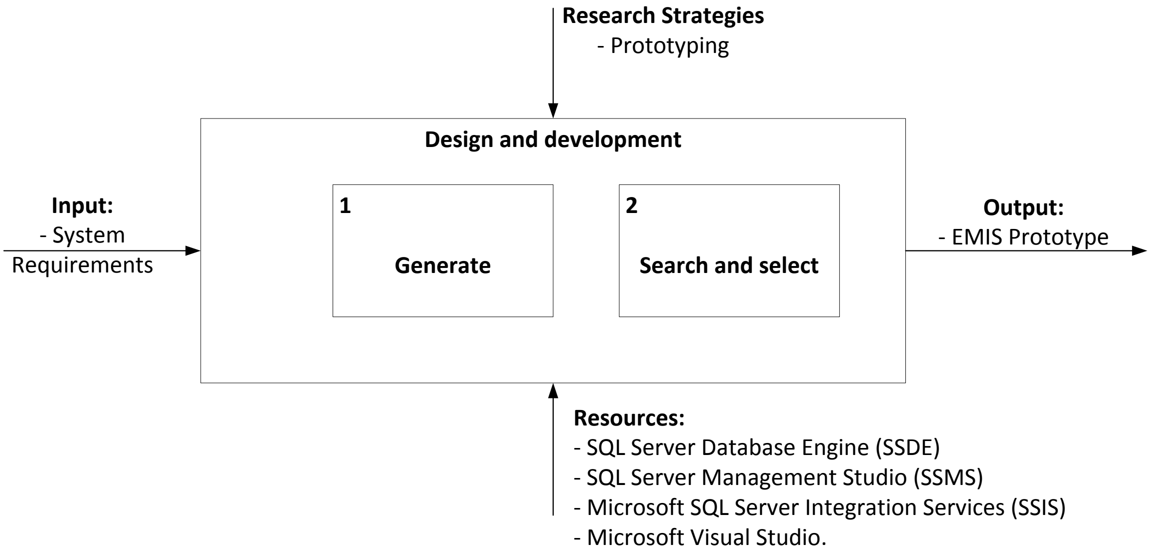


Figure 5.1: Implementation of the Design and Development Activity

The objective of this chapter (RO5) is to *Develop and implement an EMIS prototype for NMMU*. Hence, an EMIS prototype based on the EIM framework is the main deliverable to be expected from this stage of this research study (Figure 5.2). This outcome addresses the following research question:

RQ_5: How can a prototype for the sub-system of an EMIS be designed as proof of concept?

The guidelines for an EMIS (Table 3.7) were applied in order to derive the design for the EMIS components, the Operational Data Store (ODS)/central operational database and the data warehouse (Section 5.2). The environmental ODS (EnviroDB) allows for operational environmental data to be centralised (Section 5.3). For aggregated data which can be queried according to dimensions, the environmental data warehouse (EnviroDW) is proposed (Section 5.4). Several software tools were used to develop the EMIS prototype (Section 5.5). The logical designs of both components were converted to physical designs for EnviroDB (Section 5.6) and EnviroDW (Section 5.7). Conclusions can be drawn from the design decisions made and the challenges encountered in the design and development of the artifacts of this study (Section 5.8).

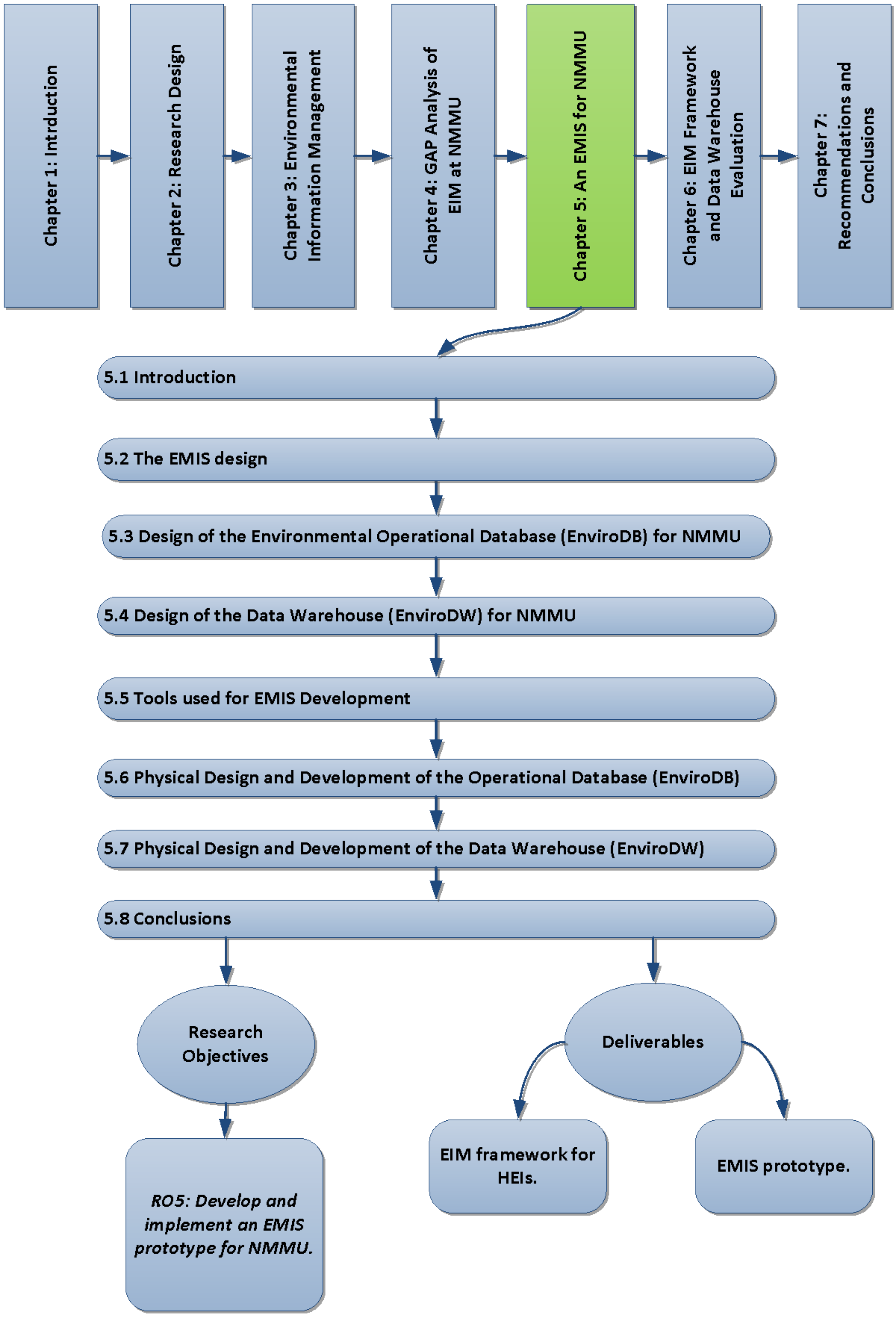


Figure 5.2: Chapter 5 Layout and Deliverables

5.2 The EMIS Design

In order to design the EMIS, a set of well-constructed guidelines for the designing and implementing an EMIS were used (Table 3.7). The guidelines for EMIS components are classified into the managerial services, contribution services and distribution services clusters. As proof of concept only a sub-system of the EMIS was implemented. The focus of the implementation was on the foundation components of the EMIS namely: a central operational database and a university data warehouse.

Central Operational Database: Guideline G5 emphasises that a HEI needs a central storage of environmental information. In addition, the To-Be processes highlighted that water, electricity and waste data needs to be stored in an operational database (Section 4.8.1). Hence, the central operational database addresses this guideline and also satisfies the requirement highlighted by the To-Be processes. Guidelines G10 and G11 indicate that there is need to automate and computerise data capturing and collection. The need for automation and computerisation of data capturing and collection was also revealed the application of the guidelines in (Chapter 4) because NMMU, like most HEIs, has mostly old-fashioned manual meters. NMMU is in the process of upgrading to smart meters (electricity meters only) and this process began in 2009 and will take years to be fully implemented.

The structure of the EMIS allows for comprehensive data gathering as it caters for both automated and manual systems. The EMIS includes a central operational database which allows for manual entries. The proposed EMIS allows for the automated collection of data from smart meters, with the added improvement of the data capturing processes for data from manual meters by the implementation of a *Mobile Reader application*. This Mobile Reader application allows for the automated collection of data from manual meters, thereby eliminating any manual entry of environmental data. The data collector enters the meter readings on the mobile device and with the push of the button the data can be submitted to a central EMIS database.

Data Warehousing: Guidelines G7, G8 and G9 focus on the structure of environmental information and how the information is analysed and presented for querying and reporting integrated data. This is in alignment with Moore and Bordeleau (2001) who propose designing an EMIS using a data warehousing approach (Section 3.3.3). The structure of the environmental information and the supply of the information are integral parts to the design of the data warehouse and EMIS.

5.3 Design of the Environmental Operational DB (EnviroDB) for NMMU

A crucial part of the implementation of an EMIS is environmental information. The researcher had to negotiate with the various parties for access to be granted to this sensitive information. The Technical Services Department is responsible for the collection of all the electricity and water readings data and management of the resources. The researcher was granted access to the hard copy files of the electricity and water data that dated back to 2008. With the help of a colleague from the Department of Computing Sciences, all the electricity and water data was captured into two Microsoft Excel files. This data only represented one aspect of the electricity and water readings data at NMMU, so the researcher sought access to the electricity data from the JCBMS smart meters. The JCBMS smart meter data was provided as a Microsoft SQL database. The Physics Department which is responsible for the energy-generated data, however they did not provide access to the energy-generated data timeously.

In an attempt to build a comprehensive EMIS and to adhere to the guidelines of EIM in HEIs, access had to be obtained to data that showed the space allocation of the different departments in buildings. The data obtained consisted of the different departments in the different buildings and also stated the area (in cubic meters) that each department occupies. This allowed for the calculation of the occupation ratio of each department in a building and for an estimation of each department's electricity and water usage.

In an attempt to cater for all the needs of the stakeholders and to ensure that NMMU migrates to using an automated data capturing system, the researcher had to implement an operational database that would complement the data warehouse. Firstly, the operational database 'EnviroDB' needed to be developed and implemented. Secondly, the historical operational data must be loaded from the Microsoft Excel files into EnviroDB which is a Microsoft SQL database (Figure 5.3). The loading of historical data is a process that is only done once. In the future, data will be entered directly into the operational database via the mobile reader application or a website.

The development and implementation of the data warehouse 'EnviroDW' is the third stage. This stage includes implementing Extract, transform and Load (ETL) processes to load data from the EnviroDB operational database into EnviroDW. This first population of the data warehouse is referred to as the initial load (Jorg & Dessloch, 2009). However loading of data from the operational database to the data warehouse is a continuous process. As data in the operational database changes, data in the data warehouse becomes out-dated hence there is a need to refresh the data warehouse on a periodical basis.

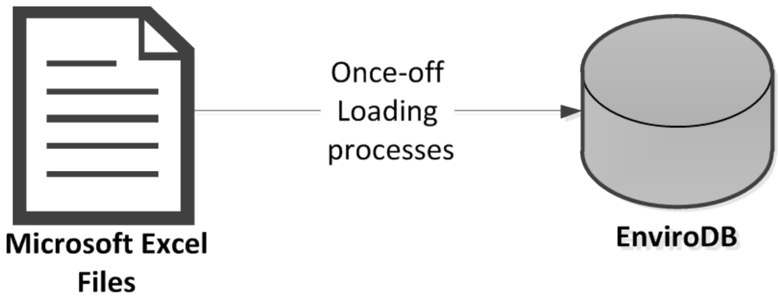


Figure 5.3: Loading of Historical Data to EnviroDB

In Chapter 4, three environmental data sources were identified of which two were handwritten files and the other a database. The two handwritten files are for water and electricity usage. The database stores the JCBMS data. Analysis on these data stores revealed that the semantics in the different sources were almost similar in terms of column naming; hence there was no need for homogenisation of data columns. Therefore, the handwritten data for water and electricity were captured into two Microsoft Excel files with no change to the column names (Figure 5.4).

Figure 5.4 illustrates the As-Is (source) data structure and the To-Be (destination) data structure. The destination database is the central operational database in which all the electricity and water data will be stored. NMMU will now move from having handwritten electricity and water data to having a central database where data will be added directly to the database from a mobile app or sensor networks or by a data manager via a dedicated website.

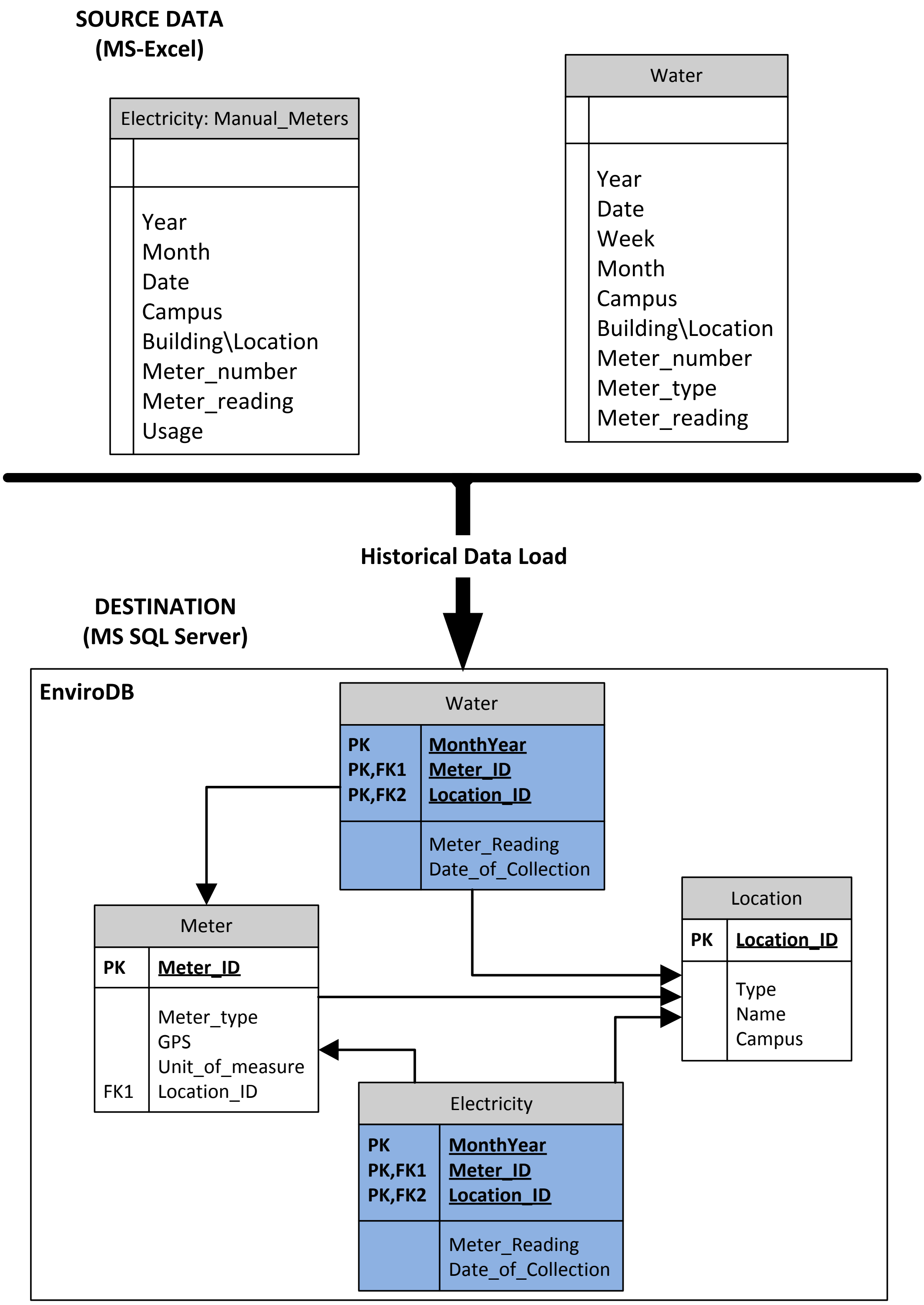


Figure 5.4: Source and Destination Data Design for EnviroDB

The design of EnviroDB was based on the To-Be data model for resource usage at NMMU (Figure 4.14). The two resource entities which will be implemented are water and electricity.

Renewable energy and waste are not included in the sub-system prototype. The campus entity is folded into location.

5.4 Design of the Data Warehouse (EnviroDW) for NMMU

Figure 5.5 highlights that, the proposed data warehouse will need to take data from three separate sources namely: EnviroDB, JCBMS smart meter database and NMMUSPACE. The NMMUSPACE database provides NMMU's infrastructure details such as the departments in a building and the space occupied by a room in cubic meters. This allows for the apportionment of resource (water and electricity) usage to the different departments (cost centres) thus the EMIS adheres to the guideline G9 and also enables prompt responses to the questions that the users of the system posed (Section 4.5).

Bero, et al. (2012) suggest adding apportionment modifiers to algorithmically apportion usage to arbitrary buildings and spaces within a metered loop. A generic apportionment modifier is simply based on square footage, but specialised modifiers can be developed to more accurately apportion usage based on efficiency of the building, type of space (labs or dorms or classrooms) and other relevant factors (Bero, et al., 2012). A generic apportionment modifier will be implemented in this research study.

A generic apportionment modifier will be able to provide information which was not available and couldn't be readily acquired, estimation of usage is calculated based on the area occupied. This estimation technique assumes that a building houses cost centres or departments that have similar resource usage patterns. This is not always the case as some buildings can have departments or cost centres that are more resource intensive. For example, the Department of Computing Sciences is co-located with the Law Department in the Embizweni building and the Department of Computing Sciences has six computer labs as compared to the Law Department that has offices and only one computer. The area occupation assumption fails because electricity consumption of the Department of Computing Sciences would be greater than estimated. The researcher incorporated the boolean attribute '*Estimated*' to notify the user so that decisions can be made with this information in mind.

In data warehousing terms, perspectives are the dimensions by which the data should be available. The logical design of the data warehouse was then derived based on these requirements. The snowflake schema was used as the logical representation of the data warehouse (Figure 5.5). A snowflake schema is a modelling paradigm in which a data warehouse consists of a fact table which contains the bulk of the data, with no redundancy, and a set of smaller tables called dimension tables. The dimensions tables are normalised by splitting the dimensions into additional tables. A star schema is one in which the dimension tables are not normalised. The EnviroDW consists of two fact tables (FactElectricity and FactWater) and three dimensions which are Time, Meter and Cost centre.

The two initial dimensions identified are the two entities in the EnviroDB operational database, namely: Meter and location. A Time dimension is added since the requirements from the interviews related to the objectives and typical question (Section 4.5) highlighted that data will be queried in specific time periods. The need for a cost centre was identified because a cost centre includes departments and services units such as street light or finance generating entities that are located at NMMU but owned by external parties (for example, shops). Cost centre is important as it helps to comply with guideline G13 of EIM at an HEI. The occupation percentage in the Cost centre dimension also helps to comply with guideline G13. Resource usage of a cost centre is calculated based on the area (in square metres) that is occupied by a particular cost centre in a location. This is the implementation of the general apportionment modifier. The resulting schema therefore has the following dimensions:

1. Time
2. Meter
3. Cost centre
4. Location

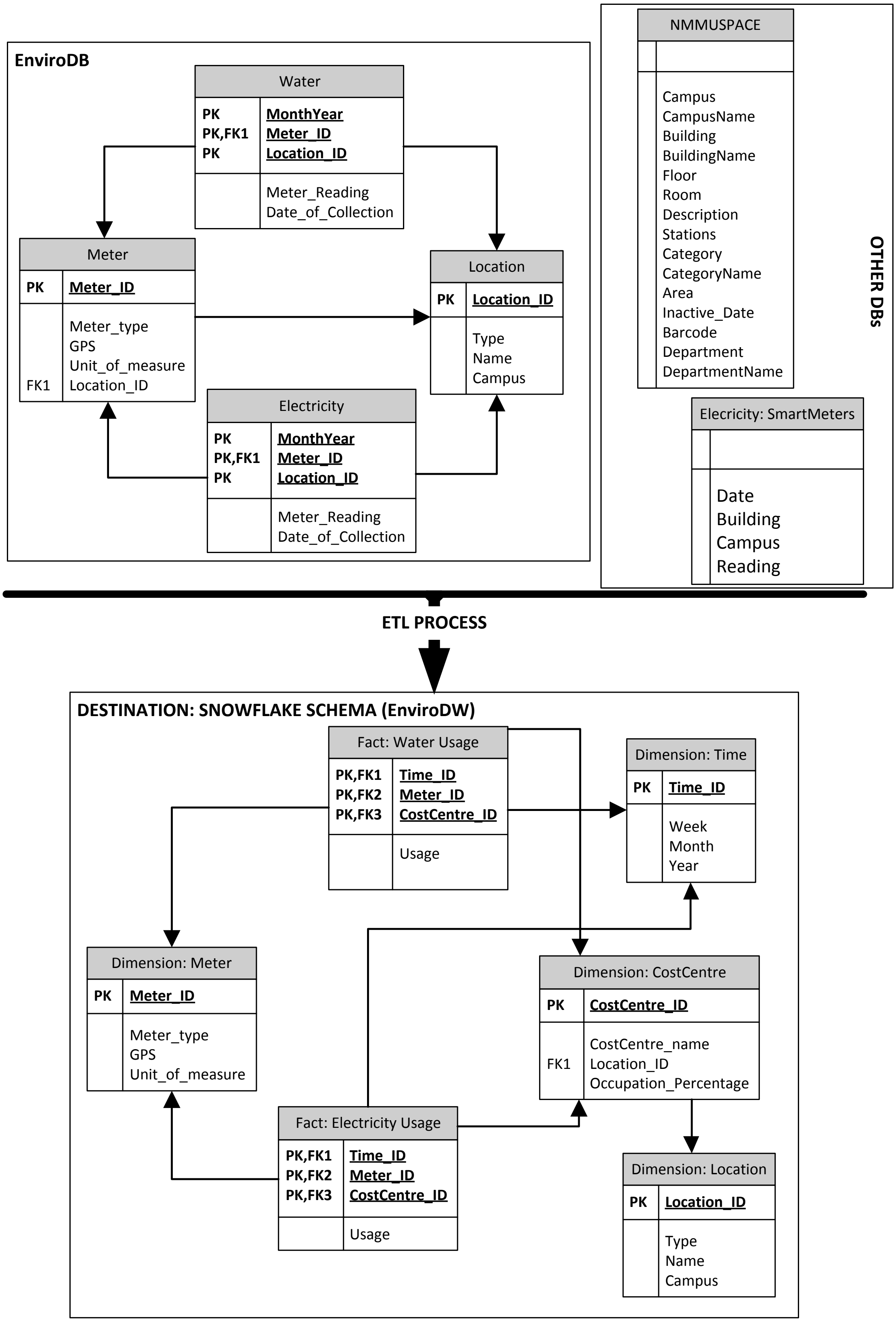


Figure 5.5: The Operational Source Data and the Data Warehouse Snowflake Schema

5.5 Tools Used for EMIS Development

In order to develop and implement the operational database and the data warehouse the Microsoft SQL Server Environment (MSSE) was used. The MSSE consists of a set of tools that can be used for the storage, management and maintenance of data. The following is the set of tools that were found to be suitable for the development of the EMIS for NMMU:

1. SQL Server Database Engine (SSDE);
2. SQL Server Management Studio (SSMS);
3. Microsoft SQL Server Integration Services (SSIS); and
4. Microsoft Visual Studio.

These tools were selected based on cost effectiveness, since NMMU already has a licence for these tools, and these tools are widely used at NMMU. The MSSE consists of other tools that allow for analysis services, management interfaces and reporting. The SSDE is a relational database management system and a user uses the SSMS to interact with the database engine to manage the data. Microsoft SSIS is a platform for building a high performance data integration service, including ETL processes for data warehouses (Microsoft, 2012a). Microsoft SSIS consists of a SSIS designer and wizards which enable users to create and debug SSIS packages easily. The SSIS designer is a graphical tool which enables users to drag and drop components for performing workflow tasks such as executing T-SQL statements, connecting data sources and destinations for extracting and loading data, transformations for cleaning, aggregating, merging, and copying data (Microsoft, 2012b; Microsoft, 2012c; Microsoft, 2012d).

An SSIS package is an organised collection of connections, control flow elements and data flow elements (Figure 5.6). The typical structure of an SSIS package has a control flow task that consists of an organised sequence of data flow tasks and each data flow task contains elements that have data, retrieved from the source and then transformed before it is stored in the destination.

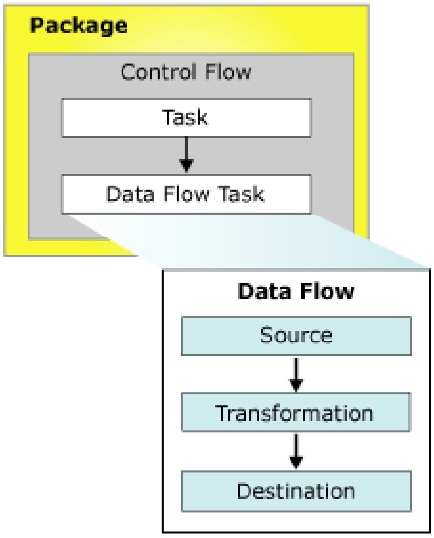


Figure 5.6: The Structure of an SSIS Package (Microsoft, 2012c)

The user can use the components listed in the SSIS toolbox pane and assemble them using the graphical designer or build programmatically (Figure 5.7). Control flow tasks enable the user to create a workflow of executable tasks. The Microsoft Visual Studio for SSIS allows the user to drag control flow tasks from the toolbox pane and drop the element in the design pane in which the workflow is designed (Figure 5.7). The precedence constraint, which is represented by a green arrow, specifies the order of execution of the control flow tasks by linking two control flow tasks and constrains the execution of the destination control flow task based on the result of the preceding control flow task (Microsoft, 2012e).

In SSIS the ETL processes of a data warehouse are designed using control flow tasks and dataflow tasks. Control flow tasks encapsulate the data flow engine that extracts data from sources to destinations and performs transformations to clean, integrate, sort, filter and merge data as it moves from the sources to the destinations (Microsoft, 2012f; De Ruiter, 2012). To design the ETL within a control flow task the user can double click on a control flow task or select the control flow and click on the data flow tab. The user can then drag data flow tasks from the toolbox and drop them in the data flow design pane where the data flow is designed (Figure 5.8). The user can retrieve the data from the sources, perform transformations on it and move it to its destination.

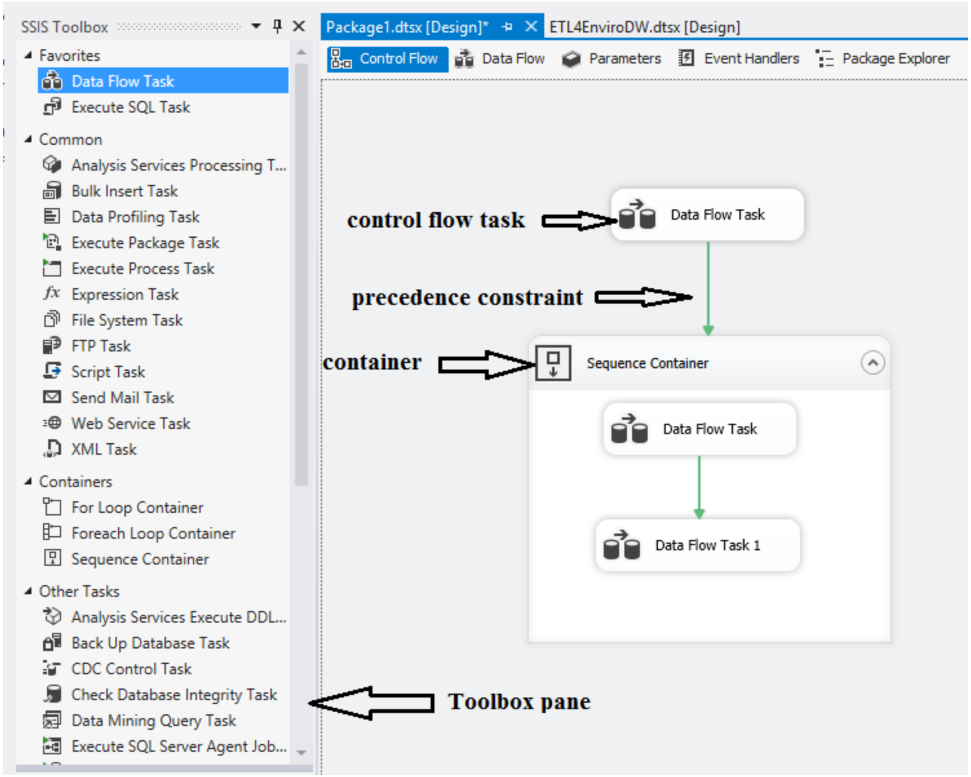


Figure 5.7: The SSIS Control Flow Interface (Microsoft, 2012b)

Figure 5.8 shows categorised data flow tasks which are created as part of a control flow task. The data flow source item uses a connection to make external data available to the other components in the data flow. There are different types of data flow source items and these depend on the type of source data files. Data can be extracted from different file data sources which include databases, flat files, Excel files or XML files (Microsoft, 2012f). Similarly, data flow destination items use connections to write data to destination files. Data flow transformation items have a broad variety of capabilities. These items are used to perform data updating, cleaning, summarising, sorting, filtering or merging tasks. This enables users to design and perform complex ETL processes for data warehouses.

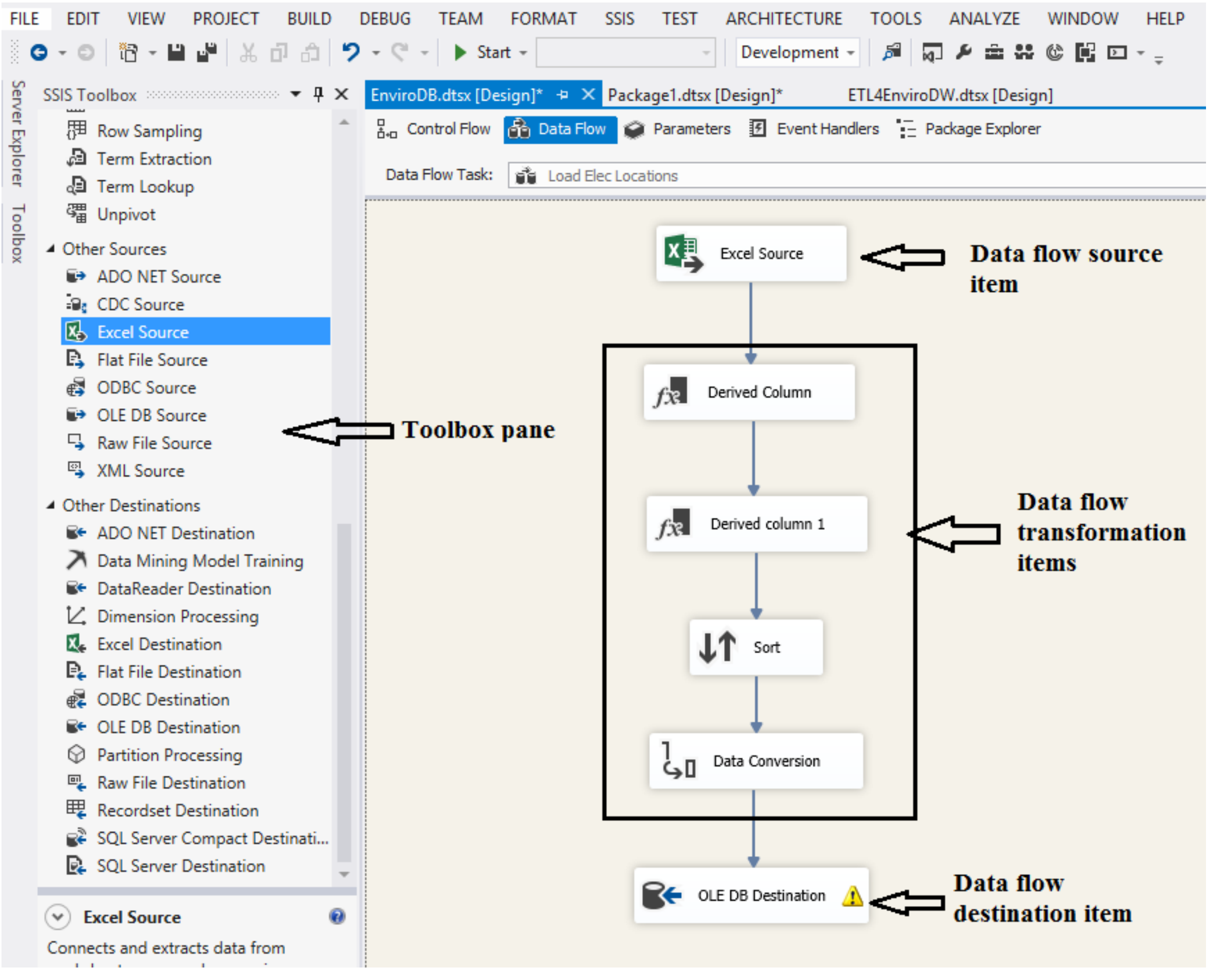


Figure 5.8: The SSIS Data Flow Interface (Microsoft, 2012f)

5.6 Physical Design and Development of the Operational Database (EnviroDB)

The database diagram represents the physical design of the EnviroDB operational database (Figure 5.9). which was implemented in SSDE using SSMS. The database consists of four tables and the relationships between the tables are shown by the primary and foreign keys (Figure 5.9).

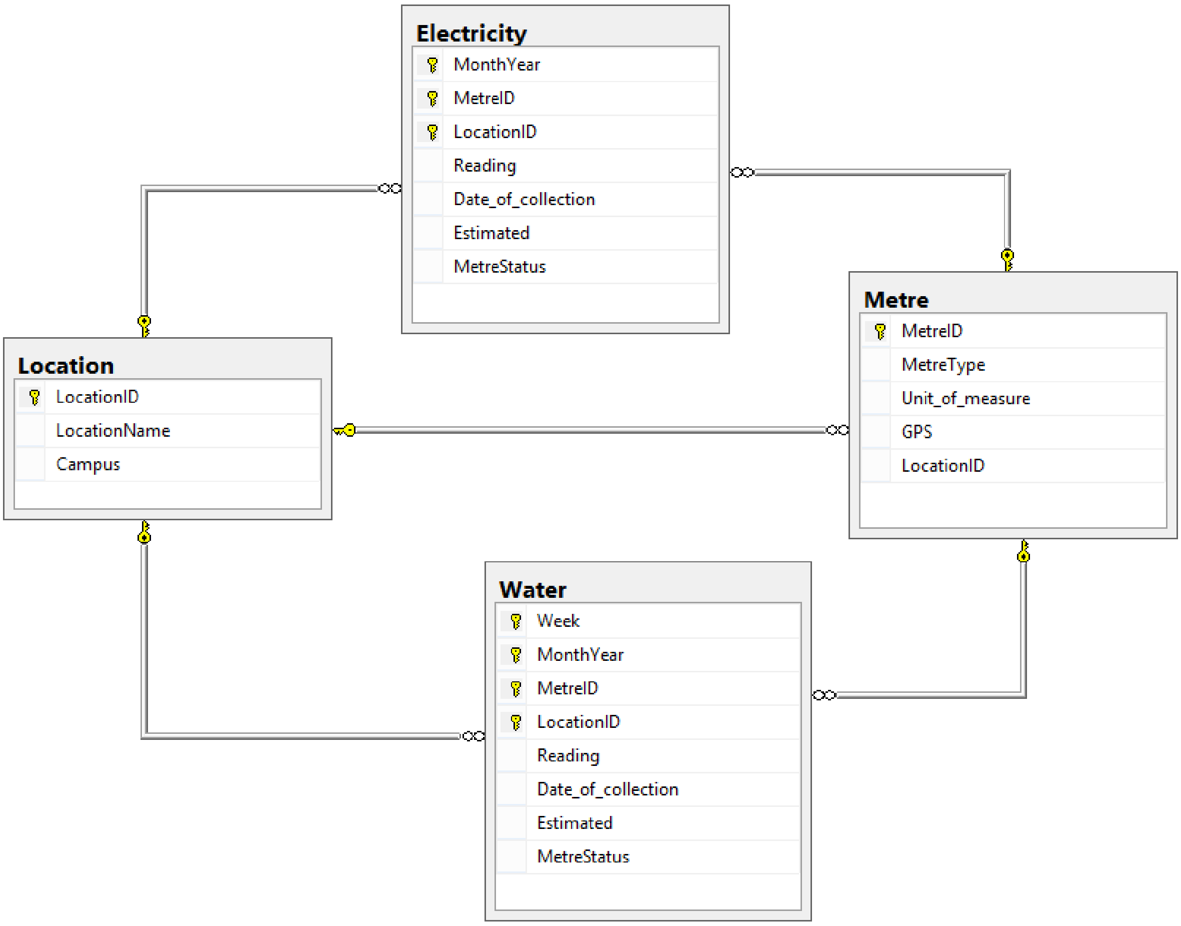


Figure 5.9: Physical Design of the EnviroDB Operational Database

The EnviroDB database stores electricity and water data that was initially stored as paper hardcopies and then captured into Microsoft Excel. ETL processes were then implemented to move the data from Microsoft Excel to the EnviroDB database (Figure 5.10). Data extraction from the Microsoft Excel files was split into two parts, electricity and water, which is represented by the two distinct containers in the ETL process. The first sequence container represents the ETL process to extract and add electricity data from the Excel file into the database. Subsequently, the second sequence container extracts and loads water data into the database.

The electricity and water data contained numerous errors, inconsistencies and blank values. Data cleaning was performed as part of the ETL process such that errors and inconsistencies could be detected and eliminated where possible (Rahm & Hai Do, 2000). Errors included misspellings, missing data or other invalid data. The boolean attribute '*Estimated*' of the water and electricity tables was added so that when data is presented to the user it can be highlighted as an estimated value and they can take that into consideration when making decisions. The attribute '*MeterStatus*' of the water and electricity tables is used to inform the system when a meter is faulty or when a meter was reset which will help in resource usage calculations. Data cleaning was done in the staging area as part of the transformation process before the data was loaded into the database. Complex transformations such as 'fuzzy' lookups or 'fuzzy' groupings were used to match values that were similar. Hence a similarity index and the level of confidence were used in the transformation to determine the level of similarity between values that were being compared.

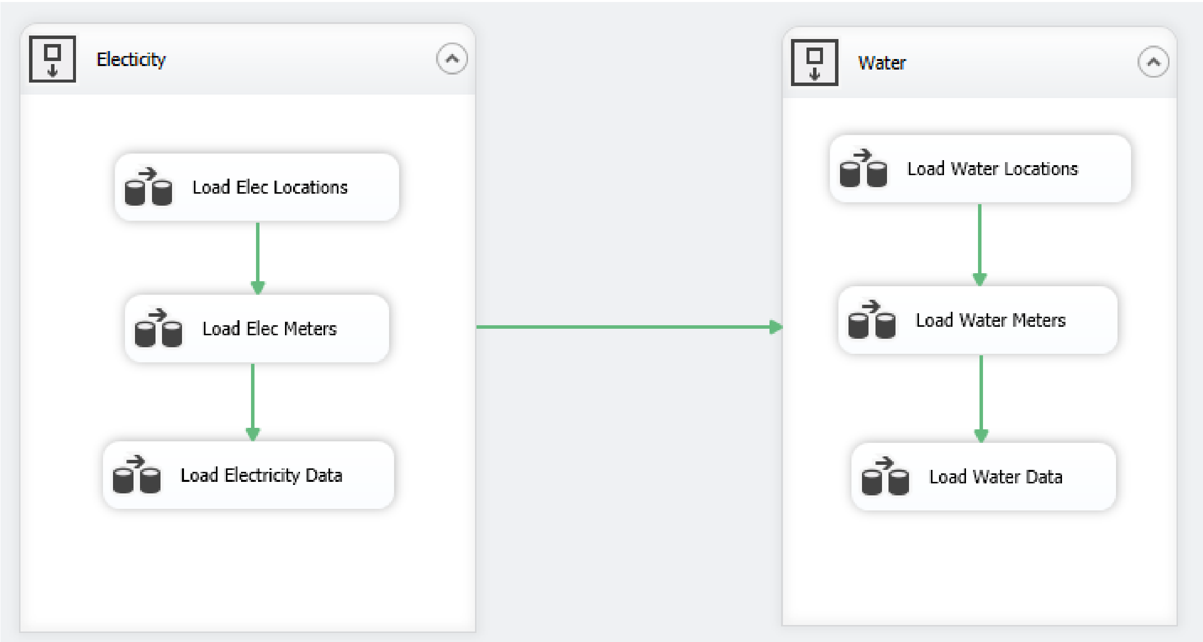


Figure 5.10: The Control Flow Implemented for the EnviroDB Historical Load ETL Processes

The data cleaning process also included manual inspection. The researcher took advantage of the Microsoft Excel functions to eliminate some of the errors. This included using the drag functionality to copy common values within the rows of the files. Database constraints such as the primary key constraint and referential integrity were enforced to ensure that invalid data could not be added into the database. A primary key constraint guarantees unique data in a table and referential integrity ensures that a foreign key in any referencing table must always refer to a valid primary key in the referenced table (Microsoft, 2003). In addition, the ETL process has a logging functionality which loads an error into an external flat file in the

ETL process. Logging also highlights which data could not be loaded and specifies the reason(s) why. All the electricity and water data was successfully loaded into the database with the exception of the invalid data which had missing meter numbers or meter readings. This data was logged into a flat file which can be edited to put in the missing values.

The individual ETL processes for loading data into the EnviroDB operational database are shown in Appendix K. The ETL process for loading data from Microsoft Excel to EnviroDB was a once off process that is never to be repeated again. To enter current data into the database, an interface to upload data directly into the database was implemented. However, the implementation of this interface was not part of the scope of this research.

5.7 Physical Design and Development of the Data Warehouse (EnviroDW)

The EnviroDW consists of five tables of which two are fact tables (FactWater and FactElectricity) and three are dimension tables (DimMeter, DimCostCentre and DimLocation). The logical design of of EnviroDW shown as a snowflake schema showed six entities (Figure 5.5). The Time dimension is not required as a physical table. The physical implementation of the data warehouse was implemented in SSDE using SSMS (Figure 5.11). The fact tables are uniquely identified by composite keys.

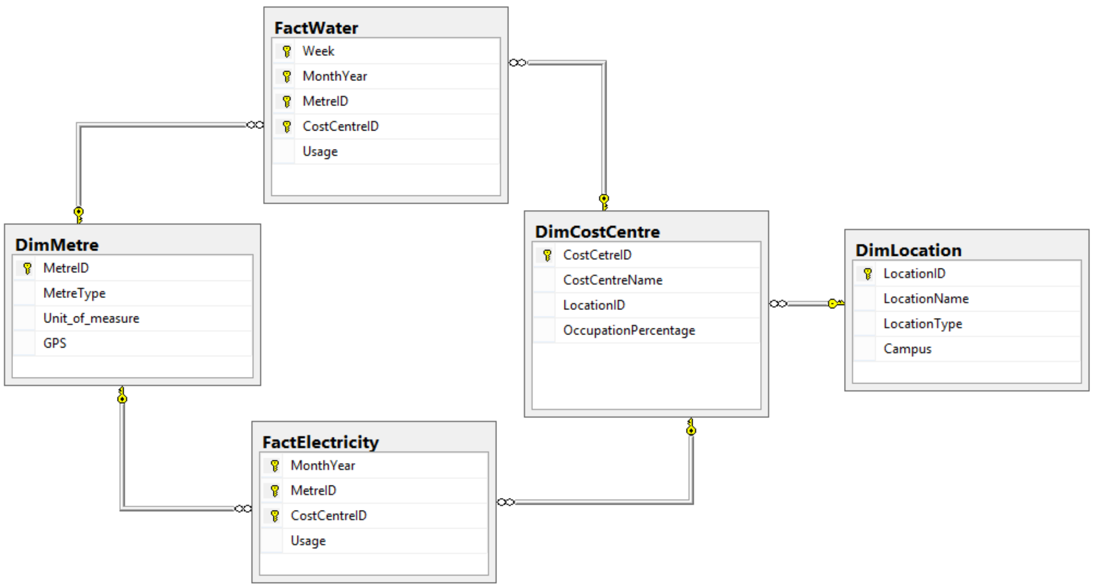


Figure 5.11: Physical Design of the EnviroDW

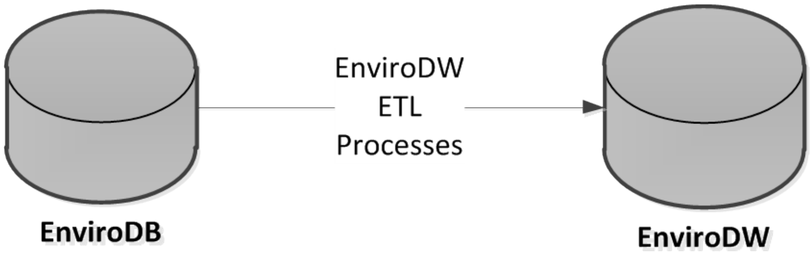


Figure 5.12: Data Loading From EnviroDB to EnviroDW

The ETL processes to extract and load data from the EnviroDB database into the EnviroDW data warehouse (Figure 5.12) are represented by two containers namely; Load Dimensions and Load Fact Tables (Figure 5.13). The ETL processes for extracting and populating the Location, CostCentre and Meter dimensions tables in EnviroDW were implemented. To populate the Location and CostCentre tables, conversion tables were employed to ensure that official NMMU building names and numbers were used, and also to ensure that the CostCentre data represented the current situation at NMMU as closely as possible.

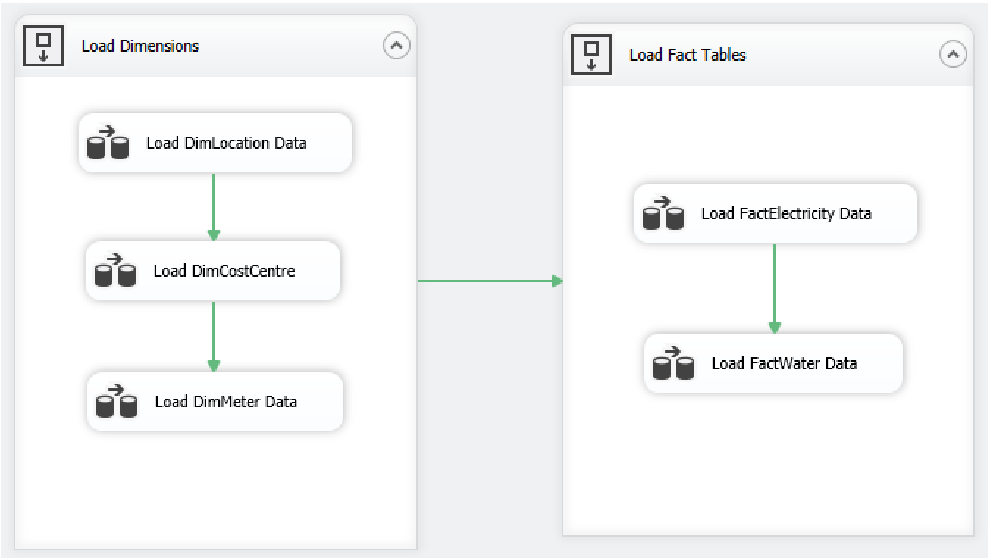


Figure 5.13: The Control Flow Implemented for the EnviroDW ETL Processes

There are basically two different approaches that could be used to refresh data in a data warehouse: *reloading or incremental loading*. Reloading is a process in which all the data is reloaded. Incremental loading only changes a small fraction of the data or adds to the existing data in the data warehouse (Jorg & Dessloch, 2009). Reloading is considered to be less efficient than incremental loading. Therefore incremental loading is desirable for the

EnviroDW, hence; the ETL processes included a data incremental feature which ensures the continuous updating of data in the EnviroDW in the future.

5.7.1 Dimension Table Population

The specifications of the data flow tasks which are used for the population of the respective dimensions are similar for the Location and CostCentre dimensions. In addition the data flow task specification of the Meter dimension is straight form loading as no transformations are done on the meter details in the EnviroDB. Therefore only the data flow task specifications for the CostCentre dimension are described for illustrative purposes (Figure 5.14). The data flow tasks specifications of the Meter and Location dimensions are provided in Appendix K.

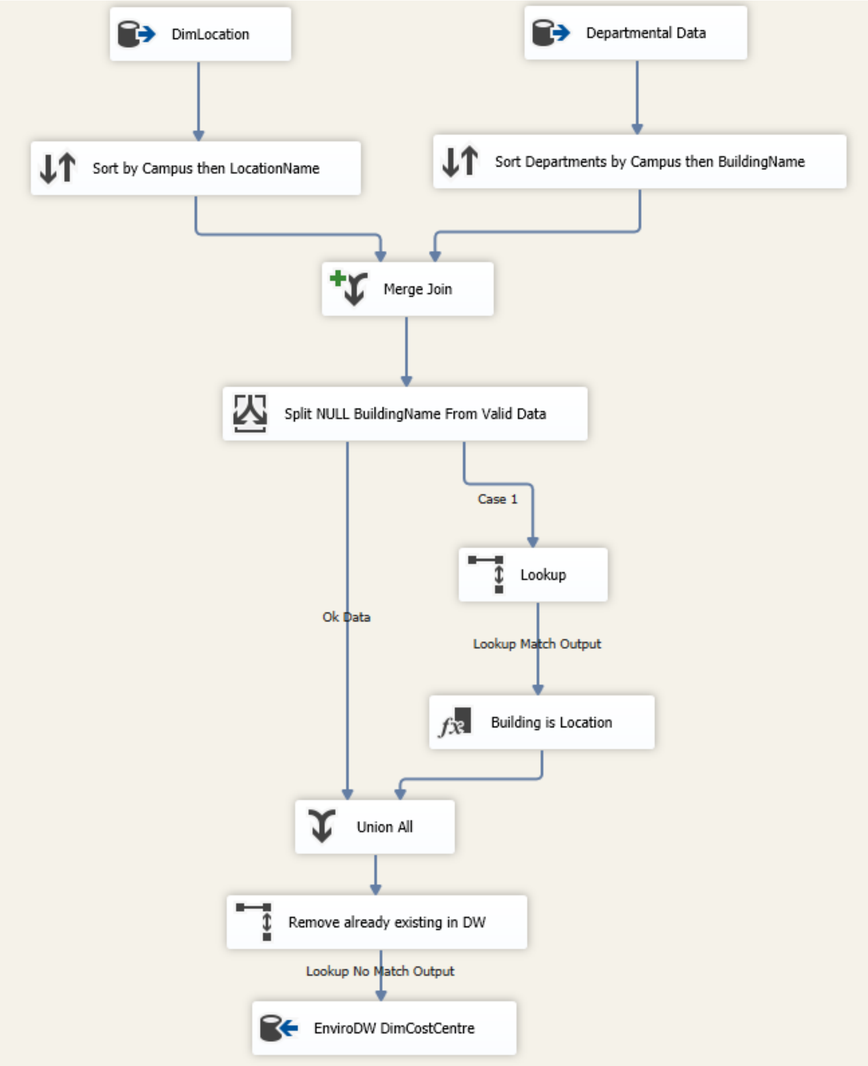


Figure 5.14: The Data Flow Task Items Used to Populate the CostCentre Dimension

The ETL process shows that the Location data extracted from the EnviroDB database is first sorted on *campus* then *location name* before it is joined with a sorted list of cost centres (Departments). The merge join transformation performs a left outer join on the two lists (Figure 5.15). The tables are joined on the campus name and then on the building or location name. The left outer join includes all rows from the left table, but only matching rows from the right table. This ensures that the complete list of locations that have data collected is generated and the join excludes departments that are not in this set of locations.

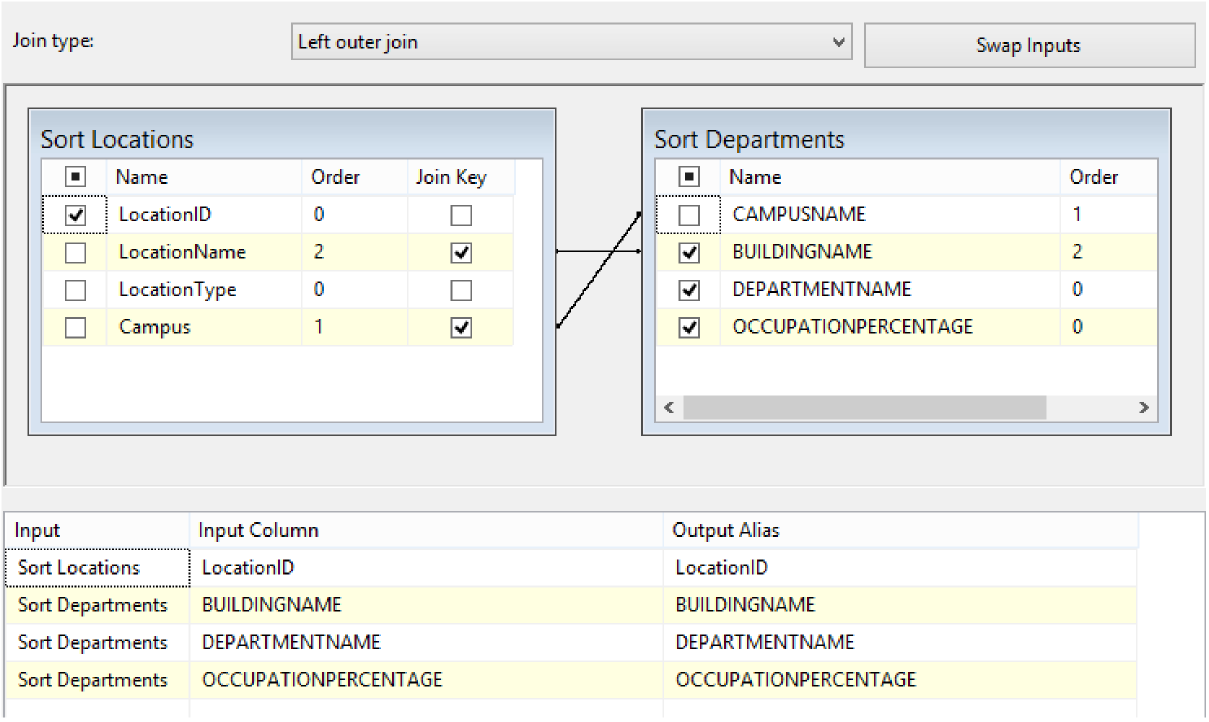


Figure 5.15: The Merge Transformation

The split condition then separates the data into two streams: Ok Data and Case 1 (Figure 5.14). Ok Data is the data that contains official NMMU locations that have departments allocated to it. However, as noticed in the operational data some of the locations are not listed in the official building list. For example, the item, STUDENT VILLAGE_STREET LIGHTS was not found in the building list as this is not a building but rather a service unit. Hence, Case 1 is data that has not officially been allocated to departments. Therefore, the location name is also assigned to be the department name and the location is given a hundred percent occupation. After the data is rectified the data is then united to form one table which is then written to the CostCentre Dimension table.

5.7.2 Fact Table Population

Only the specifications of the data flow tasks which are used for the population of the Electricity fact table are described as they are also representative of the similar process for loading the Water fact table (Figure 5.16).

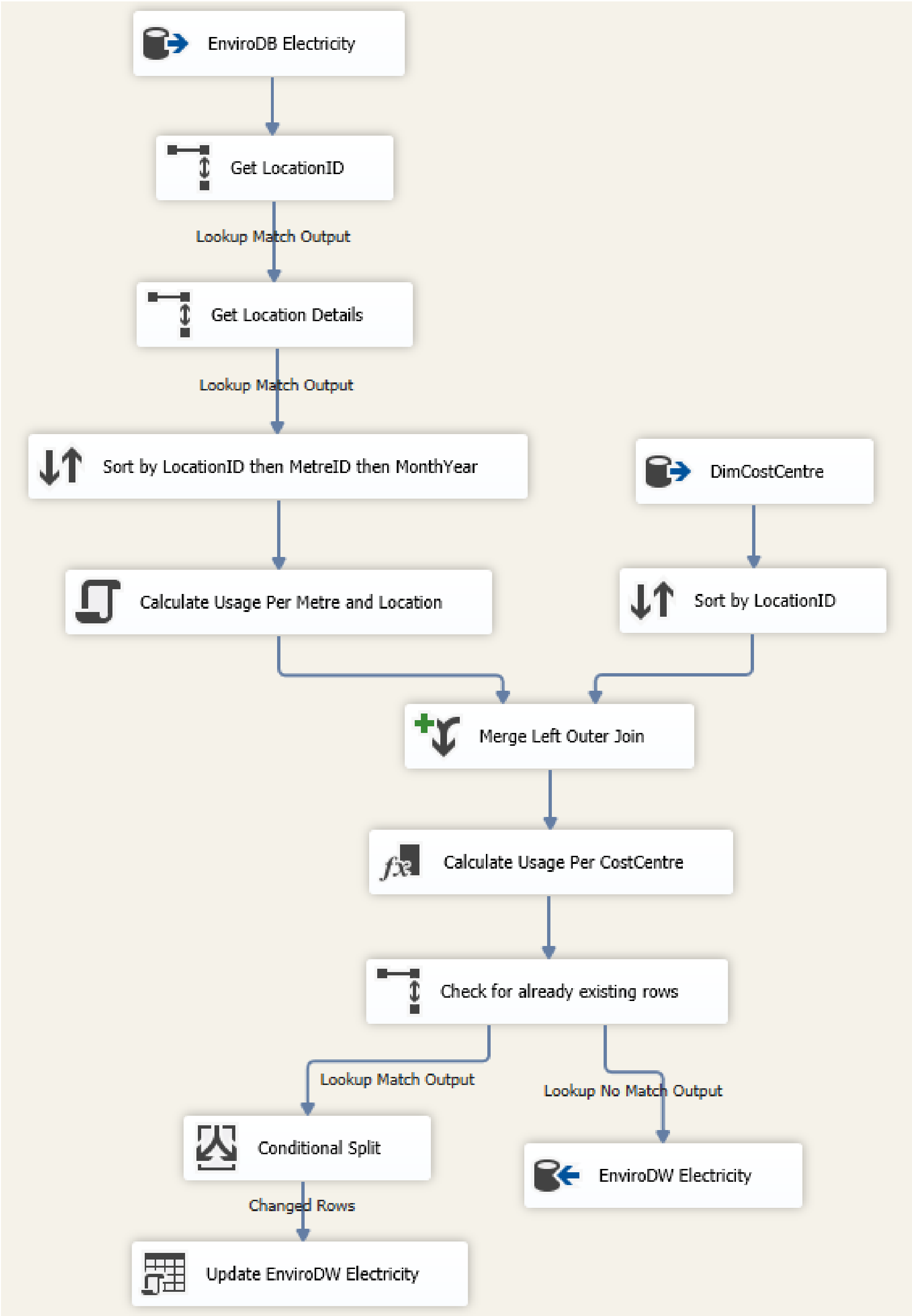


Figure 5.16: The Data Flow Task Items Used to Populate the Electricity Fact Table

Data records are extracted from the Electricity table in the EnviroDB operational database. A lookup transformation is then employed to determine the LocationID from the Location dimension table (Figure 5.16). Another Lookup transformation is used to obtain the details of the Location based on the LocationID. Data is then sorted on LocationID, then MeterID and then MonthYear. This is to ensure that successive readings from the same location and meters are consecutive rows in the table of the staging area. This will allow for the calculation of the usage by subtracting readings from consecutive rows that is, the resource usage is obtained by subtracting the reading in the previous row from the reading of the current row. The script transformation is where the calculation of the usage per meter per location is done (Figure 5.17).

```
[Microsoft.SqlServer.Dts.Pipeline.SSISScriptComponentEntryPointAttribute]
public class ScriptMain : UserComponent
{
    Help:  Using Integration Services variables and parameters

    Help:  Using Integration Services Connnection Managers

    Help:  Firing Integration Services Events
    // Variables to store the previous row
    string Metre = "";
    double PrevReading = 0;


    /// <summary> ...
    public override void PreExecute()...

    /// <summary> ...
    public override void PostExecute()...

    /// <summary> ...
    public override void Input0_ProcessInputRow(Input0Buffer Row)
    {
        // Compare current key with previous key
        if (Row.MetreID == Metre && !((Row.MetreStatus).Trim() == "RESET"))
        {
            Row.RUsage = Row.Reading - PrevReading;
        }
        else
        {
            Row.RUsage = Row.Reading;
        }
        // Store current row values in the variables for the next row
        Metre = Row.MetreID;
        PrevReading = Row.Reading;
    }

}
```

Figure 5.17: T-Script C# Implementation of the Calculation of the Electricity Usage per Meter per Location

After the calculation of the electricity usage per meter per location a merge join transformation is used to perform a left outer join on two lists that are sorted on Location

(Figure 5.18). This splits the Location into its CostCentre which in turn allows for the allocation of resource usage based on the occupation percentage of each CostCentre.

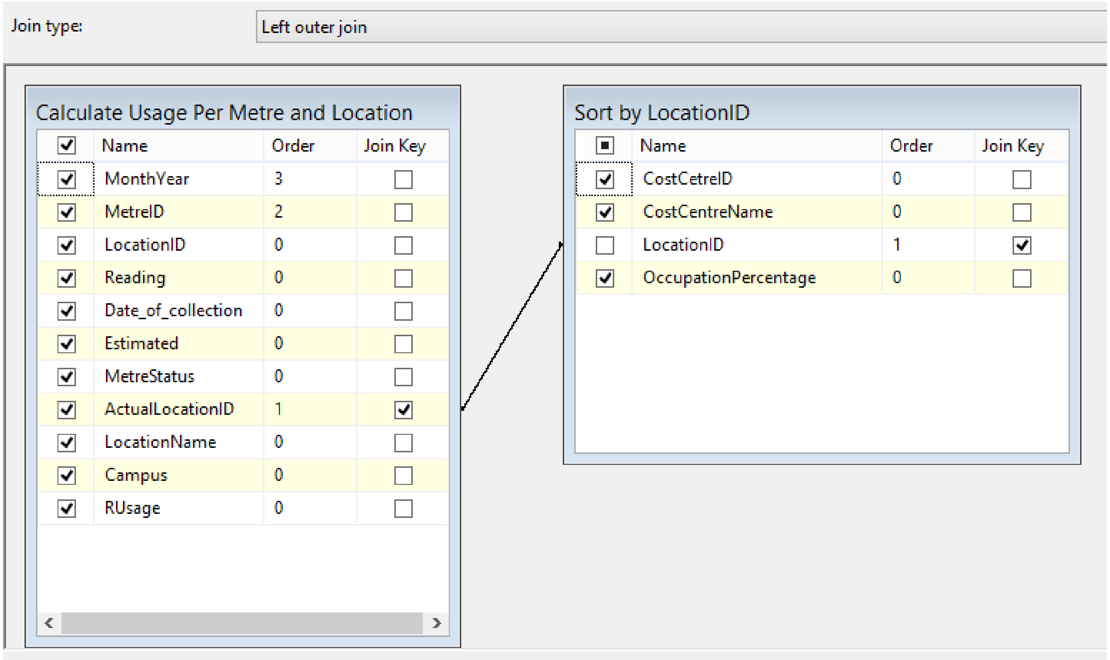


Figure 5.18: Implementation of the Merge Join Transformation

An additional filtering condition was implemented for the incremental updating of the fact table. This is required to ensure that data that is already loaded to the destination table is not repeatedly considered when the data warehouse is updated. There the '*Check for already existing rows*' checks for primary keys that are already inserted and it splits the rows into already existing rows and new rows. New rows are then added into the data warehouse where existing rows are checked to see if any of them were updated in the operational database, if so, they are also updated in the data warehouse.

5.8 Conclusions

This chapter described the design an EMIS for NMMU guided by the EIM framework. The framework showed that a complete and comprehensive EMIS is a combination of different technologies and systems. The EMIS consists of various databases from legacy Information Systems, the EMIS data layer (data warehouse), reporting layer, analysis layer, monitoring layer and the presentation layer. The chapter further describes the design and development of an EMIS sub-system which consists of two components namely; the various databases from

Information Systems and the data warehouse (data layer). The deliverable that was presented as a result is the EMIS sub-system.

The operational database EnviroDB and the data warehouse EnviroDW were physically implemented in the SSDE using the SSMS. Historical data was captured into Microsoft Excel and then one-time ETL processes were used to extract and load the historical data into the EnviroDB database. Data cleaning mechanisms were used to ensure that the data is of high quality. Misspellings were rectified, missing data was filled in were possible. Data logging was also used to write invalid data that could not be added into the database to a flat file. ETL processes to extract and load data from the operational database into the data warehouse were implemented. This satisfies the objective that was set out for this chapter which is: *RO5 – To develop and implement an EMIS prototype for NMMU*, which answers the research question: *RQ_5: How can a prototype of the sub-system of an EMIS be designed as proof of concept?* The next chapter attempts to evaluate the effectiveness and the efficiency of the EMIS sub-system. Since the design of the EMIS was based on the suggested EIM framework, evaluation of the EMIS will serve as an evaluation of the EIM framework.

Chapter 6: EIM Framework and Data Warehouse Evaluation

6.1 Introduction

Chapter 5 focused on the design and development of two artifacts namely: an EIM framework for HEIs and a sub-system of an EMIS to serve as proof of concept. Evaluation constitutes is an important stage in the development of artifacts. This chapter will therefore answer the research questions:

RQ_6: What methods can be used for the evaluation of the artifacts (framework and prototype)?

RQ_7: Are the artifacts acceptable and usable by the stakeholders?

This purpose of this chapter is to discuss how the two activities of the DSR methodology namely; demonstration of the artifact and evaluation of the artifact (Figure 6.1) were executed. These activities form part of the design cycle of DSR. Evaluation of the artifacts involves determining the extent to which the proposed EIM framework facilitates the integrated management of environmental information at an HEI and extent to which the EMIS sub-system supports the integrated management of environmental information at an HEI.

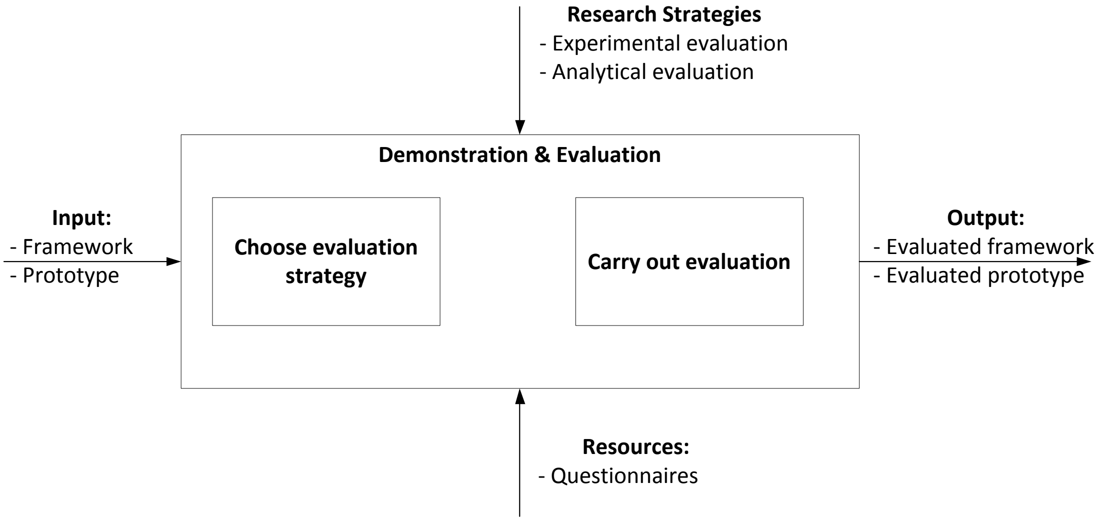


Figure 6.1: Implementation of the Demonstration and Evaluation Activities

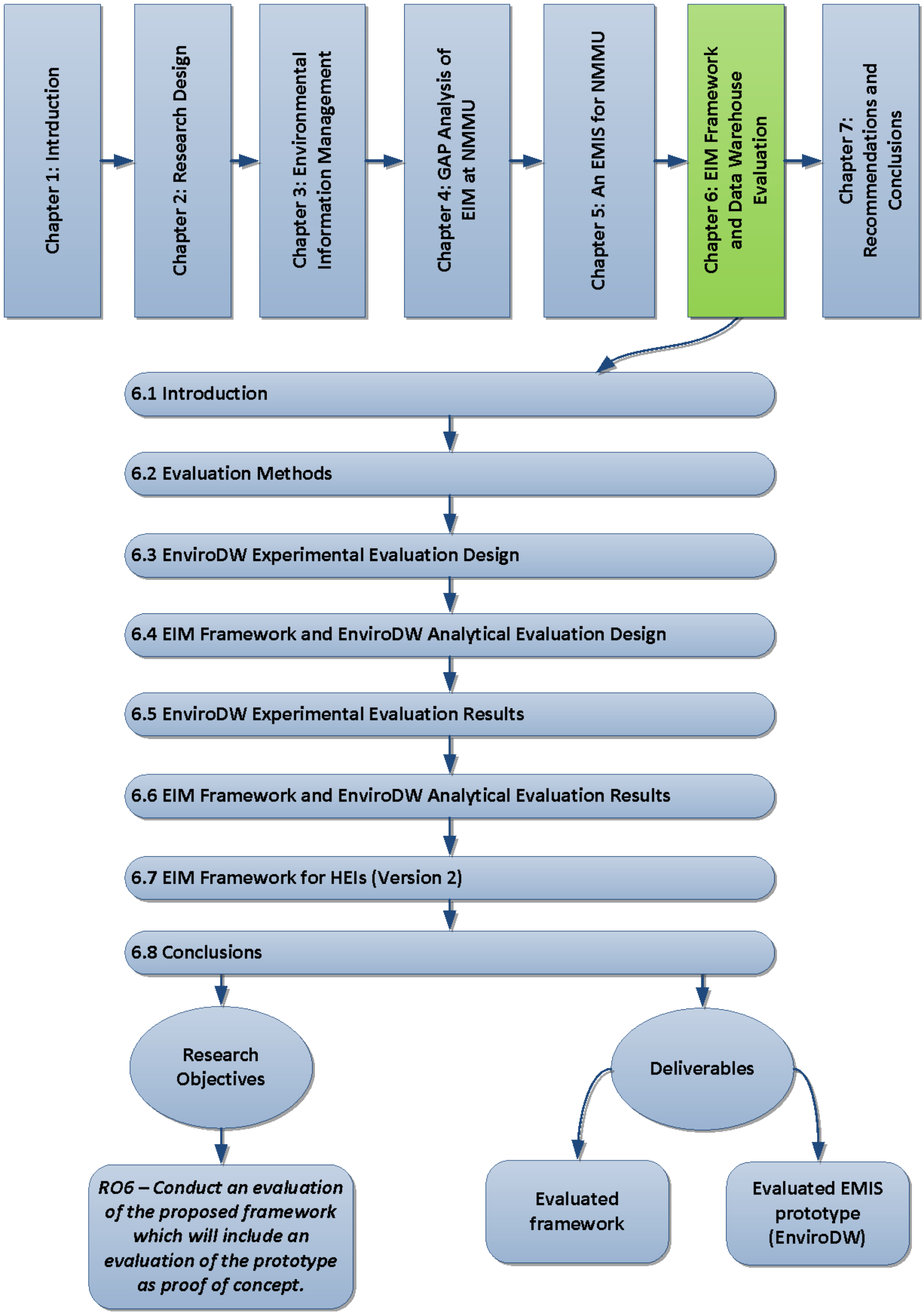


Figure 6.2: Chapter 6 Layout and Deliverables

The chapter will commence with a discussion on how to evaluate the artifacts (Section 6.2). The design of the experimental evaluation of the performance, effectiveness and efficiency, of the data warehouse (Section 6.3) is followed by the design of the analytical evaluation of the theoretical EIM framework and the data warehouse (Section 6.4). Results of the experimental evaluation of the performance of the data warehouse are described (Section 6.5). The results of the analytical evaluation of the theoretical EIM framework (Section 6.6) and the data warehouse (Section 6.7) are presented. Several conclusions and recommendations are then made based on the results of the evaluation (Section 6.8).

6.2 Evaluation Methods

Experimental and analytical evaluation methods (Table 2.1) are used to evaluate the EnviroDW and the EIM framework respectively. Experimental evaluation methods will be used to evaluate EnviroDW in terms of effectiveness and efficiency. The analytical evaluation method will be used to determine the extent to which the EIM framework is complete and acceptable. Feedback from these evaluations could uncover problems and reveal areas of improvement of the artifacts. As a result, the artifacts will be amended so that improved artifacts will be obtained. Table 6.1 shows details of the methods used to evaluate artifacts.

Table 6.1: Evaluation Methods, Artifacts and Evaluation Metrics

Evaluation Method	Artifact	Evaluation Metrics	Evaluator	Research Instrument
Experimental Evaluation (Hevner, et al., 2004)	EnviroDW	Efficiency • Response time Effectiveness • Accuracy (ISO, 2003)	Researcher IS Expert (**P2**)	Development tools
Analytical Evaluation (Hevner, et al., 2004)	EIM framework	Completeness Acceptance	EIM Experts (**P1**,**P2**,**P3**,**P4**)	Questionnaire (Appendix N)
	EnviroDW	Relevance Timely access Ad hoc querying Understandable	Target Users (**P1**,**P2**,**P4**,**P5**)	Questionnaire (Appendix P)

In the experimental evaluation of EnviroDW, evaluation will be made on the efficiency of the ETL processes and the efficiency of ad hoc queries. The experimental evaluation of

EnviroDW also includes the accuracy of the outputs to ad-hoc queries. The analytical evaluation of EnviroDW will consist of a questionnaire in which participants are asked to evaluate EnviroDW on relevance, response time to ad-hoc queries, and how understandable the information provided from ad-hoc queries is. The analytical evaluation will also include the evaluation of the EIM framework by using a questionnaire. These evaluations are interdependent as the evaluation of the data warehouse reflects on the extent to which the proposed EIM framework facilitates the integrated management of environmental information at an HEI.

6.3 EnviroDW Experimental Evaluation Design

The EMIS sub-system (EnviroDW) which was developed to serve as a proof of concept also serves as the foundation on which all the other components of the EMIS can be built. The data warehouse (data layer) will provide data to third party applications that will serve the other components of the EMIS. The evaluation process will establish the feasibility of the data warehouse as the foundation of a comprehensive university-wide EMIS. The evaluation process for the data warehouse will be divided into parts namely:

1. ***Experimental***: The main goal of the experimental evaluation of the derived EnviroDW structure was to ensure that the data warehouse's performance in terms of effectiveness and efficiency in providing support for the analysis of environmental data. This evaluation component will be done by the researcher by testing the performance of the data warehouse by using a sample set of ad hoc queries.
2. ***Analytical***: These include personnel from the Technical Services Department, ICT Services Department and third party applications. Evaluation was done to ensure that business objectives are met and users are given satisfaction.

The data warehouse should ensure that the data contained in the data warehouse is an accurate aggregated representation of the data contained in the respective data sources of the data warehouse. Effectiveness of EnviroDW is evaluated by measuring the quality of the data warehouse to provide accurate data (Section 6.3.1). Hence, effectiveness is measured by accuracy. The EnviroDW is also required to support the efficient analysis of environmental data in terms of the amount of time required to obtain results to ad-hoc queries. Efficiency of the data warehouse is measured in two parts: firstly, by the efficiency of the ETL process in populating the data warehouse structure with source data and the efficiency of the data warehouse's structure in supporting ad-hoc queries compared to the Technical Services Department processes (Section 6.3.2). Therefore, the efficiency of the data warehouse is measured by the response time taken to load source data into the data warehouse and the response time for ad-hoc queries. The data warehouse must be effective in supporting management to efficiently obtain answers to ad-hoc queries.

A set of ad-hoc queries was identified as a representative sample of ad-hoc queries that management would want answers to and are representative of the target user's business goals. (Section 4.5). All eleven queries were used in the efficiency evaluation of EnviroDW. However only query number 6 to 10 were used in the effectiveness evaluation as currently NMMU does not have a method of allocating electricity usage per cost centre (department) so queries 1 to 5 cannot be answered. This is an area that needs to be recommended for improvement. The queries identified are:

1. What is the monthly usage of electricity for '*residences'* in 2013?
2. Which department used the most electricity in 2013?
3. Which department used the least electricity in 2013?
4. What is the average electricity usage for '*residences'* in 2013?
5. What is the total electricity usage for '*residences'* in 2013?
6. What is the monthly usage of electricity for '*Unitas building*' in 2013?
7. Which building used the most electricity in 2013?
8. Which building used the least electricity in 2013?
9. What is the average electricity usage for '*Unitas building*' in 2013?
10. What is the total electricity usage for '*Unitas building*' in 2013?
11. Compare the monthly electricity usages for buildings '*Unitas*','*Veritas*' and '*Melodi*'.

6.3.1 Effectiveness Evaluation

The accuracy of the data warehouse is determined by comparing the observed output of ad hoc queries on the data warehouse and the expected output. A difference between the observed output rows and the expected output rows of a query is determined by the number of rows in the observed output rows that are not in the set of expected output rows. The accuracy of the data warehouse is calculated by using the following equations:

$$X_i = \frac{A_i}{B_i} \qquad \text{Equation 6.1}$$

Where

$X_i = difference\ ratio\ for\ ad\ hoc\ query\ i;$

$A_i = \#\ DW\ ad\ hoc\ query\ output\ rows\ that\ differ\ from\ expected\ for\ query\ i;\ and$

$B_i = \#\ ad\ hoc\ query\ output\ rows\ expected\ for\ query\ i.$

$$Y = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} Bi} \qquad \text{Equation 6.2}$$

Where

$Y = total\ ad\ hoc\ query\ difference\ ratio;$

$A_i = \#\ DW\ structure\ ad\ hoc\ query\ output\ rows\ that\ differ\ from\ expected\ for\ query\ i;$

$B_i = \#\ ad\ hoc\ query\ output\ rows\ expected\ for\ query\ i;\ and$

$n = total\ \#\ ad\ hoc\ queries.$

Output from the set of ad hoc queries is obtained from the data warehouse (EnviroDW) while the typical process applied by the Technical Services Department is used to obtain the expected output rows for the ad-hoc queries. Output obtained by using the data warehouse is obtained by executing the ETL process once to populate the data warehouse with source data. Once the data warehouse is populated, ad hoc querying can be done on the data warehouse to promptly obtain the output.

The current typical process used by the Technical Services Department can be used to obtain the output for the ad-hoc queries. This process involves executing queries on the operational databases that is EnviroDB, Campus Infrastructure and JCBMS DB. In executing these queries, a temporary data store is used to store aggregated data which is then combined to provide output for the ad hoc queries. In comparison, the proposed To-Be data warehouse approach to obtain output for the ad hoc queries extracts data from the various data sources only once, whereas the typical approach requires data to be extracted to a temporary data store every time an ad hoc query needs to be executed.

The query output rows obtained from using the typical Technical Services Department process represents the expected output of the ad-hoc queries considered for this evaluation. The query output rows obtained from the data warehouse approach are compared to the expected output rows. This allows for the calculation of the difference ratio (Equation 6.1) as well as the total difference ratio (Equation 6.2). If the difference ratio is calculated to be zero for an ad-hoc query it can be concluded that the data warehouse is effective based on the accurate ad-hoc query results.

6.3.2 Efficiency Evaluation

EnviroDW is required to support the efficient analysis of electricity and water data in terms of the amount of time required to obtain the results of an ad hoc query. EnviroDW is populated with source data using the described ETL process (Section 5.4). The efficiency of EnviroDW is evaluated by using the response time metric recommended by ISO (2003).

The response time metric requires that the start and end times of the execution process are recorded in order to obtain the time taken. Two different experiments are done to evaluate the efficiency of EnviroDW and the response time metric is used for both experiments. The first experiment involves evaluating the efficiency of the ETL process to populate EnviroDW with source data. The second experiment evaluates the efficiency of EnviroDW in obtaining results of ad hoc queries and this is compared to the typical Technical Services Department process.

The aim of the first efficiency evaluation experiment is to determine whether EnviroDW's ETL process supports the efficient propagation of data from the various sources of data. EnviroDW will typically be updated on a monthly basis since water and electricity data is collected once a month. This data will be also loaded on a monthly basis.

The equation that was used to calculate the efficiency of EnviroDW's ETL processes is presented (Equation 6.3).

$$W_i = |D_i - C_i| \qquad \text{Equation 6.3}$$

Where

$W_i = DW\ Structure\ ETL\ processes\ execution\ time\ for\ month\ i$

$C_i = DW\ Structure\ ETL\ processes\ execution\ start\ time\ for\ month\ i$

$D_i = DW\ Structure\ ETL\ processes\ execution\ end\ time\ for\ month\ i$

The execution times of the ETL processes for a specified number of months are captured in order to derive descriptive statistics of the ETL process. Data for 2012 and 2013 is used for this experiment, this gives a total of 24 months. Based on an ICT Services Department (reasonable) time estimate, a benchmark of ten minutes is used, which means the ETL process is considered to be efficient if the ETL process's execution time of monthly data is less than ten minutes. In addition to capturing the execution times of the ETL processes, the size of the data that was uploaded to the data warehouse will be captured. This allows for the analysis of the effect that the size of data transmitted to the data warehouse has on the execution times.

The second efficiency evaluation experiment involves evaluating the efficiency of EnviroDW. The equations used to calculate the efficiency of EnviroDW are as follows:

$$T = |E_{End} - E_{Start}| \qquad \text{Equation 6.4}$$

Where

$T = total\ DW\ ETL\ processes'execution\ time$

$E_{Start} = DW\ ETL\ processes'execution\ start\ time$

$E_{End} = DW\ ETL\ processes'execution\ end\ time$

$$S_z = (\textstyle\sum_{i=1}^{z} |G_i - F_i|) + T \qquad \text{Equation 6.5}$$

Where

$S_z = cumulative\ DW\ ad\ hoc\ query\ processing\ time\ for\ z\ \#\ ad\ hoc\ queries$

$F_i = DW\ ad\ hoc\ query\ i\ execution\ start\ time$

$G_i = DW\ ad\ hoc\ query\ i\ execution\ end\ time$

$T = total\ DW\ ETL\ processes'execution\ time$

$$R_z = \sum_{i=1}^{z}(|I_i - H_i| + |K_i - J_i|) \quad \text{Equation 6.6}$$

Where

$R_z = cumulative\ typical\ TSD\ process\ ad\ hoc\ query\ processing\ time\ for\ z\ \#\ ad\ hoc\ queries$

$H_i = typical\ TSD\ process\ source\ query\ execution\ start\ time\ for\ ad\ hoc\ query\ i$

$I_i = typical\ TSD\ process\ source\ query\ execution\ end\ time\ for\ ad\ hoc\ query\ i$

$J_i = typical\ TSD\ process\ ad\ hoc\ query\ i\ execution\ start\ time$

$K_i = typical\ TSD\ process\ ad\ hoc\ query\ i\ execution\ end\ time$

6.4 EIM Framework and EnviroDW Analytical Evaluation Design

The design of the evaluation of the EIM framework for HEIs is described (Section 6.4.1). The design of the analytical evaluation of EnviroDW is presented (Section 6.4.2).

6.4.1 EIM Framework Evaluation

An expert review is used to evaluate the theoretical EIM framework for HEIs. The expert review will consist of a questionnaire which will evaluate the theoretical components and the guidelines for the components of the EIM framework (Appendix N). Participants for the expert review will be personnel that are directly responsible for the management of environmental information and personnel that already use some tools for the management of environmental information at NMMU.

An invitation to participate in the evaluation will be sent out as emails. Upon acceptance follow-up emails will be sent in which the following documents will be attached: consent form with a cover letter (Appendix O), the EIM Framework and the evaluation questionnaire which also has a brief explanation of the purpose of the evaluation (Appendix N). The participants will be requested to read through the documentation before the evaluation sessions in order to prepare for the sessions and to be able answer the questions regarding the EIM framework and the guidelines. This will keep interviews focused and short with a maximum of 45 minutes per session. The questionnaire (Appendix N) addresses two sets of questions. The first are questions based on the proposed guidelines and the participants will be asked to agree or disagree with each guideline. The second set of questions addresses the EIM framework for HEIs as a whole.

6.4.2 EnviroDW Analytical Evaluation

The degree of satisfaction of the stakeholder is investigated to determine the extent to which the EnviroDW fulfils the stakeholders needs. Satisfaction will be measured by collecting data about stakeholders' perceptions of the data warehouse. Participants (stakeholders) for this evaluation will include personnel from the Technical Services Department and the ICT Services Department at NMMU. These participants are people who are directly responsible for the management of environmental information and some use tools for the management of environmental information at NMMU. Participants will be asked to use the data warehouse to perform ad-hoc queries which they helped identify in the requirements gathering phase (Section 4.5). Participants will be supplied with a post-test questionnaire (Appendix P).

6.5 EnviroDW Experimental Evaluation Results

The effectiveness and efficiency evaluation was done as described in Section 6.3. The results were captured for the effectiveness evaluation (Section 6.5.1); the efficiency evaluation (Section 6.5.2) of EnviroDW is described.

6.5.1 Effectiveness Evaluation Results

The number of output rows for each ad-hoc query executed by using the typical Technical Services department process were captured and compared to the number of output rows obtained from EnviroDW after it was populated by the ETL process. The results of the effectiveness of EnviroDW (Table 6.2) show a difference ratio, $\boldsymbol{X_i}$ (Equation 6.1), for each ad-hoc query that is between the range of 0 and 1. It was observed that 40% (n=4) had a difference ratio of 0 and 10% (n=1) with a difference ratio of 0.8. Fifty percent (50%, n=5) ad-hoc queries had a difference ratio that was above 0.1, these queries are identified as queries 4, 5, 6, 9 and 10.

Table 6.2: The Effectiveness Evaluation Results

Query Number ($\boldsymbol{i}$)	Number of Expected Rows ($\boldsymbol{B_i}$)	Number of Observed Rows	Number of Rows Different From Expected ($\boldsymbol{A_i}$)	Difference Ratio ($\boldsymbol{X_i}$)	Time to complete (seconds)
1	12	12	1	0.083333	0.00
2	1	1	0	0	0.00
3	1	1	0	0	0.00
4	1	1	1	1	0.00
5	1	1	1	1	0.00
6	12	12	4	0.333333	0.00
7	1	1	0	0	0.00
8	1	1	0	0	0.00
9	1	1	1	1	0.00
10	1	1	1	1	0.00

A desirable difference ratio should be close to 0, in this case, 60% (n=6) are close to zero with a ratio difference below 0.5 while 40% (n=4) ad hoc queries have a difference ratio that is equal to 1. This might be seen as a negative result, however, the difference is mainly due to the fact that the ETL process of EnviroDW extrapolates and approximates missing values from the source data and this contributes to the 40% ad-hoc queries with difference ratios that are equal to 1. Hence, a total difference ratio (Equation 6.2) of 0.28125 was observed. This means that 28% of the ad-hoc queries were found to be different from the expected ad hoc query outputs.

6.5.2 EnviroDW ETL Efficiency Results

The response times of the execution of the ETL processes for the monthly population of EnviroDW (Equation 6.3) for 4 subsequent years were analysed (Table 6.3). In addition to the response times, the total number of rows that was transferred during the execution of the ETL processes for each subsequent month were analysed.

Analysis of the evaluation results illustrated that there is a linear relationship between the total data populated into EnviroDW and the ETL response time. Jorg and Dessloch (2009) discuss and show that an incremental loading ETL process has a linear relationship to the efficiency of updating data in the data warehouse. EnviroDW's performance closely resembles a linear relationship to incrementally updating data in a data warehouse (Figure 6.3). The line of best fit has R^2 equal to 0.9938, this value shows how well the the data closely conforms to a linear relationship. The closer the value is to 1 the more the data reflects a linear relationship. Figure 6.4 shows the series of the number of transferred rows and the series of the response time as the number of months increased. The number of rows transferred varied from month to month however, a linear relationship of the response time was maintained over the months.

Table 6.3: EnviroDW's ETL Process Response Times and Number of Rows Transferred

Year	Month	Month(*i*)	# of Rows Transferred Monthly	Total Rows in EnviroDW	Time (sec)
2010	January	1	431	0	3,922
2010	February	2	431	431	4,828
2010	March	3	509	862	5,812
2010	April	4	430	1371	6,219
2010	May	5	515	1801	7,438
2010	June	6	373	2316	7,906
2010	July	7	429	2689	8,922
2010	August	8	517	3118	9,828
2010	September	9	432	3635	10,703
2010	October	10	432	4067	11,375
2010	November	11	457	4499	12,797
2010	December	12	265	4956	12,657
2011	January	13	540	5221	13,844
2011	February	14	450	5761	14,391
2011	March	15	452	6211	15,625
2011	April	16	434	6663	16,093
2011	May	17	538	7097	16,969
2011	June	18	451	7635	17,89
2011	July	19	365	8086	18,781
2011	August	20	538	8451	19,797
2011	September	21	363	8989	20,453
2011	October	22	431	9352	21,171
2011	November	23	432	9783	21,969
2011	December	24	260	10215	21,969
2012	January	25	446	10475	23,765
2012	February	26	449	10921	23,75
2012	March	27	359	11370	24,359
2012	April	28	442	11729	25,375
2012	May	29	452	12171	26,047
2012	June	30	364	12623	27,391
2012	July	31	447	12987	27,875
2012	August	32	449	13434	28
2012	September	33	448	13883	29,203
2012	October	34	506	14331	30,109
2012	November	35	449	14837	31,14
2012	December	36	275	15286	31,359
2013	January	37	257	15561	31,735
2013	February	38	358	15818	34,328
2013	March	39	450	16176	34,531
2013	April	40	537	16626	36,938
2013	May	41	362	17163	36,484
2013	June	42	453	17525	38,25
2013	July	43	250	17978	37,609
2013	August	44	275	18228	39,14
2013	September	45	362	18503	40,57
2013	October	46	450	18865	41,65
2013	November	47	537	19315	43,04
2013	December	48	362	19852	44,28

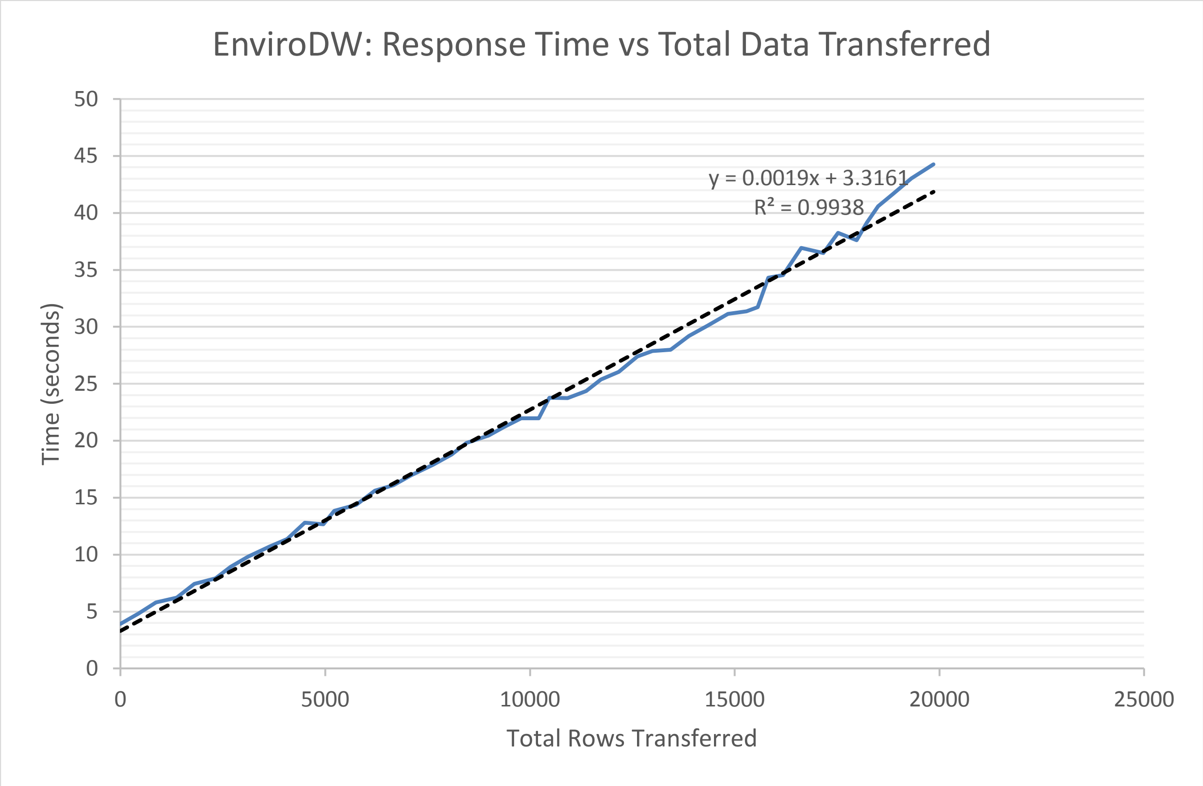


Figure 6.3: Relationship between Total Data Transferred and ETL Response Time

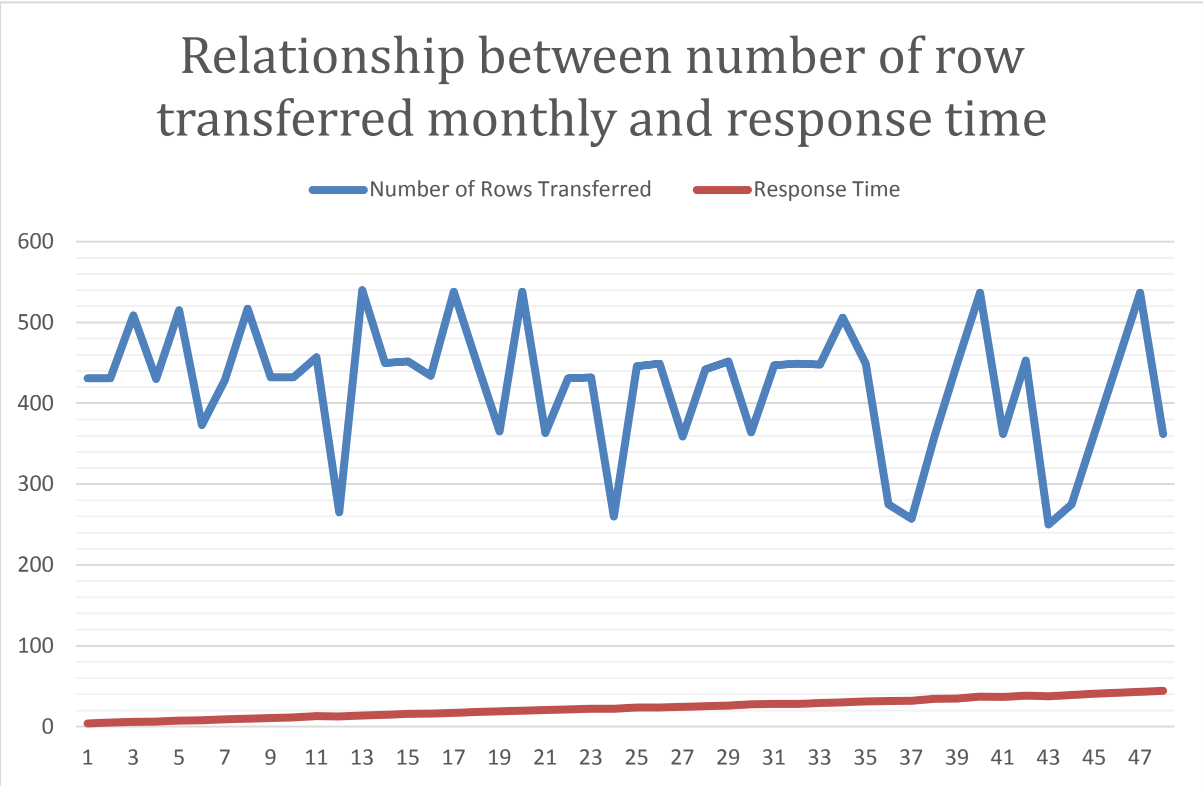


Figure 6.4: Relationship between Monthly Data Transferred and ETL Response Time

6.6 EIM Framework and EnviroDW Analytical Evaluation Results

Evaluations of the EIM framework for HEIs and EnviroDW were done as described in Section 6.4. The results are discussed in the following sub-sections.

6.6.1 EIM Framework Evaluation Results

Results of the expert review of the EIM Framework for HEIs were captured (Table 6.4). A tick (✓) indicates that the participant agreed with the guideline while an 'X' indicates that the participant disagreed with the guideline. Participants were also asked open-ended questions which evaluated the EIM framework for HEIs as a whole. All participants think that the proposed EIM framework for HEIs can be useful to HEIs.

All participants agreed with guidelines G1 to G13 which are guidelines of components under the sustainability strategy cluster, the managerial services cluster and the contribution services cluster (Table 6.4). However, participant **P1** disagreed with guidelines G14 and G15 under the distribution services cluster. Participant **P1** explained that these guidelines can pose a security risk and can cause negative publicity for the HEI. In addition, the participant indicated that there is risk of misinterpretation of the environmental information.

> Participant **P1** said "*making all the information available to the public and external parties may present a security risk to the HEI. Access should be granted upon request with approved, restricted access in order to protect the HEI from bad/negative publicity etc. or from misinterpretation of the available information.*"

Participant **P1** disagreed that the EIM framework was complete. The participant suggested adding a new cluster which she termed as a 'Motivational Cluster'.

> Participant **P1** explains further by saying, "*a MOTIVATIONAL CLUSTER is a forecast for each building/unit of what its environmental usages and tolerances should be. This will add to the functionality of comparing actual vs planned usage.*"

Table 6.4: Verification of Guidelines per Participant

No.	Guidelines	Participants P1	P2	P3	P4
Sustainability Strategy Cluster					
G1	A gap analysis can be used to identify areas for improvement in environmental information management processes.	✓	✓	✓	✓
G2	Top management support is important for the success of EIM efforts in HEIs.	✓	✓	✓	✓
G3	Environmental indicators for HEIs must be identified and prioritised at a strategic level.	✓	✓	✓	✓
G4	EIM efforts need to be aligned with the strategic goals of the HEI.	✓	✓	✓	✓
Contribution Services Cluster					
G5	There is need for centralised storage of environmental information and support for legacy systems in an HEI.	✓	✓	✓	✓
G6	HEIs need a computerised process for capturing of environmental data (e.g. water and electricity meter readings).	✓	✓	✓	✓
G7	HEIs need to automate environmental data collection processes where possible (e.g. sensor based collection; smart meters).	✓	✓	✓	✓
G8	It is important that HEIs perform quality assurance (data validation and verification) on environmental data collected.	✓	✓	✓	✓
Management Services Cluster					
G9	Environmental sustainability reporting should be automated wherever possible.	✓	✓	✓	✓
G10	Data analytics and monitoring of EIM should be provided.	✓	✓	✓	✓
G11	Simplified aggregated data summaries of EIM must be available.	✓	✓	✓	✓
G12	Data processing should be provided (Ad-hoc querying, modelling of data and decision support).	✓	✓	✓	✓
G13	There should be support for allocating resource usage to buildings and campus facilities such as sports grounds and departments.	✓	✓	✓	✓
Distribution Services Cluster					
G14	There should be support for public awareness and outreach by allowing access to environmental information by HEI stakeholders (student, staff, board members, management, government bodies etc.).	X	✓	✓	✓
G15	Third party applications should be granted access to environmental information where possible.	X	✓	✓	X

Participant **P2** agreed that the framework was complete however, the participant suggested that the quality assurance component should examine all data sources. The participant highlighted that quality assurance is one of the most important components for EIM.

> Participant **P2** said, *"The QA layer should examine all data sources, not just the human captured ones. It should also generate alerts to maintance staff for meters that are not working so that they can resolve issues."*

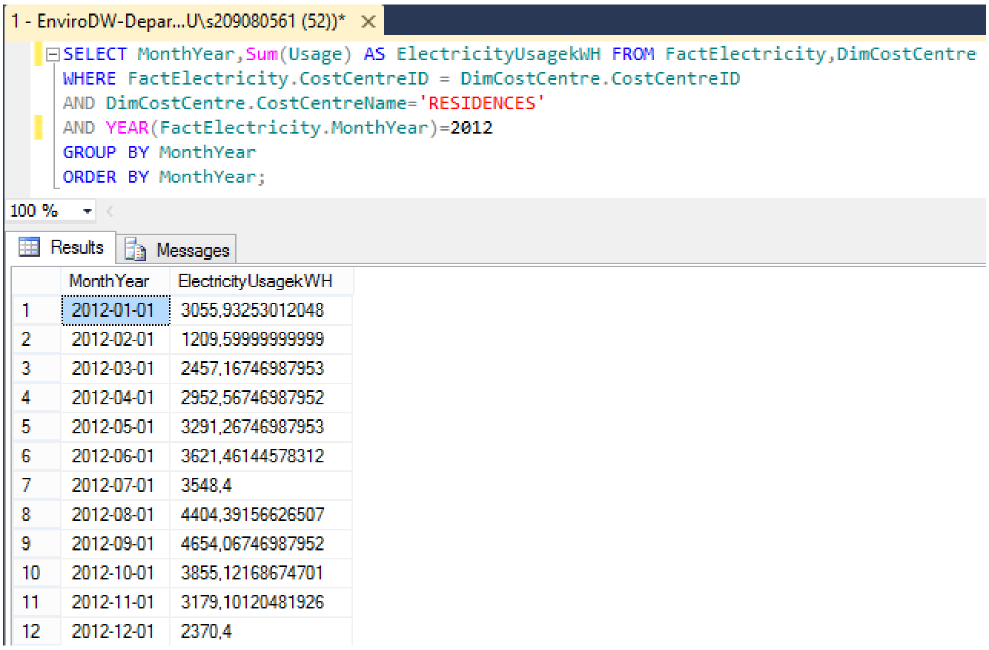
Participant P2 also mentioned that they recently discovered a smart meter that had been providing the same reading for months. In addition, participant **P2** said, *"with data warehouses it is garbage in garbage out."* This means that if data provided to the data warehouse is not accurate this will result in erroneous information.

> Participant **P2** also gave recommendations regarding the EIM framework saying, *"Real-time data capturing is essential for monitoring live and detecting possible data errors (e.g. meters not working) to keep the results accurate."*

6.6.2 EnviroDW Analytical Evaluation Results

Evaluators of the EnviroDW were required to use EnviroDW to perform ad-hoc queries. Ad-hoc queries 1-10 from Section 6.3 were implemented and the evaluators chose any number of queries to perform at random (Appendix Q). On average an evaluator performed four queries and some edited the SQL queries to obtain the results for other years or other locations or departments. Figure 6.5 shows the outcome of the ad-hoc query for determining the monthly electricity usage for the '*Residences'* in the year 2012. The allowed the researcher to observe the type of data, accuracy of the data and the performance of the EnviroDW.

In an attempt to show the evaluators the underlying data that EnviroDW could supply a visualisation tool was used. This allowed the evaluators to get a holistic view of the information in the EnviroDW. Tableau Desktop is the visualisation tool that was used. The tool produces interactive data visualisation on business intelligence. Figure 6.6 shows the electricity usage of the ICT Department across the university. Figure 6.6 also shows the electricity usage of the two locations were the ICT Department is located.



1 - EnviroDW-Depar...U\s209080561 (52))*

```sql
SELECT MonthYear,Sum(Usage) AS ElectricityUsagekWH FROM FactElectricity,DimCostCentre
WHERE FactElectricity.CostCentreID = DimCostCentre.CostCentreID
AND DimCostCentre.CostCentreName='RESIDENCES'
AND YEAR(FactElectricity.MonthYear)=2012
GROUP BY MonthYear
ORDER BY MonthYear;
```

100 %

Results | Messages

	MonthYear	ElectricityUsagekWH
1	2012-01-01	3055,93253012048
2	2012-02-01	1209,59999999999
3	2012-03-01	2457,16746987953
4	2012-04-01	2952,56746987952
5	2012-05-01	3291,26746987953
6	2012-06-01	3621,46144578312
7	2012-07-01	3548,4
8	2012-08-01	4404,39156626507
9	2012-09-01	4654,06746987952
10	2012-10-01	3855,12168674701
11	2012-11-01	3179,10120481926
12	2012-12-01	2370,4

Figure 6.5: Outcome of an Ad-hoc Query in MS SQL Server 2012

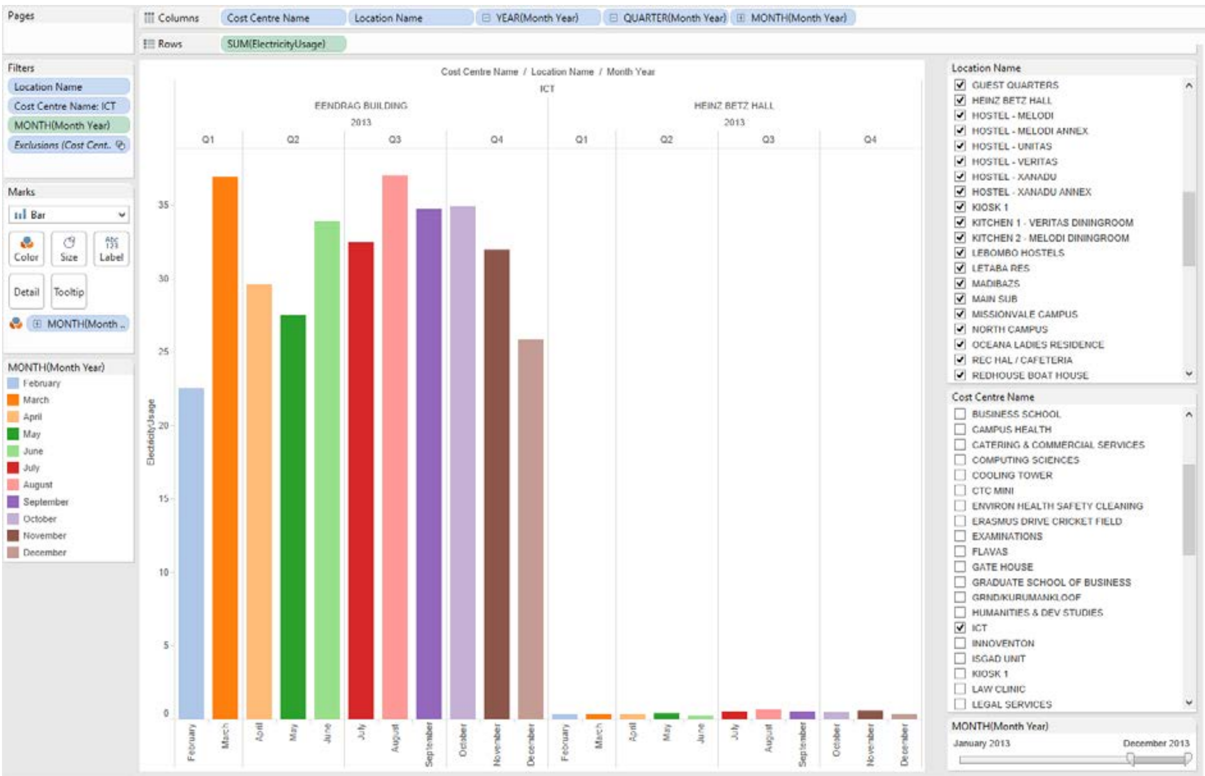


Figure 6.6: Electricity Usage for Cost Centre ICT Viewed in Tableau

Results of some of the questions of the EnviroDW evaluation questionnaire were captured (Table 6.4). A tick (✓) indicates that the participant agreed with the statement while an "X" indicates that the participant disagreed with the statement. All participants indicated that they agreed with all statements. Participants P1 and P2 indicated that currently at NMMU, manually collected data cannot be used to obtain the kind of information that EnviroDW provides. Participants P4 and P5 could not agree or disagree with the availability of the kind of information provided by EnviroDW. Instead they said:

- Participant **P4** said, *"One can probably get all this information but it would require doing a lot of calculations and it is difficult to estimate the effort and the time it would take."*
- Participant **P5** said, *"Some of the information such as usage per month or per building can be found easily, however, information such as the building using the least or most electricity cannot be found currently."*

Table 6.5: EnviroDW Evaluation Results to Questionnaire (Appendix P)

Statements	Participants			
	P1	P2	P4	P5
1. Information provided by the data warehouse is relevant to me.	✓	✓	✓	✓
2. The data warehouse provides timely access to information.	✓	✓	✓	✓
3. It is easy to get access and answers to ad hoc queries.	✓	✓	✓	✓
4. Information provided by the data warehouse is understandable.	✓	✓	✓	✓

All participants offered future recommendations for the data warehouse. The recommendations are:

- Participant **P1** said, *"The extent of the DW capabilities depends on the data captured/available. Ultimately it would be good to get real-time data refreshed on a daily basis."*
- Participant **P2** said, *"Allocation of departments to meter sites is dependent on proper ERP space data. Inaccurate meter reading is also a concern."*

6.7 EIM Framework for HEIs (Version 2)

The former proposed EIM framework for HEIs (Section 3.6) only has the quality assurance component associated with manual distributed entry of data. However, results show that (Section 6.5) quality assurance needs to be done on all data sources. Therefore the updated version of the EIM framework for HEIs places the quality assurance component between the ETL component and all the data sources (Figure 6.7). Results also highlighted that there is need for alerting maintenance staff about meters that are not working as their not working affects the accuracy of the data warehouse. This is an important aspect that needs to be added into the EIM framework for HEIs (Figure 6.7). Adding this component will also add a new guideline under the contribution cluster to: *G9 – There is need to generate alerts to maintenance staff for meters that are not working so that they can fix the meters.*

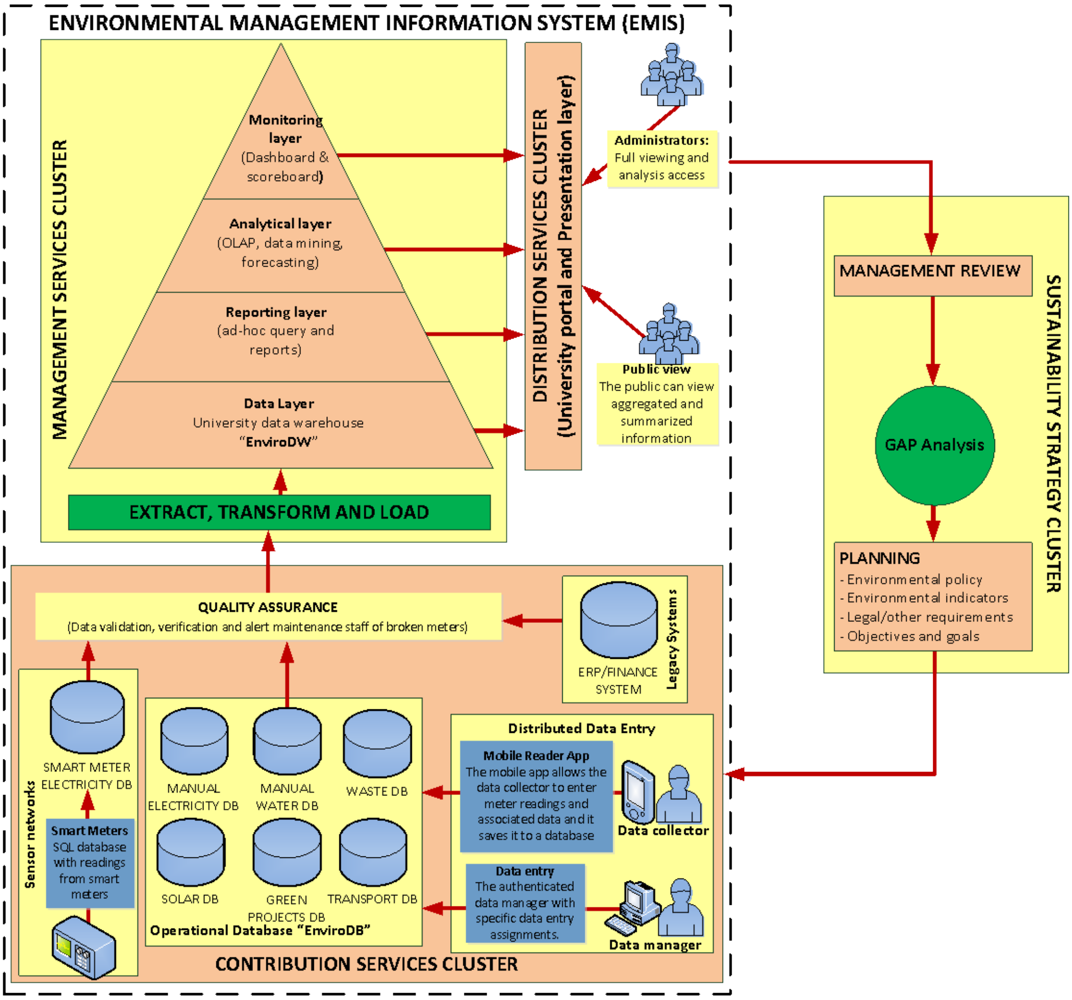


Figure 6.7: EIM Framework for HEIs (Version 2)

Results from the evaluation of the EIM framework also suggested adding a motivational cluster in which a building can set a target/goal for maximum resource usage. This should form part of the planning component in the sustainability strategy cluster of the EIM framework for HEIs. By adopting this with guideline G4 into EIM efforts, a department can set a target maximum resource usage for itself and this can be shown as actual usage against planned usage in the monitoring layer. With these improvements to the EIM framework for HEIs, HEIs will be able to effectively and efficiently manage their environmental information which can lead to effective and efficient reporting of environmental information. Table 6.6 shows the updated sixteen guidelines for the components of EIM framework for HEIs.

Table 6.6: Guidelines for the Components of the EIM Framework for HEIs (Version 2)

No.	Guidelines
Sustainability Strategy Cluster	
G1	A gap analysis can be used to identify areas for improvement in environmental information management processes.
G2	Top management support is important for the success of EIM efforts in HEIs.
G3	Environmental indicators for HEIs must be identified and prioritised at a strategic level.
G4	EIM efforts need to be aligned with strategic goals of the HEI.
Contribution Services Cluster	
G5	There is need for centralised storage of environmental information in an HEI.
G6	HEIs need a computerised process for capturing environmental data (e.g. water and electricity meter readings).
G7	HEIs need to automate environmental data collection processes where possible (e.g. sensor based collection; smart meters).
G8	It is important that HEIs perform quality assurance (data validation and verification) on environmental data collected.
G9	There is need to alert maintenance staff for meters that are not working so that they can fix the meters
Managerial Services Cluster	
G10	Environmental sustainability reporting should be automated wherever possible.
G11	Data analytics and monitoring of EIM should be provided.
G12	Simplified aggregated data summaries of EIM must be available.
G13	Data processing should be provided (Ad-hoc querying, modelling of data and decision support).
G14	There should be support for allocating resource usage to buildings and campus facilities such as sports grounds and departments.
Distribution Services Cluster	
G15	There should be support for public awareness and outreach by allowing access to simplified aggregated data summaries of system data for access by HEI stakeholders (student, staff, board members, management, government bodies etc.).
G16	Third party applications should be granted access to environmental information where possible.

6.8 Conclusions

This chapter successfully addressed research question RQ_6*: What methods can be used for the evaluation of the artifacts (framework and prototype)?* The experimental and analytical evaluation methods were used for evaluating EnviroDW and the EIM framework for HEIs.

The first set of evaluations was an experimental evaluation to determine the performance (effectiveness and efficiency) of a component of the EIM framework namely the data warehouse (EnviroDW). The accuracy of the data warehouse in answering ad hoc queries was determined and the difference ratio was calculated to be 0.28125. This means that only 28% of the ad hoc queries were found to be different from the expected ad hoc query outputs. Evaluation of the efficiency of the data warehouse's ETL processes showed that the data warehouse's efficiency is of good standard as Jorg and Dessloch (2009) showed that there needs to be a linear relationship between the data transferred and the response time.

The second set of evaluations was the evaluation of the theoretical EIM framework for HEIs. The theoretical framework was evaluated by four experts. In this evaluation experts answered a questionnaire indicating whether they agreed or disagreed with a guideline that corresponded to a component of the framework. All participants agreed with at least 12 of the EIM guidelines and confirmed that the EIM framework for HEIs is complete. One participant indicated concern about the security of the institution if environmental information were published. Another participant recommended modifying a component to include quality assurance of all source data and to alert the maintenance staff regarding broken meters. The EIM framework was modified to incorporate these recommendations.

A third set of evaluations evaluated the EnviroDW from the user's perspective. Generally, all users indicated that the EnviroDW will be useful to an HEI and it would timeously provide information that currently HEIs might not have access to. The chapter also successfully addressed the seventh research question RQ_7*: Are the artifacts acceptable and usable by the stakeholders?* The results from the evaluation of EnviroDW concluded that the data warehouse is acceptable but data from the sources needs to be accurate and accessible for the data warehouse to provide valuable information. The results from the evaluation of the EIM framework highlighted that the framework is acceptable and will be useful to HEIs.

The next chapter offers some recommendations and conclusions drawn from the study. The research objectives achieved will be illustrated and the significant theoretical and practical contributions made in this study will be described.

Chapter 7: Recommendations and Conclusions

7.1 Introduction

Environmental sustainability in HEIs has become an issue of global concern. A combination of the realisation of the enormous negative impact that the various activities and operations at HEIs have on the environment and the pressure from government, environmental protection agencies and HEI stakeholders has resulted in HEIs taking action to reduce their negative environmental impact. For example, In the USA, the Environmental Protection Agency (EPA) holds HEIs to the same standards as industry in terms of environmental sustainability (Savely, et al., 2007). In addition, the South African Department of Higher Education and Training on 9 June 2014 issued a report that stipulates that from 2015 HEIs in South Africa should start reporting on environmental sustainability.

Literature shows that EMIS and EIM forms the backbone of any environmental management efforts (Jones, et al., 2011; Disterheft, et al., 2012). However, currently there is limited formal guidance in establishing integrated, effective and efficient EIM processes that are tailored for HEIs. HEIs and pioneers in this domain are still experimenting to find the most effective system to use for EIM, hence manual systems are still used at some HEIs.

This research study focused on the development of two artifacts: a framework to guide HEIs to establish integrated, effective and efficient EIM processes and an EMIS prototype to serve as the proof of concept. Two versions of the EIM framework for HEIs have been proposed (Section 3.6 and Section 6.7). The EIM framework illustrates the relationships between the components and also provides a set of guidelines for the EIM components.

This chapter focuses on the communication activity of the DSR methodology. The communication activity communicates the research contributions. This activity forms part of the rigor cycle of the DSR methodology. The chapter layout is shown for this chapter in Figure 7.1. A discussion on the research objective that were achieved shows the research progress and verifies whether each research objective was achieved and how it was achieved (Section 7.2). The theoretical and practical research contributions of this study are highlighted (Section 7.3). A number of limitations and problems were encountered during the progress of the study (Section 7.4). Recommendations and future research are proposed (Section 7.5). The key contributions of this study are summarised in Section 7.6.

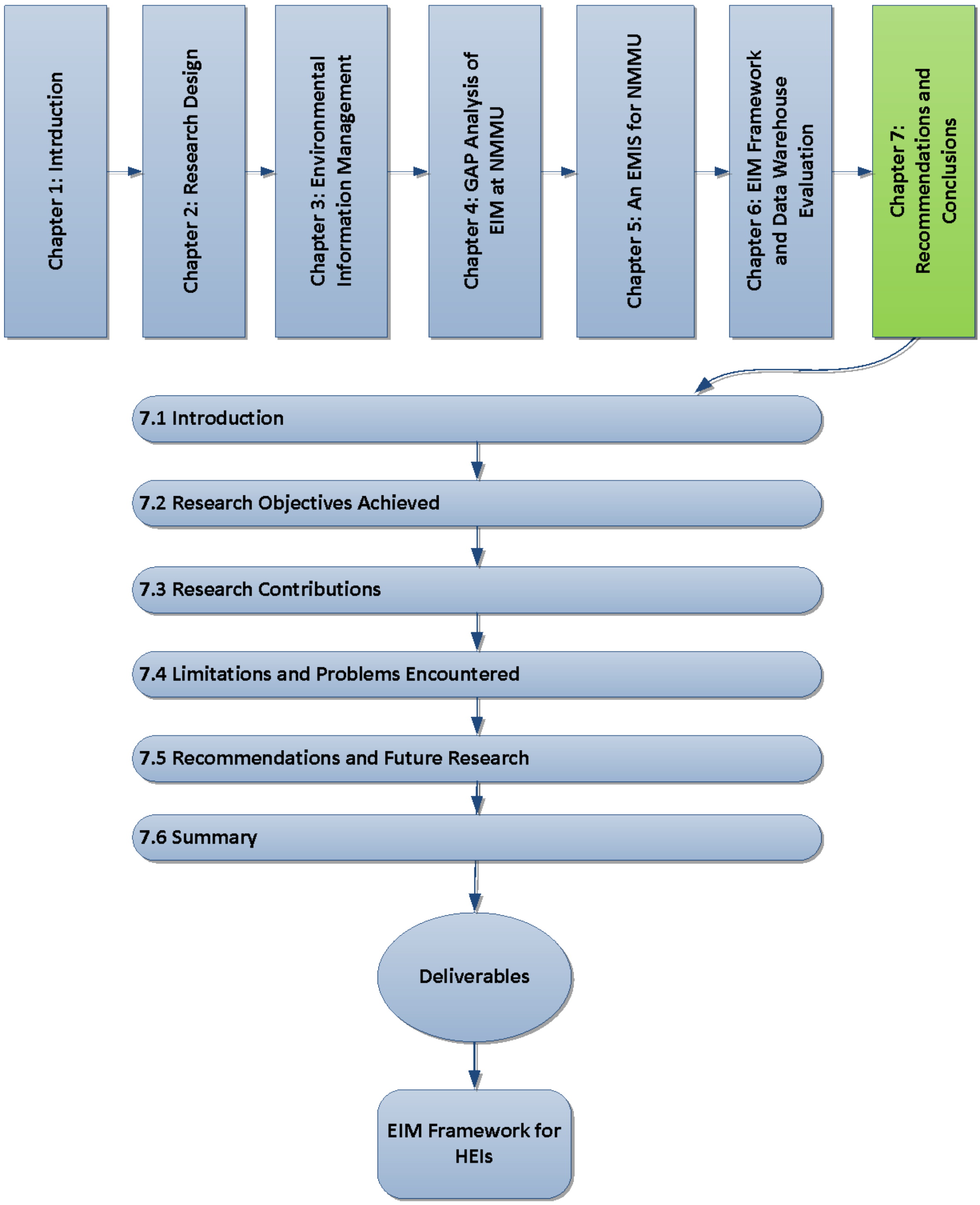


Figure 7.1: Chapter 7 Layout

7.2 Research Objectives Achieved

The main objective of this study was: *To propose and develop a framework that supports the effective and efficient management of environmental information in HEIs.* Six secondary research objectives (ROs) were identified in order to achieve the main objective, namely:

> RO1: Determine the types of IT solutions that are used in Environmental Management in organisations and HEIs.
>
> RO2a: Identify the components of a framework for Environmental Information Management in HEIs.
>
> RO2b: Design a framework for Environmental Information Management in HEIs.
>
> RO3: Analyse the As-Is processes and data stores at NMMU which are related to Environmental Information Management.
>
> RO4: Propose the To-Be processes and data stores for the management of environmental information at NMMU.
>
> RO5: Develop and implement an EMIS prototype for NMMU.
>
> RO6: Conduct an evaluation of the proposed framework which will include an evaluation of the prototype as proof of concept.

Different research questions were created to address the relevant research objectives. The main research question of this study was: "*What are the components of a framework that supports the effective and efficient management of environmental information at HEIs?*" Table 7.1 illustrates the secondary research questions which were derived from the main research question, the research objectives and the relevant chapters where these were addressed.

Table 7.1: Research Questions and Chapters Addressing the Questions

Research Questions		Chapter	Research Objective
RQ_1	*What types of IT solutions are used to aid Environmental Information Management efforts in organisations and HEIs?*	Chapter 3	RO1
RQ_2	*How can a framework for environmental information management at HEIs be designed?*	Chapter 3	RO2a and RO2b
RQ_3	*What are the As-Is processes and data stores at NMMU which are related to environmental information?*	Chapter 4	RO3
RQ_4	*What are the To-Be processes for the management of environmental information at NMMU?*	Chapter 4	RO4
RQ_5	*How can a prototype for the sub-system of an EMIS be designed as proof of concept?*	Chapter 5	RO5
RQ_6	*What methods can be used for the evaluation of the artifacts (framework and prototype)?*	Chapter 6	RO6
RQ_7	*Are the artifacts acceptable to the stakeholders?*	Chapter 7	RO6

The first research objective (RO1) was achieved as an investigation into literature revealed the various IT solutions that are used in EIM efforts, namely: GIS, EIS, EMIS and EDSS (Section 3.3). Chapter 3 also managed to establish the importance of EMIS in EIM and revealed some of the common components of EMIS tools. The first part of the second research objective (RO2a) was achieved as the components of the EIM framework were identified (Table 7.2).

The second part of the second research objective (RO2b) required that an EIM framework for HEIs be designed. This objective was achieved as the EIM framework for HEIs, which consists of a diagram and guidelines that accompany it, was designed in Section 3.2 and updated in Section 6.7. The third research objective (RO3) was achieved as the As-Is processes and data stores at NMMU which related to EIM were determined (Section 4.6). The As-Is processes and data stores for electricity, renewable energy, water, transport and commuting, waste management and educational programmes were clearly determined. The EIM framework was applied at NMMU in order to analyse the current As-Is processes and to design the desired To-Be processes for the case study this led to the achievement of the fourth research objective. The fourth research objective (RO4) was achieved because To-Be processes and data stores at NMMU which related to EIM were designed (Section 4.7).

Table 7.2: Components of an EIM framework for HEIs

Category	Components
Sustainability Strategy Cluster	Management Review
	Planning
	Gap Analysis
Contribution Services Cluster	Operational Data Store (ODS) : operational database "EnviroDB"
	Distributed data entry
	Sensor networks
	Legacy systems
	Quality assurance (data validation and verification)
Management Services Cluster	Monitoring Layer
	Analytical Layer
	Reporting Layer
	Data Layer (Data Warehouse - EnviroDW)
	Extract, Transform and Load (ETL)
Distribution Services Cluster	University portal and presentation layer

The fifth research objective (RO5) was also achieved because a prototype of the EMIS for NMMU was developed (Chapter 5). The prototype of the EMIS was a sub-system of the EMIS. The sub-system consisted of an operational database (EnviroDB) and a data warehouse (EnviroDW). This also allowed for the sixth research objective (RO6) to be achieved. The sixth research objective was achieved in two parts. The first part was determining the methods which could be used for the evaluation and this part was achieved in Section 6.2. The second part involved determining if the artifacts (framework and prototype) were acceptable. This was achieved, as the evaluation generally indicated that the framework and prototype were acceptable both from an expert's view and from an experimental view (Section 6.5 and Section 6.6).

7.3 Research Contributions

The achievement of the research objectives allowed for significant research contributions. The research contributions from this study include both theoretical and practical contributions. Section 7.3.1 discusses the theoretical contributions of this study while Section 7.3.2 discusses the practical contributions of this study.

7.3.1 Theoretical Contribution

Theoretical contributions of this study are illustrated by using the theoretical findings of this study. The theoretical contributions that were identified after a literature study are:

- The list of components of a EIM framework for HEIs (Chapter 3);
- the EIM Framework for HEIs (Chapter 3);
- the guidelines of the components of the EIM framework for HEIs (Chapter 3).

A rigorous literature review revealed that there are four common components of an EMIS, namely: data collection, central data storage and access, data processing and monitoring and reporting. An investigation into past, current and future implementations of EMISs and EISs also revealed that the four common components can be categorised as service clusters, namely: the contribution services cluster, the management service cluster and the distribution service cluster. Literature and the investigation into implementation of EMISs and EISs showed that these clusters can be divided to produce the best-practise components of EMISs (Table 7.2).

An investigation into HEIs frameworks resulted in the identification of the PMS framework. The similarity of the components of PMS framework the components of an EMIS showed that the PMS framework could be adapted for EIM. The components of the PMS and the EMIS were merged and renamed to produce the components of the EIM framework. On inspection the EIM framework was found not to be complete and an investigation into EMS showed that the EIM framework lacked a component which was termed the sustainability strategy cluster. Hence, some of the components from the EMS were added to the EIM framework to produce a comprehensive EIM framework for HEIs which consists of four clusters, namely: the contribution service clusters, the management services cluster, the distribution services cluster and the sustainability strategy cluster (Table 7.2).

Figure 7.2 shows the relationships between the components of the EIM framework. A gap analysis is the first step in establishing EIM processes at an HEI. The gap analysis is used to determine the current state of EIM processes at an HEI and then management and the institution's staff can plan for improvement (the desired To-Be state). The institution also needs to identify and prioritise environmental indicators based on its chosen environmental policy and the legal requirements that the institution must comply with. EIM processes are then established for the contribution of environmental data from various data stores. The EIM framework suggests comprehensive data acquisition processes that cater for data from manual meters, legacy systems, disparate databases and sensor networks. These best practice EIM processes can dramatically improve the efficiency and availability of environmental data. The collected data can then be processed and analysed to provide reports, aggregated data and monitoring capability. Data can also be made available to HEI stakeholders. Management can review progress and plan for improvement. This results in a continual EIM process.

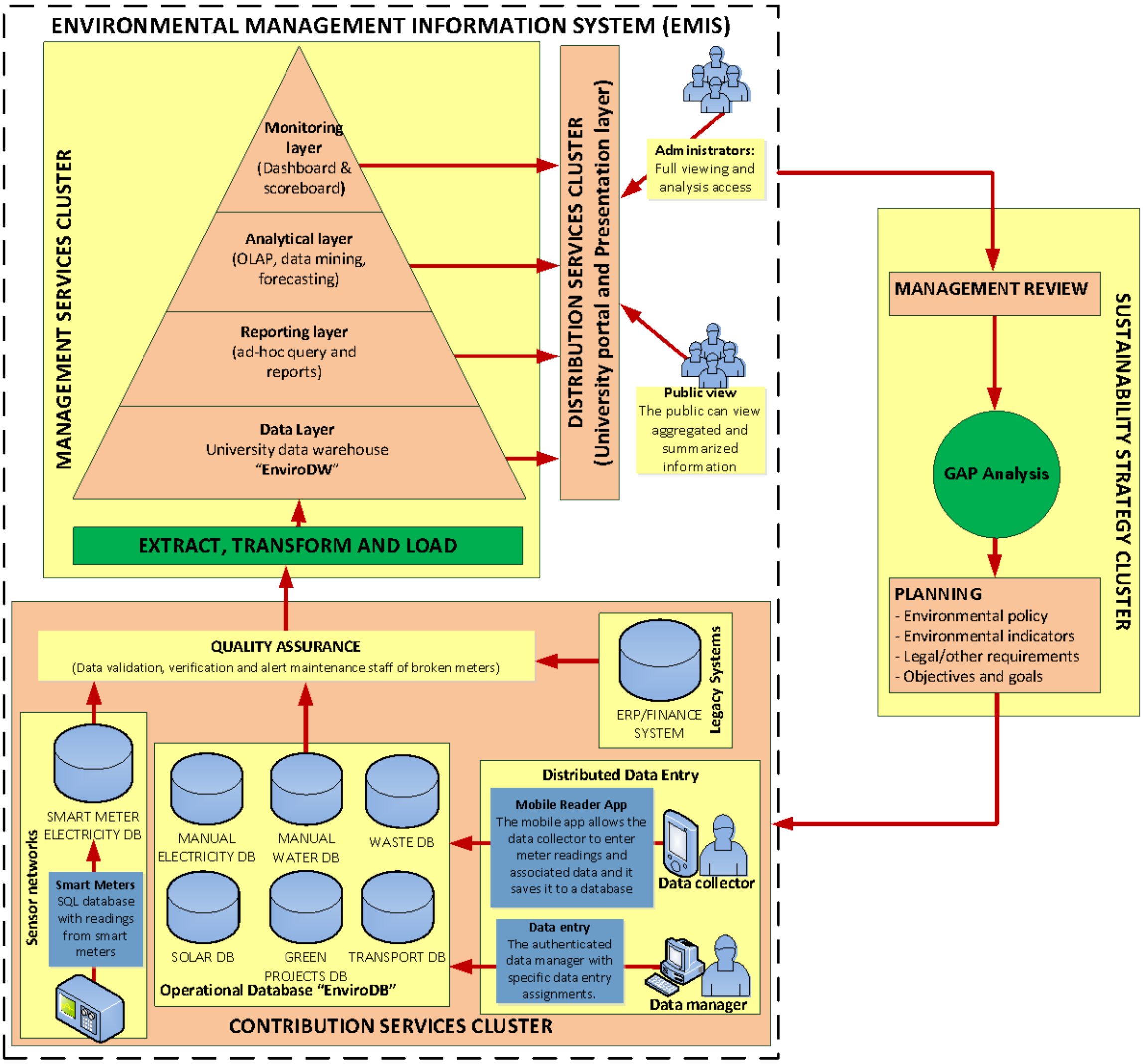


Figure 7.2: EIM Framework for HEIs

Table 7.3 provides guidelines of the EIM framework for HEIs. These guidelines can be used to determine the current state of EIM processes at an HEI.

Table 7.3: Guidelines for Components of EIM Framework for HEIs

No.	Guidelines
Sustainability Strategy Cluster	
G1	A gap analysis can be used to identify areas for improvement in environmental information management processes.
G2	Top management support is important for the success of EIM efforts in HEIs.
G3	Environmental indicators for HEIs must be identified and prioritised at a strategic level.
G4	EIM efforts need to be aligned with strategic goals of the HEI.
Contribution Services Cluster	
G5	There is need for centralised storage of environmental information in an HEI.
G6	HEIs need a computerised process for capturing environmental data (e.g. water and electricity meter readings).
G7	HEIs need to automate environmental data collection processes where possible (e.g. sensor based collection; smart meters).
G8	It is important that HEIs perform quality assurance (data validation and verification) on environmental data collected.
G9	There is need to alert maintenance staff for meters that are not working so that they can fix the meters
Managerial Services Cluster	
G10	Environmental sustainability reporting should be automated wherever possible.
G11	Data analytics and monitoring of EIM should be provided.
G12	Simplified aggregated data summaries of EIM must be available.
G13	Data processing should be provided (Ad-hoc querying, modelling of data and decision support).
G14	There should be support for allocating resource usage to buildings and campus facilities such as sports grounds and departments.
Distribution Services Cluster	
G15	There should be support for public awareness and outreach by allowing access to simplified aggregated data summaries of system data for access by HEI stakeholders (student, staff, board members, management, government bodies etc.).
G16	Third party applications should be granted access to environmental information where possible.

7.3.2 Practical Contribution

The primary practical contribution provided by this study entailed the implementation of a prototype, EMIS prototype, as proof of concept for the proposed EIM framework. The implementation of the EMIS prototype comprised a central operation environmental database (EnviroDB) and an environmental data warehouse (EnviroDW) which are components of the EIM framework for HEIs. The secondary practical contribution provided by this study was the practical evaluation of the EIM framework and EnviroDW.

The EIM framework was evaluated by several stakeholders. The stakeholders were either ICT experts or environmental experts. The experts were required to answer a questionnaire indicating whether they agreed or disagreed with each guideline that corresponded to a component on the EIM framework. All participants agreed with at least 12 of the guidelines and confirmed that the EIM framework for HEIs was complete. However, one participant indicated their concern about the security of the institution upon publishing environmental information. Another participant suggested modifying a component to include quality assurance of all source data and alert the maintenance staff about any broken meters. These comments resulted in the modification of the EIM framework to produce a final version of the framework and guidelines.

7.4 Limitations and Problems Encountered

One major limitation was encountered in this study. The major limitation was data acquisition (availability and access to environmental data). The challenges experienced with data acquisition were:

1. Meters associated with individual buildings were exceptions. More commonly, sub-loops in the distribution grid or groups of buildings shared meters; fine-grained utility data were only available for specific buildings or parts of buildings where distinct entities (for example, food service, book stores and conference centres) were separately billed. This made it difficult, if not impossible, to allocate resource usage to a particular building within the institution. Hence, information that can be provided by the data warehouse is not comprehensive.
2. Where records of historical resource usage existed, they often varied in granularity (monthly, annually) and completeness (gaps in the record). Most of the data which was captured by hand was found to have missing and/or erroneous data.
3. The EMIS has not been handed over to the ICT Services Department as was required.
4. The system has not been tested in an operational environment.

7.5 Recommendations and Future Research

The results of this study have shown the importance of EIM in HEIs and have provided a formal guide for HEIs that want to manage their environmental information. With the recent

South African HEI reporting regulation, it is recommended that future studies can investigate the implementation of the EIM framework for HEIs in South African HEIs. Future research can be done in the development of a mobile reader app to facilitate for distributed data entry at HEIs. It is also recommended that EnviroDB and EnviroDW be implemented and tested in an HEI environment. There is also a need to alert maintenance staff about meters that are not working as their not working affects the quality of the data. Future research can be done to integrate the central database (EnviroDB) with the institution's maintenance system if it exists or develop that particular component for the central database if it does not exist at the institution.

The development of the fully analytical tools to support senior management in decision management is important. Hence, future research can also be done in the field of Environmental Performance Dashboards (EPD) that will allow communication of the environmental data from different perspectives and present information in a way that the community can understand without posing any risk to the HEI's image. HEIs are generally publicly funded, hence transparency and community involvement and uplifting are of utmost importance.

7.6 Summary

This study has produced two artifacts while following the DSR methodology, namely:

- The environmental data warehouse (EnviroDW) and the operational database (EnviroDB).
- The EIM framework for HEIs and its guidelines.

The EIM framework should be used by HEIs that want to implement EIM processes and systems at the institution. The EIM framework can help transition an institution's EIM processes from no support to full support. Through the use of the EIM framework's guidelines an HEI can determine its current level for support for EIM and compare this with the best-practice EIM processes. The EIM framework will therefore propose approaches for HEIs to move from their current As-Is state to a desired holistic To-Be state for EIM. The application of the EIM framework can improve EIM and reporting to the HEI community.

NMMU was used as a case study and the EIM framework was used to evaluate and determine the current As-Is state at NMMU. The EIM framework assisted in the design of the desired best-practise and holistic To-Be EIM processes. The EnviroDW data warehouse was developed as a proof-of-concept. EnviroDW showed that such a system can provide valuable information that at present NMMU does not have access to. This information can help management to make informed decisions and plan for improvement. Both artifacts, EIM framework for HEIs and EnviroDW, were successfully evaluated by experts and target users. The results showed that the two artifacts were acceptable and can provide valuable input to HEIs which, in turn, can help an institution towards becoming a sustainable HEI. There have been limitations to conducting this research; however, recommendations of future research have outlined possibilities available to provide improvements to the EIM framework and the EMIS prototype.

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Nelson Mandela Metropolitan University

for tomorrow

Office 1706 Main Building

Summerstrand South Campus

Tel . +27 (0)41 504-2016/7 Fax. +27 (0)41 504-2885

E-mail: thoko.mayekiso@nmmu.ac.za

28 October 2013

Blessing T Jonamu

A FRAMEWORK FOR MANAGEMENT OF ENVIRONMENTAL INFORMATION IN HIGHER EDUCATION INSTITUTIONS

According to the internal regulatory code for ethical clearance institutional permission is required to implement institutional studies on campus.

I, Professor Thoko Mayekiso, DVC Research and Engagement hereby consent to the above study and am satisfied that all pre requisite ethical clearance for the implementation thereof will be adhered to.

SIGNATURE _________________________.

DATE: 28 October 2013 .

Appendix B: Survey

Human Ethics Ref: H13-SCI-CSS-23

Dear Sir / Madam,

I am a Master's student at the Nelson Mandela Metropolitan University (NMMU) and am currently doing my first year of my Master's degree. Research needs to be conducted in the form of a treatise to be submitted to fulfil the requirements of the Master's degree. The aim of this research is to investigate Green Initiative projects undertaken at NMMU and identify the different data stores and the current approach to managing environmental information at NMMU. The ultimate objective of the study is to propose a framework that can be used at a Higher Education Institution to manage environmental information. An artifact in the form of an application is to be developed to serve as "proof of concept" and the artifact is to be demonstrated at NMMU.

The information obtained from this study will be treated with strict confidentiality, and will not be used for any purpose other than for academic purposes. The identity of the participants will be withheld in any publications written by the researchers. Your cooperation to participate in this survey is greatly appreciated.

You can indicate at the end of the questionnaire if you would like a copy of the summarised results of this study. Thank you for your co-operation.

Yours sincerely,

Blessing Jonamu
Master's student
Supervisors: Prof Andre Calitz and Dr Brenda Scholtz

University Sustainability

Universities are not immune to the global environment problems and now some government bodies and NGOs are putting pressure on universities to act towards environmental sustainability. Some agencies are now holding Higher Education Institutions (HEIs) to the same standards as industries so as to “create a safe haven for human health and the environment”. The United Nations Educational, Scientific and Cultural Organisation (UNESCO) have even proclaimed the Decade of Education for Sustainability Development 2005-2014.

Environmental Information Systems, broadly, are tools developed to assist with the monitoring and measurement of environmental information within an organisation.

Purpose of this Questionnaire

The purpose of the survey is to find out the Green Initiative projects that are undertaken at NMMU, specifically those that collect environmental information such as water, carbon emissions, energy consumption, renewable energy generated/consumed, reclaimed water consumption and more. This will help to identify which projects handle environmental information and where the information is located.

The information gathered from the survey will be primarily used to propose and developed an IT tool to aid in the management of environmental information. It should also help to clarify the current sustainability state of the university and the Green Initiative projects that are currently being implemented and improve. This can help management to make environmental management decisions to better the university’s sustainability status.

<u>Questionnaire Instructions:</u>

- Please indicate your answer by making an “X” in the appropriate box or writing your answer in the space provided; and
- Please answer ALL the appropriate questions in this questionnaire.

1. Do you know of any green initiative projects that are undertaken at NMMU, specifically those that collect environmental information such as water, carbon emissions, energy consumption, renewable energy generated/consumed, reclaimed water consumption, waste management, chemicals & hazardous waste and more?

   Yes/no

2. If yes, please list them and the corresponding contact person for that project.

Project	Contact Person	Tel/Office/email of contact person

Thank you for your participation. Your valuable contribution to this study is sincerely appreciated.

Appendix C: List of Projects (Survey 1)

1. Augmented reality of Environmental data
2. Rainfall record
3. Renewable energy harvesting E block N campus
4. Solar cooker for heating water and cooking
5. Electric Bicycle charged by Research & Engagement
6. S-Y Creations
7. NMB Business Chamber Greening Business initiative
8. The Eco-brick exchange project
9. Flooding in the U.K PhD project
10. Embedded Energy Generation

Appendix D: Interview Questionnaire 1

Name of Interviewee:	

PROJECT

1. What is the name of the project?

2. Please provide a brief description of the project.

3. What is/was the nature of the project?
   ☐ External e.g. Eskom embarking on a save electricity campaign
   ☐ Academic
   ☐ Administration
   ☐ Research

4. Which department is/was the project associated with?

   a) What data are collected? **(E.g. Water consumption, non-renewable energy consumption, renewable energy consumption, reclaimed water consumption etc.)**

   b) How are the data captured?
      ☐ Manually ☐ Using software/IT tool ☐ Other

   c) If manually, how is the data retrieved & captured? (**Please describe the process in detail - step by step**)

d) If the data is captured is using a software system or an IT tool, please specify the name of the tool or system.

e) If other specify.

f) Contact person of IT tool (e.g. operator or person in charge)

g) What data metrics are collected? (E.g. Litres, Kilo-Watts, etc.)

h) What is the frequency of data collection? (E.g. daily, weekly, bi-monthly, etc.)

i) What type of meters (measurement instruments) are used? (e.g. Smart meters)

j) How are the meters distributed? (per building, per campus)

k) What is the basic unit of data apportionment that can be done (e.g. per campus or per building or service unit)

l) How is data validation or verification done?

m) Where is the data stored? **(Tick all that apply)**

Excel file	☐	**Handwritten document**	☐
Database	☐	**Pdf document**	☐
Email	☐	**Word document**	☐
Other(Specify):			

n) For what purpose is the data collected? **(Tick all that apply)**

Financial support	☐	**Reduce institutional consumption patterns**	☐
Research interests	☐	**Sustainability Reporting support**	☐
Other(Specify):			

o) We would like to have access to this data.
Is that possible? ______________________

GENERAL COMMENTS

____

____

____

____

____

____

____

I would like a copy of the summarised results of this study. ☐ Yes ☐ No

If yes, please make sure you have provided your email address.

Email: ______________________

Appendix E: Interview Questionnaire 2

Name of Interviewee:	

DATA STORES

p) What data are collected? **(E.g. Water consumption, non-renewable energy consumption, renewable energy consumption, reclaimed water consumption etc.)**

___

___

q) How are the data captured?

☐ Manually ☐ Using software/IT tool ☐ Other

r) If manually, how is the data retrieved & captured? (**Please describe the process in detail - step by step**)

___

___

___

___

___

s) If the data is captured is using a software system or an IT tool, please specify the name of the tool or system.

___

t) If other specify.

___

___

___

u) Contact person of IT tool (e.g. operator or person in charge)

___

v) What data metrics are collected? (E.g. Litres, Kilo-Watts, etc.)

___

w) What is the frequency of data collection? (E.g. daily, weekly, bi-monthly, etc.)

x) What type of meters or measurement instruments are used? (e.g. Smart meters)

y) How are the meters or measurement instruments distributed? (per building, per campus)

z) What is the basic unit of data apportionment that can be done (e.g. per campus or per building or service unit)

aa) How is data validation or verification done?

bb) Where is the data stored? **(Tick all that apply)**

Excel file	☐	**Handwritten document**	☐
Database	☐	**Pdf document**	☐
Email	☐	**Word document**	☐
Other(Specify):			

cc) For what purpose is the data collected? **(Tick all that apply)**

Financial support	☐	**Reduce institutional consumption patterns**	☐
Research interests	☐	**Sustainability Reporting support**	☐
Other(Specify):			

dd) We would like to have access to this data.
Is that possible?

GENERAL COMMENTS

I would like a copy of the summarised results of this study. ☐ Yes ☐ No

If yes, please make sure you have provided your email address.

Email: ____

Appendix F: Handwritten Electricity Data Collected from Meters

STUDENT VILLAGE MINI SUB: A -BLOCK

MONTH	DATE	METRE 156754	USUAGE	METRE 157492	USUAGE	METRE 159452	USUAGE	TOTAL	TOTAL X 160
	4/11/13	5641,7	147	1668,9	123	3867,2.	80	350	56000
DECEMBER 2013	2/12/13	5761	120	1768	100	3917	50	270	43200
JANUARY 2014	15/1/14	5792	(151 - 120) 31	1801	(133 - 100) 33	3954	(87 - 50) 37	101	16160
FEBRUARY	05/02/14	5822	30	1831	30	3972	18	78	12480
MARCH									
APRIL									
MAY									
JUNE									
JULY									
AUGUST									
SEPTEMBER									
OCTOBER									
NOVEMBER									
DECEMBER									

te12/13/2013

C:\Users\barnardo\Desktop\Electrical Data Sheets\

Appendix G: Electricity Consumption Excel File for South Campus NMMU

M E M O R A N D U M

REF:SRAEL13 12

TO : [redacted]
Finances Finances

CC: [redacted]
Finances

FROM : [redacted]
Technical Services

DATE : 13 February 2014

RE - ACC NO : **600 006 834 900** **December-13**

SOUTH CAMPUS
ELECTRICITY & RATES

DESCRIPTION		**ENT/ACC NO**	**AMOUNT**	**VAT**	**TOTAL**
ELECTRICITY	**UNITS**		934838		
1. Initial Campus			[redacted]		
Madibas	1342	[redacted]			
Flavas South	900	[redacted]			
Rehab	1905	[redacted]			
1. Campus total	687633,12	[redacted]			
		[redacted]			
2. Residences	186968	[redacted]			
3. Sport	56090	[redacted]			
		TOTAL	[redacted]		
RATES	**Increase 0.51982%**	**Dec-13**	782369,81		
1. Campus		6620-1750	[redacted]		
2. Residences		5740-1750	[redacted]		
3. Sport		6010-1750	[redacted]		
		TOTAL	[redacted]		
SC Total units	#REF!				
KVA	#REF!				

Discount					
		GRAND TOTAL			

Statement date of 31 December 2013

Expense s/sheet updated: ☐ Date: ____________________

Appendix H: JCBMS Smart Meters at NMMU

Power Meters NMMU Campuses

Campus	Meter	Campus	Meter
South Campus	Main Incomer Pulse Count Meter	2nd Avenue	Main
	Sub B Res North		Residences
	Sub D Res South		Ceramics Department
	Sub E Old Mutual		
	Sub F Sanlam/Edu/HMS	North Campus	E Block Main 1/2
	Sub G Building 35		E Block Main 2/2
	Sub H Library South		Administration
	Sub H Library North		Workshops
	Sub O Tech Serve		Lebombo Residence
	Sub P Biology North		Letaba Residence
	Sub Q Physics North		MTLC
	Sub Q Physics South		R Block
	Sub P Biology South		Art and Design
	Sub O Horticulture		Conference Centre
	Sub L Kraal Shops		
	Sub L Kraal Bank & Lights	George	Main
	Sub N Senate		Administration
	Sub N Auditorium		
	Sub N Main/Embizweni/Music		
	HRTEM Main power meter		
Missionvale	Mini-Sub 1 (Physics/Chemistry)		
	Mini-Sub 2 (Geography/Block D /Lecture Halls A,B,C)		
	Mini-Sub 3 (Administration)		
	Mini-Sub 4 (Psychology)		
	Mini-Sub 5		
	Mini-Sub 6 (Sportds Arena)		

Appendix I: STARS Table of Credits

STARS 1.2 Table of Credits

Category 1: Education & Research (ER)		
Credit Number	**Credit Title**	**Possible Points**
	Co-Curricular Education	
ER Credit 1	Student Sustainability Educators Program	5
ER Credit 2	Student Sustainability Outreach Campaign	5
ER Credit 3	Sustainability in New Student Orientation*	2
ER Credit 4	Sustainability Materials and Publications	4
Tier Two	*Co-Curricular Education Tier Two Credits*	2
	Curriculum	
ER Credit 5	Sustainability Course Identification	3
ER Credit 6	Sustainability-Focused Courses	10
ER Credit 7	Sustainability-Related Courses	10
ER Credit 8	Sustainability Courses by Department*	7
ER Credit 9	Sustainability Learning Outcomes*	10
ER Credit 10	Undergraduate Program in Sustainability*	4
ER Credit 11	Graduate Program in Sustainability*	4
ER Credit 12	Sustainability Immersive Experience*	2
ER Credit 13	Sustainability Literacy Assessment	2
ER Credit 14	Incentives for Developing Sustainability Courses	3
	Research	
ER Credit 15	Sustainability Research Identification*	3
ER Credit 16	Faculty Engaged in Sustainability Research*	10
ER Credit 17	Departments Engaged in Sustainability Research*	6
ER Credit 18	Sustainability Research Incentives*	6
ER Credit 19	Interdisciplinary Research in Tenure and Promotion*	2
	Total	**100**

* credit does not apply to all institutions

Category 2: Operations (OP)		
Credit Number	**Credit Title**	**Possible Points**
	Buildings	
OP Credit 1	Building Operations and Maintenance	7
OP Credit 2	Building Design and Construction*	4
OP Credit 3	Indoor Air Quality	2

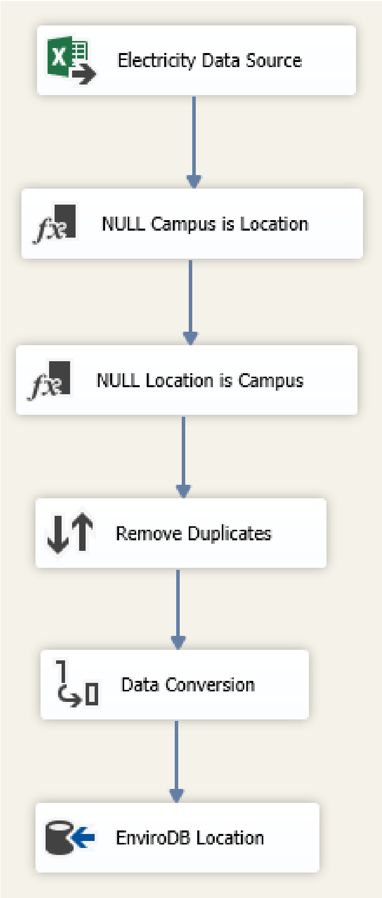
Climate		
OP Credit 4	Greenhouse Gas Emissions Inventory	2
OP Credit 5	Greenhouse Gas Emissions Reduction	14
Tier Two	*Climate Tier Two Credits*	0.5
Dining Services		
OP Credit 6	Food Purchasing*	6
Tier Two	*Dining Services Tier Two Credits*	2.5
Energy		
OP Credit 7	Building Energy Consumption	8
OP Credit 8	Renewable Energy	7
Tier Two	*Energy Tier Two Credits*	1.5
Grounds		
OP Credit 9	Integrated Pest Management*	2
Tier Two	*Grounds Tier Two Credits*	1.25
Purchasing		
OP Credit 10	Computer Purchasing	2
OP Credit 11	Cleaning Product Purchasing	2
OP Credit 12	Office Paper Purchasing	2
OP Credit 13	Vendor Code of Conduct	1
Tier Two	*Purchasing Tier Two Credits*	0.5
Transportation		
OP Credit 14	Campus Fleet	2
OP Credit 15	Student Commute Modal Split*	4
OP Credit 16	Employee Commute Modal Split	3
Tier Two	*Transportation Tier Two Credits*	3
Waste		
OP Credit 17	Waste Reduction	5
OP Credit 18	Waste Diversion	3
OP Credit 19	Construction and Demolition Waste Diversion*	1
OP Credit 20	Electronic Waste Recycling Program	1
OP Credit 21	Hazardous Waste Management	1
Tier Two	*Waste Tier Two Credits*	1.5
Water		
OP Credit 22	Water Consumption	7
OP Credit 23	Stormwater Management	2
Tier Two	*Water Tier Two Credits*	1.25
	Total	**100**

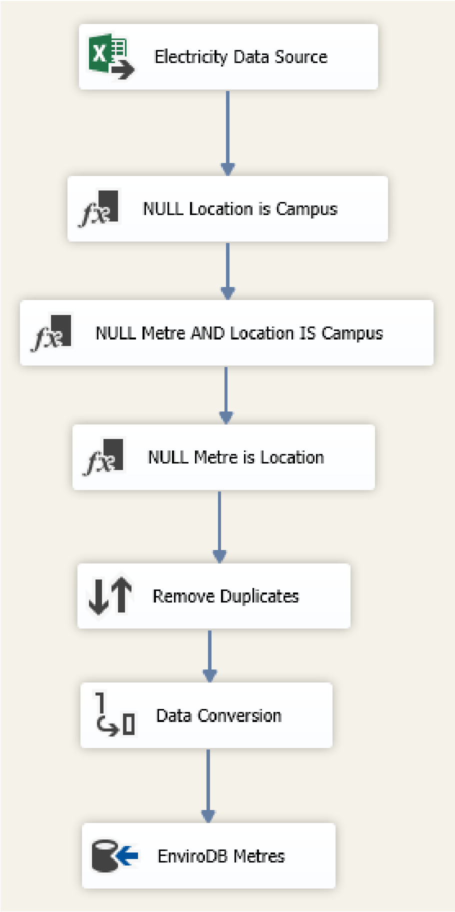
* credit does not apply to all institutions

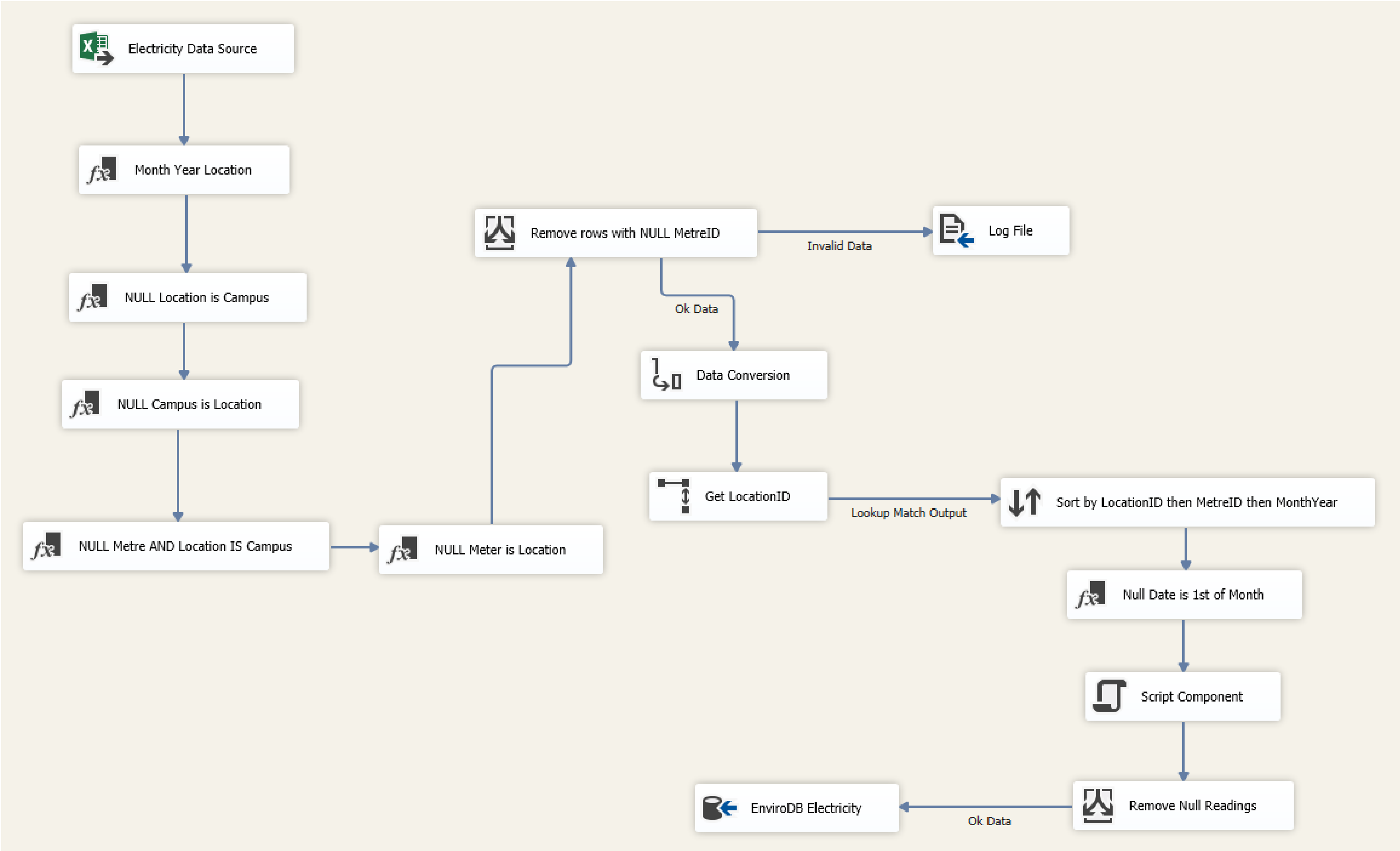
Appendix J: Recycling Stats from Service Departments at NMMU (March 2014)

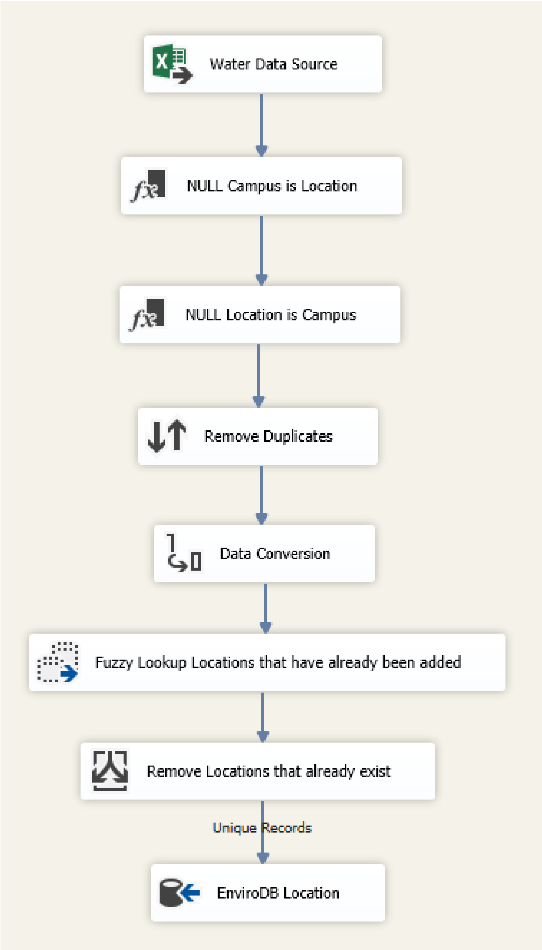
Material	Monthly average 2013	Volume 2014	Income generated?	Destined for landfill	Departmental responsibility	Recorded as
Wooden pallets	15 units	180 (units)	yes	no	Stores	Departmental record
PC's	50units	600 (units)	no	no	Stores	Green index points
Broken consumables	2.5units	30 (ldv loads)	no	yes	stores	Departmental record
General waste	390cbm	4680kg	no	yes	SS	Departmental record
Cardboard	700kg	8400kg	no	no	ss/hs/res	Departmental record
Plastic	15kg	180kg	no	no	ss/hs/res	Departmental record
Glass	25kg	300kg	no	no	ss/hs/res	Departmental record
office Paper	350kg	4200kg	no	no	ss/hs	Departmental record
Newspaper	10kg	120kg	no	no	ss/hs	Departmental record
PET	15kg	180kg	no	no	ss/hs	Departmental record
Cans	10kg	120kg	no	no	ss/hs/res	Departmental record
Metal	6cbm	72cbm	yes	no	es/ts	Departmental record
Garden byproduct for compost		960cmb	no	no	hs/ts	Departmental record

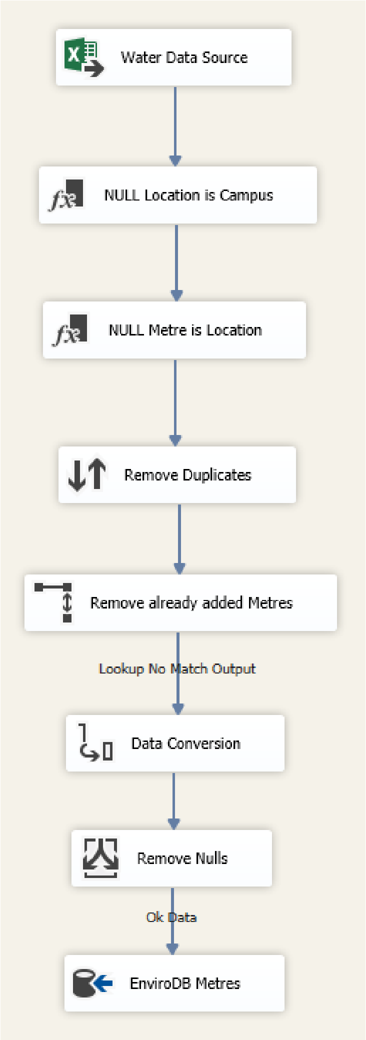
Appendix K: EnviroDB ETL Processes

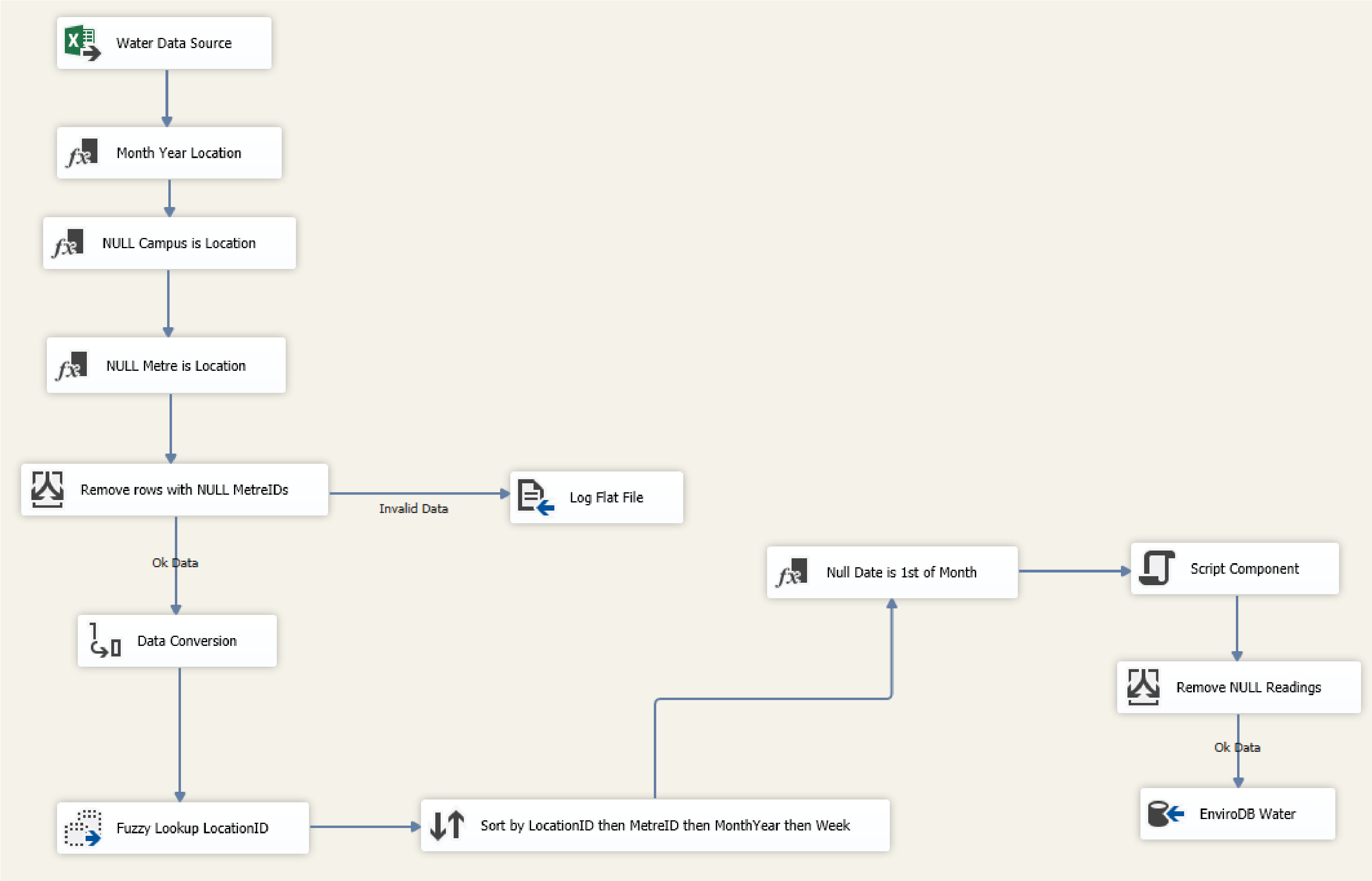




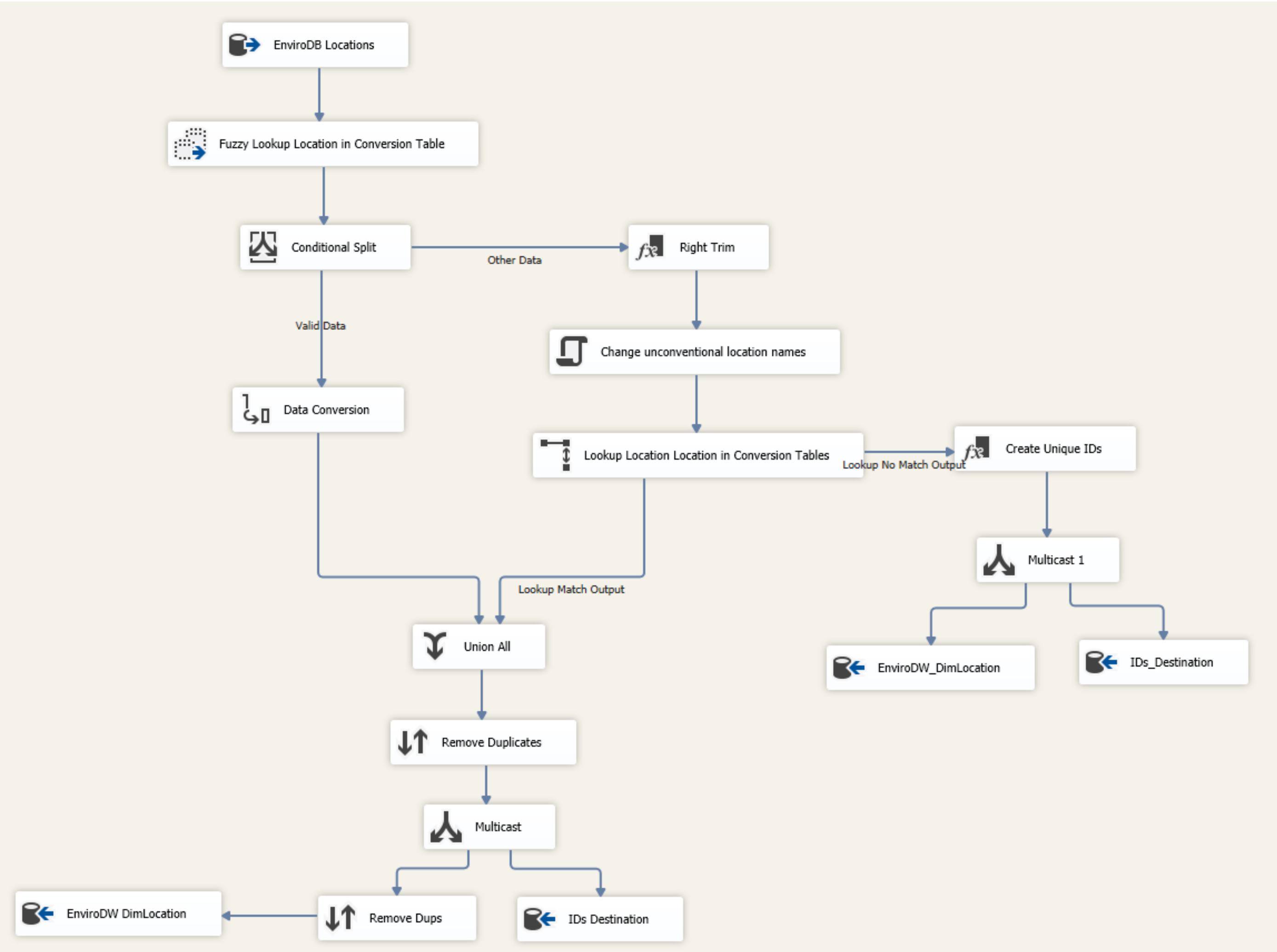

Electricity Data Source
Month Year Location
NULL Location is Campus
NULL Campus is Location
NULL Metre AND Location IS Campus
NULL Meter is Location
Remove rows with NULL MetreID
Invalid Data
Log File
Ok Data
Data Conversion
Get LocationID
Lookup Match Output
Sort by LocationID then MetreID then MonthYear
Null Date is 1st of Month
Script Component
Remove Null Readings
Ok Data
EnviroDB Electricity

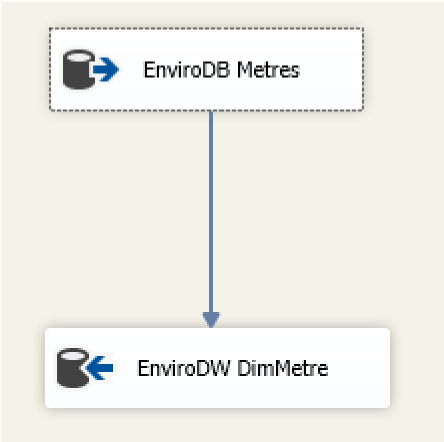

Water Data Source
NULL Campus is Location
NULL Location is Campus
Remove Duplicates
Data Conversion
Fuzzy Lookup Locations that have already been added
Remove Locations that already exist
Unique Records
EnviroDB Location


Water Data Source
NULL Location is Campus
NULL Metre is Location
Remove Duplicates
Remove already added Metres
Lookup No Match Output
Data Conversion
Remove Nulls
Ok Data
EnviroDB Metres


Water Data Source
Month Year Location
NULL Campus is Location
NULL Metre is Location
Remove rows with NULL MetreIDs
Invalid Data
Log Flat File
Ok Data
Data Conversion
Fuzzy Lookup LocationID
Sort by LocationID then MetreID then MonthYear then Week
Null Date is 1st of Month
Script Component
Remove NULL Readings
Ok Data
EnviroDB Water

Appendix L: EnviroDW ETL Processes





Appendix M: IDIA Conference Paper

A Gap Model for Environmental Information Management in an African Higher Education Institution

Brenda Scholtz
Nelson Mandela Metropolitan University
South Africa

Andre Calitz
Nelson Mandela Metropolitan University
South Africa

Blessing Jonamu
Nelson Mandela Metropolitan University
South Africa

Abstract

The increase in awareness of social and environmental responsibilities has led Higher Education Institutions (HEIs) to invest in developing inclusive communities. HEIs are increasing the awareness of environmental sustainability by monitoring and managing the impact of communities on their environment and, by involving them in sustainability efforts, are developing an inclusive community. The relatively low adoption of the concept of environmental sustainability in African HEIs is due to a number of factors; such as problems with data access and quality of information. This paper investigates best practices for information on environmental management and data centralisation in HEIs and analyses some of the as-is processes relating to the management of environmental information at a South African HEI. The paper proposes a model for addressing the gap between the existing as-is level of information on environmental management and the desired to-be level of information on environmental processes in HEIs. The application of the model can improve environmental- information management and reporting to the HEI community. This, in turn, can raise the environmental awareness of students, staff and external stakeholders of the institution and they can take action to reduce their contribution to the negative impact of the institution on the environment.

Keywords: Environmental sustainability, Inclusive communities.

Introduction

The topics of environmental sustainability and management of environmental information at Higher Education Institutions (HEIs) have gained increased interest internationally, particularly in Europe, the United States (U.S.A), Asia, Australia, Canada and South America (Disterheft, da Silva Caeiro, Ramos and de Miranda Azeiteiro, 2012; Velazquez, Munguia, Platt and Taddei, 2006). However penetration into African institutions has been relatively low (Velazquez, et al., 2006). Despite this low penetration, there have been some isolated attempts to introduce environmental sustainability at a number of South African HEIs which have strategic plans to be environmentally sustainable in the near future (Ducie, 2013; Rhodes, 2014; Scott, McGibbon and Mwalemba, 2012). However, environmental-sustainability efforts in African HEIs lack proper coordination and this has prompted increased attention to this research topic in recent years. Sammalisto and Arvidsson (2005) argue that the lack of strong regulations placed on African HEIs by African governments or Non-Governmental Organisations (NGOs) might be the reason why HEIs in developing countries are lagging behind in terms of environmental-sustainability efforts. Other possible reported factors could be the lack of data access, lack of communication and the lack of integrated and accurate information (Velazquez, Munguia and Sanchez, 2005). This is confirmed by the study of Bero, Doerry, Middleton and Meinhardt (2012) who reported that the management of environmental information is a key factor in achieving environmental sustainability at HEIs.

HEIs have followed the trend in industry of developing environmental programmes and systems (Bero, et al., 2012). However, HEIs have a unique set of challenges with regard to environmental-information management and these are different to the industrial context (Bero, et al., 2012; Kamal and Asmuss, 2013). The benefits of having environmental information readily available include the reduction in the environmental footprint of the institution, in terms of a reduction in water usage, an improvement in energy efficiency and a reduction in pollution (Jones, et al., 2011). Effective analysis of environmental information allows for top management to make well-informed decisions that will result in the optimal use of resources such as energy and water.

The United States of America's Environmental Protection Agency (EPA) highlighted that the environment has become everyone's business and everyone now has a right to access high quality environmental information (EPA, 2009). One benefit of having environmental information readily available to the public is that it can raise the environmental awareness of an institution's community about the environment (Jones, et al., 2011). An institution's community includes students, staff members and external stakeholders. Making environmental information accessible to the public is a significant step in developing an inclusive community around an HEI. An inclusive community is defined as a welcoming environment that promotes the full participation of all faculty, staff, and students in the life of the institution (Christie, 2014). An inclusive community engages all its citizens in decision-making processes that affect their lives and gives them full access to resources (University of Kansas, 2013). Educating an institution's community with regard to their environmental footprint promotes their involvement in decision making and enables them to take action to reduce their contribution to the negative impact of the institution on the environment. Effective management of environmental information and reporting systems can support inclusive communities by supplying relevant information to the stakeholders at the HEI, which facilitates improved and informed decision making with regard to environmental impact.

According to Velazquez et al. (2006), an HEI is considered to be a sustainable institution if the institution addresses, involves and promotes the lessening of the negative impact on daily environmental, economic, social and health activities involved in the functioning of the institution. Sustainable, green universities have influence to the extent that they help regional or global societies to make the transition to a sustainable livelihood. Whilst the importance of environmental sustainability and the relevant role of Environmental Information Management and reporting in higher education has been emphasised in HEIs, Africa is lagging behind (Fonseca, Macdonald, Dandy and Valenti, 2011). Studies of environmental sustainability and the role of information management in African HEIs are limited.

The aim of this paper is to propose a gap model for Environmental Information Management (EIM) in African HEIs. A gap model describes the transition process from the current state (as-is state) to the desired state (to-be state) Harmon, 2007). This model will therefore propose approaches for HEIs to move from their current as-is state to a desired to-be state for environmental, information management which will assist in their environmental sustainability efforts. This paper also highlights the critical role that EIM plays in environmental sustainability efforts at HEIs. There is a lack of formal guidance for migrating from the existing as-is to the desired to-be environmental information processes in HEIs. An EIM framework which can assist with designing the gap model is proposed. The proposed framework is then applied at a South African HEI in order to analyse the current as-is processes and to design the desired to-be processes for the case study. Several conclusions can be made based on the literature review, the design and application of the EIM framework for HEIs and the gap model for NMMU.

The next section provides a concise description of the research objectives and the methodology that was employed in this study. This is followed by a extensive literature review that highlights that EIM is pivotal to any environmental sustainability efforts. An investigation into the current as-is processes and proposed to-be processes of the case study are analysed. The South African HEI: *Nelson Mandela Metropolitan University (NMMU)* was used as the case study. Several conclusions and recommendations are then made based on the literature review and the design of the EMIS for HEIs.

Research Objectives and Methodology

EIM has been identified as a key factor for achieving environmental sustainability in HEIs. HEIs have been called on not to be bystanders as the world faces increasing environmental issues and they need to take action and be pioneers in driving environmental sustainability into the community (Watson, et al., 2010). However, there is limited formal guidance or frameworks for HEIs that wish to adopt environmental sustainability practices, particularly for the management of environmental information (Bero, et al., 2012). Therefore, the main research objective of this paper is: "*To design a gap model that supports the efficient management of environmental information at a HEI."*

In order to derive this model, three secondary objectives must be achieved:

1. Describe the as-is processes, structure and information stores at NMMU which are related to Environmental Information Management.
2. Propose the to-be processes for the management of environmental information at NMMU.
3. Identify the elements of the *gap* model for Environmental Information Management in HEIs.

This research followed a case study approach in which NMMU was the HEI that was used as the case study. A careful rigorous investigation into literature, previous research and extant systems was done in order to gain an understanding of the research domain. This allowed for the identification of some of the key elements of the *gap* model. In an attempt to understand and describe the current processes that are involved in the management of environmental information at NMMU, a two phased approach was followed. The first phase was to conduct a short survey aimed at determining the various administrative and non-administrative projects that affect or influence the university's environmental indicators. The second phase was to conduct interviews with selected individuals, in projects or administrative service units, responsible for the alignment and reporting of the major environmental indicators at NMMU. The first survey was sent out as an email to all the current university students and staff members. A list of projects and the contact people involved was generated from the survey. Each of the contacts was then interviewed. These interviews allowed the researcher to gain a deeper insight into the processes involved in the management of environmental information. Furthermore, document studies were done in an attempt to uncover underlying problems that interviewees were not willing to point out.

Environmental Information Management

Environmental sustainability is multifaceted; however most aspects of it, if not all, are tightly dependent on the availability and accessibility of correct and current environmental information (Frysinger, 2001). Hence, environmental sustainability requires correct environmental information management. Organisation stakeholders need access to environmental information to evaluate and assess the environmental dimension of organisational decisions, both at a managerial level and at a strategic level (El-Gayar and Fritz, 2006).

The most necessary initiative to enhance environmental sustainability in HEIs is the implementation of Environmental Management Systems (EMS) at these institutions (Disterheft, et al., 2012; Jones, et al., 2011). The ISO 14001 standard, specified by the International Standardisation Organisation (ISO), defines an EMS as a part of a management system that consists of planning activities, processes, procedures and resources for developing and maintaining environmental policies within an organisation (ISO, 2004). An EMS is not a computer system but rather a set of management tools and principles designed to aid an organisation to incorporate environmental concerns in their daily business activities (Speshock, 2010).

An Environmental Management Information System (EMIS) can be defined as a class of Information Systems (IS) that are focused on the automation of environmental information (ISESS, 2000). Watson, Boudreau and Chen (2010) discuss how an EMIS can take the central role in supporting environmentally sustainable practices. An EMIS is identified as a precondition to environmental management efforts by supporting the organisation's EMS and by meeting the reporting needs of stakeholders (El-Gayar and Fritz, 2006; Stuart, 2000). Hence, EMIS and EMS are closely linked and complementary to one another. The planning phase of the EMS helps to implement an effective EMIS and allocate resources (Speshock, 2010). The planning phase of an EMS is where the institution's stakeholders, such as top management and the Information Technology (IT) department, establish the policies and objectives of their EMS (UNECE, 2014). The elements included in this phase are:

1. *Environmental policy*: An environmental policy is a commitment that an organisation makes. The commitment states the organisation's stance towards the environment (UNECE, 2014). Environmental policies may be established by an organ of the government or by a Non-Government Organisation.
2. *Environmental aspects and indicators*: The team identifies the environmental impacts of all activities on which the institution has influence . The institution can choose which environmental aspects and indicators to prioritise (for example, water or energy).
3. *Legal and other requirements*: An institution may be allowed to comply with some regulations. However, because legal requirements are enforced on institutions in the United States of America and Europe there may not be as much freedom of choice when compared to institutions in Africa,
4. *Objectives and goals*: The team establishes objectives and goals which will allow measurement of assessment and improvement.

Once the planning stage of an EMS has been completed, the environmental information architecture must be determined (Speshock, 2010). Muntean, Sabau, Bologa, Surcel and Florea (2010) proposed an architectural framework for a Performance Management System (PMS) for HEIs. A PMS can be identified as the process of quantifying action which leads to organisational efficiency, competitiveness and growth (Ohemeng, 2011). The PMS uses data-warehousing technology to manage data from various pools of data and displays meaningful information by means of a performance dashboard. A performance dashboard is an application that allows stakeholders to measure, monitor and manage the performance of an organisation more effectively (Muntean, et al., 2010).

The PMS framework uses data-warehousing technology to Extract, Transform and Load (ETL) the data in the ETL layer. The ETL processes will then allow for data aggregation, normalisation and integration. Data is extracted from various sources and is stored in the database of the data warehouse which is in the data layer. The reporting layer allows users to access and query data. In addition, the reporting layer allows for ad-hoc querying and standard report generating from the university portal and is valuable for managerial decision making (Muntean, et al., 2010). The analytical layer is a useful tool for management to make decisions and strategise. . This layer allows for advanced functionality such as data mining, Online Analytical Processing (OLAP), forecasting, decision support and data visualisation (Lih Ong, Hwa Siew and Fan Wong, 2011). The monitoring layer is for performance monitoring. Tools that are available in this layer include dashboards and scorecards (Muntean, et al., 2010). The university portal which is also a presentation layer is the hub of all the university IT applications and services needed by students, administrators, faculty and staff.

The PMS framework can be applied to the domain of environmental sustainability performance management and environmental information management. The framework can also be extended to incorporate the iterative planning and review elements recommended by the ISO 14001 (2004) for environmental impact management. The resulting extended framework is an EIM Framework for HEIs (Figure 1) and is iterative in nature, similar to ISO14001. Planning is the first stage in the framework and this is where environmental policy is determined and indicators are identified and prioritised. The design of an architecture for EIM is the second stage and here reports can be generated for the stakeholders to check progress and to see if they have or will achieve their goals. This phase can therefore provide guidance for designing the desired to-be information stores and processes for EIM and reporting in an HEI. In the last phase of the proposed EIM framework for HEIs, the stakeholders will have a chance to do a management review in order to assess their performance, improve their goals, set new ones and even add or remove environmental indicators and the cycle can begin again.

Analysis of literature shows that the architecture of an EMIS is similar to that of the PMS (Gunther, Marx Gomez and Rautenstrauch, 2004; Yang, Li and Wang, 2012). An EMIS is typically implemented in a large organisation where there are several data sources which are characteristically in different physical locations and diverse implementations (El-Gayar and Fritz, 2006). These organisations already have other information systems in place to automate aspects of the organisation, for example Enterprise Resource Planning (ERP) systems. An EMIS can also be used as a tool to support and complement environmental management efforts (Moore and Bordeleau, 2001). An analysis of several studies (Alshuwaikhat and Abubakar, 2008; Disterheft, et al., 2012; El-Gayar and Fritz, 2006; Frysinger, 2001; ISESS, 2000) of EMIS reveal four commonly identified features of an EMIS:

- Data collection,

- Centralised data storage and access,
- Data processing,
- Reporting.

Data collection within an EMIS includes the integration of legacy and heterogeneous systems. Data collection mechanisms vary depending on the legacy systems or the lack of legacy systems. Data collection includes the mechanisms that are used for data acquisition and data pre-processing which include data cleaning, validation, integration and normalisation. After the retrieval of the data from the various data sources, data can be stored and processed to produce meaningful information (Athanasiadis, 2006). Some EMIS are also developed to cater for document management. In efforts concerning the environment, documents such as environmental policies need to be stored in a safe and secure environment.

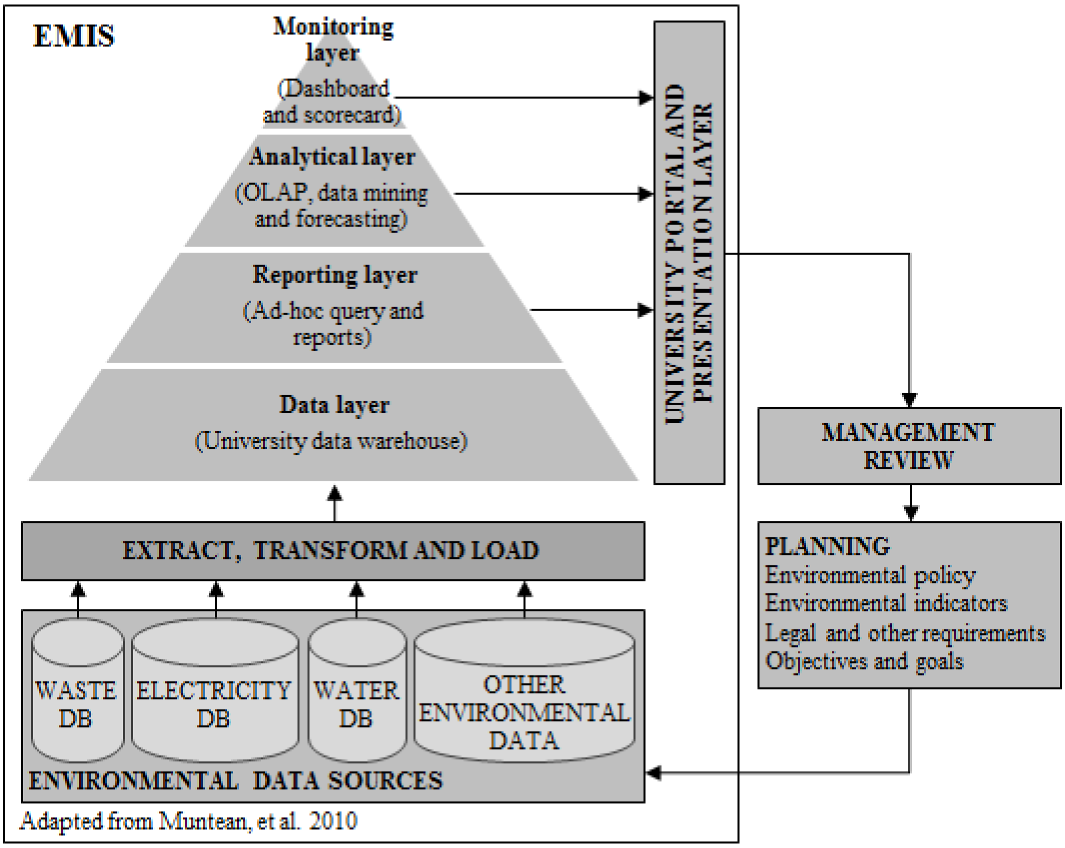


Figure 1: An EIM Framework for HEIs

The Green Reporting Initiative (GRI) is a popular standard for establishing environmental indicators in industry (GRI, 2013). Non-institutional organisations usually have a main focus which determines their environmental indicators, for example, pharmaceutical companies would have their environmental indicators focused on hazardous waste. HEIs have a broad set of institutional activities and facilities including offices, laboratories, operating machinery, classrooms, dining halls, dormitories and maintenance, hence environmental indicators associated with HEIs are diverse. The Sustainability Tracking, Assessment and Rating System

(STARS) is a voluntary, self-reporting framework for recognising and gauging sustainability performances for an HEI (AASHE, 2012).

Organisations need to process environmental data into useful information which can be used to draw meaningful conclusions (Speshock, 2010). Advanced EMIS offer the capability to analyse environmental information, stimulate and provide support for decisions. These capabilities are useful and make an EMIS valuable to the top management of any institution. Data processing further involves complex algorithms that provide aggregation, ad-hoc querying and modelling of environmental data and processes (El-Gayar and Fritz, 2006).
Reporting of sustainability information can foster public participation, social responsibility and promotion of sustainability in teaching and research (Alshuwaikhat and Abubakar, 2008). The Adaptive Intelligent Service Layer for Environmental Information Management (AISLE) is one such service-oriented EMIS that mediates between providers of environmental data and actual end-user applications that require pre-processed environmental information (Athanasiadis, 2006). An example of a web-based EMIS that offers an extensive, sustainability-reporting capability is the Sustainable Online Reporting Model (STORM) (Solsbach, Supke, Wagner vom Berg and Marx Gomez, 2010).

Determining the Gap Model for the NMMU Case Study

Water management is crucial in developing communities (Jonker, 2007). Ferguson and Maxwell (2010) highlight that developing countries, in particular, need to manage their water resources carefully. Podmore, Larsen, Louie and Waldron (2011) argue that the scarcity of electricity in developing communities such as those in sub-Saharan Africa is a major problem since 75% of households do not have access to basic lighting. Developing countries need to use resources such as water and energy sparingly and efficiently as these resources are limited (Von Bormann & Gulati, 2014). South African HEIs, therefore, need to address these two areas of sustainability as a top priority. However, a lack of co-ordinated effort and poor decision making with regard to achieving environmental sustainability at these institutions in Africa has been reported (Jones, et al., 2011). This poor decision making can be attributed to the lack of efficient processes, structures and information systems which support centralised environmental data sources and eliminate information silos in different departments, faculties and campuses (Bero, et al., 2012; Jones, et al., 2011; Velazquez, et al., 2005).

In South Africa, the Nelson Mandela Metropolitan University (NMMU) has identified sustainability as a key strategy in its Vision 2020 (NMMU, 2010).This is in alignment with the South African National Development Plan (NDP) which aims to develop inclusive communities by 2030 (National Planning Commission, 2012). NMMU has undertaken several Green Campus Initiatives in an attempt to implement this strategy. These initiatives require an integrated database which facilitates decision making regarding the strategic focus of the institution on the reduction of environmental impact based on several key indicators such as resource usage (water and electricity), transportation and waste management. The application of the EIM framework to the NMMU case study took part in two phases, the planning phase and the design phase.

The proposed EIM framework for HEIs (Figure 1) was applied to the NMMU. The first phase of this framework is the planning phase. During the planning phase of the framework, several priorities and objectives for environmental sustainability at NMMU were identified. The following is the list of the main objectives and high-priority areas regarding environmental sustainability at NMMU (NMMU, 2009);

- Energy efficiency and conservation;
- Energy management, monitoring and reporting system;
- The use of renewable energy;
- Water conservation and management;
- Protecting the environment;
- Vehicle Fleet Management.

The STARS framework was used at NMMU to identify the environmental indicators for the selected high-priority areas. Moreover, several studies, interviews and document studies revealed that the common environmental indicators actually implemented at NMMU can also be linked to the STARS system and indicators (Table 1). The scope of this paper is limited to energy management, monitoring and reporting, and water conservation and management, since they have been given top priority at NMMU.

STAR indicator name	NMMU Indicator	
STAR energy and water interventions	**Utilities usage**	**STAR indicator**
Building energy consumption	Electricity usage	✓
Clean and renewable energy	Renewable electricity generation (Solar)	✓
Water consumption	Potable water usage (municipal water)	✓
Storm water management	Non-potable water usage (reclaimed water, borehole water, rain harvested water)	✓
Transportation interventions	**Transportation and commuting**	
Student and employee commute model split	Faculty, staff and student commuting	✓
Campus fleet	NMMU campus service and utility vehicles	✓
	Shuttle/bus ridership	✓
	Air travel (NMMU official business)	
Waste interventions	**Waste generation**	
Waste reduction and diversion	Solid waste	✓
Hazardous waste management	Hazardous waste	✓
Greenhouse gas emissions inventory and reduction	Air emissions	✓
Electronic waste recycling	Electronic waste, recycling, composting,	✓

programme	landscaping wastes	
Education and Research	**Educational Programs**	
Curriculum Interventions	Environmental study programmes	✓
Co-curricular education interventions	Student organisations (Green Campus Initiative)	✓
	On-campus programmes and outreach programmes	
Research interventions	Related research projects	✓
Grounds interventions	**Grounds/natural heritage**	
Integrated pest management	Pesticide/herbicide, fertilizer use	✓
Dining services and purchasing interventions	**Purchasing/food services**	
Food and beverage purchasing	Dining services	✓
Cleaning products purchasing	Janitorial products	✓
Computer purchasing		
Office paper purchasing		
Vendor code of conduct		

Table 1: List of environmental indicators at NMMU

The second phase of the EIM framework is the design and implementation of an EMIS. In order to design such an EMIS, the first step is to analyse the existing environmental data sources and stores and the related processes that are involved in the management of environmental information. Interviews were therefore conducted at NMMU and the as-is processes for electricity and water were analysed and documented (Figure 2). Electricity and water are two of the main priorities of NMMU's environmental sustainability objectives. The existing data collection process for electricity at NMMU consists of two main sub-processes; the manual electricity reading process and the smart reader process. This is because the institution has been gradually installing Johnson Control Building Management System (JCBMS) smart meters and the old meters are replaced with smart meters. Hence some buildings are monitored by the JCBMS smart meters and others still have the old manual meters. At the time of this study there were no smart readers for water readings installed at NMMU. A similar process that is used to acquire electricity readings from manual meters is used to acquire the water readings from manual water meters.

The manual electricity reading process: An electrician goes around the various campuses reading data from each meter and records it into a handwritten document which is filed at the technical services department. The data manager at the technical services department then captures a summary of the usage into an Excel file, which is used for reporting or reconciling bill -payment purposes.

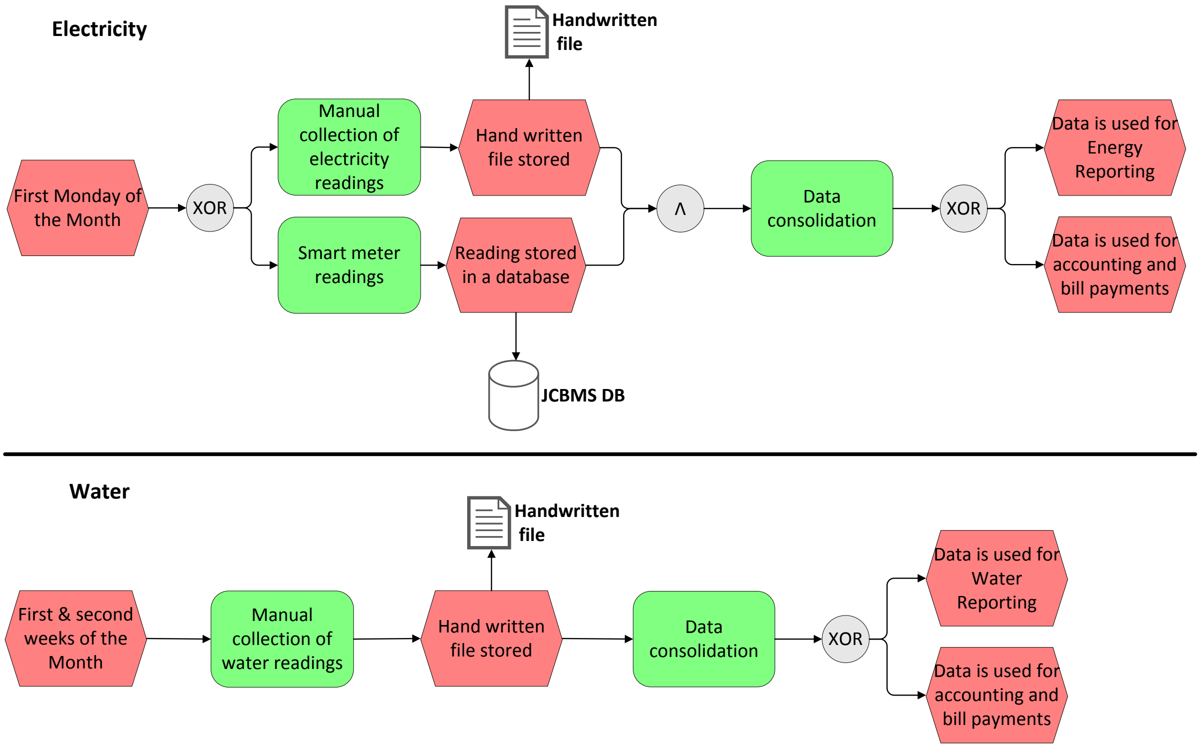


Figure 2: The as-is electricity and water data acquisition processes at NMMU

The electricity smart reader process: Data from the smart readers are automatically stored in the JCBMS database and can be extracted from the smart meter, at the user's request, for reporting or bill-payment purposes. However, currently only summarised data is available.

From the analysis of the processes it can be deduced that the manual process is cumbersome, time-consuming and inefficient. Moreover, there is much human intervention which can only increase the chances of errors.

To design the gap model for an HEI, the guidelines for the design and implementation of an EMIS from the study by Bero et al. (2012) were used. These best practice guidelines are:

7. Support for automated, sensor-based collection of data;
8. Improve processes relating to inefficient, manual entry of environmental data;
9. Provide support for allocating resource usage to buildings, and campus facilities such as sports grounds;
10. Support public awareness and outreach by allowing access by the community to simplified aggregated summaries of system data.

The processes at NMMU can therefore be improved by applying these four guidelines in order to derive the proposed, desired to-be processes for EIM at NMMU (Figure 3). The processes allow for realistic and comprehensive data gathering as they cater for manual systems. NMMU is in the process of upgrading to smart meters (electricity meters only). This process began in 2009 and will take several years to be fully implemented.

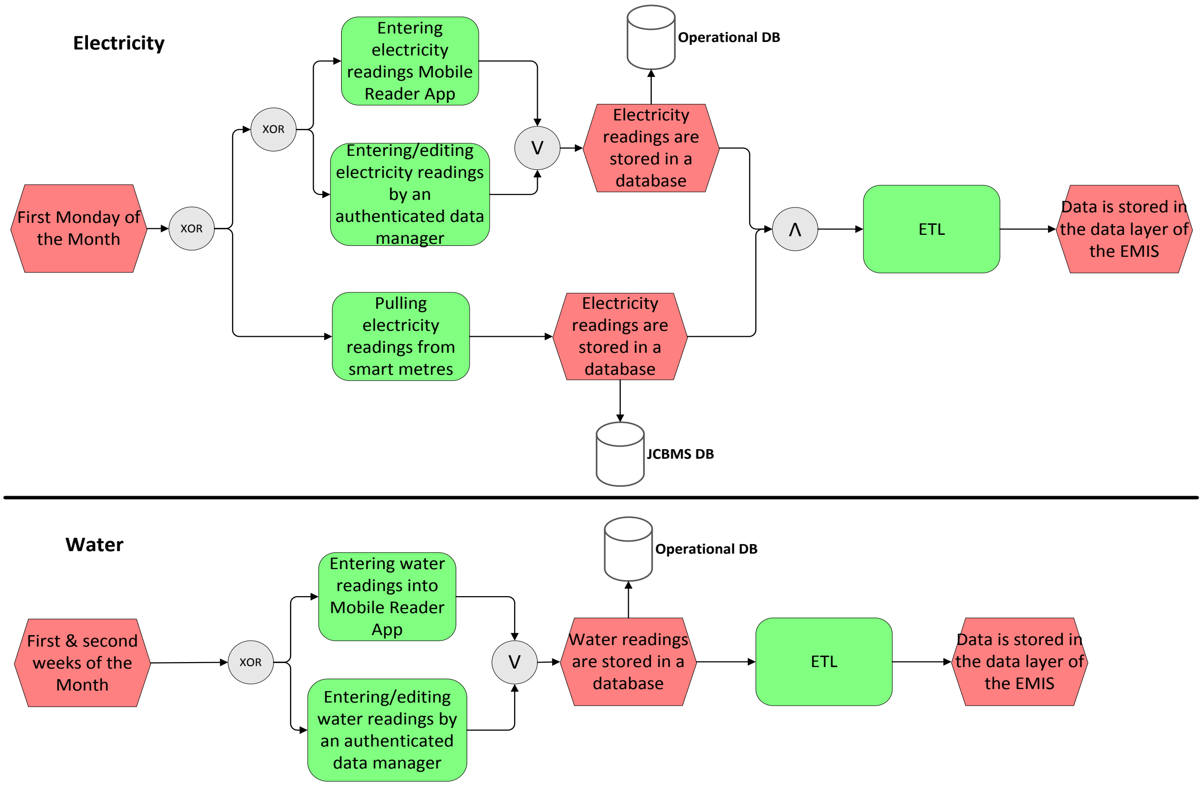


Figure 3: The proposed To-Be Processes for NMMU

The desired processes allow for the automated collection of data from smart meters, and improve the efficiency of collection processes for data over manual meters by the implementation of a Mobile Meter Reader app. This Mobile Meter Reader app allows the automated collection of data from manual meters, thereby eliminating any manual entry of environmental data. The data is saved on the mobile device and with the push of the button the data can be submitted to a central EIM database.

The gap model proposed for EIM in HEIs (Figure 4) highlights the importance of providing access for stakeholders to environmental information through the university portal. Access to information is important for inclusive communities and stakeholders with direct interests in the HEIs and thus provides the required institutional sustainability information. The institution's community can therefore have access to the environmental data via the public view to the university portal. The stakeholders include the entire community, for example, staff, management, board, sponsors, students and future students. The university portal can therefore increase sustainability awareness by educating internal and external society about its impact on the environment and involves them in sustainability efforts. Making environmental information public between departments can foster healthy competition in which departments become more aware of environmental issues in their daily operations. Hopefully they will attempt to get credit for improvements, or cost saving and avoidance and will celebrate accomplishments.

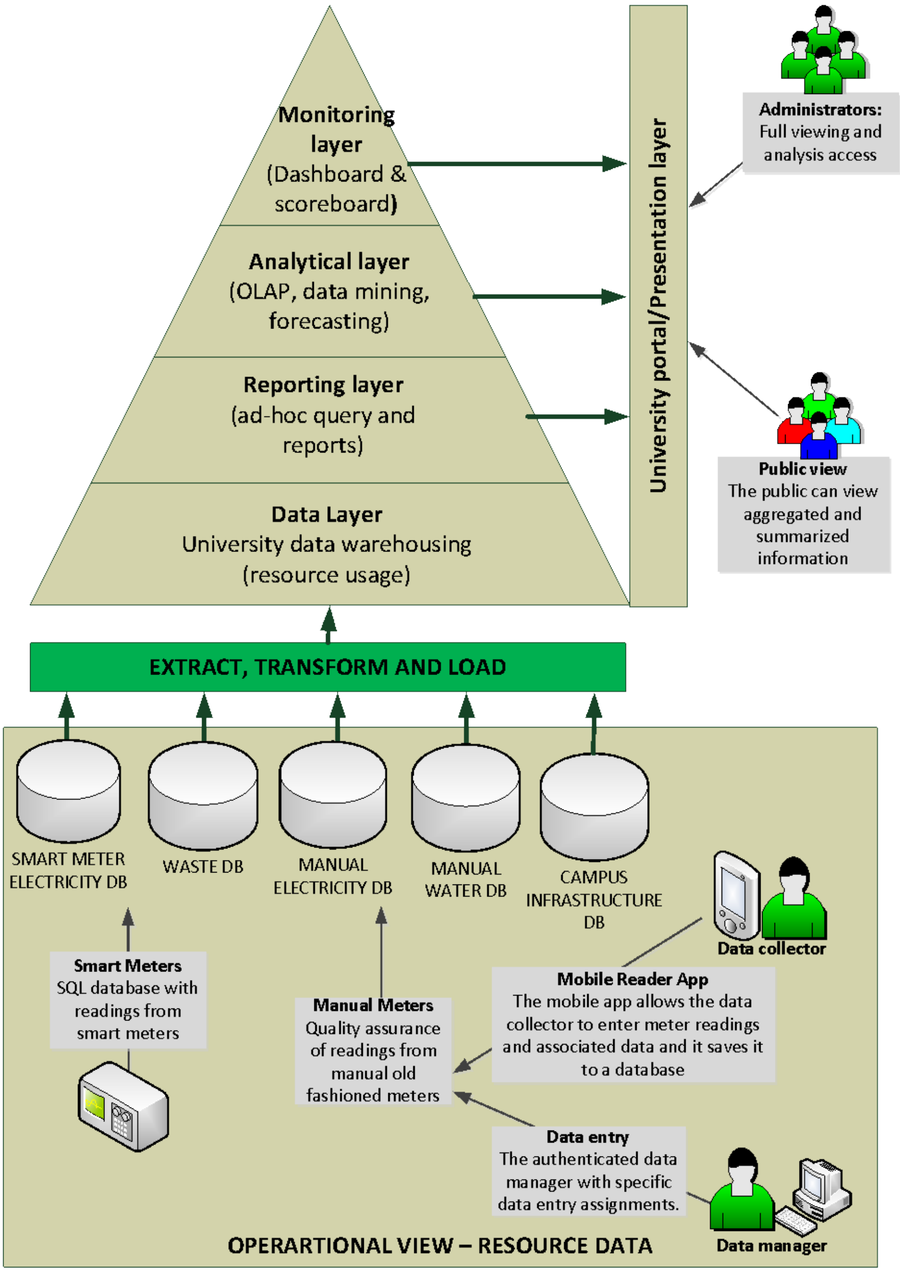


Figure 4: The design of an EMIS for HEI

Conclusions and recommendations

This paper proposed a framework which can assist HEIs to move from their as-is processes towards a desired to-be situation and therefore create a gap model. The framework facilitates the involvement of the HEI community. The framework was successfully applied at NMMU and several improvements to the data collection processes were made. Application of the framework exposed the ever-increasing complexity of campus infrastructure and showed the varying quality of datasets and the differences in data collection procedures. The urgent necessity is the implementation of a robust and comprehensive EMIS that can accommodate automated and manual data collection. An improvement in EIM can facilitate improvement in decision making, environmental awareness and community involvement.

This study forms part of a larger research study which aims to design and develop a university-wide environmental information-data warehouse. The development of the data warehouse is focused on making environmental data accessible for querying and for end-user applications. This will allow for the development of innovative end - user applications to serve as the portal by which stakeholders can access environmental information and view it in a meaningful way. This research in this paper is to serve as proof-of-concept with the hope of enticing senior management to support a drive towards creating an environmentally sustainable institution and an inclusive community.

The development of the fully analytical tools to support senior management in decision management is important. Future research can also be done in the field of Environmental Performance Dashboards (EPD) that will allow communication of the environmental data from different perspectives and present information in a way that the community can understand. HEIs are generally publicly funded, hence transparency and community involvement and uplifting are of utmost importance.

Appendix N: Framework Evaluation

Participant: ________________________

This questionnaire (which starts on the following page), gives you an opportunity to tell us your reactions to the theoretical framework you just saw. Your responses will help us understand the extent to which the framework addresses important Environmental (EN) aspects associated with Higher Educational Institutions.

Please read each statement and indicate how strongly you agree or disagree with the statement by ticking in the box corresponding to a number on the scale.

As you complete the questionnaire, please do not hesitate to ask any questions.

Thank you!

EVALUATION

The proposed framework should be evaluated based on the following questions.

1. **Do you agree/disagree with the following guidelines which apply to the components of Environmental Information Management (EIM) at Higher Education Institutions (HEIs)?**

No.	Guidelines	Agree	Disagree
Sustainability Strategy Cluster			
G1	A gap analysis can be used to identify areas for improvement in environmental information management processes.		
G2	Top management support is important for the success of EIM efforts in HEIs.		
G3	Environmental indicators for HEIs must be identified and prioritised at a strategic level.		
G4	EIM efforts need to be aligned with the strategic goals of the HEI.		
Managerial Services Cluster			
G5	Environmental sustainability reporting should be automated wherever possible.		
G6	Data analytics and monitoring of EIM should be provided.		
G7	Simplified aggregated data summaries of EIM must be available.		
G8	Data processing should be provided (Ad-hoc querying, modelling of data and decision support).		
G9	There should be support for allocating resource usage to buildings and campus facilities such as sports grounds and departments.		
Contribution Services Cluster			
G10	There is need for centralised storage of environmental information in an HEI.		
G11	HEIs need a computerised process for capturing of environmental data (e.g. water and electricity meter readings).		
G12	HEIs need to automate environmental data collection processes where possible (e.g. sensor based collection; smart meters).		
G13	It is important that HEIs perform quality assurance (data validation and verification) on environmental data collected.		
Distribution Services Cluster			
G14	There should be support for public awareness and outreach by allowing access to environmental information by HEI stakeholders (student, staff, board members, management, government bodies etc.)		
G15	Third party applications should be granted access to environmental information where possible.		

2. **Do you agree with the proposed components of the EIM framework/guidelines for HEIs?**
   □ **Yes** □ **No**
   If not, which components do you disagree with? Explain the reasons you disagree.
   ____
   ____
   ____
   ____

3. **Do you think this EIM framework can be useful to HEIs?**
   □ **Yes** □ **No**

   If not, explain the reasons why.
   ____
   ____
   ____
   ____

4. **In your opinion, is the EIM framework complete?**
   □ **Yes** □ **No**
   If not, what would you suggest adding?
   ____
   ____
   ____
   ____

5. **Do you have any other recommendations regarding the EIM framework? If so please specify here.**
   ____
   ____
   ____
   ____

Thank you for your participation. Your valuable contribution to this study is sincerely appreciated.

Appendix O: Consent Form

NELSON MANDELA METROPOLITAN UNIVERSITY

INFORMATION AND INFORMED CONSENT FORM

RESEARCHER'S DETAILS	
Title of the research project	**A Framework for Management of Environmental Information in Higher Education Institutions**
Reference number	**H13-SCI-CSS-23**
Principal investigator	**Blessing Jonamu**
Contact telephone number (private numbers not advisable)	**041 504 2094**

A. DECLARATION BY OR ON BEHALF OF THE PARTICIPANT		Initial
I, the participant and the undersigned	(full names)	

A.1. HEREBY CONFIRM AS FOLLOW		Initial
I, the participant was invited to participate in the above-mentioned research project		
that is being undertaken by	**Blessing Jonamu**	
from	**Department of Computing Sciences**	
The Nelson Mandela Metropolitan University		

A.2 THE FOLLOWING ASPECTS HAVE BEEN EXPLAINED TO ME, THE PARTICIPANT					Initial
	Aim	Evaluation of prototype The information will be used for research academic purposes.			
	Procedures	I understand that I am required to complete a questionnaire regarding the above mentioned research. I understand that they may be a follow-up questionnaire.			
	Risks	I understand that there are no risks involved in participating in this process.			
	Confidentiality	My identity will not be revealed in any discussion, description or scientific publications by the investigators.			
	Access to findings	Any new information or benefit that develops during the course of the study will be shared as follows: ON REQUEST			
	Voluntary participation / refusal / discontinuation	My participation is voluntary	**YES**	**NO**	
		My decision whether or not to participate will in no way affect my present or future career/employment/lifestyle	**TRUE**	**FALSE**	

	No pressure was exerted on me to consent to participate and I understand that I may withdraw at any stage without penalisation	

	Participation in this study will not result in any additional cost to myself	

I HEREBY VOLUNTARILY CONSENT TO PARTICIPATE IN THE ABOVE-MENTIONED PROJECT:		
Signed/confirmed at	on	20
Signature	Signature of the witness:	
	Full name of witness:	

Preamble Letter

NMMU
Tel: +27 (0)41 504-2079 Fax: +27 (0)41-504-2831
E-mail Faculty Chairperson: Kirsten.longe@nmmu.ac.za

Date: 30 September 2013

Ref: H13-SCI-CSS-23

Contact person: Blessing Jonamu

Dear Participant

You are being asked to participate in a research study. We will provide you with the necessary information to assist you to understand the study and explain what would be expected of you (participant). These guidelines would include the risks, benefits, and your rights as a study subject. Please feel free to ask the researcher to clarify anything that is not clear to you. To participate, it will be required of you to provide a completed written consent form that will verify that you understand and agree to the conditions.

Furthermore, it is important that you are aware of the fact that the ethical integrity of the study has been approved by the Research Ethics Committee (Human) of the university. The REC-H consists of a group of independent experts that has the responsibility to ensure that the rights and welfare of participants in research are protected and that studies are conducted in an ethical manner.

Participation in this research is completely voluntary and you are not obliged to take part. If you do partake, you have the right to withdraw at any given time during the study without penalty or loss of benefits. However, if you do withdraw from the study, you should return for a final discussion or examination in order to terminate the research in an orderly manner. The study may be terminated at any time by the researcher, the sponsor or the Research Ethics Committee (Human). Although your identity will at all times remain confidential, the results of the research study may be presented at scientific conferences or in specialist publications.

Yours sincerely

Blessing Jonamu

Appendix P: Data Warehouse Evaluation

Participant: _______________________

System: __________________________

This questionnaire (which starts on the following page), gives you an opportunity to tell us your reactions to the system you used. Your responses will help us understand what aspects of the system you are particularly concerned about and the aspects that satisfy you.

To as great a degree as possible, think about all the tasks that you have done with the system while you answer these questions.

For statements 1- 4 please read each statement and indicate how strongly you agree or disagree with the statement by ticking in the box corresponding to a number on the scale.

As you complete the questionnaire, please do not hesitate to ask any questions.

Thank you!

1. **Currently, using data collected manually can you get similar information as provided by the data warehouse?**
   - ☐ **Yes** ☐ **No**

   If yes, please provide an estimate of how much time and effort it takes to get similar information.

____

____

____

____

2. **Please indicate (using a tick or X) if you agree or disagree with the following statements**

	Yes	No
5. Information provided by the data warehouse is relevant to me.	☐	☐
6. The data warehouse provides timely access to information.	☐	☐
7. It is easy to get access and answers to ad hoc queries.	☐	☐
8. Information provided by the data warehouse is understandable.	☐	☐

3. **Do you have any future recommendations for the data warehouse?**

____

____

____

____

Thank you for your participation. Your valuable contribution to this study is sincerely appreciated.

Appendix Q: SQL Statements for EnviroDW

1. What is the monthly usage of electricity for '*residences*' in 2013?

```
SELECT MonthYear,Sum(Usage) AS ElectricityUsage FROM FactElectricity,DimCostCentre
WHERE FactElectricity.CostCentreID = DimCostCentre.CostCentreID
AND DimCostCentre.CostCentreName='RESIDENCES'
AND YEAR(FactElectricity.MonthYear)=2013
GROUP BY MonthYear
ORDER BY MonthYear;
```

2. Which department used the most electricity in 2013?

```
SELECT  top 1 CostCentreName, Sum(Usage) AS TotalUsage FROM
FactElectricity,DimCostCentre
WHERE FactElectricity.CostCentreID = DimCostCentre.CostCentreID
AND YEAR(FactElectricity.MonthYear)=2013
GROUP BY CostCentreName ORDER BY TotalUsage DESC
```

3. Which department used the least electricity in 2013?

```
SELECT  top 1 CostCentreName, Sum(Usage) AS TotalUsage FROM
FactElectricity,DimCostCentre
WHERE FactElectricity.CostCentreID = DimCostCentre.CostCentreID
AND YEAR(FactElectricity.MonthYear)=2013
GROUP BY CostCentreName ORDER BY TotalUsage ASC
```

4. What is the average electricity usage for '*residences*' in 2013?

```
SELECT AVG(Temp.ElectricityUsage) AS AverageUsage
FROM
(SELECT Sum(Usage) AS ElectricityUsage FROM FactElectricity,DimCostCentre
WHERE FactElectricity.CostCentreID =DimCostCentre.CostCentreID
AND DimCostCentre.CostCentreName='RESIDENCES'
and YEAR(FactElectricity.MonthYear)=2013
GROUP BY MonthYear) AS Temp
```

5. What is the total electricity usage for '*residences*' in 2013?

```
SELECT Sum(Usage) AS TotalUsage FROM FactElectricity,DimCostCentre
WHERE FactElectricity.CostCentreID = DimCostCentre.CostCentreID
AND DimCostCentre.CostCentreName='RESIDENCES'
and YEAR(FactElectricity.MonthYear)=2013;
```

6. What is the monthly usage of electricity for '*LETABA RES*' in 2013?

```
SELECT MonthYear, Sum(Usage) AS ElecUsage
FROM FactElectricity, DimCostCentre, DimLocation
WHERE FactElectricity.CostCentreID = DimCostCentre.CostCentreID
AND DimCostCentre.LocationID = DimLocation.LocationID
AND DimLocation.LocationName ='LETABA RES'
AND YEAR(FactElectricity.MonthYear)=2013
GROUP BY MonthYear
ORDER BY MonthYear;
```

7. Which building used the most electricity in 2013?

```
SELECT TOP 1 LocationName, Sum(Usage) AS TotalUsage
FROM FactElectricity, DimCostCentre, DimLocation
WHERE FactElectricity.CostCentreID = DimCostCentre.CostCentreID
AND DimLocation.LocationID = DimCostCentre.LocationID
AND YEAR(FactElectricity.MonthYear)=2013
GROUP BY LocationName ORDER BY TotalUsage DESC
```