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Multi-dimensional Business Process Optimisation for Greenhouse Gas (GHG) Emission Management

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Dedication

I dedicate this thesis to:

My wonderful parents;

Mr. Dharmasiri Samarasinghe Ekanayake and *Mrs. Wasantha Ekanayake* for your endless love, support, sacrifices, and encouragement,

My amazing husband;

Devashi Amrith Wesumperuma for your loving heart and caring soul,

My precious daughter and son;

Ameeshi and *Denith* for being the greatest joys of my life,

My darling brothers;

Gayan and *Danesh* for your love and support.

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Statement of Authentication

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

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(Ashini Emalka Wesumperuma)

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Abbreviations

AA - Acetaldehyde

ABC - Activity Based Costing

ABM - Activity Based Management

AS - Australian Standard

ADH - Average Distance Heuristic

BRE - Building Research Establishment

BREAM - (BRE Environmental Assessment Method)

BPA - Business Process Analysis

BPM - Business Process Management

BPML - Business Process Modelling Language

BPMN - Business Process Modelling Notation

BPR - Business Process Re-engineering

CO_2 *- Carbon Dioxide*

CE - Carbon Emissions

CEO - Chief Executive Officer

CAE - Computer-Aided Engineering

CEMS - Continuous emission–monitoring systems

CPM - Critical Path Management

CRM - Customer Relationship Management

DEFRA - Department for Environment, Food & Rural Affairs

EF - Earliest finish

ES - Earliest start

EIO - Economic Input-Output

ERP - Enterprise Resource Planning

ES - Evolution Strategies

EA - Evolutionary Algorithm

EP - Evolutionary Programming

XML - Extensible Markup Language

FF - Finish-to-Finish

FS - Finish-to-Start

GA - Genetic Algorithms

GP - Genetic Programming

GHG - Greenhouse Gas

HCFC - Hydrochlorofluorocarbon

HFC - Hydrofluorocarbon

OH - Hydroxyl

IS - Information Systems

IT - Information Technology

IBM - Injection Blow Molding

ICOM - Input, Control, Output and Mechanism

ICAM - Integrated Computer-Aided Manufacturing

IDEF - Integrated DEFinition

IPCC - Intergovernmental Panel on Climate Change

ISO - International Organisation for Standardisation

IV - Intrinsic Viscosity

JCP - Jobs and Competitiveness Program

KVA - Kilovolts ampere value

kW - Kilowatt

LULUCF - Land Use, Land-Use Change, and Forestry

LF - Latest finish

LS - Latest start

LCA - Life Cycle Assessment

LCI - Life Cycle Inventory

CH_4 *- Methane*

MOEAT - Multi Objective Evolutionary Algorithms Tool

MOPO - Multi-Objective Process Optimisation

MOGA - Multiple Objective Genetic Algorithm

NCOS - National Carbon Offset Standard

NGA - National Greenhouse Account

NGER - National Greenhouse and Energy Reporting Technical

NREL - National Renewable Energy Laboratory

NPGA - Niched-Pareto Genetic Algorithm

N20 - Nitrous Oxide

NSGA - Non Dominated Sorting Genetic Algorithm

NSGA II/ NSGA2 - Non-Dominated Sorting Genetic Algorithm

NSW New South Wales

PFC - Perfluorocarbon

PET - PolyEthylene Terephthalate

PEMS - Predicative emission–monitoring systems

PAS - Publicly Available Specification

RAD - Role Activity Diagrams

SME - Small to Medium Enterprise

SF - Start-to-Finish

SS - Start-to-Start

SPEA2 Strength Pareto Evolutionary Algorithm2

SPEA - Strength Pareto Evolutionary Algorithm

SF6 - Sulphur hexafluoride

TBL - Triple Bottom Line

UML - Unified Modelling Language

UOB - Unit of Behaviour

UK - United Kingdom

UNFCCC - United Nations Framework Convention on Climate Change

USA - United States of America

VEGA - Vector Evaluated GA

WfMS - Workflow Management System

WBCSD - World Business Council for Sustainable Development

WRI - World Resources Institute

Abstract

Anthropogenic Greenhouse Gas (GHG) emission from activities conducted within business organisations is a major contributor to climate change. A *business process* is a set of tasks and activities. At business process level, business objectives such as cost of production and time to market are managed and optimised by organisational middle level managers. At present, GHG emission related information is not available to facilitate decision making at process level to achieve GHG related objectives. For organisations to remain sustainable and decision making to be effective, managers need a holistic approach to manage and optimise GHG emissions together with other business objectives. Therefore, this research addresses the overarching knowledge gap in *business process level GHG emission modelling, calculation, reporting, and optimising*.

The purpose of this thesis is to undertake a qualitative and quantitative examination of managing GHG emissions to achieve multi-dimensional business process optimisation while considering other process level objectives like cost and time, to support and empower organisational middle level managers in decision making. In the pursuit of finding a solution to this problem the researcher has created an artefact, *"Green Multi-Objective Process Optimisation (Green MOPO) Framework".* This framework extends the boundaries of human and organisational capabilities to solve the real world research problem.

The framework consists of four major stages, each sub-divided into steps. Each step provided guidance to compute relevant parameters to assist in achieving GHG emission related objectives alongside other process level objectives. The researcher investigated theories relating to each step and discovered gaps in knowledge that has to be addressed to complete each stage. By addressing these gaps six constituent artefacts were produced.

- Current emission measuring tools and guidelines are not aimed at measuring emissions of organisational processes. *Constituent Artefact-I* assists to identify a business process and its different abstraction levels as activity, sub-process, process, and to apportion shared or overhead emissions, e.g. lighting and heating.
- *Constituent Artefact-II* is a tool and a methodology named *Green Activity Based Management (ABM)* that allows GHG, time, cost modelling and further analysis, calculation, and reporting at different process levels.
- *Constituent Artefact-III* is a set of formulas that allows GHG emissions to be calculated and consolidated at different business process abstraction levels identified by the first artefact.

- Current reporting tools only offer top-down organisational level reporting summaries and are not adequately detailed for middle management to manage GHG emissions. *Constituent Artefact-IV* is an international standards based reporting tool that allows bottom-up reporting of GHG emissions, to provide a bird's eye view of emissions and their sources.
- Currently, there is no proper methodology to perform optimisation simultaneously for several dimensions including GHGs. To introduce such optimisation, possible process level changes need to be captured. The study first develops a taxonomy of business process element changes which then helps to derive a multi-objective mathematical model/formula that captures these changes. *Constituent Artefact-V* proposes selection criteria for an optimisation technique that can optimise the derived formula. The artefact compares and contrasts a set of multi-objective optimisation techniques to select one that best suits the application context.
- *Constituent Artefact-VI* solves the multi-objective formula by applying the optimisation technique against the derived formula. This optimisation resulted in a set of optimal solutions. Using computer based simulation, the artefact relates the optimal solutions back to the business domain, and specifies what the optimisation parameters and their values are in a manner that is clearer and concise to business managers.

This research employs the *Design Science Research* paradigm. In design science research, knowledge and understanding of the design problem and its solution is gained while building an artefact and during the application of that artefact. The research evaluates the main artefact, *Green MOPO Framework* against real-life business processes in the Polyethylene terephthalate (PET) package manufacturing sector. This type of manufacturing processes consumes a large quantity of energy and hence greatly contributes to GHG emissions. The thesis showcases that the main artefact is useful for the specific purpose it was built for and relates the performance to the intended use of the artefact.

The thesis clearly pin points the contributions to the knowledgebase and to practice from the main artefact and its constituent artefacts. It shows how these artefacts add extensions to existing theories and provide new and innovative solutions. The study identified and demonstrated the implications of understanding GHG emission management at a business process level, which paves the way to continuous business process improvement and achievement of multi-dimensional business process optimisation and organisational sustainability. The threat from climate change is serious, growing and urgent. Hence, any contributions from this research will help the present generation to better respond to this major global challenge that shows no boundaries. Further, alongside contributions to research and practice, the limitations of this study opens up many important future research avenues.

List of related publications

- WESUMPERUMA, A., GINIGE, J. A., GINIGE, A. & HOL, A. Framework for Multi-dimensional Business Process Optimization for GHG Emission Mitigation. 22nd Australasian Conference on Information Systems ACIS 2011 - Paper 91, 2011. AIS Electronic Library.
- WESUMPERUMA, A., GINIGE, A., GINIGE, J. A. & HOL, A. Green Activity Based Management (ABM) for Organisations. 24th Australasian Conference on Information Systems (ACIS), 2013 Melbourne, Australia. Melbourne: RMIT Library Research Repository, 11.
- WESUMPERUMA, A., GINIGE, A., GINIGE, J. A. & HOL, A. Green Activity Based Reporting for Organizational Business Process Management. 10th Asia Pacific Conference on Sustainable Energy & Environmental Technologies (APCSEET 2015), 2015 Korea. 4.

CHAPTER 1 : Introduction to the Research

1.1 Chapter Introduction

Today, business organisations operate in a highly competitive, technology driven turbulent business environment. They face daily challenges in many facets such as achieving high productivity, effectively engaging the workforce, and responding to new customer demands. Further, due to the increase in human induced Greenhouse Gas (GHG) emissions and its impact on global climate, businesses are forced to cut down on emissions. At present, the GHG emission management challenge for business organisations is very real and growing.

Amidst facing these daily challenges, businesses need to achieve several day to day business objectives such as reducing production costs and reducing time to market. Hence, organisations need to become more agile and respond well to change. Thus, the primary goal of this research is to addresses this knowledge gap of *business process level GHG emission modelling, measuring, calculating, reporting, and optimising*. In a business organisation, a set of tasks and activities are generally called a *business process*. Through continuous improvement of core business processes, they can optimise and achieve some of these business objectives. Presently, business process level optimisation is generally sought for cost and time. The business world is still not considering GHG emission management as one of the objectives that has to be optimised alongside other process objectives at business process level. Bearing in mind that this is a global issue, very little attention has been given both in academia and in practice.

This chapter introduces the research the thesis is based on. The next section situates the study by providing context to it and pin points specific areas of concerns. Thereafter, grounded in the context, this chapter introduces the research problem. Finally, the chapter concludes with an overview of the study which acts as a storyline synopsis of the thesis.

1.2 Context of the Study

Anthropogenic climate change is becoming a major global challenge in its potential impacts to humanity. Human activity induced GHG, of which *Carbon emissions* is a major pollutant, are rapidly changing the Earth's climate. Around the globe, governments, economists, and business leaders agree the best way to reduce pollution is putting a price tag on pollution (ACF, 2011). Some governments have already implemented various carbon or environmental taxes as an incentive to make people and organisations actively seek other options such as cleaner energy sources (e.g. solar, wind, and geothermal power).

The previous Australian federal government announced a framework to implement a *Carbon tax* from July 1, 2012 (ACF, 2011). This was repealed in July 1, 2014 by the present government (DE, 2014). Instead, the present government has proposed the *Direct action plan.* Currently, major political parties, Coalition and Labour, agree on the need to reduce GHG emissions by five per cent below year 2000 levels by the year 2020 (DE, 2014). However, the methods the two parties propose to achieve the same target differ.

Much research has been carried out globally as well as nationally on methods of identifying, quantifying, calculating, and managing GHG emissions (Fransen et al., 2007, Bhatia, 2008, Garnaut, 2008, Doherty et al., 2010, Easterbrook, 2010). Currently, emission calculations are mainly estimated at national, economic sector, organisational or individual level. Broad brushed figures produced by high level calculations are not useful from a management perspective. Further, present GHG emission calculating initiatives have overlooked an important aspect of organisations, which is the *Business process level*.

From the organisational management's perspective, organisations function as a set of business processes. An organisational middle level manager has the control over a particular process that he/she overlooks. Business process has received significant attention both in academia and business practice. There are many *Business process modelling* techniques (e.g. role activity diagrams, entity relationship diagrams) with approaches that capture different aspects of a business process. However, business process modelling still does not capture GHG emissions. Therefore, need of a business process modelling technique that will enable further *Business process analysis*, in terms of GHG emission management is of significant value

Business processes are continuously improved or optimised to meet several business goals. Within an organisation, process level optimisation can happen and this can lead towards optimisation of the whole set of processes. *Business process optimisation* in comparison with business process modelling and business process analysis has not received much attention in literature. Business process optimisation is often attempted with a single goal like reduction of time or cost. However, in reality organisational management wants to achieve several goals simultaneously. Sometimes conflicting goals bring in several dimensions to consider (i.e. multi-dimensional in nature) and as a result are complex. Due to this, multi-dimensional business process optimisation has received even less attention. Moreover, management of GHG emissions is never considered as an objective or a goal at the process level.

Performing multi-dimensional optimisation for an entire organisation will require considerable amount of effort. Whether it is a *Small to Medium Enterprise (SME)* or a multinational company, optimising at an organisational level involves many of the top level managements' very careful and precise decision making. Hence, its time consuming and pain staking to perform. Whereas, if the empowered middle management can look at processes within their purview and take the most appropriate action to optimise them, the effort required would be considerably less and thus much more practical.

As shown in the Figure 1.1, typical manufacturing processes can be within a single department or they can span over two or more departments and in some instances processes may interact with external entities as well (e.g. outsourcing transportation of goods to an external organisation). Each process will be under the supervision of a middle level manager (e.g. warehouse manager). As depicted in the diagram, the focus of this study is in optimisation of a business process (e.g. Put-away business process). Thus, GHG emission management can start at business process level, while considering other business objectives.

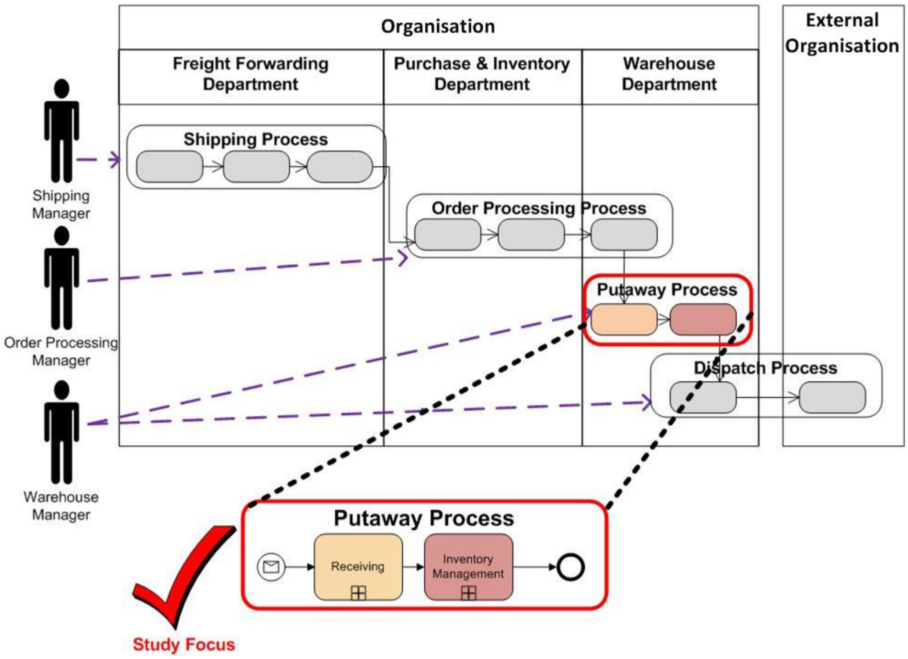

Figure 1.1: Research Study Focus Area

1.3 Motivation of the Study

The primary motivation for this study comes from a problem presented by an organisation that wanted to effectively measure and manage their GHG emissions to be a sustainable organisation. Environmental sustainability is an important objective within the context of organisational business process management (Seidel and Recker, 2012). For organisations to become sustainable, managers need a holistic approach to manage GHG emissions together with other business objectives such as time and cost. Organisations have to capture, model, measure, and report GHG emissions at a business process level, in order to make the correct decisions to manage GHGs, .

If management uses a current emission calculator to measure these emissions, they end up getting broad brushed figures at organisational level categorised according to GHG Protocol's Scope 1, Scope 2, and Scope 3 (WBCSD-WRI, 2004). Scope 1 refers to all direct emissions except from combustion of biomass. Scope 2 is GHG emissions from generation of purchased electricity. Scope 3 emissions refer to all other indirect emissions such as raw material processing, transportation of fuels/waste, employee business travel, and employee commuting (WBCSD-WRI, 2004). Apart from categorising and summarising organisational level GHG emissions according to the above mentioned scopes, present emission calculators are not very informative. The calculators fail to provide GHG emission related information to the degree that is useful to managers. Hence, for many managers *"where and how much was emitted"* remains a mystery.

Managers use the process level information related to cost and time to continuously improve the business processes to meet these objectives. Due to the lack of business process level GHG emissions related information emission figures are not further analysed at business process level to optimise along with other important business goals such as cost and time. Thus, the following section first states the purpose statement of this thesis followed by the central research questions that this research will investigate.

1.4 Research Questions

The purpose statement to pursue this investigative journey is as follows:

> *"The purpose of this thesis is to undertake a qualitative and quantitative examination of managing Greenhouse Gas (GHG) emissions to achieve multi-dimensional business process optimisation while considering other process level objectives like*

cost and time, to support and empower organisational middle level managers in decision making."

This research restates the purpose statement in more specific terms as a central research question. The research sets out to find answers to this research question and it will guide the research process. Further, the main research question scaffolds the entire research project. Following is the central research question this research will investigate.

"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"

To answer this question, the research sub divides the main research question further into two sub research questions. Each of these questions is examined in detail using investigative questions.

1.4.1 First Sub-research Question

1. *"How can GHG emissions at a business process level be modelled, measured, calculated, and reported efficiently?"*

Investigative Questions

1.1. *"What are the levels of a business process, in which GHG emissions can be modelled?"*

1.2. *"How can GHG emissions be modelled, measured, and calculated* in above identified *business process levels?"*

1.3. *"How can GHG emissions associated with a business process be reported in three emission categories identified by the GHG Protocol, namely Scope 1, Scope 2, and Scope 3?"*

1.4.2 Second Sub-research Question

2. *"How can a set of multi-dimensional parameters including GHG emissions associated with a business process be optimised effectively?"*

Investigative Questions

2.1. *"How can other business objectives such as cost and time be modelled against GHG emissions in a business process?"*

2.2. *"What is the criterion for selection of an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions?"*

2.3. *"How can a selected optimisation technique (based on the criterion set* above in *investigative question 2.2) be applied for business process optimisation for GHG emission management alongside other business objectives?"*

1.5 Research Aim, Objectives and Scope

In order to respond logically to the research problem, a research needs to have an aim. It is important for this aim to be singular. Otherwise the research will have to fulfil all aims and the thesis will be split according to the aims and will need merging at the end of the thesis (Evans et al., 2011). Thus, this research will stick to a single aim. This section will first express the research aim, followed by research objectives and finally the section will explain the scope of the study.

1.5.1 Research Aim

The main aim of this research is "*to develop a framework to perform multi-dimensional business process optimisation including GHG emission management to support and empower organisational middle level managers"*. Hence, the framework should be able to:

(1) Model, measure, and calculate GHG emissions at a business process level and report at corporate level as required by the GHG Protocol standard;

(2) Analyse GHG emissions against other business objectives to arrive at an optimal solution in GHG emission management.

The above singular aim is targeting a holistic approach to manage GHG emissions together with other business process level objectives, in empowering organisational middle level managers in decision making.

1.5.2 Research Objectives

The previous sub section stated the single paramount aim of this study. The issues involved in achieving this aim require fulfilment of several research objectives. Thus, these objectives and related issue are:

- *To devise a mechanism to quantitatively capture GHG emission figures using an appropriate business process modelling technique at various business process levels.*
- *To develop a formal mathematical model that can be used to optimise the business process multi-dimensionally (i.e. considering GHG emissions, cost of production, and time to market) using the captured GHG emissions.*

This study intends to fulfil the above stated objectives to achieve its aim.

1.5.3 Research Scope

Based on the identified research objectives this section sets the limits for the research. The research scope identifies the boundaries of the research study. A *business process* in this research is *"A collection of activities that takes one or more kinds of input and creates an output that is of value to the customer.",* as stated by the pioneers of Business Process Re-engineering (BPR), Hammer & Champy (1993, p.90). Further, as List and Korherr (2006, p.2), have said *"The basic elements of a business process are Activities. They can be either Atomic Activities or Sub-Processes, which are recursively refined by activities."* The research limits to business processes in the manufacturing and logistics sector. Hence, the identified issues and proposed solutions are related to the business processes in the manufacturing and logistics sector.

Due to several factors, e.g. duration of the PhD, there are several limitations in the study. As explained earlier, only manufacturing and logistic sector is considered. Even though, this proposed framework can be applied to many processes from different sectors, it was not evaluated against them. Moreover, the business processes considered are stable business processes as the core processes do not change comparatively with time but only the business decision rules within them will change. Further, in this study only carbon emissions are considered for the final evaluation. However, several other GHG emissions can be incorporated with extensions to the emission calculation formulas and theses are produced by the GHG protocol (WRI-WBCSD, 2013). The study only uses a mathematical multi-objective optimisation technique but there are other optimisation techniques that are not considered in this study, such as simulation. In addition to the prominent limitations mentioned in this paragraph there are other content specific limitations which will be mentioned later in the relevant chapters.

1.6 Significance of the Study

This research is the first of its kind to bring new knowledge in *"how to multi-dimensionally optimise a business process including GHG emissions"*. The proposed research represents a substantial and original contribution to both practitioners and research community. Practitioners from environmental regulatory authorities or governments will be able to directly apply contributions from this study in their respective organisations. Contributions from this to the research community can lead toward generation of new knowledge or enhancement of existing knowledge.

The proposed framework is applicable in any country within a similar context. Among the anticipated benefits to practitioners include the following:

- The study will make a significant impact by empowering the organisational middle level management with detailed information necessary to reduce GHG emissions from a business process.
- The study identifies various levels of a business process in which GHG emissions can be modelled practically.

- Using the above mentioned business process levels organisational managers will be able to measure and calculate GHG emissions.
- In Australia, even after the abolition of the *Carbon Tax*, it is still compulsory for large organisational GHG emitters to report their GHG emissions according to Scope 1, 2, and 3, as defined by the GHG Protocol. In the future, it may be compulsory for many organisations to account and report their own emissions. This study makes it possible to roll-up the emissions captured at the above mentioned business process levels according to scopes. This type of reporting will make the organisational processes more transparent and credible in terms of reporting GHG emissions. Thus, governments or environmental regulatory authorities can analyse this detailed transparent information and gain many insights that can lead towards identifying current issues faced by organisations, contemporary organisational practices that have to change to reduce GHG emissions and areas where governments have to provide incentives to reduce emissions. Overall, governments and environmental regulatory authorities will be able to better understand organisations and their issues related to GHG emission reduction in context.

This research extends original theories and methods and builds new artefacts. Therefore, this research employs the *Design Science Research* paradigm. In design science research, knowledge and understanding of the design problem and its solution is gained while building and deploying the artefact (Hevner et al., 2004). The major contribution to the knowledgebase is the main artefact, named as *"Green Multi-Objective Process Optimisation (Green MOPO) Framework"* built as an answer to the research problem. In addition, the following are the main contributions by this study to the knowledgebase:

- Firstly, the study extends the GHG Protocol recommended steps for calculating GHG emissions and reporting at corporate level as a set of guidelines which identifies a business process and its different abstraction levels i.e. activity level, sub-process level, process level, and shared levels.

- The study extends Activity Based Costing (ABC) and Critical Path Method (CPM) principals to model and analyse GHG emissions in a methodology called *"Green Activity Based Management (ABM) Methodology"*. This methodology allows the GHG, time, and cost modelling and further analysis at different business process levels. Thus, the study shows how quantitative objectives, which can be measured at the process level, can be simultaneously modelled visually as well as formally.
- This study comes up with a set of formulas that allows GHG emissions to be calculated and consolidated at different business process levels. This set of formulas adds to the formulas introduced by WBCSD and WRI (2004).
- The study extends the *"top down"* organisational level reporting into activity based reporting. It helps to collate calculated GHG emissions figures according to the *scopes*. This reporting is a *"bottom-up"* approach as oppose to the top-down approach introduced by the GHG Protocol (WBCSD-WRI, 2004). Hence, it contains more detailed process level GHG emission related information for the organisational management.
- Previous studies have not attempted to optimise a business process for several objectives including GHG emissions simultaneously. Therefore, it is important to select the best optimisation technique that can give the best possible set of optimal solutions in this context. This research identifies possible process level changes that allows optimisation and builds a taxonomy that captures these changes. This taxonomy helps to derive a multi-objective optimisation formula which reflects the process changes capable of achieving business process optimisation. Thereafter, the study sets the criteria to select an optimisation technique. Using these criteria it shows how to select the most appropriate optimisation technique.
- Multi-objective optimisation problems are complex by nature. For better understanding, mapping between the multi-objective optimisation formula or the formal model and the optimisation technique is vital. The study shows how to bridge this gap by

programmatically solving a multi-objective problem and thereafter relating the optimal solution set back to the business domain, in terms of the parameters and their values, in a manner that is coherent to business managers.

The framework provides systematic business process optimisation for several quantitative dimensions. This study brings together new knowledge in multi-dimensionally optimising a business process including GHG emissions. The study is significant to practitioners and researchers in several ways as this is the first study of its kind to address the knowledge gap of *business process level GHG emission modelling, measuring, calculation, reporting, and optimising*.

The contribution of knowledge from this study would be significant, as businesses can use this study to optimise their processes from grass root level, to reduce emissions while still being able to achieve their goals. The next section provides an annotated version of the table of contents to show how the storyline of this thesis flows.

1.7 Chapter Conclusion and Overview of the Study

This introductory chapter detailed the research problem, context, motivation, research questions, main research aims, objectives, scope, and significance of the study. The remainder of the thesis is organised in a way the storyline flows in a sequential manner to communicate research findings. The Figure 1.2 demonstrates this thesis layout.

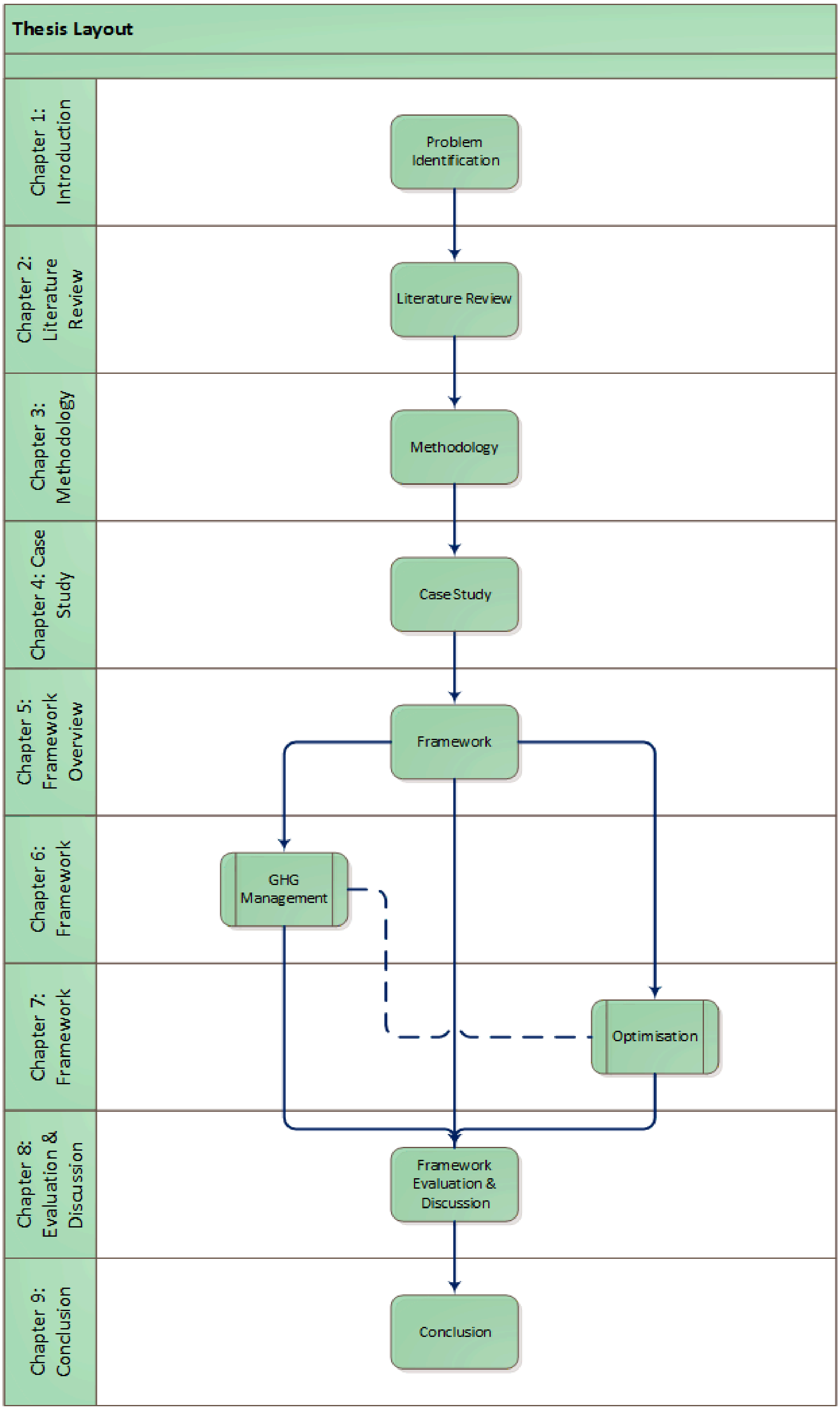

Figure 1.2: Thesis Organisation

Following is the overview of the study that describes how the chapters relate to the research storyline.

- This chapter, Chapter 1, provided the background to this study including the problem statement, study's aim, objectives, and scope and finally provides with an overview of the study.
- Chapter 2 presents the background knowledge by positioning this research in context of what has taken place before, what is taking place currently, and how research in this context is currently being conducted.
- Chapter 3 details the systematic plan employed to solve the research problem. It discusses the steps adopted in studying the research problem, along with the logic behind each decision.
- Chapter 4 describes the case study design employed in pilot study and the main case study.
- Chapter 5 presents a concise description of the new and innovative artefact, *Green Multi-Objective Process Optimisation (Green MOPO) framework* built as an answer to the research problem.
- Chapter 6 and 7 provide the detailed descriptions of constituent artefacts of the proposed framework and show how they answer the related investigative questions. These two chapters show how these artefacts would contribute to the knowledge base.
- Chapter 8 evaluates and argues that each and every artefact served its intended purpose rigorously in terms of utility, quality, and efficacy by using well executed evaluation methods.
- Chapter 9 concludes this study. It points out how the conclusions were drawn from relating the framework performance to the intended use as argued in the evaluation and discussion chapter.

CHAPTER 2 : Literature Review

2.1. Chapter Introduction

Chapter 1 introduced the study background and highlighted the real world problems faced by businesses. In particularly, to survive in the present business environment, businesses need to look at a situation from several angles such as reducing production cost and time, improving quality and complying with the needs of effectively managing GHG emissions; and not just at one aspect in isolation. As GHG emission management is becoming an essential aspect of conducting business, Chapter 1 summarised the importance of making GHG emission as one of the business goals. Chapter 1 further stated the importance of optimising a business process for GHG emission management along with other process level objectives. It stated the study is conducted in context of manufacturing and the logistics sector.

Along the lines recommended by Evans et al. (2011), this chapter tries to establish the context of study further. It identifies current theories, discoveries and debates the relevance to the study topic, and nominates knowledge gaps found in literature. In addition, the chapter provides a comprehensive discussion on current practices and technologies. It then draws focus to areas that would warrant further investigation. Following are the key objectives of this literature review.

- To clearly establish the key terminologies which form the baselines for this research.
- To exhibit the rationale behind the key variables selected for the analytical and summative research investigation.

- To develop a theoretical framework to show the links this research has with the existing body of knowledge.
- To describe the research gaps found as a result of the research investigation and the importance of addressing them.

To achieve the above mentioned key objectives, this chapter first introduces the key concepts that form the foundation for this research study. Next, it describes the theoretical rationale behind this study by looking at the sustainability of an organisation, the role Information Systems (IS) play currently, and green business process management. Then, it presents the theoretical framework of this investigation, which consists of three important areas of: GHG emissions, business process modelling, and optimisation. To address key objectives, the chapter examines the current research topics and restates the research questions.

2.2. Key Concepts

This section establishes a set of concepts that will form the basis for the topics discussed in this research. This set comprises of *Climate Change and Greenhouse Gas (GHG) Emissions, Corporate/ Organisational Sustainability, Information System (IS), Business Process, Business Process Management (BPM), Green Business Process Management, Optimisation, and Multi-objective Optimisation.*

2.2.1. *Climate Change and Greenhouse Gas Emissions*

In September 2008, the Garnaut Climate Change Review stated climate change as the "*Diabolical Policy Challenge*" of our generation (Garnaut, 2008). Left unmitigated, the whole world is at the risk of surrendering to this climate change challenge. According to the United Nations Framework Convention on Climate Change (UNFCCC or FCCC), climate change is defined as:

> *"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC, 1992).*

The UNFCCC (1992) states that *Greenhouse Gases* (GHG) causes global warming and climate change. The more damaging GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20). Even though Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6) are less prevalent, they are much more destructive to the earth's climate even in small doses. The Earth's climate differs considerably on a regional and local basis. The danger posed by just considering the global averages is such that they tend to mask large regional variations (Garnaut, 2008).

GHG emissions have *Emission Sources* and *Emission Sinks*. An emission source will emit GHGs in to the atmosphere as a result of a human activity (e.g. fossil fuel combustion) or as a consequence of a natural process's output (e.g. respiration of plants and animals). An emission sink will remove emissions from the Earth's atmosphere by converting emissions in to a different chemical compound (E.g. Photosynthesis from green plants). Before human activities influenced an increase in GHG emissions, there were stable GHG concentration levels in the Earth's atmosphere. Today, there is an imbalance between the emission sources and sinks (Denman, 2007). Table 2.1 shows a summary of GHG emission sources and sinks.

Table 2.1: 1 Sources and sinks of the GHG emissions (Denman, 2007, Garnaut, 2008)

Gas	Natural sources	Dominant anthropogenic sources	Natural sinks
Carbon dioxide	Respiration from living organisms	Fossil fuel combustion and the global manufacture of cement	Photosynthesis by green plants - land based
	Volcanic eruptions	Deforestation - Land-use change	Photosynthesis by phytoplankton - ocean based
	Forest fires	Changing agricultural practices - Land-use change	Dissolution - ocean based
	Decomposition of dead animals and plants	Other land-use change	Acid-base reactions - ocean based
	Outgassing from the ocean		Carbonate-forming reactions of many marine organisms - ocean based
Methane	Oceans	Energy production from natural gas, coal and petroleum	Oxidation by hydroxyl radicals, ·OH
	Termites	Decomposition in landfills	
	Anaerobic decay of vegetation from wetlands	Raising ruminant animals	
	Hydrates	Rice farming	
		Permafrost melting in the Arctic - due to global warming	
Nitrous oxide	Oxidation of ammonia in the atmosphere and from nitrogen in soils	Extensive use of nitrogenous fertilisers	Atmospheric N_2O destruction in the stratosphere (photolysis)
		Fossil fuel combustion	
		Decay of livestock manure	
		Biomass burning	
		Industrial activities such as nylon manufacture	
HFCs	Some PFCs and all HFCs have no detected natural sources	Refrigeration	
		Air conditioning	
		Solvents	
		Fire retardants	
		Foam manufacture	
		Aerosol propellants	
PFCs	Volcanic activity	Aluminium production	
Sulphur hexafluoride	Volcanic activity	Electricity supply industry (switches and high-voltage systems)	
CFCs and HCFCs		Propellants in aerosol cans	
		Refrigerants in refrigerators and air conditioners	
		Manufacture of foam packaging	

In the context of Australian emission sources, nearly 82% of its total emissions are attributable to the industrial sector and the remainder is from the residential sector (Garnaut, 2008). The main emission intensive industrial sectors consist of energy (electricity, stationary energy excluding electricity, transport, fugitive emissions), industrial processes, agriculture, and waste sectors (NGGI, 2013).

As shown in Figure 2.1, industries in energy and agricultural sectors are responsible for large amounts of GHG emissions. Within these different sectors, GHG emissions are generated by various emission sources e.g. boilers, heaters, furnaces, turbines, incinerators (WBCSD-WRI, 2004). Thus, one can deduce that organisations in these industrial sectors are largely responsible for GHG emissions generation. In this study industries are sometimes referred to as company, business or organisation.

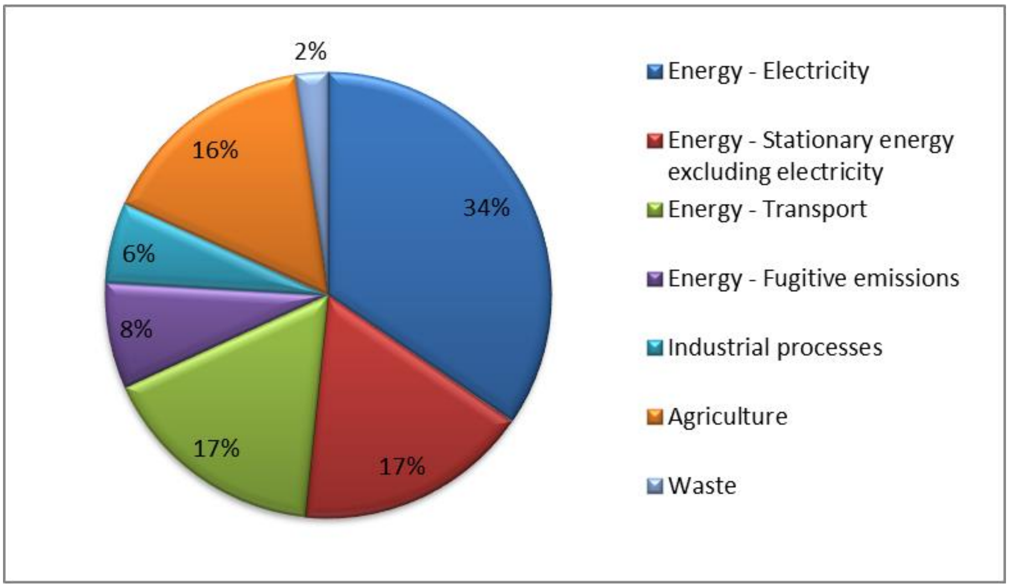

Figure 2.1: Australia's National Greenhouse Gas Inventory - Emissions by sector, adopted from NGGI (2013)

In order to account for the GHG emissions of a company's operations, emission data needs to be linked with relevant operations, sites, geographic locations, business processes, and owners. Moreover, accounting of GHG emissions needs to be analysed with a globally agreed set of standards. Currently, the World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) jointly convened GHG Protocol provides the most widely accepted guide for accounting for GHG emissions from organisations and emission reduction projects (WBCSD-WRI, 2004). National Level GHG Inventories presently rely on Intergovernmental Panel on Climate Change (IPCC) methodology reports as a guidance (IPCC, 2007). Furthermore, the International Organisation for Standardisation (ISO) also provides some general standards including (i) greenhouse gas emissions at organisation level (ISO 14064 - 1) and (ii) greenhouse gas emissions at project level (ISO 14064 - 2) (ISO, 2006a).

GHG Protocol has listed the steps in identifying and calculating emissions as:

1. Identification of emission sources;

2. Selection of the calculation approach;

3. Data collection and selection of emission factors;

4. Application of calculation tools;

5. Rolling-up of data to corporate level (WBCSD-WRI, 2004).

GHG Reporting is performed to suite various government and organisational reporting uses as well as users. To effectively manage GHGs, setting up the organisational and operational boundaries are important (Fransen et al., 2007).

According to the GHG Protocol, emissions are broadly categorised into two spectrums as *Direct Emissions* and *Indirect Emissions*. Emissions from sources which are owned or controlled by a particular company are termed as *Direct Emissions* (Daviet, 2006). Emissions from combustion in owned or controlled boilers, furnaces, vehicles; emissions from chemical production in owned or controlled process equipment are some examples that belong to this category. When GHG emissions are due to activities of the reporting company, but occur at sources controlled or owned by another company are said to be *Indirect Emissions (Daviet, 2006)*. Some examples of indirect emissions are GHG emissions from: the generation of purchased electricity consumed by the company; extraction of purchased material; production of purchased material; transportation of purchase fuels; and use of purchased services and products (WBCSD-WRI, 2004).

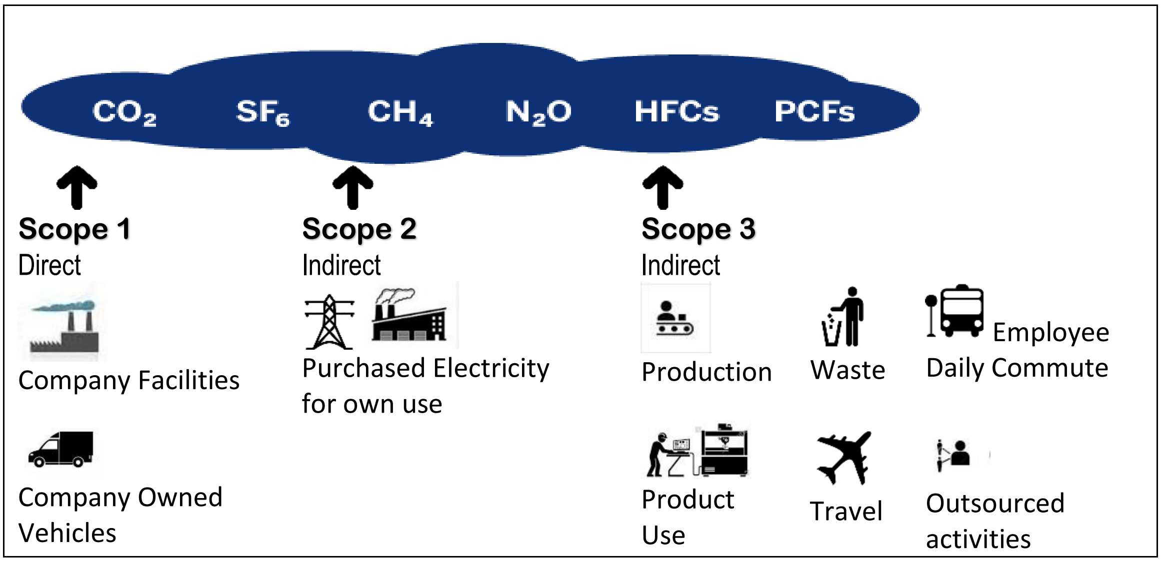

Figure 2.2: GHG Emissions with relation to Scope 1, Scope 2 and Scope 3 adopted from Daviet (2006)

For GHG accounting and reporting purposes, GHG Protocol defines three Scopes: Scope 1, Scope 2, and Scope 3 (Figure 2.2). Direct emissions except from combustion of biomass are considered as Scope 1. Scope 2 is for *Electricity indirect* GHG emission or GHG from generation of purchased electricity. Scope 3 emissions are termed as all other indirect GHG emissions and considered as optional in terms of reporting.

2.2.1.1. Scope 1 emissions:

Emissions from sources owned or controlled by the reporting company.

- Stationary fuel combustion
- Mobile and transportation source emissions
- Process emissions (e.g. Oil and Gas Energy Sector)
- Fugitive emissions

2.2.1.2. Scope 2 emissions:

Emissions belonging to this category physically take place at the location where the electricity is generated (WBCSD-WRI, 2004). Scope 2 emissions are:

- Stationary fuel combustion (consumption of purchased electricity, heat or steam)
- Electricity and/or steam imports.

2.2.1.3. Scope 3 emissions:

These GHG emissions are the reporting company's indirect emissions other than those covered in Scope 2, e.g. Extraction and production of purchased material. Scope 3 emissions are:

- Stationary combustion (e.g. raw material processing)
- Process emissions (e.g. during production of purchased materials)
- Mobile combustion (e.g. transportation of fuels/waste, employee business travel, employee commuting)
- Fugitive emissions (CH_4 and CO_2 from waste landfills, pipelines, SF_6 emissions).

All these emissions can only be quantified if they are accurately measured or estimated. Thus, it is important to know emission measurement and estimation techniques available to do this.

2.2.1.4. Emission Measurement and Estimation Techniques

At present, there are four major emission measurement and estimation techniques (Daviet, 2006).

(1) Emission factors–based approaches

(2) Mass (material) balance measures

(3) Predictive emission–monitoring systems (PEMS)

(4) Continuous emission–monitoring systems (CEMS)

The above mentioned measurement and estimation techniques, measure or estimate GHGs, SO_2, and NO_x emissions. The advantages and disadvantages of usage of a particular technique depend on the emission source and the gasses involved. The following provides a brief discussion on each of these techniques.

Emission factors–based approaches

An emission factor is an activity specific figure. A particular activity will have its own emission factor value. An emission factor converts activity data into emission values (Pino et al., 2006). According to Daviet (2006, p. 30), an emission factor is

> *"a coefficient that quantifies the emissions or removals of a gas per unit activity, and it often is based on a sample of measurement data, derived as a representative rate of emissions for a given activity level under a particular set of operating conditions."*

The emission factor will specify, the kilograms of CO_2 equivalent emitted per a unit of activity performed (NCOS, 2012). The following formula is used to calculate the GHG emissions with the emission-factor based method.

$$\text{GHG emissions } (e.g. tonnes\ of\ CO_2) = \text{activity data } (e.g. litres\ of\ fuel\ consumed) * \text{emission factor } (e.g. tonnes\ of\ CO_2\ per\ litre) \ldots\ldots\ldots\ldots (2.1)$$

As shown in the above formula, in the emission factors–based approaches, the activity data is multiplied by the emission factor to get the associated emissions. This approach is popular as it does not require the user to be on-site to gather emission related data. Generally, relevant authorities publish the country specific emission factors. For example, in Australia, the Department of Climate Change and Energy Efficiency (2012) publishes this information in the National Greenhouse Account (NGA) Factors report (OME, 2007).

Mass (material) balance measures

In the mass balance method, the law of conservation mass is applied to a process or a facility. As chemical elements (e.g. carbon, hydrogen, and oxygen) cannot be created or destroyed, the emissions are calculated based on the difference of a unit operation. This method is generally applied to calculate emissions from a stationary combustion sources where the actual carbon content of the fuel is known (OME, 2010, Daviet, 2006). The generic equation (2.2) used is:

$$\text{Input} = \text{Output} + \text{Emissions} \quad \ldots\ldots\ldots\ldots (2.2)$$

Input = Amount of the input stream chemical element being tracked (e.g. carbon)

Output = Amount of the output stream chemical element that was not emitted in to the atmosphere (e.g. carbon in fly ash).

Emissions = Resultant GHG emissions

For this type of measurement to be accurate, the actual carbon content of the fuel being used should be known prior. This measurement gives relatively accurate results for CO_2 emissions from stationary combustion sources (Daviet, 2006).

Predictive emission–monitoring systems (PEMS)

The term "Predictive" in this context means the analysis of historical and current data to make predictions about the amount of GHG emissions that will result from an activity during a certain time period. PEMS formally models a correlation between process-related parameters (e.g. fuel usage, furnace temperature) and contaminant emission rates. According to PEMS, a "contaminant" is when an unwanted substance is found above a certain threshold which may be harmful to humans, animals and natural environment. "Contaminant emission rates" is when anthropogenic GHG emissions rates are above the accepted threshold. These thresholds are published by standard authorities. This system does not continuously monitor emission concentrations only to determine the amount of emissions. It is a combination of continuous monitoring and stack tests. A stack test provides a snapshot of the emission concentrations during a test time period. This involves obtaining samples from chimney stacks or other chosen discharge points in order to determine the characteristics of the emissions, (OME, 2010, EPA-SA, 2012, OME, 2007).

Continuous emission–monitoring systems (CEMS)

CEMS consists of all the necessary equipment to measure emission concentration levels on site from a smoke stack of any stationary combustion unit for CO_2, SO_2, and NO_x gases and at times for N_2O emissions. These monitoring systems can provide accurate real time data.

In Australia, the National Greenhouse and Energy Reporting (Measurement) Technical Guidelines assist organisations by outlining calculation methods and the criteria for determining GHG emissions, energy production and consumption. Emission source descriptions are based on IPCC Guidelines for National Greenhouse Gas Inventories, while estimation techniques are those that are used in National Inventory Report guidelines as required by UNFCCC (NGER, 2011).

In this study only the first measurement and estimation technique, *Emission factors based approach* would be used as it is the most accurate estimate for carbon emissions (Daviet, 2006). The source of any GHG emission is due to some kind of an activity and often the unprecedented GHG emissions are due to human involvement. Thus, even the climate change is sometimes referred to as "*Anthropogenic"*, with regard to the human impact on the environment (Rosenzweig et al., 2008). Therefore, in this study the climate change is often referred as anthropogenic climate change.

2.2.2. Corporate/ Organisational Sustainability

Currently, we are consuming Earth's resources at an unsustainable rate and this has created many environmental problems. The World Commission on Environment and Development in 1987 defined sustainable development as:

> *"The development that meets the needs of the present world, without compromising the ability of future generations to meet their own needs (Brundtland, 1987, p. 16)"*

Due to the rapid depletion of natural resources and ever increasing disparity in wealth as well as concerns over corporate social responsibility, the *sustainability* in an organisational context is becoming important within business research and practices (Dao et al., 2011). The ultimate goal of sustainability is to satisfy three interdependent and mutually reinforcing pillars (UN, 2002) i.e. economic sustainability, social sustainability, and ecological sustainability (Chen et al., 2008). However, today businesses tend to focus only on economic sustainability. Due to this, businesses mostly achieve short term success. They need to focus on all three sustainability dimensions to attain long-term sustainability (Chen et al., 2008).

Some authors point out that the three pillars described above were first introduced by Elkington (1998) as the *Triple Bottom Line (TBL)*. According to Elkington (1998), the TBL combines traditional economic goals with contemporary environmental and social issues (Figure 2.3). Moreover, within the business world, environmental performance is becoming a competitive and strategic issue. As a result, environmental concerns are opening out new avenues in a far-reaching and challenging sustainable development agenda.

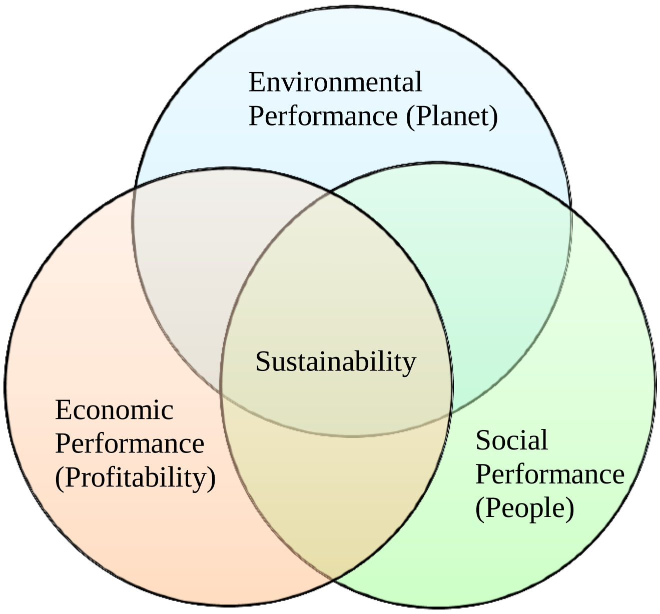

Figure 2.3: The Triple Bottom Line of sustainability adopted from Dao et al. (2011)

Economic sustainability is achieving success in profit generation that leads towards: creating value to the stakeholder, increased competitiveness, and market share (Chen et al., 2008).The popular definition of economic sustainability is the *'maintenance of the capital'*. On close inspection, the capital consists of four forms as: human made, social, human, and natural. The natural capital (e.g. forests and clean air) was comparatively the least scares out of the four forms of capital. Thus, since ancient traders from the middle-ages to current economists, were rarely concerned about it. Moreover, in economics the value is often measured in monetary terms. Natural capital is difficult to value in monetary terms as sometimes the value is intangible and sometimes it consists of commonly accessed resources (e.g. air). This resulted in natural capital being treated as an external cost rather than an internal cost. However, today the natural capital is steadily becoming internalised due to sound environmental policies and improved valuation techniques (Goodland and Daly, 1996).

In economic sustainability, the main focus is for the organisations to constantly generate value to its stakeholders. However, the environmental sustainability focus goes beyond the current generations. It emphasises on our generation's social responsibility towards the future generations as they will be the ones to bear the burden of the damage caused by the present generation's relentless resource consumption.

The social capital of economic sustainability is closely linked with the social sustainability. Social capital consists of trust, sense of community and social integration (Elkington, 1998). However, social capital which is not rigorously measured is perhaps the most valuable aspect for social sustainability. Social sustainability needs to be maintained by shared values, equal rights, and cultural and religious interactions. If these are not met issues will depreciate the social capital along with physical capital. Systematic community participation and a strong civil society will lead towards social sustainability (Goodland and Daly, 1996).

The origin of environmental sustainability lies in social concerns that seek to improve human welfare and social sustainability by ensuring resource protection and waste management for the betterment of humans. Thus, humans and living beings need environmental sustainability. Further, environmental sustainability aims to maintain the natural capital which is one of the three forms that act as the basis for economic sustainability (Goodland and Daly, 1996). In addition, environmental sustainability extends the social, organisational as well as individual domains to incorporate the natural environment (Melville, 2010).

Businesses, Government and Civil Society form an important triangular relationship. Each of these three aspects has a mechanism that will coordinate their behaviours to fulfil the role within the society. Governments create and maintain the legislation. Businesses generate wealth via cooperation and competition. Civil society will structure and shape the society through collective action and participation. Today, due to complexities in each of these aspects, businesses, governments and the civil society are inter-dependent. As a result businesses have to learn to operate within interfering coordination mechanisms. This is more prominent now as governments are leaving responsibility for societal problems more and more within the authority of corporations. (Marrewijk, 2003).

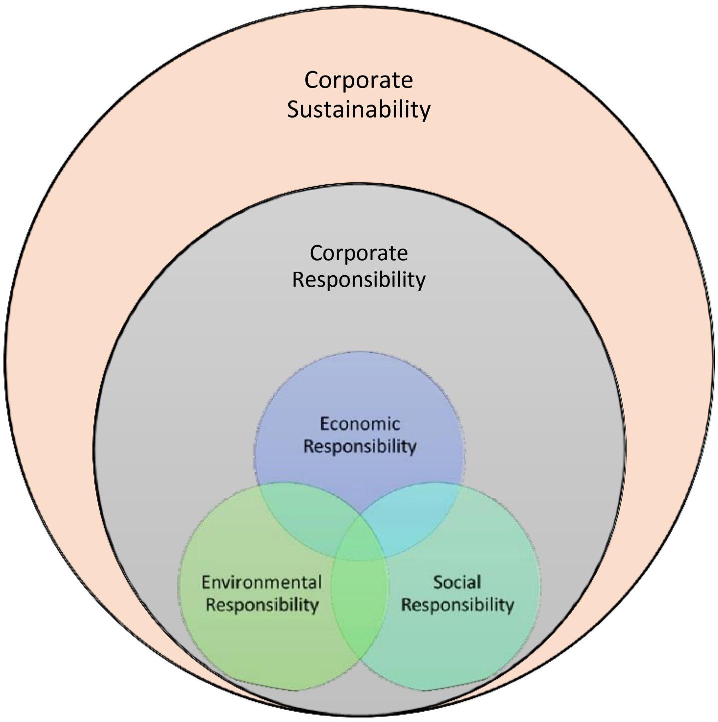

Figure 2.4: The relationship between corporate sustainability, corporate responsibility and corporate social responsibility adopted from Marrewijk (2003)

Today, corporate responsibility incorporates many facets. The economic, environmental, and social sustainability aspects form the corporate responsibility that companies have to be concerned about. Figure 2.4, illustrates this relationship between the corporate sustainability, corporate responsibility and corporate social responsibility (Marrewijk, 2003).

At present, many *Triple Bottom Line (TBL)* advocates firmly believe, that corporates have social responsibilities that goes beyond generating values to the stakeholder. Corporate social responsibility is synonymous with the TBL (Norman and MacDonald, 2004). For example, a statement by a CEO of a corporate giant in Canada (Vancouver City Savings Credit Union) agrees with this claim. Mowat (2002, p.1) states the TBL approach to business as:

> *"Taking environmental, social and financial results into consideration in the development and implementation of a corporate business strategy."*

2.2.3. Information Systems

Sustainability requires sustainable business practices. Today, Information Systems (IS) are becoming an integral part of doing business (Esty, 2006). According to Englander (2009) a system is a collection of components that are linked and organised to be recognised at a unit. Along the same lines, an information system consists of a set of components to collect, store, process data and deliver information, knowledge and digital products (e.g. online auctions).

Businesses depend on information systems to carry out and manage their business operations, maintain relationships with customers and suppliers as well as to compete in marketplaces (Zwass, 2013). According to Watson et al. (2008, p.2)

> *"An information system (IS) is an integrated and cooperating set of software using information technologies to support individual, group, organisational, or societal goals."*

Businesses are different from one another in how they do business. Therefore, businesses need different information systems for decision making and other work related activities that serve different management levels, functions and business processes within the organisation. There are three types of information systems as: *operational support and* *enterprise systems, knowledge work systems,* and *organisational management support systems* (Zwass, 2013).

Operational support and enterprise systems include transaction processing systems, customer relationship management systems, and supply chain management systems. Transaction processing systems support organisational operations which help to design, market, produce, and deliver products. Customer relation management systems deal with business's customers for sales, marketing, servicing. (Zwass, 2013). Supply chain systems are developed to improve the long term performance of the individual companies in terms of the whole supply chain. This is achieved through systematic and strategic coordination of business functions and tactics (Mentzer et al., 2001).

Knowledge work systems are used to manipulate and abstract information and knowledge according to the context. Some of these include: Professional support systems (e.g. Computer-Aided Engineering (CAE) software and virtual reality systems to test new engine models), collaboration systems (e.g. workflow systems) and knowledge management systems which assemble and act on the accumulated knowledge throughout the organisation.

Organisational management support systems comprise of a large number of systems such as management reporting systems, decision support systems and business intelligence and executive information systems. Each manager in an organisation is responsible for a specific area. Management reporting systems provide routine, detailed, and voluminous reports to help with management. Decision support systems help support organisational decision making. These systems analyse large amounts of data to provide many insights. Thus, they are also known as business intelligence applications. Executive information systems makes available summaries of critical data in a convenient form (e.g. graphical digital dashboards) (Zwass, 2013).

A new branch of information systems is emerging today to combat climate change. This is known as the Green Information Systems (IS). Green IS are considered as a potential solution to current environmental problems. Dedrick (2010, p.2) refers to Green IS as:

“The use of information systems to achieve environmental objectives, while Green IT emphasizes reducing the environmental impacts of IT production and use“

Presently, emerging Green IS literature is taking two paths: top-down and bottom-up. The top-down path is survey and interview based and tries to look at relationships, common trends. On the other hand, the bottom-up approach looks at the application of IS and the usefulness of IS to reduce the carbon foot print in a cost effective and socially acceptable way. The bottom-up research is again two fold as it either creates theory based-frameworks or come up with Information Technology (IT) based practical and localised activities which may influence an individual or group behaviours (Hasan and Dwyer, 2010).

Green IS are one of the latest developments in the area of sustainable business practices as sustainability is a complex phenomenon which goes beyond just environmentally friendly computing (Brooks et al., 2012). Thus, Green IS are designed and implemented to contribute to sustainable business processes (Boudreau et al., 2008).

In the organisational sustainability sphere there is another concept called *Green Information Technology (IT)* or *Green IT* gaining popularity. In essence, Green IT means environmentally friendly and sound IT. Across the globe businesses are becoming aware of new IT innovations and advances and rapidly adopting them. Along with this increased IT adaptation brings environmental concerns like considerable increase in power consumption, and IT hardware production and disposal. Day by day the IT industry is growing and so are its environmental impacts. As a result there is a push for businesses to make IT systems *“Greener”*(Murugesan and Gangadharan, 2012) by a sector of the public and academics who have realised this potential danger. Green IT encompasses the study and the practices involved in IT hardware design, manufacture, usage and disposition effectively and efficiently so that it causes minimal or no damage to the environment (Murugesan and Gangadharan, 2012).

In academia, on one hand some authors distinguish between the Green IT and Green IS. On the other hand, some argue that both address the same issues. According to Butler (2011), Green IT is environmentally sustainable design, manufacture, packaging, and distribution of IT artefacts. Butler (2011) shows through empirically theoretical propositions that Green IS can support sense-making, decision-making and knowledge-sharing within organisations as well as for creation, design and manufacture of Green IT. Accordingly, Green IT-enabled IS can play a key role by making the business processes and resulting products sustainable.

Further, due to the size of IT investments, practitioners of IT have realised the importance of greener IT practices. They have proposed the use of Green IT as a solution to support environmentally friendly business practices (Brooks et al., 2012).

Even though, some use the terms Green IT and Green IS interchangeably, by definition IT and IS mean different aspects. Whereas IT emphasises on technical infrastructure (Brooks et al., 2012), IS is considered as the integration and cooperation of people, processes, software and IT to support individual, organisational, and social goals. Thus, the focus of IT is much narrower and IS comparatively broader and provides many more initiatives to support business processes (Watson et al., 2010). Therefore, Green IT is considered as a part of Green IS. The Green IS goes beyond Green IT and includes technology, people, the organisational mindset and the culture (Brooks et al., 2012). Further, Boudreau et al (2008) claims that Green IS tackles a much larger problem than Green IT. Green IS has much greater potential than Green IT, as it is geared towards making the entire system sustainable.

Today, business organisations are aware of the fact that they need to move towards more sustainable and IT-enabled business processes, geared toward achieving economically, ecologically, and socially sustainability. To deliver business benefits whether it is cost saving or time saving or even sustainability, IT-enabled systems play a key role in achieving these benefits. Comprehensive understanding of business processes will lead towards identification of process-centred business opportunities to become sustainable or *Green* (Seidel, 2011).

As explained in this sub-section, at present, organisations need to become sustainable not just for their organisational longevity but to combat climate change for the sake of the future generations. Literature examined in this sub-section reflects that sustainable organisations require sustainable business practices equipped with ISs that support the organisational business processes. Therefore, a true Green IS which is designed and implemented to contribute towards sustainable business processes will look at GHG emissions management as well as other process level business objectives.

2.2.4. Business Process

The section begins with the concept of a *Business Process*, which has received much attention in a broad spectrum of related areas. Many authors have tried to define this term of *"Business Process"*. Most of the early definitions have their origins in Production (Lindsay et al., 2003). With time definitions have shifted the emphasis from merely production based process environments to office based process environments. However, the most cited definitions are from Hammer & Champy (1993, p. 90) and Davenport (1993 , p. 24). As more recent definitions stem from these past business process definitions, next paragraphs review these past definitions.

Pioneers of Business Process Re-engineering (BPR), Hammer & Champy (1993, p. 90) state:

> *"A business process is a collection of activities that takes one or more kinds of input and creates an output that is of value to the customer. A business process has a goal and is affected by events occurring in the external world or in other processes."*

Hammer & Champy (1993, p. 90) emphasis on process behaviour with pre-conditions as inputs and post-conditions as outputs. However, as the terms *"collection of activities"* does not imply the ordering of neither the activities nor the execution of its constraints, this definition is quite liberal and open to interpretation (Weske, 2010).

Another popular definition is by Davenport (1993 , p. 24), he claims a business process as:

> *"A structured, measured set of activities designed to produce a specific output for a particular customer or market."*

Davenport (1993, p.24) identifies the ordering of process activities and It is constrains. It implies a strong emphasis on how work is done within an organisation, in contrast to a product focus's emphasis on what. He identified a set of characteristics of a business process in relation to business logic.

Lam et al.(2009) states a business process as a framework, in which activities participate and interact, to produce a product or a service, to achieve well defined business objectives. The structure of the framework affects the overall business performance. Better the business performance, the greater the business competitiveness in todays' global economy.

A more recent definition by Weske (2010, p.5) takes in to account the organisation of activities and the constrains brought in by the environment that governs them. According to his definition

> *"A business process consists of a set of activities that are performed in coordination in an organisational and technical environment. These activities jointly realize a business goal. Each business process is enacted by a single organisation, but it may interact with business processes performed by other organisations."*

The terms *“organisational”* and *“technical environment”* imply the business rules which define or constrain some aspects of the business as well as the technical enablement.

Business processes can be categorised into three categories as: *core/operational processes; management processes;* and *support processes* (Grant, 2011). Output of a core processes would be generation of a product or a service and would add value to the company. Typical core processes are purchasing, manufacturing, advertising and marketing, and sales (Harmon and Davenport, 2007). Management processes are there to govern the operations of a system, e.g. corporate management or strategic management. In order for the operational processes to perform work smoothly, support processes must be performed harmoniously (Grant, 2011).

Harmon’s (2007) study identifies a specific value chain within an organisation with strategic goals. He subdivides the value chain into its major processes. Then further sub divides major processes into sub processes. If required further subdivision of sub processes is carried out as well. Thereafter, he argues that activities are the smallest process element that is modelled. Most detailed analysis is undertaken at this activity level. He states that work within a business is done by processes which build that business and similarly actual work done by a process is ultimately done by the activities which make up that process (Harmon and Davenport, 2007).

List and Korherr (1983 , p.2) think that:

> *‘The basic elements of a business process are “Activities”. They can be either Atomic Activities or Sub- Processes, which are recursively refined by activities.’*

They claim that this as the functional perspective of a Business Process.

Contradictory to these definitions, Australian Government’s Jobs and Competitiveness Program (JCP) has come up with an approved set of activity definitions for the purpose of GHG emissions related data collection by the industry. For an example, Alumina Refining is an activity definition. Under this program, Alumina refining activity encompasses several key processes. These processes are generally performed to transform bauxite into alumina through the Bayer Process (DCCEE, 2011). The Bayer process, which is basically a chemical engineering process comprised of wet grinding, digestion, clarification, precipitation, calcination, and the processing of bauxite residue. The term *"process"* in this context is quite different to the context of management, which is used in this document. According to these activity definitions, an *"activity"* is not the basic element of a business process. However, the JCP admits that the set of activity definitions is an *"overarching approach that has been adopted by the Government"* (DCCEE, 2011). Therefore in the study reported in this thesis the term "*activity"* takes the meaning of what is stated earlier by Davenport (1993 , p. 24), List and Korherr (1983 , p.2), Harmon (2007) and Weske (2010).

This section described several key concepts that formed the basis for the study. Above mentioned concepts are important to explain the theoretical rationale behind the theoretical framework. Rationale will state the fundamental reasons for selecting the specific areas relevant to this study. Then it will identify the relationships between these specific areas under investigation. This linkage will help to establish the context of the research problem. Therefore, the next section presents the theoretical rationale.

2.2.5. Business Process Management and Green BPM

The explicit representation of business processes along with their related activities and the execution constraints between them forms the basis of *Business Process Management (BPM)*. BPM incorporates concepts, techniques, and methods which support the process: design, configuration, administration, enactment, and analysis (Weske, 2010). This support allows for the focus of BPM technology to be on achieving better understanding, modelling, improving or optimising of business processes. Organisations apply BPM technologies to reduce time, save money, improve quality, and flexibility (Nowak et al., 2011). Since sustainability aims at things like the use of alternative green energy sources and reduction of GHG emission foot print of an activity, BPM is well placed to support this.

Organisational BPM involves the use of IT-based systems to improve and manage business processes to achieve business objectives like cost and time savings, flexibility, quality improvement or to attain environmental, ecological or social sustainability. At this juncture, between the process change and the IT-system enablement lays the opportunity for sustainable initiatives. Any major organisational sustainability initiative will involve business process re-design. It is impossible to undertake any such change without considering the benefits and opportunities information technology would bring along. At the same time employees of an organisation and the management of them is vital to the success for any transformation to sustainable business practices and solutions. Hence, BPM presents the opportunities for a holistic and integrated sustainability management approach (Seidel, 2011).

Use of existing and extended BPM technologies to achieve *"green"* goals is termed as Green BPM. Ghose et al.(2010, p.1) defines Green BPM as:

> *"A novel class of technologies that leverage and extend existing BPM technology to enable process design, execution and monitoring in a manner informed by the carbon footprint of process designs and instances"*

2.2.6. Optimisation

In the Macquarie Dictionary (2009), the term *"Optimisation"* comes up as *"to achieve the best possible result"*. The Merriam-Webster dictionary (2011) goes into a bit more details as it defines optimisation as:

"An act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible",

while the Oxford English Dictionary (2011) defines optimisation as

"make the best or most effective use of (a situation or resource)".

2.2.7. Multi-objective optimisation

This key concept is discussed in detail in the *"2.3.3. Business Process Optimisation"* section of the *"Theoretical Framework"*. The next section propose a theoretical framework to facilitate modelling, measuring, analysing, and reporting GHG emissions as well as to enable organisational management to optimise their business processes for GHG emission management, alongside other vital business objectives.

2.3. Theoretical Framework

This section organises the research problem into groups according to relationships and distinguishes between these groups. The framework presented illustrates the contribution of each of these groups to creating the whole research problem under investigation. It further justifies the research synthesis by: showing how the primary studies were selected for review; focusing on the actual study specific variables, characteristics, and data reported in primary studies; compiling findings and pursuing generalisations by looking at categories of data that cut across studies; creating as systematic interpretation as possible about what has been done and what has to be done.

This research mainly draws knowledge from three areas; 1) current ways to perform GHG emissions measurements, calculation and reporting at corporate level; 2) business process modelling techniques; and 3) optimisation (as shown in Figure 2.5).

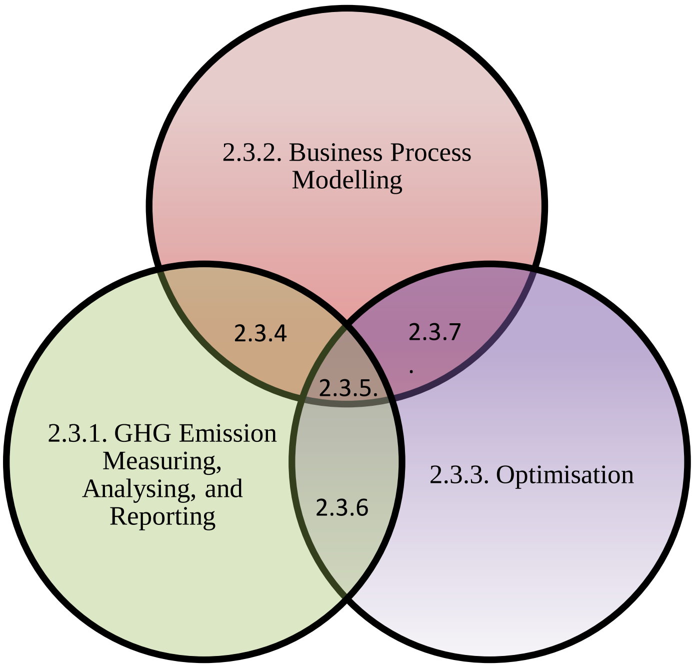

Figure 2.5: Theoretical Framework Surrounding Research Presented in this Thesis

The next section investigates Business Process Modelling, Analysis and Reporting in detail. This section corresponds with 2.3.1 of the theoretical framework shown in the Figure 2.5. Subsequent sections *"2.3.2. Business Process Modelling"* and *"2.3.3 Business Process Optimisation"* corresponds with areas "2.3.2" and "2.3.3" of the theoretical framework illustrated in Figure 2.5

2.3.1. GHG Emission Measuring, Analysing and Reporting

Governments around the world recognise that many individuals and organisations are worried about climate change and seeking to make their contributions towards reduction of GHG emissions. Thus, they have provided organisations with *"standards"* to take additional actions to reduce GHG emissions e.g. Australian "*The National Carbon Offset Standard"*. The Australian government developed this standard in consultation with the stakeholders. If an organisation wanted to be carbon neutral or develop carbon neutral products this standard provided the guidance. According to NCOS (2012), carbon neutrality means:

> *"The net emissions associated with a product or an organisation's activities are equal to zero. For an organisation or product to become carbon neutral that organisation must:*
>
> 1. *measure its carbon footprint;*
> 2. *reduce emissions; and*
> 3. *offset any residual emissions."*

They further state that to better manage organisational GHG emissions, it is important to measure and report them. If the reporting organisation publishes the steps they took to measure, reduce and offset their emissions, it will offer the general public an opportunity to validate the emissions reduction or carbon neutral claims.

Intergovernmental bodies (i.e. IPCC, ISO) and government authorities which registers or regulates GHG emissions have published standards as a basis for GHG emission accounting and reporting (LMI-WRI, 2009).

The following table illustrates some of the international and Australian standards. The first column shows the standard name. The second column tells the target group this standard is useful for (i.e. national, organisational, project, facility). The third column summarises the nature or the purpose of the standard.

Table 2.2: GHG emission measuring standards and the focus level

Standard Name	**Relevance**	**Focus Level**	**Summary of the Nature / Purpose of the Standard**
GHG Protocol – A corporate accounting and reporting standard (revised edition)	International	Organisation	Provides a set of methodologies which the businesses and other organisations can use to prepare inventories and reports for all the GHG emissions they generate (WBCSD-WRI, 2004).
GHG Protocol - Project Accounting	International	Project	Provides an accounting tool to calculate GHG emission reductions

Standard Name	Relevance	Focus Level	Summary of the Nature / Purpose of the Standard
Protocol and Guidelines			from GHG emission reduction projects. This quantifies the benefits of climate change projects comprehensively and is a policy neutral tool (WBCSD-WRI, 2005).
GHG Protocol - The Land Use, Land-Use Change, and Forestry (LULUCF) Guidance for GHG Project Accounting (LULUCF Guidance)	International	Project	Supplements the Protocol for Project Accounting (Project Protocol). This provides more specific guidance, appropriate terminology, quantifies concepts and reports GHG reductions for Land Use, Land-Use Change, and Forestry projects (WRI, 2006).
GHG Protocol - The Guidelines for Grid-Connected Electricity Projects	International	Project	Supplements the Protocol for Project Accounting (Project Protocol). Applicable to projects which supply electricity to the grid and projects that reduce consumption of grid (WRI-WBCSD, 2007).
GHG Protocol – Corporate Value Chain (Scope 3) Accounting and Reporting Standard	International	Organisation	Asses the entire value chain emission impact and identifies the ways to reduce them. As most off the organisational emissions are Scope 3 emissions this provides the opportunity for the organisations to look at climate impacts throughout the value chain together with suppliers and customers (WRI-WBCSD, 2011a).
GHG Protocol – Product Life Cycle Accounting and Reporting Standard	International	Product (Good or Service) Life Cycle	Provides an account of the life cycle emissions of a product. Allows for focus on GHG emission reduction opportunities. Provides better opportunities for product design, increasing efficiencies, reducing costs and remove risks. Makes the communication between the organisations and its customers regarding the environmental aspects of the products much easier (WRI-WBCSD, 2011b).
ISO 14040: Environmental management – Life cycle assessment – Principles and frameworks (ISO 14040:2006)	International	Product Life Cycle	Pinpoints the framework, principles and requirements to conduct and report product life cycle assessments. Identifies environmental performance improvement opportunities that exist in a product life cycle. Relays these opportunities to the decision makers in strategic planning, priority setting, product/process design or re-design. Selection of best suited

Standard Name	Relevance	Focus Level	Summary of the Nature / Purpose of the Standard
			environmental performance indicators for measurement techniques and declarations (ISO, 2006b).
ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines (ISO 14044:2006)	International	Product Life Cycle	This provides requirements and guidelines for life cycle assessment which includes the life cycle inventory analysis, life cycle impact assessment and scope, interpretation, reporting, critical review and limitations of life cycle assessments (ISO, 2006c).
PAS 2050:2011 – Specification for the assessment of the life cycle greenhouse gas emissions of goods and services.	The United Kingdom	Product Life Cycle	Provides a common basis for quantifying GHG emission to inform and enable meaningful GHG emission reduction programmes. It provides organisations improved understanding of GHG emissions produced from their supply chains (BSI, 2011).
Australian Standard (AS) ISO 14064 Greenhouse gases Part 1: Specification with guidance at the organisation level for the quantification and reporting of greenhouse gas emissions and removals (AS ISO 14064.1:2006)	Australia	Organisation	Designs and develops organisational GHG emission inventory documentation and reports. Specifies the organisational level GHG emission quantification and reporting principles and requirements. These requirements include organisation's GHG emission inventory design, development, management, reporting and verification (SA, 2006a).
AS ISO 14064 Greenhouse gases Part 2: Specification with guidance at the project level for quantification and reporting of greenhouse gas emission reductions and removal enhancements (AS ISO 14064.2:2006)	Australia	Project	Specifies the project level GHG emission quantification, monitoring and reporting of activities which have the potential to reduce emissions or enhance removal of them. These requirements include project level GHG emission identification, selection of emission sources and sinks, monitoring, quantification, documentation and reporting (SA, 2006b).
National Greenhouse and Energy Reporting Technical Guidelines (NGER Technical Guidelines)	Australia	Facility	Provides the guidance for reporters to estimate GHG emissions under the NGER system. This is based on the National Greenhouse and Energy Reporting (Measurement) Determination 2008 as amended (the Determination) by the National

Standard Name	Relevance	Focus Level	Summary of the Nature / Purpose of the Standard
			Greenhouse and Energy Reporting (Measurement) Amendment Determination 2013 (No. 1) (DIICCSRTE, 2013c).

As can be interpreted from Table 2.2 there are a number of standards and guidelines available to measure GHG emissions. These are aimed at different levels of the organisations. National standards and guidelines are mostly in accordance with the international standards. GHG inventories are prepared according to these standards.

As shown in Figure 2.6, there is a relationship between different inventory levels. There are four types of GHG emission inventories as: Source Inventory, Facility Inventory, Corporate Inventory and National Inventory (Bhatia, 2008). These inventories are compiled according to the GHG protocol standards. Different standards provided by GHG Protocol can be linked as they are based on the same principles.

A source inventory can provide information required by the facility inventory. The facility inventory can provide necessary information to the corporate inventory. As these measurements are not mandatory it will provide some information to the national inventories but this relationship is not very strong. However, in some countries for those organisations that generate GHG emissions above a certain threshold the reporting is mandatory, e.g. Australian National Greenhouse and Energy Reporting Act 2007. National level inventories conform to international guidelines adopted by the United Nations Framework Convention on Climate Change (UNFCCC) (DIICCSRTE, 2013b).

As can be seen from Figure 2.6, Source, Facility, Corporate and National Inventories depend on GHG calculation tools to provide correct information. When developing these inventories, they will be accurate and useful only if careful attention is given to quality control issues and activity data.

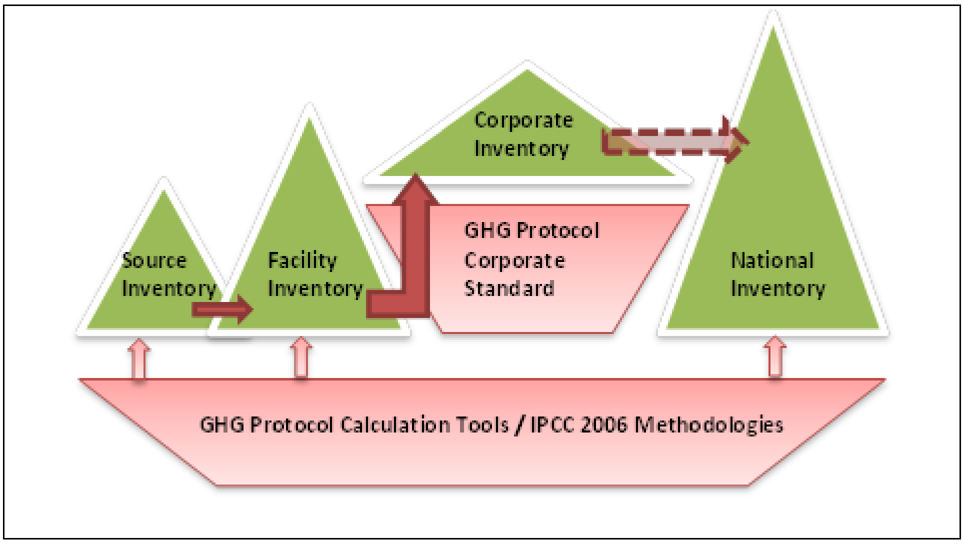

Figure 2.6: Relationship between different inventories (adopted from Bhatia (2008))

GHG emission calculation tools allow organisations to build comprehensive and reliable inventories. They assist organisations to quantify emissions from their business activities and operations (WRI-WBCSD, 2013). There are many emission calculation tools available today. Credible tools from intergovernmental panels and governments reflect methods that are industry best practises, tested many time over by industry experts. Often these tools come with a guide to help the users.

According to Table 2.2, emission measurement standards can be found mostly for the following categories.

- Corporate
- Product (Good or Service) Life Cycle
- Product (Good or Service) Supply Chain
- Project

Corporate standards help and support organisations to identify their emissions, calculate and report accurately, completely, relevantly, and transparently. These provide the organisations guidance on: correctly identify organisational boundaries; how to track emissions over time; report emissions. Moreover, Corporate Standards provides guidance on: GHG accounting and reporting principles, business goals and inventory designs, management of inventory quality; how to perform accounting for GHG reductions; verification of GHG emissions; and setting GHG emission targets (Bhatia and Ranganathan, 2004).

Product (Good or Service) Life Cycle Assessment (LCA) is a popular overarching method for accounting product related GHG emissions. This includes all stages of a product life i.e. raw material acquisition, fabrication, distribution and retail, use, and end-of-life. This cradle to grave approach is in growing demand these days due to the need to compare similar products based on their life cycle related GHG emissions. This method evaluates the environmental impacts related with a product, service or a process (Bhatia, 2009).

There are two types of LCA methods as process-based LCA and Economic Input-Output LCA (EIO-LCA):

- In process-based LCA, the reporter first identifies the required inputs and outputs for manufacturing, distributing, and disposing of the product under inspection. However, in this method reporters would need to identify all the emissions that occur during the lifetime of a product. The process-based LCA is a bottom-up approach and the results are comparatively more accurate to that of the EIO-LCA.
- The EIO-LCA method is a top-down method and is comparatively less precise. EIO-LCA looks at financial transactions between industrial sectors and identifies goods and service consumption in a product life cycle. This information is mathematically paired with national environmental information.

Currently, in order to overcome limitations in both these LCA methods, hybrid methods have been developed. These Hybrid-process-EIO-LCA methods offer the best of breed methods in ecological economic modelling (Rajagopal and Zilberman, 2013, Turconi et al., 2013, Ketchman and Bilec, 2013, Wiedmann et al., 2011).

Product (Good or Service) supply chain standards allow companies to look at their entire supply chain or value chain. They can identify the GHG emission reduction opportunities that lie within the value chain. This will allow them to make more sustainable business decisions not only regarding company activities but products they buy from suppliers and what they produce. Thus, they can aim towards reducing the GHG inventory of a product over time (WRI-WBCSD, 2011a).

Project standards specially aim GHG emission reduction projects. Standards specify the principles, concepts and the methods to quantify and report GHG emission reductions. This GHG emission reduction may result due to decrease in GHG emissions or due to an increase in GHG emission removal or storage (WBCSD-WRI, 2005).

GHG protocol is currently used as the international standard by many countries including Australia. The GHG Protocol provides a set of sector specific tools and cross sector tools. Sectors represent industry groups (WRI-WBCSD, 2013).

Sector specific tools are there for the following industry sectors: production of Adipic acid, Aluminium, Ammonia, Cement, HCFC-22, Iron and Steel, Lime, Nitric acid, Pulp and paper, Refrigeration and AC, Semiconductors, Wood products, and Service Sector. Cross sector tools are not aimed at a specific sector. Thus, these can be used by many industries regardless of the sector i.e. GHG emissions from purchased electricity, refrigeration and air-conditioning, stationary combustion, transport or mobile sources, combined heat and power plants (WRI-WBCSD, 2013).

Apart from the GHG Protocol tools there are many other tools available. Most of these are international standards compliant i.e. DEFRA (2011), Australian National Greenhouse Factors (2012), IPCC (2006). Following Table 2.3 illustrates some of these tools. The table provides a summary of widely used GHG emission measuring tools, guideline, and databases. The relevance/focus level column tells the level which these tool/guides are applicable to and the focus level tells which type of assessment the tool/ guide provide e.g. organisational, product LCA. The tools and guide comply with a standard and the compliance column tells which standard is employed by that particular tool/guide. This column is followed by a summary of the purpose of the tool/guide.

Table 2.3: GHG emission calculation tools, focus level, and standards

Calculation Tool / Guide/ Databases	**Relevance / Focus Level**	**Standard Compliance**	**Purpose**
GHG Protocol (WBCSD-WRI, 2004)	International/ Organisation	2006 IPCC Guidelines for National Greenhouse Gas Inventories	Provides cross sector and sector specific tools to calculate emissions of an organisation. Cross sector tools can calculate emissions from all companies who engage in activities that: consume purchased electricity; stationary combustion; refrigeration and air-conditioning. There are two categories of sector specific tools as industry sector and service and office-based organisations' sector. Industry sector specific tools calculate emissions from an organisation which falls in to a specific industry sector. i.e. production of cement. Office based organisations and services sector include banks, hospitals.
Hot Climate, Cool Commerce: A service sector guide to greenhouse gas management (Pino et al., 2006)	International/ Organisation	GHG Protocol	It details a step by step guide for the companies that do not undertake manufacturing activities to compile their GHG inventory, issues and a guide to manage emissions over time. Organises which fall in to this comprise banks, insurance, retail, law firms, real estate, publishing, shipping, marketing and consulting companies
2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)	International/ National	1996 IPCC Guidelines, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (GPG2000), Good Practice Guidance	Contains five volumes. Volume 1 tells the basic steps in developing inventories and offers GHG emissions and removals estimates. Volumes 2 to 5 contain guidance to estimate GHG emissions from different sectors in the economy e.g. energy, industrial processes, agriculture, forestry and other land use, waste.

Calculation Tool / Guide/ Databases	Relevance / Focus Level	Standard Compliance	Purpose
		for Land Use, Land-Use Change and Forestry3 (GPG-LULUCF)	
Working 9 to 5 on Climate Change – An Office Guide	International/ Organisation	GHG Protocol	This provides office-based organisations with: an introduction to climate change and how offices contribute to this global issue; steps to measure organisational CO2 emissions; Suggestions to reduce emissions.
Australian National Greenhouse Accounts (NGA) Factors (DIICCSRTE, 2013a)	Australia / Organisation	GHG Protocol	Prepared by the Australian government for organisations or individuals to calculate GHG emissions.
National Greenhouse and Energy Reporting (Measurement) Technical Guidelines (DIICCSRTE, 2013c)	Australia / Organisation	NGER (Measurement) Determination 2008	This guideline helps organisations and liable entities to get a clear understanding and apply the NGER (Measurement) 2008. This outlines the calculation methods and the criteria for determining GHG emissions, energy production, energy consumption, potential GHG emissions embodied in natural gas.
Canadian Raw Materials Database (CRMD, 2000)	Canada / LCA	Canadian Standards Association (CSA) PLUS 1116	This involves a cross section of the Canadian material industries i.e. aluminium, glass container, plastics, steel, wood. This aimed to build a database to profile the environmental inputs and outputs that are related to producing Canadian commodity materials.
National Renewable Energy Laboratory (NREL) Life Cycle Inventory (LCI) (NREL, 2012)	US/ LCA	ISO 14048	Helps organisations to define goal and scope; analyse the LCI; assess the impacts; interpret the assessment results. This provides a transparency and maintains data quality. This encompasses commonly used products, processes and raw materials in USA.
Building Research Establishment (BRE) (BRE, 2013)	UK/ LCA	ISO14040, ISO 14025	BRE is a widely used environmental assessment method for buildings called BREAM (BRE Environmental Assessment Method). Provides the organisations with the standards for best practices in sustainable building design, construction and use. This provides environmental profiles relating to building material and construction.
Department for Environment, Food & Rural Affairs (DEFRA) (DEFRA, 2013)	UK/ Organisation	Climate Change Act 2008 (an Act of the Parliament of the United Kingdom.)	This aids the organisations to comply with the GHG reporting regulation which is a requirement of the Climate Change Act 2008.

As can be seen from Table 2.3, there are number of GHG emission calculation tools available. Some tools only offer support to measure CO_2 and do not support other GHG emissions. These tools are generally aimed at the organisation, product i.e. LCA or individuals. Some tools claim they are aimed at a process but what they are actually aimed at an industry sector e.g. Cement clinker production in NGA (DIICCSRTE, 2013a). For the Cement manufacturing process, GHG Protocol calculates the Scope 1 emissions at the plant level for CO_2 emissions from raw material calcination as well as from CO_2 emissions from organic carbon in raw materials. Then, the protocol calculates Scope 2 indirect GHG emissions from purchased electricity (e.g. grid) at the plant level. Thus, resulting emissions are only calculated at the plant level. However, the protocol recommends including the team and the manufacturing processes which actually produce the products and integration with the management processes to maintain quality of the GHG inventory (WBCSD, 2005).

2.3.2. Business Process Modelling

Real world systems are often modelled to filter out unwanted complexities attached to them. This allows the decision makers to focus their attention on the parts of the systems under study (Giaglis, 2001). A successful process modeller needs a thorough understanding of the business process functions, data, and resources (Zakarian, 2001).

Within the business process perspective, many have tried to model the business process. In general, such a process model will include a set of activities organised in a specific order and these activities have clearly identified inputs and outputs. Ideally, when an activity receives an input it should transforms it into an output of value to its customer, who is the downstream recipient. A business process output can be either goods or services (Zakarian, 2001).

There are many advantages in modelling a business process. Business process modelling is very important as it will play a major part in better understanding and enhancing the perception of a business process (Vergidis et al., 2008). Moreover, the model will provide this understanding without disturbing the actual environment. E.g. Manufacturing processes will need to respond to a market change and may need to deliver new products. A decision maker can analyse a properly modelled manufacturing business process model to assess its capability to respond to such a market change. This will allow the decision maker to correctly identify the reconfigurations needed for the new product (Zakarian, 2001).

Today, it is a common practice to describe an organisation as a set of business processes. These processes when modelled provide the ability to analyse and improve (Melão and Pidd, 2000). Hence, this allows improved business performance and competitive advantage (Lam et al., 2009). Business process modelling is important not only at the process level but at the enterprise level as well. An enterprise is often integrated and analysed through its business processes (Aguilar-Savén, 2004). With the analysed results the business processes can be redesign or re-engineer to obtain great benefits to the enterprise (Lam et al., 2009).

2.3.2.1. Business Process Modelling Categorisation

Business process modelling is a widely researched area. As such there are a number of attempts to categorise business process modelling techniques. This section attempts to discuss some of these attempts found in literature.

Several authors have tried to categorise business process modelling. Some of these attempts have been cited by several other researchers. Among them are Curtis et al.(1992), Kueng et al. (1996), Kettinger and Teng (1997), Melão and Pidd (2000), Aguilar-Savén (2004), and Vergidis et al.(2008).

Curtis et al.(1992) proposed a set of four modelling perspectives: functional, behavioural, organisational, and informational. The functional perspective signifies what process elements are performed and these process elements may include data, artefacts or products. The behavioural perspective signifies *when* particular process elements are performed (e.g. sequencing, feedback loops, iterations, conditions, entry and exit criteria). The organisational perspective signifies *here* in the process and *by whom* (which agent) the process elements are performed. The informational perspective signifies the informational entities produced and manipulated by a process.

Kueng et al. (1996) attempts to group business process modelling approaches under four broad categories as: (1) Activity-oriented approaches; (2) Object-oriented approaches; (3) Role-oriented approaches; (4) Speech-act oriented approaches. The activity-oriented approaches define a business process as a specific ordering of activities sometimes referred as tasks. These are good for refining process models but may fail to represent the true complexity of work carried out by a business process. Object-oriented approaches are based on principles of object orientation such as encapsulation and specialisation. However, process owners and team members describe their work in terms of activities rather than objects. Role-oriented approaches imply that many things can be considered as a role. A role has a set of responsibilities and therefore has a set of activities that it has to perform. These approaches can describe process behaviour at different levels. However, role-oriented approaches are not suited to express an intricate sequencing logic. The speech-act oriented approaches are built upon speech-act theory. According to this a workflow consists of a four-phased loop: proposal, agreement, performance, and satisfaction (Medina-Mora et al., 1992). Though, this approach allows distinguishing between a customer and a performer these fail to provide support to analyse existing processes or to create new processes.

Business process models are useful for process change management. Change management needs to learn, analyse, monitor, and control a business process and thus this needs descriptive and decision support models. Business Process Reengineering (BPR) is one such popular approach (Aguilar-Savén, 2004). Hammer & Champy (1993), proposed the BPR concept. According to Giaglis (2001), typical BPR projects aim to deliver process improvements and therefore these concentrated more on the behavioural aspect of the modelling. Kettinger and Teng (1997) reported an empirical investigation on BPR tools, techniques and methods and presented them within a reference framework. Their survey included 25 methodologies, 72 techniques, and 102 tools to show how tools and techniques were engaged in conducting BPR. This enabled them to build a generic methodology to match business process reengineering stages with available tools and techniques. Though, this study does not give a detailed description of the tools and techniques it paved the way to several studies to investigate on these tools and techniques (Aguilar-Savén, 2004, Kettinger and Teng, 1997).

Melão and Pidd (2000), first group the research in business process modelling as:

- Reports by practitioners;
- Attempts to develop a theoretical position (e.g. Curtis et al.(1992));
- Discussions based on the nature of a business process.

Thereafter, proposes a framework with four different perspectives on business process modelling to understand the nature of business processes and thereafter identifies the most common modelling approach for each of these views as: deterministic machines, complex dynamic systems, interacting feedback loops and social constructs. Business processes as a deterministic machines view, considers a process as a well-defined sequence of activities or tasks which converts inputs into outputs to achieve clear objectives. To facilitate this view, are process flow charts and its extensions, IDEF0 and IDEF3, Role Activity Diagrams (RADs). Business processes as a complex dynamic systems view, considers a process as assemblies of interchangeable components and focuses on the complex, dynamic, and interactive features of business processes. Further, they suggest discrete event simulation as the modelling approach. Business processes as an interacting feedback loops view, highlights the information feedback structure of business processes. They recommend system dynamics modellers for this perspective. Business processes as a social constructs view, has its emphasis on people's side of a business. People with different values, expectations and agendas (possibly hidden) make and enact business processes (Melão and Pidd, 2000). They suggest the use of soft unstructured illustrative models to model this perspective.

Another notable classification of business process modelling is done by Aguilar-Savén (2004). In this study they state that, even though the business process modelling field is much researched, it is not well structured or classified. Thus, in their first business process modelling perspective they attempt to classify into four main categories based on the four different purposes of use as:

1) descriptive models for learning;
2) descriptive and analytical models for decision support to process development and design;
3) enactable or analytical models for decision support during process execution, and control;
4) enactment support models for information.

The second perspective distinguishes between active and passive models. Active models are considered as dynamic as they allow the user to interact with them and passive models in contrast do not interact with the user.

A very pragmatic approach to modelling, analysing and optimising of a business process is carried out by Vergidis et. al. (2008). They argue that different business process modelling frameworks have come up according to each author's focus on specific directions. Three modelling sets were identified as: diagrammatic model set with visual representation; mathematical model set with formal under pinning; business process languages set with software-based language modelling. Some modelling approaches may combine two approaches. Petri net for example combines visual representation using standard notation with an underlying mathematical representation. In this study, process modelling categorisations are considered along this classification. Especially the formal and visual ability of process modelling is explored in detail.

2.3.2.2. *Business Process modelling representations*

There are many different business process modelling techniques. Selecting the best business process modelling technique is vital, as a business process would become as expressive and communicative as the business process modelling technique that was used to model it (Vergidis et al., 2008). This section summarises some of the business process modelling techniques frequently encountered in literature.

Flowcharts

Flowcharts are among the very first visual diagramming techniques used in business process modelling. Flowcharts have several advantages. They possess the ability to show the structure of a system. Then, flowcharts can illustrate the flow of information and work. Moreover, these have the ability to show the physical media where data is entered, produced, and stored. In addition these pin point the key decision points and processing points. Today, their use is limited. These simple visual means of communication is no longer adequate to model a business process as business processes are much more complicated and difficult to follow just by using flowcharts (Giaglis, 2001).

Integrated Definition (IDEF)

In 1981, as a part of the Integrated *Computer-Aided Manufacturing (ICAM)* project, IDEF was first introduced. IDEF which is a visual modelling technique consists of several methods. Out of these IDEF0 and IDEF3 serve as the business process models. IDEF0 focusses on activity modelling. Each activity represented by four elements: input, control, output and mechanism or ICOM. Therefore, a process is a composition of ICOMs. IDEF0 depicts the functional perspective of a process and it captures *"what"* and organisation does. The ICOM's simplicity is perhaps the main strength of IDEF0 (Bosilj-Vuksic et al., 2001). IDEF3 has its focus on *"how"* things work in an organisation. IDEF3 models the business process as an ordered sequence of event or activities. Therefore, it is a scenario-driven process flow modelling technique that captures precedence and causality relations in situations and events. IDEF3 models from several perspectives and multiple-levels of abstraction. Just like IDEF0 the main strength of IDEF3 is perhaps in the one basic construct called the Unit of Behaviour (UOB). IDEF3 supports both process-centred and object-centred analysis (Fu-Ren et al., 2002, Bosilj-Vuksic et al., 2001).

Role Activity Diagrams (RADs)

As the name implies this technique allows visual representation of a business process with the use of roles, goals, activities, interactions, and business rules (Melão and Pidd, 2000). In RADs the primary unit of analysis is the *"role"* which can be an individual or a group. In instances where human element is critical in process change, this technique is very insightful (Giaglis, 2001). In here, the processes are divided over the roles which are represented as separate shaded areas. The process goals are symbolised by states represented as vertical lines. The main features in RADs are that they define and describe the role's work, the degree of empowerment, illustrate process function, and aid decision making (Fu-Ren et al., 2002).

Petri nets

Originally used for systems modelling (Giaglis, 2001), Petri nets is a visual business process modelling technique that allows modelling of system behaviour and at the same time introduces mathematical formal rules to define system behaviour (Bosilj-Vuksic et al., 2001). Petri nets assist in analysis of the structural and dynamic behaviour of a system. Basic Petri nets were not useful in modelling complex business processes and as a result a number of extensions (e.g. notations of colour, time and hierarchy) were proposed and collectively they were named as *high-level Petri nets* (Giaglis, 2001). Today, Petri nets are widely used for modelling parallel dynamic systems due to their: simplicity; representation power that includes concurrency; resource sharing ability; strong mathematical background which allows formal analysis; and application of software tools (Bosilj-Vuksic et al., 2001, Vergidis et al., 2008, Aalst, 1998).

Unified Modelling Language (UML)

UML was originally designed to model aspects of software systems. Currently, UML consists of a set of extensions called *Eriksson-Penker Business Extensions* to model the business systems (Eriksson, 2000). These contain several objects that collectively allow system modelling. UML extensions provide a set of symbols to model processes, resources, rules, and goals of a business. These represent four essential perspectives that include: functional, behavioural, organisational, and informational (Fu-Ren et al., 2002). Still the activity diagram is the most important as it illustrates a business process. The *Eriksson-Penker Business Extensions* consists of four different views of a business as business vision view, business process view, business structural view, and business behavioural view. However, these views are not separate as they are inter-dependent. Together they claim to represent the complete business model.

Business Process Modelling Language (BPML)

Presently, there are a number of business process languages available. In order to describe a business process adequately many forms of information should be integrated into the model. When needed, this information can be extracted from the process model. Among the business related information needed can be: who is doing a particular activity; where it will be performed and when; how it is going to be performed; and who is dependent on the activity being performed (List and Korherr, 2006).

BPML was published by Business Process Modelling Initiative (www.bpmi.org). BPML is a XML-based language which encodes the process flow in an executable form. Business Process Modelling Notation (BPMN) is BPML's counterpart based on visual flowcharting. Each of the BPML processes consists of a name, a set of activities, and a handler. Smith (2003) states that BPML presents a metalanguage which is process-centric as well as an executional model for business systems. Further, it has an underpinning mathematical foundation.

The following Table 2.4 shows an analysis on business process classification and techniques. The modelling classification is a combination proposed by Curtis et al. (1992) and Vergidis et. al. (2008). Curtis et al.'s (1992) four modelling perspectives include functional, behavioural, organisational and informational aspects. In literature many have cited these four perspectives. They have either mentioned (Solaimani and Bouwman, 2012) or come up with proposals based on extensions of these perspectives (Giaglis, 2001, Fu-Ren et al., 2002, Melão and Pidd, 2000) or most of these perspectives (Giaglis et al., 1999). These perspectives are popular because though they are separate, they are interrelated. For analysing and extracting information all these perspectives are important. Thus, in this summarising analysis shown in Table 2.4, these perspectives are considered as well.

Three other business process modelling perspectives considered are visual, business process language and formal/mathematical, proposed by Vergidis et. al. (2008). Visual representations bring in all the advantages in visualisation of process models. The formal underpinning will add the ability to extract quantitative measures of process models. The Software-based process languages will allow optimisation extensions. This will then pave the way to analysing business process optimisation opportunities.

Table 2.4: A comparison of popular business process modelling techniques against business process classifications

Modelling Technique	Functional	Behavioural	Informational	Organisational	Visual	Mathematical /Formal	Business Process Language
Flowcharts	(+) [1] [2]	(-)	(<) [1] [2]	(<) [2]	(+) [1][3]	(-)	(-)
Integrated Definition (IDEF0)	(+) [4] [5][2][6]	(<) [5][2]	(-)	(-)	(+) [6][5][2]	(-)	(-)
Integrated Definition (IDEF3)	(<) [1][7]	(+) [4][5][7][2]	(-)	(-)	(+) [6][1][2]	(-)	(-)
Role Activity Diagrams (RADs)	(+) [6]	(+) [6][1]	(-)	(+) [4][6][1]	(+) [4][1]	(-)	(-)
Petri nets	(+) [1]	(+) [1]	(-)	(-)	(+) [1]	(<) [8][1][2][5]	(-)
Unified Modelling Language (UML)	(+) [1][9]	(<) [1][9]	(+) [9]	(<) [9]	(+) [1][9][2]	(-)	(<) [9]
Business Process Modelling Language (BPML) & Notation (BPMN)	(+) [10][11][12]	(+) [10][11][12]	(+) [11][12]	(<) [10][11]	(+) [10][11]	(+) [12]	(+) [10]

Table 2.4, uses several notations. The (+) sign denotes full support, the less than sign (<) sign indicates that some support is provided in the current form, the greater than (>) sign indicates some support can be provided with known extensions or modifications, the minus sign (-) denotes support is not provided in the current form, the question mark (?) indicates that though this is mentioned there is insufficient details or is unclear. Following is a list of references used to build the table 2.4.

1. Giaglis, G.M., *A Taxonomy of Business Process Modeling and Information Systems Modeling Techniques.* International Journal of Flexible Manufacturing Systems, 2001. **13**(2): p. 209-228.
2. Aguilar-Savén, R.S.R.S., *Business process modelling: Review and framework.* International Journal of Production Economics, 2004. **90**(2): p. 129-149.
3. Vergidis, K., A. Tiwari, and B. Majeed, *Business Process Analysis and Optimization: Beyond Reengineering.* Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on, 2008. **38**(1): p. 69-82.
4. Melão, N. and M. Pidd, *A conceptual framework for understanding business processes and business process modelling.* Information Systems Journal, 2000. **10**(2): p. 105-129.
5. Bosilj-Vuksic, V., G. Giaglis, and V. Hlupic, *IDEF diagrams and petri nets for business process modeling: suitability, efficacy, and complementary use*, in *Enterprise information systems II* B. Sharp, J. Cordeiro, and J. Filipe, Editors. 2001, Kluwer Academic Publishers.
6. Fu-Ren, L., Y. Meng-Chyn, and P. Yu-Hua, *A generic structure for business process modeling.* Business Process Management Journal, 2002. **8**(1): p. 19-41.
7. Zakarian, A., *Analysis of Process Models: A Fuzzy Logic Approach.* The International Journal of Advanced Manufacturing Technology, 2001. **17**(6): p. 444-452.
8. Hofstede, A.t., M. Weske, and W. van der Aalst, *Business Process Management: A Survey*, in *Business Process Management*. 2003, Springer Berlin / Heidelberg. p. 1019-1019.
9. Eriksson, H.-E., *Business modeling with UML : business patterns at work*, ed. M. Penker. 2000, New York Chichester: New York Chichester : Wiley.
10. List, B. and B. Korherr, *An evaluation of conceptual business process modelling languages*, in *Proceedings of the 2006 ACM symposium on Applied computing*. 2006, ACM: Dijon, France. p. 1532-1539.
11. White, S.A. *Using BPMN to Model a BPEL Process*. 2005. 1-18.
12. Wohed, P., et al., *On the Suitability of BPMN for Business Process Modelling*, in *Business Process Management*, S. Dustdar, J. Fiadeiro, and A. Sheth, Editors. 2006, Springer Berlin Heidelberg. p. 161-176.

From the analysis shown in Table 2.4, it is clear that almost all modelling techniques try to model the functional perspective. Even though not as popular as the functional perspective, the behavioural perspective is modelled by most. The organisational and informational perspectives are not considered as important as the functional and behavioural perspectives. All the modelling techniques considered here offer the visual perspective. As it is among the most popular and more prevailing techniques it can be inferred that visual perspective is extremely important in business process modelling.

The other two remaining perspectives i.e. business process language and formal / mathematical perspectives are not supported by most of the modelling techniques. As the business process language and formal / mathematical perspectives are not supported by many, further analysis that can lead towards business process improvements or optimisations is limited in those techniques. However, the Business Process Modelling Language (BPML) and its counterpart Business Process Modelling Notation (BPMN), together supports almost all considered perspectives. This gives the indication that a combination of good techniques may be more beneficial than trying to address all in one technique.

A business process model systematically represents the business process flow. Once the modelling is done, Business Process Analysis (BPA) can be carried out. Thus, the business process analysis will be based on the business process flow or the business process model the business has used (Lam et al., 2009). However, there is a lack of business process analysis tools associated with business process modelling. The most popular modelling methods are by nature, qualitative and static. This can be seen from Table 2.4. So, more formal techniques are needed to investigate the quantitative nature of the business process (Zakarian, 2001). A formal model is not ambiguous. If such a model is accompanied by a formal language, the behaviour of the business process can be interpreted with the formal semantics of that particular formal language (Hofstede et al., 2003).

2.3.2.3. *Business Process Analysis*

Business process analysis is pursued with the goal of verification or validation of the process execution against a prescribed or expected process and to timely identify potential business process improvements (Pedrinaci and Domingue, 2007). According to Pedrinaci and Domingue (2007, p. 82),

> *"Business Process Analysis (BPA) aims at monitoring, diagnosing, simulating and mining enacted processes in order to support the analysis and enhancement of process models."*

In business process analysis, attention is given to business process properties which are neither obvious nor trivial (Hofstede et al., 2003). Business process analysis is mainly used by business users and process architects to enhance their understanding, streamline and automate business processes and communicate user's needs to IT professionals (Blechar, 2008).

Business process analysis of a business is a significant phase. It studies, tests, evaluates the existing systems and processes (Celino et al., 2007). According to Pedrinaci et al. (2008) there are two main goals in doing business process analysis. First goal is to verify and validate the execution with respect to expected or prescribed processes. The second goal is to identify potential improvements. Celino et al. (2007) list more aims in addition to Pedrinaci et al.'s (2008) main goals. According to Celino et al. (2007) business process analysis aims to identify the current state of processes, point out problems, identify bottlenecks, measure key performance areas, and suggest potential improvements. Hofstede et al. (2003) agree that business process models can be used to investigate ways of business process improvements. In addition, a thorough analysis will reduce the risk of costly correction of business processes. Further, Boekhoudt (2000) states that business process analysis allows the comparison of process improvement alternatives.

2.3.2.4. Business Process Analysis Types

The term "*Business process analysis*" covers a broad range of actions. For example, it includes simulation and diagnosis, verification, validation, and performance analysis (Hofstede et al., 2003). The business process models with a formal underpinning and process languages with formal semantics are the best candidates for business process analysis (Boekhoudt, 2000). In addition, process monitoring and process mining are also important aspects of process analysis (Pedrinaci and Domingue, 2007).

According to Aalst (1998), there are three basic types of analysis: validation; verification; and performance analysis.

- Validation: This analysis tests if the workflow behaves as expected. Compared to the other two techniques, this is the basic analysis. This can be performed by interactive simulation where a several hypothetical business scenarios are fed in to the system to see if these are handled well.
- Verification: This aims to establish the correctness of a workflow. This checks to see if the model is free of logical errors.
- Performance analysis: This analysis evaluates the business process's ability to meet requirements with respect to service levels, through-put times, and utilisation of resources.

In literature, several more business process analysis types are found. Tiwari et al. (2006) while including validation, verification, performance analysis / evaluation, add some more types and provide a more comprehensive list of analysis types as:

1. Observational analysis
2. Performance evaluation, validation, verification (Aalst, 1998)
3. Algorithms
4. Simulation
5. Workflow model analysis

Observational analysis is performed primarily via process inspection after mapping of the current process using a diagrammatic representational model (Aldowaisan and Gaafar, 1999). Simulation can be used to analyse performance and visualisation of a process (Aalst, 1998). Domain experts can recognise correctness of business process models and often can propose modification to the original process model when real-world business processes are simulated. This is known as simulation and diagnosis (Hofstede et al., 2003). However, development, execution, and interpretation of results of simulation models are often seen as complicated by most business analysts (Ramachandran et al., 2006). In addition simulation models possess the ability to show a graphical display of process models which can then be interactively edited and animated to show process dynamics (Hlupic and Robinson, 1998).

There are several business process analysis tools available today to support analysis types (Yu and Wright, 1997). Business process analysis tools help business process architects to document, analyse, and streamline complex processes. Other than process architects, these tools are useful to many roles including business managers, and business analysts who perform business and technical modelling (Blechar, 2008).

Presently, a major challenge faced by business process analysis tools is that they need to gather and integrate large amounts of heterogeneous but interrelated data in a single entity (Pedrinaci and Domingue, 2009). Data warehousing is one solution to the above challenge. A data warehouse consolidates different types of corporate information and enriches this information with derived statistical data (Chaudhuri et al., 2001).

A business process is analysed to assess the current situation of a business as well as to improve the performance of a process. Around the globe, organisations are becoming business process centred and are realising the value of optimising their own business processes to becoming intelligent organisations. Business process optimisation is the key to gaining competitive advantage in the current business environment (Castellanos, 2008).

Table 2.5, summarises a set of articles found in the area of business process analysis. In this particular set of articles, all of them first model the business process. Then, the analysis types are applied. Thus, this research looks at which modelling set the modelling technique belongs to. As Vergidis et al.(2008) show there is a link between the business process modelling set and the type of analysis one can apply. The summary of literature presented in Table 2.5, shows that this is true.

Table 2.5: Summary of literature in the area of business process analysis types and related business process modelling set

Publication	Modelling Set			Business Process Analysis Types						
	Visual	**Formal**	**Business Process Language**	**Observational analysis**	**Performance Evaluation, Verification, Validation**	**Algorithm**	**Simulation**	**Workflow Model Analysis**	**Process Monitoring**	**Process Mining**
(Aalst, 1996)	(+)	(+)	(-)	(+)	(<)	(+)	(<)	(-)	(-)	(-)
(Hlupic and Robinson, 1998)	(+)	(?)	(-)	(+)	(?)	(-)	(+)	(-)	(-)	(-)
(Aalst, 1998)	(+)	(<)	(?)	(+)	(+)	(-)	(+)	(+)	(+)	(-)
(Aldowaisan and Gaafar, 1999)	(+)	(<)	(-)	(+)	(<)	(<)	(-)	(?)	(-)	(-)
(Boekhoudt, 2000)	(+)	(+)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(-)
(Zakarian, 2001)	(+)	(<)	(-)	(+)	(-)	(-)	(?)	(-)	(-)	(-)
(Sadiq et al., 2004)	(+)	(<)	(<)	(+)	(<)	(?)	(-)	(+)	(?)	(-)
(Dustdar et al., 2005)	(+)	(+)	(-)	(+)	(+)	(+)	(-)	(+)	(-)	(+)
(Branimir Wetzstein, 2007)	(+)	(-)	(?)	(+)	(-)	(+)	(-)	(<)	(+)	(+)
(Pedrinaci et al., 2008)	(+)	(-)	(+)	(+)	(<)	(-)	(-)	(-)	(+)	(?)
(Ouyang et al., 2009)	(+)	(+)	(+)	(+)	(<)	(+)	(-)	(?)	(-)	(-)
(Pedrinaci and Domingue, 2009)	(-)	(<)	(<)	(-)	(<)	(-)	(-)	(-)	(<)	(-)

Table 2.5, uses several notations. The (+) sign denotes full support, the less than sign (<) sign indicates that some support is provided in the current form, the greater than (>) sign indicates some support can be provided with known extensions or modifications, the minus sign (-) denotes support is not provided in the current form., the question mark (?) indicates that though this is mentioned there is insufficient details or unclear.

According to Table 2.5, the visual business process models all allowed observational analysis. If a formal modelling technique was used, it allowed performance evaluation, verification and validation (Aalst, 1996, Dustdar et al., 2005, Ouyang et al., 2009, Pedrinaci et al., 2008). Business process language models allowed algorithmic performance evaluation (Boekhoudt, 2000). Further business process models with a formal underpinning allowed performance evaluation, verification, and validation analysis (Pedrinaci et al., 2008, Pedrinaci and Domingue, 2009, Ouyang et al., 2009). Simulation allows both visualisation and performance analysis (Aalst, 2001). In addition to being visual, the workflow models have a formal underpinning as well (Aalst, 1998, Sadiq et al., 2004, Dustdar et al., 2005). Some formal models pave the way for business process monitoring (Aalst, 1998, Sadiq et al., 2004, Dustdar et al., 2005). Several business process language models allowed process monitoring (Pedrinaci and Domingue, 2009, Pedrinaci et al., 2008). Process mining has been done on visual formal models (Dustdar et al., 2005) and visual business process language models as well (Branimir Wetzstein, 2007).

2.3.2.5. Link between BPA and Improvements, Optimisation

According to Lam et al. (2009) There is still room for business process modelling and analysis types to improve as a majority of modelling and analysis types focus on a qualitative approach that looks at logical correctness of the defined process rather than on the performance of the defined process. Zakarian (2001) indicates lack of analysis tools attached to business process modelling is the most frequently recognised shortcoming. Thus, to make business process modelling more appealing, formal types for analysis of business process models are needed.

There are number of business process modelling types available. These types are geared toward capturing and addressing different aspects of business processes. A limited number of these types allow further quantitative analysis and even a lesser number of them allow structured process improvements (Vergidis et al., 2008). Business process modelling is not useful unless it allows further inspection and analysis. Likewise, business process analysis does not add much value if it does not help in improving the current state of a business process or optimising it to achieve the best possible result (Hofstede et al., 2003). As analysed results will pave the way for business process improvement, re-design, re-engineering (Lam et al., 2009), and optimisation (Vergidis et al., 2008), businesses can then realise the great benefits of enhanced competiveness (Lam et al., 2009). Realising this potential, today, conceptual business process models are deployed on a large scale. This allows business process support software development to permit the analysis and re-engineering or improvement (Aguilar-Savén, 2004) leading towards process optimisation.

As explained in the paragraph above, business process optimisation will bring in greater benefits to the business. Only a properly modelled analysed business process will be a suitable candidate for business process optimisation. This section showed the important link between business process modelling and business process analysis.

2.3.3. Business Process Optimisation

A business process is composed of a series of tasks and activities known as process elements. As part of the business process modelling, it is essential to identify the various characteristics (parameters) of each process element. Evaluation of business processes should be against a set of multidimensional parameters, especially those such as cost, time and resources.

In literature, to the author's knowledge there are very few definitions for the term *"business process optimisation"*. Vergidis et al. (2008) defined business process optimisation as the automated improvement of business processes using pre-defined quantitative measures of performance or objectives. This study considers that a business process needs to meet several business objectives simultaneously. Thus, the study defines business process optimisation as:

> *"A continuous simulated business process improvement to meet a set of pre-defined business objectives to achieve greater efficiency and effectiveness of the business process and its' interactions, within the organisation"*

In the field of optimisation simulations are frequently used. Simulation enables assessment of process change. It allows testing of a proposed business process in a new hypothetical environment prior to implementing it in the real environment (April et al., 2006). This structured environment allows one to understand, analyse and improve a certain business process, and is helpful in business decision making (Vergidis et al., 2008).

A business process undergoes changes to achieve significant performance improvements (Gunasekaran and Kobu, 2002). Improvement of a business process does not guarantee that the improvements are optimum (Tiwari et al., 2006) or if it is using its resources and situation in the most effective way.

According Olkhovich (2006) business process optimisation brings in several benefits. Mostly, it will reduce the waiting times, make the throughput higher, and will optimise the resource utilisation. Business process performance improvements are not only important to the process but will greatly affect overall organisational profit. Tang et al. (2006) too agree with this statement and they further state business process efficiency is vital to the success of the organisation. Currently, the organisations need to make sure that they carry out their business processes in the most efficient manner. Moreover, processes should be designed to optimise their customer service and streamline the co-ordination with vendors and external partners.

Some of the negative environmental impacts of products can be reduced or on some occasions even eliminated by making changes to the business processes that produce them.

These processes might include purchasing, production, and selling. By changing the processes desired change in the product can be achieved (Cancer, 2000).

Tang et al. (2006) argue that business process optimisation is at the core of all the questions regarding the organisational performance improvement. Moreover, it is the key issue of business process management, business process re-engineering, and business process re-design.

Quan and Tian (2009) state that business process optimisation is not simple. It is a dynamic and a complex task. Therefore, the available traditional optimisation models fail to optimise a business process to its full potential. Presently, techniques like simulation modelling have proved their worth in process optimisation. As business process's multiple objectives may have conflicting interests, (e.g. reducing cost of production and improving the product quality) a balance point between these objectives is the best optimal result.

Currently, Genetic Algorithm methods have been designed for multi-dimensional parametric optimisation of business processes. Genetic Algorithms can handle business processes related optimisations to scheduling of resources and utilities. In this study this is discussed in detail in later chapters.

Tang et al. (2006) categorise business process optimisation methods into three categories as: participation-type, principle-type, and analytical-type. Participation-type employs several teams of professionals including process specialists, process operators, and process managers. They discuss and evaluate business process alternatives via interviews and workshops to identify important aspects of the business process. However, in practice this is not recommended as the process itself is tedious and information collected may be subjective, fragmented, and possible unreliable. Principle-type, is not strictly an optimisation method category. This type contains several technical or heuristic principles that may guide the business process design. Analytical-type optimisation methods try to use formal theories and techniques to model and derive the process design by using process parameters. The optimised results are gained through employing certain algorithms and/or logic reasoning.

Vergidis et al. (2008) categorised business process optimisation techniques, according to the business process model used to model the process and the related analytical method used to derive information of the process. They again categorised optimisation methods into three groups.

First group consisted of the diagrammatic modelling set which allowed observational analysis as the business process analysis technique. This group only allowed unstructured trial and error modifications as the optimisation techniques.

The second group was derived from the mathematical / formal modelling set. This allowed performance analysis and simulation as the business process analysis types. The optimisation techniques consisted of algorithmic object-oriented approaches and activity/ task consolidation.

The third group is related to the business process language modelling set. Business process language models allowed algorithmic-performance analysis and simulation. This group is consisted of executable models with optimisation potential.

Further, they showed one more sub group which belonged to two afore mentioned groups. The sub group had modelling origins in diagrammatic and mathematical / formal groups. Thus, business process analysis types like observational analysis, validation, verification, performance analysis, and simulation was possible. It allowed graph reduction as the optimisation technique. Mostly, Petri-net models belong to this category.

Along the lines of Vergidis et al. (2008), this research investigates the business process optimisation techniques. Business process modelling plays a major role in further actions leading towards analysis and optimisation of a business process. Hence, it is important to show the relationship between modelling, analysis, and optimisation. Yonghua and Yuliu (2003a) show that there is a need for business process planning and control tools that support modelling, analysis, decision and optimisation. Following Table 2.6 shows a summary of business process optimisation techniques found in literature.

Table 2.6: Summary of literature in the area of business process optimisation techniques, related business process modelling set and business process analysis

	Business Process Modelling Category			Business Process Analysis Types					Business Process Optimisation		
Publication	**Visual**	**Mathematical / Formal**	**Business Process Language**	**Observational analysis**	**Simulation**	**Performance analysis**	**Algorithm**	**Process mining**	**Graph reduction**	**Algorithmic optimisation**	**Activity Task consolidation**
(Tanaka et al., 1995)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(-)
(Dewan et al., 1998)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(-)	(+)
(Sadiq and Orlowska, 1999)	(+)	(+)	(+)	(+)	(-)	(-)	(+)	(-)	(+)	(-)	(-)
(Cancer, 2000)	(-)	(+)	(-)	(-)	(+)	(-)	(+)	(-)	(-)	(+)	(-)
(Hofacker and Vetschera, 2001)	(+)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(-)
(Moudani et al., 2001)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(-)
(Yonghua and Yuliu, 2002)	(+)	(+)	(-)	(+)	(-)	(-)	(+)	(-)	(-)	(+)	(-)
(Tang et al., 2006)	(+)	(+)	(-)	(+)	(-)	(-)	(-)	(+)	(-)	(+)	(-)
(Olkhovich, 2006)	(+)	(?)	(+)	(-)	(?)	(+)	(-)	(-)	(+)	(-)	(-)
(Vergidis et al., 2006)	(<)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(-)
(Quan and Tian, 2009)	(<)	(+)	(-)	(-)	(+)	(+)	(-)	(-)	(-)	(+)	(-)
(Evins, 2010)	(-)	(+)	(-)	(-)	(-)	(-)	(+)	(-)	(-)	(+)	(-)

Table 2.6 uses several notations. The (+) sign denotes full support, the less than sign (<) sign indicates that some support is provided in the current form, the greater than (>) sign indicates some support can be provided with known extensions or modifications, the minus sign (-) denotes support is not provided in the current form., the question mark (?) indicates that though this is mentioned there is insufficient details or unclear.

According to the literature review conducted in Table 2.6, visual business process models allowed observational analysis (Sadiq and Orlowska, 1999, Yonghua and Yuliu, 2002, Tang et al., 2006) . These models were then analysed and optimised. However, all of them had a formal under pinning. Thus, none of them were purely visual business process models. Sadiq and Orlowska (1999) modelled the business process using visual, formal/ mathematical, and business process language models. They were able to apply observational analysis and an algorithm to analyse the process. As a result of modelling in three different types (visual, formal/ mathematical, and business process language model), they were able to use graph reduction techniques to improve the process to pave the way for optimisation. Olkhovich (2006) too performed graph reduction to achieve optimisation. Their approach modelled the processes using a process modelling language based visual modelling that had a formal underpinning. It is very clear from the table that all the optimisation attempts were first formally modelled or they had a formal underpinning that allowed process improvements that enabled optimisation. Algorithmic optimisation techniques are by far the most popular technique while activity task consolidation is the least popular technique.

This section reviewed literature in the field of business process optimisation. It further showed the important relationship between the business process modelling techniques, the business process analysis types, and the business process optimisation technique.

2.3.4. Knowledge Gap in Business Process Level GHG Emission Modelling, Measuring, Calculation, and Reporting

In the area of GHG emission management, current emission measuring, calculation, and reporting happen at national, organisational, project, and facility levels. However, GHG protocol recommends that in order to improve the quality of the GHG emission calculations, the process level and the teams involved should be included.

As our target is to optimise the business process, it is important to first model and then analyse it. Therefore GHG emissions need to be modelled first. Then only will it allow further analysis. In this situation, further analysis is GHG emission calculation, measuring, and reporting at the business process level. This is the first gap identified by this research.

Today, there are a handful of literature developed in parallel with this study. However, this research gap of *"Business Process Level GHG Emission Modelling, Measuring, Calculation, and Reporting",* is still very much unexplored. This area contains many avenues for further research study to benefit business process level GHG emission management.

In Figure 2.5, depicting the theoretical framework, this section is identified as "2.3.4". This section highlights a very important contemporary knowledge gap in literature. Thus, for the purpose of this thesis, the following research question is derived.

Research Question 1

"How can GHG emissions at a business process level be modelled, measured, calculated, and reported efficiently?" The identified research question is described using the following investigative questions.

Investigative Questions

1. *"What are the levels of a business process, in which GHG emissions can be modelled?"*
2. *"How can GHG emissions be modelled, measured, and calculated in above identified business process levels?"*
3. *"How can GHG emissions associated with a business process be reported in three emission categories identified by the GHG Protocol, namely Scope 1, Scope 2, and Scope 3?"*

As described in the "1.2 Context of the Study" section, it is generally the organisational middle level managers that have direct control over processes. With the use of business process based GHG emission modelling techniques that capture different aspects of the business process, it is possible to analyse these processes in detail to empower the middle level manager. If the specific levels in which GHG emissions could be modelled at are identified as well as the relationships amongst these levels are established, it would add more value to the middle level managers. Thus, they will be in a position to systematically analyse GHG emissions and incorporate GHG emission management alongside other process level objectives.

This section addressed the first research knowledge gap this thesis will address. It links the research questions with the first research gap found in literature. Next section addresses the second knowledge gap found in literature. The section links this second knowledge gap with the second research question identified in this thesis.

2.3.5. Knowledge Gap in Multi-dimensional Business Process Level Optimisation for GHG Emission Management

In the theoretical framework shown in Figure 2.5, the area "2.3.6" marks the business process optimisation attempts found in literature. There are a number of these business process optimisation attempts. E.g. Quan and Tian (2009), Moudani et al. (2001), Hofacker and Vetschera (2001), Yonghua and Yuliu (2002), Vergidis et al.(2006), Tiwari et al.(2006), Yoo et al.(2007), Yonghua and Yuliu (2003b), and Yonghua and Yuliu (2003a). None of the attempts consider GHG emissions as an optimisation objective. Therefore, a knowledge gap exists in business process level optimisation for several dimensions that included GHG emission management. This area is denoted as "2.3.5" in the theoretical framework illustrated in Figure 2.5. Therefore, the second research question is:

Research Question 2

"How can a set of multi-dimensional parameters including GHG emissions associated with a business process be optimised effectively?" This research question is further analysed using three more descriptive investigative questions.

Investigative Questions

1. *"How can other business objectives such as cost and time be modelled against GHG emissions in a business process?"*
2. *"What is the criterion for selection of an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions?"*
3. *"How can a selected optimisation technique (based on the criterion set above in investigative question 2.2) be applied for business process optimisation for GHG emission management alongside other business objectives?"*

In the context of research Investigative Question 2.1, modelling costs and time against GHG emissions refers to, quantifying and recording cost and time related figures along with GHG emission figures at appropriate levels such as process, activity and sub-process level.

2.4. Chapter Conclusion

In this chapter, the extant literature of GHG emission management, business process modelling and optimisation was analysed. This allowed the research problem outlined in the Chapter 1 to be reviewed in detail. Thus, the presented literature review meets the chapter objectives outlined in the section 2.1 (page 16). The chapter discussed current theories and practices under the topic area. It clearly showed the theoretical rationale behind the handling of GHG emissions alongside other business process level objectives like time and cost. The theoretical framework presented an analytical and summative review of the literature for the topic area and linked and positioned this research among the existing body of knowledge. The review identified the *knowledge gaps* in the theoretical framework and the areas which remain relatively unexplored by the previous investigators (Evans et al., 2011). It formulated the research questions as a result of the detailed investigations undertaken.

The knowledge gaps unearthed by this review are:

1. *Knowledge gap in business process level GHG emission modelling, calculation, measuring and reporting*
2. *Knowledge gap in multi-dimensional business process level optimisation for GHG emission management*

In summary this chapter established the context of the research and reviewed current theories, discoveries, and debates useful and salient to the topic area. The next chapter discusses the research methodology guided by the research questions.

CHAPTER 3 : Research Methodology

3.1. Chapter Introduction

Chapter 1 outlined the problem definition and research objectives leading into the specific research questions. In Chapter 2 with a detailed review of prior work related to this study further established the importance of addressing the identified research questions.

Aim of this *Research Methodology* chapter is to discuss the employed research approach. Research methodology is a division of knowledge that deals with research methods and how these methods are applied in practice (Evans et al., 2011). In this thesis, the term *"Methodology"* denotes the theoretical rationale behind how research should be undertaken (Saunders et al., 2009).This chapter will explain how the researcher systematically solves the research problem. It will discuss the steps adopted by the researcher, in studying the research problem, along with the logic behind them.

This chapter is organised as follows. First, the chapter discusses what research is about. Then, the research paradigm employed is discussed. Thereafter, the design science paradigm, which is the selected research paradigm, is explained along with the three research cycles and the five stage research plan.

3.2. Research

Research aims to acquire knowledge and develop an understanding, collect facts and interpret these facts to build up a mental model of the world around us and sometimes within us. Thus, it is important for a researcher to hold a view on what knowledge is about and to make sense of his or her surroundings. The philosophical stance a researcher takes will be based on this view (Walliman, 2011). Further, *Research* is seen as an activity that will contribute to the understanding of a *phenomenon*. *Phenomenon*, usually a set of behaviour of a particular entity, is what has captured the attention of a researcher (Hevner et al., 2010).

Maylor and Blackmon (2005, p.4) define *Research* as,

> *"A systematic process that includes defining, doing, and describing an investigation in to a research problem"*

Thus, it is a process of information gathering investigation of the unknown, to solve a problem (Maylor and Blackmon, 2005).

According to Thomas, Nelson et al.(2010), an investigation into research techniques and procedures or methods adds value to a research in many folds. In particularly, they identify four distinctive positive outcomes as:

1) Make the researcher aware of the wide range of research methods available to collect and analyse data;

2) Make the researcher aware of certain *"dos"* and *"don'ts"* in applying a certain research method;

3) Provide insights into the overall research process;

4) Help to identify what constitutes a good or poor research.

Research process is the general plan regarding how research questions will be answered by the researcher (Saunders et al., 2009). Others point out that the pursuit of knowledge through questioning is what research is about. These questions would then be addressed by the researcher and act as the key tools to frame, focus, critique, and finally resolve the research goals. Further, the research questions will reveal the intension of research, foreshadow the answers, insights, and the knowledge that may emerge (Higgs et al., 2009). Thus, the following is the main research questions of this study, which would be central to assessing the appropriateness of the selected methods and topic.

Main research question this research addresses is: *"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"*

To answer this question, the research sub divides the main research question further in to two sub research questions and each of these are further divided into more specific investigative questions. These sub research questions and investigative questions were stated in the sections "2.3.4" (page 74) and "2.3.5" (page 76) of the previous chapter.

Research question formulation governs what the study investigates and what kind of answers an empirical study should provide. Often, meta-theoretical or philosophical assumptions underpin the type of research questions and the way questions are formulated. However, it is not a case where a researcher consciously thinks of his or her meta-theoretical assumptions and then formulates the research questions. It is rather, the way they approach a particular research problem and their assumptions of the world, that are shaped by these more or less consciously held assumptions (Cecez-Kecmanovic and Kennan, 2013).

3.3. Research Paradigm

A particular meta-theoretical perspective is also known as a research paradigm (Cecez-Kecmanovic and Kennan, 2013). Vaishnavi and Kuechler (2004, p. 1) define a research paradigm as:

> *"the set of activities a research community considers appropriate to the production of understanding (knowledge) in its research methods or techniques."*

Research paradigms in Information System (IS) research are twofold. It can relate to *Behavioural Science* or *Design Science*. The behavioural science paradigm through developing and verifying theories attempt to explain or predict human behaviour. The design science on the other hand tries to create new and innovative artefacts to extend the boundaries of human and organisational capabilities. Behavioural science stems from natural science research methods and thus, seeks to find the truth and often researcher starts this journey with a hypothesis (Hevner et al., 2004). Design science has its roots in the engineering and the sciences of the artificial. According to Simon (1996), design science allows researchers to solve real world problems by developing innovative artefacts. Further, the domain knowledge and understanding is gained while building and deploying the artefact (Hevner et al., 2004). Design science research in particular shows similar characteristics to this research.

Another important aspect that is linked with the research question is *"what is the best suited time horizon?"* Time horizons of a research are two-fold. It can be a *Cross sectional study* or a *Longitudinal study*. A cross sectional study is dependent on a particular time and is called a *snap shot*. Longitudinal study takes several snap shots or time periods into consideration (Saunders et al., 2009). Due to the constraints on time and the nature of the research questions, this study will be a cross sectional study.

The research approach depends on the usage of subject related theory. Basically there are two approaches known as deductive and inductive. A deductive approach will develop a theory or a hypothesis and collected data is used to test the hypothesis (Saunders et al., 2009). Inductive approach collects the data first and theory or hypothesis is built as a result of the data analysis (Korpel, 2005). Therefore, this research is more inductive in nature with some deductive characteristics. Thus, the research combines both inductive and deductive reasoning to come up with results. This combined reasoning of induction and deduction is known as the *Hypothetico-deductive reasoning or Scientific method* (Walliman, 2011).

3.3.1. Design Science Research: Overview and Selection Justification

First, this section provides an overview of the design science research. Next, the section will discuss design science applicability in this research context and justifies the selection of the research paradigm. Hevner et al. (2010, p.5) define design science paradigm as,

> *"a research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artefacts, thereby contributing new knowledge to the body of scientific evidence. The designed artefacts are both useful and fundamental in understanding that problem."*

Design science research results in a purposely built artefact, to solve a certain organisational problem (Hevner et al., 2004). Therefore, it is worthwhile to study what constitutes an artefact.

3.3.1.1. Artefact

Simon (1996) claims, the term *"artefact"* is something that does not occur naturally and it is something artificially constructed by humans. March and Smith (1995) identify four different types of outputs or artefacts in design science research as: constructs (vocabulary or symbols), models (abstraction and representations), methods (algorithms and practices) and instantiations (implemented and prototype systems). In this research, the main objective is to build an artefact to solve a problem, which in this research is to build a framework for multi-dimensional business process optimisation for GHG emissions. Thus, the framework which incorporates models, methods and an instantiation becomes the artefact and the research problem discussed in Chapter 1 becomes the problem the artefact is attempting to solve. Further, design science research inherently evaluates the built artefact. This is evident when considering the three research cycles that has to be present in a high quality design science project.

The following Table 3.1 provides a summary of this research process. This research process builds the main artefact termed as *"Green Multi-Objective Process Optimisation"* or "*Green MOPO"* framework. The main artefact is made up of six constituent artefacts which provide answers to the investigative questions.

Table 3.1: A summary of the *Research Process*

Main Research Question	**"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"**
Main Artefact	**Green Multi-Objective Process Optimisation (Green MOPO) Framework**

Sub Research Questions	Investigative Questions	Output/ Constituent Artefact
1. How can GHG emissions at a business process level be modelled, measured, calculated, and reported efficiently?	1.1. What are the levels of a business process, in which GHG emissions can be modelled?	**I**. A set of guidelines to assist identification of a business process and its different abstraction levels i.e. activity level, sub-process level, process level and shared level.
	1.2. How can GHG emissions be modelled, measured, and calculated in above identified business process levels?	**II**. A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time, and cost modelling and further analysis at different business process levels.
		III. A set of formulas that allow GHG emissions to be calculated at different business process levels.
	1.3. How can GHG emissions associated with a business process be reported in three emissions categories identified by the Greenhouse Gas (GHG) Protocol, namely Scope 1, Scope 2, and Scope 3?	**IV**. A reporting tool that allows reporting of GHG emissions according to the scopes defined by the GHG Protocol.
2. How can a set of multi-dimensional parameters including GHG emissions associated with a business process be optimised effectively?	2.1 How can other business objectives such as cost and time be modelled against GHG emissions in a business process?	**II**. A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time, and cost modelling and further analysis at different business process levels.
	2.2 What are the selection criteria of an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions?	**V**. The selection criteria of an optimisation technique that can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions with other objectives.
	2.3 How can a selected optimisation technique (based on the selection criteria set above) be applied for business process optimisation for GHG emission management alongside other business objectives?	**VI**. Two-way mapping between the derived formula and the Elitist Non-Dominated Sorting Genetic Algorithm (NSGA II/ NSGA2), which is the selected optimisation technique.

3.4. *Research Cycles in Design Science Research*

Hevner et al. (2007), present three design science research cycles that should be clearly identified and presented in a high quality design science project as *Relevance cycle*, *Rigor cycle*, and *Design cycle*. This is illustrated in the Figure 3.1. As can be observed, the *Relevance cycle* connects the research project environment (contextual) with design activities. Similarly, the *Rigor cycle* bridges the knowledge base (Scientific theories and methods, experience and expertise, and meta-artefacts i.e. design products and processes) with the design activities. In the *Design cycle*, research activities iterates between building an artefact, evaluation of it, and then use of feedback to improve the design. This thesis aims to produce a high quality design science research in IS. Hence, it is important to examine what forms each of these cycles.

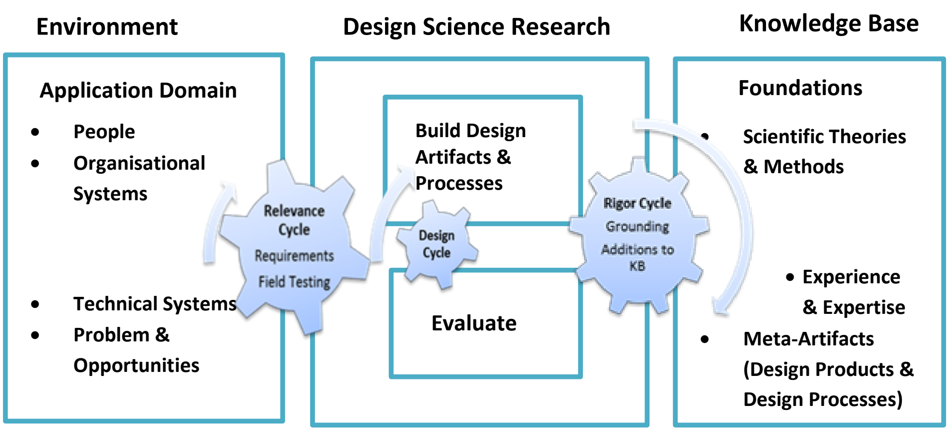

Figure 3.1: Design science research cycles adopted from Hevner et al. (2007)

One of the recurringly discussed topics in all disciplines including information technology is the relevance gap between academic research and the world of practice (Kuechler and Vaishnavi, 2011). *Information Systems Research* is often criticised for having little influence on practice. Cole et al. (2005) propose a proactive stance in investigating information systems in organisations. They examine two research methods: *Action Research* and *Design Research*. Cole et al. (2005) analysed two modes of proactive research and synthesised a new research process that fully integrate the two approaches. Both of these methods are known to intervene in "*real world*" domains and promote changes to these domains. Based on their analysis of similarities of the two approaches and interesting parallels, they propose a research process that fully integrates the two research methods. Their four stage model has: Problem definition stage; Intervention stage; Evaluation stage; and Reflection and learning stage (Cole et al., 2005).

3.5. Research Plan

This research intends to intervene in a *"real world"* domain. This domain is a business process of an organisation and research looks at possible process level changes to optimise a business process for several dimensions that included GHG emission management. Thus, Cole et al.'s (2005) integrated four stage research method is very much in line with the path this research takes. Further, this research extends the rigor cycle of Cole et al.'s (2005) research method by adding a fifth stage named as *"Thesis and Publication"*. This addition forms a complete Rigor cycle. Figure 3.2 gives an overview of this research plan. Further, it shows the cyclical nature of the research plan and customises the four stage model proposed by Cole et al. (2005). In order to show the relationship, this five stage plan has with the three research cycles in design science research, Figure 3.2, groups the stages according to cycles.

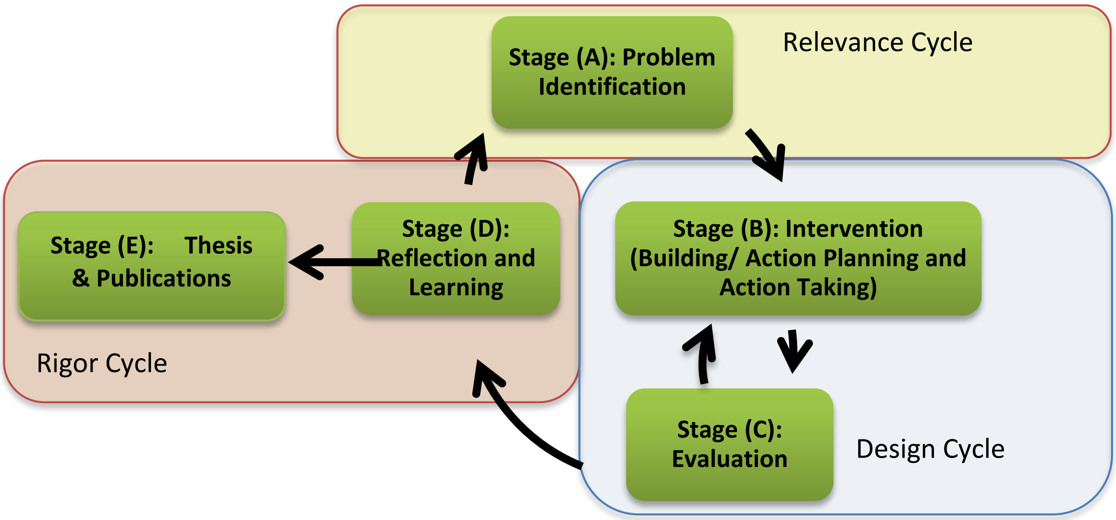

Figure 3.2: Research plan

The first stage or problem identification stage identifies a deficiency in current systems. The research begins with a thorough field study. The study examines each identified problem in-depth. Next, the research study would reveal previous attempts to tackle the identified problem. If the previous studies failed to answer the identified problem, study progresses to the next stage.

The second stage builds an artefact as a solution to the problem identified in the first stage. Action planning guided by the theoretical framework and action taking to introduce change, take place in this stage. Action or intervention brings domain understanding and knowledge.

The third stage named as evaluation performs analysis of the system built or in other words evaluates the artefact. This will involve field trials. System success will be analysed according to pre-defined measures of success.

The fourth stage involves reflection and learning. Reflection on both the process and the product is done at this stage. Findings are generalised; assumptions are either confirmed or rejected; effects of change are identified; theorised; and if a next iteration is required, it will be based on findings on this stage (Cole et al., 2005, Rossi and Sein, 2003)

In the proposed five staged research plan, Stage (A) clearly identifies the research requirements of the problem. As design science is by nature a problem solving process, the solution has to be achieved while building and deploying the artefact (Hevner et al., 2004). During the relevance cycle research design requirements will be clearly identified. Thus, the next section discusses the relevance cycle in detail.

3.6. The Relevance Cycle

In relation to the relevance cycle, the environment defines the problem space where problems and opportunities or phenomena reside (Simon, 1996). In the application domain, people, organisational systems, and technical systems interact with one another to achieve a goal (Figure 3.2). The application domain presents problems and opportunities to be addressed. These form the research requirements and often lead to a good design science project initiation. Further, they set the acceptance criteria for research result evaluation (Hevner, 2007).

3.6.1. Stage (A): Problem Identification

Research topic investigation and problem identification began with investigating the researcher's own strengths. These included academic knowledge, work experience, and personal interest. Obtaining ideas by discussions with supervisors played an important part of problem identification. Initial literature review was invaluable in this context as information was gathered from various sources. Creswell (1994), recommends structuring the literature review as: journal articles; whole books on the topic; recent conference papers; and relevant thesis. Saunders et al. (2009) suggest keeping up to date with the media as a very rich source of ideas. They further recommend keeping a note book of ideas. A preliminary study was conducted to check the capability of the research topic to see if the topic was worthwhile pursuing.

The application domain of this study consists of the organisational sector and more specifically, the business processes where actual work happens. Organisational managers (people) manage day to day tasks and activities at the business process level (e.g. manufacturing factory floor). Technical systems may consist of manufacturing machines and robots. Managers use organisational systems like supply chain management systems, human resource management systems, customer relationship management systems, and activity based costing systems to support their tasks and activities at business process level. These systems generally handle business process level business objectives like time reduction and cost reduction.

Based on related work, this study identified the research context and clearly defined research questions at the beginning of the research process. It is of prime importance to have clear conclusions drawn from collected data otherwise research questions may not generate new insights. In the preliminary literature review, the research questions investigate what is currently known in the literature as well as the gaps in context. This revelation of related models or frameworks helped in defining the research process. At the end of this stage: the investigation outlined the research scope, formulated research questions and investigative sub-questions, and identified the requirements in section 1.4 (page 5).

According to Hevner et al.(2004), a *"Case Study"* is a design evaluation method which is used to study an artefact in depth in a business environment. The case study results of the framework provide feedback necessary to decide whether to proceed with another iteration of the relevance cycle. This allows the researcher to verify if required inputs (for the design science research) are correct and complete, resulting an artefact that would demonstrates its utility, quality, and efficacy in context. It may result in restatement of the research requirements.

In this research, case study evaluation was performed for each of the requirements identified. Case study tests are part of the action taking and evaluation aspects of the five stage research plan. However, this evaluation is in the application environment. In the design cycle, evaluation included testing, simulation, and experimentation of the artefact in a laboratory environment. This is performed before the case study conducts.

3.6.1.1. Case Study Method Overview

A case study will facilitate the researcher in capturing and describing the complexity of a real life scenario. Yin (2014) distinguishes between three types of case studies used in research as:

- Exploratory case studies are mostly designed to answer *"what"* questions when forming research questions or hypothesis.
- Explanatory case studies in general used to answer *"how"* and *"why"* questions to determine whether there are causal relationships between variables or events.
- Descriptive case studies are typically designed to answer another form of *"what"* questions which are more of *"how many"* or *"how much"* line of inquiry (Yin, 1994). According to Tobin (2010), p. 289, a descriptive case study is "*one that is focused and detailed, in which propositions and questions about a phenomenon are carefully scrutinized and articulated at the outset. This articulation of what is already known about the phenomenon is called a descriptive theory."* Moreover, findings of these descriptive case studies can be generalised as theoretical propositions.

3.6.1.2. Case Study Design

In this research, the researcher uses two real life case studies. Thus, the *"Case Study Design"* is composed of two main phases. During the first phase, the first case study is used as a pilot study to clarify the researcher's understanding of the problem and to seek new insights. The pilot case study was exploratory in nature and it helped to crystallise the main case study design for the final evaluation and the new insights gained while conducting the pilot study aided in building theories. In parallel to the pilot study, the researcher conducted a literature review on relevant literature. This helped the researcher to gain a rich understanding about the prevailing theories as well as empirical observations.

The second phase is the main case study used in this research. This was studied over a period of one year. This allowed the researcher to study the business domain in detail. Hence, this second main case study is more *"Descriptive"* in nature. During the second phase, the detailed evaluation was conducted. The theories that were built, as a result of conducting the first phase together with the ongoing literature review, were tested with the use of a single descriptive case study.

3.6.1.3. Phase 1: Exploratory Pilot Case Study

The organisation selected for this study is one of the largest distributors of office stationary products in both Australia and New Zealand. The company employs more the 200 employees within its' eight locations. The organisation's head office and the main warehouse are in a same site in Western Sydney area.

Long (2004) points out that the *"Unit of analysis"* is the most basic element of a research project and *"it is the subject (the who or what) of study about which an analyst may generalize"*. Hence, the unit of analysis in this research is the *"business process"*. The warehouse management process of the organisation was examined in this plot case study.

The case study was guided by the main research question of *"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"* The sub research questions and their investigative questions guided the data collection and analysis of data.

3.6.1.4. Phase 1: Data Collection

The initial meeting included the researcher, the organisational top management and middle level management. During this first meeting, the researcher provided an overview of this research project to the participants of the company. In addition, an organisational top level manager provided an introduction to the organisation and its major business processes to the researcher. During the second meeting, the researcher provided a more detailed overview of the research project. At this time, a brief visit to the warehouse helped the researcher to observe how the warehouse process was conducted and the scope of the process prior to detailed data collection. The third visit involved collecting data related to GHG emissions from the warehouse management process. Researcher used semi-structured interviews, observations, and surveys to collect data. This was relatively an in-depth data collection. Data collection was conducted for all the activities, all the sub-processes, and for the warehouse management process as a whole.

Data Analysis of this pilot case study investigation revealed that it is not possible to practically collect all the data related to a business process only at the business process level. The literature review investigation that was conducted in parallel to the pilot case study provided new insights on this issue. This in-depth literature review in business process modelling identified gaps in modelling GHG emissions at process level. Activity-based costing, a related process level modelling approach categorises activities into different levels. Similarly, GHG emissions measuring can happen at various business process levels. A semi-structured interview together with a questionnaire revealed three levels in business process level GHG emissions (activity level, sub-process level, and business process level) and a shared organisational level.

During data collection it became clear that all emissions related data cannot be collected only at a particular time. The study pilot identified GHG emission frequency patterns. These GHG emission frequency patterns are useful to calculate emissions for the reporting time period (e.g. monthly, annually). The study names these two major emission frequencies as: *ad-hoc emissions* and *routine emissions*. Ad-hoc emissions do not fall in to a specific time frame. Therefore, they are non-generalizable. Routine emissions fall into four categories: daily, weekly, monthly, and yearly. Daily activities include employees' commute to work and computer usage. Weekly activities are activities such as garbage disposal. A monthly activity can be goods receiving and a yearly activity can be stock taking.

This pilot case study provided the researcher with insights: to identify the levels of a business process, in which GHG emissions can be captured; how detailed the questionnaire should be; how to abstract a business process into different process levels with relation to GHG emissions.

3.6.1.5. Phase 2: Descriptive Case Study

This section will go in to details of the main case study used. Case study selection was done by considering the amount of GHG emissions produced by this business organisation. At present, there are many business organisations that use a lot of energy. As shown, in the Table 2.1 in Chapter 2 (page 19), manufacturing businesses are among the dominant anthropogenic GHG emission sources. Therefore, in this study priority was given to select and employ a manufacturing organisation which is responsible for a considerable amount of GHG emissions.

3.6.1.6. Phase 2: Data Collection

Initial data collection sessions of the manufacturing organisation included a site tour which covered all of the organisational processes. During this session, the researcher used interviews and observational data gathering techniques to get an overall understanding of the organisation and its business processes. This data gathering session was conducted with the top level organisational management.

Second data collection session focussed on the selected business process which was the PET manufacturing process. This session involved top, middle, lower level management and other employees. As part of the investigation, semi-structured interviews and online questionnaires and surveys were conducted.

Semi-structured interviews were conducted on site. The employees were asked about how they performed their day to day activities. Based on the responses, the researcher collected additional data by questioning them and getting the participants to explain their day to day tasks and activities. To collect data related to GHG Protocol's Scope 3 GHG emissions, individual data was collected as well. Individual data is basically related to simple questions with regard to the mode of transport used by employees to and from work.

Due to these reasons *Research Ethics Approval* from a *Human Research Ethics Committee* was needed. Prior to engaging with the organisation for data collection, researcher attended a workshop on *"Designing for Research Ethics Approval"* organised by the University of Western Sydney (UWS), Office of Research Services. Thereafter, ethics approval was sought from *University of Western Sydney Human Research Ethics Committee* (EC00314) and approval was granted.

The researcher used a web-based tool to collect data via questionnaires and surveys. The web-based tool was built in the .NET platform. It collected data from higher, middle and lower management, and individuals. This web-based tool and *Green Activity Based Management (ABM)* approach possess a direct link to assist seamless mapping between the two. The data collection was performed at the activity level, sub-process level, process level, and shared level. Details of this web-based tool to collect organisational data are provided in the *"Appendix - A: Online tool to collect organisational* data*"* (page 292) of this thesis.

3.7. The Design Cycle

The design cycle iterates between activities that would build the artefact and evaluate it. The artefact is built according to the requirements identified in the relevance cycle. Then, evaluated for utility, quality, and efficacy of the artefact (Hevner et al., 2004). In the five stage research plan illustrated in Figure 3.2 (page 88), stage (B) and stage (C) builds and evaluates the artefact.

3.7.1. Stage (B): Intervention (Building/ Action Planning and Action Taking)

After initiating the design science research within the application context, which provided the research requirements and the scope, the relevance cycle next moves on to the design processes (Hevner et al., 2004). March and Smith (1995) state, build and evaluate as the two design processes. In the Cole et al. (2005) approach, the Stage B, performs action planning and action taking to build the artefact. The stage B consists of six levels:

- B.1 Identification of various GHG emission levels of a business process:

  A semi-structured interview together with a questionnaire and the literature review revealed three levels in business process level GHG emissions (activity level, sub-process level, and business process level) and a shared organisational level. This clearly showed the inductive nature of the research.

- B.2 GHG emissions calculation at various business process levels:

  In this, the GHG emissions were calculated according to the emission levels identified in the sage B.1. Findings from the stage B.1, led to the formation of a new theory which was deduced from existing theories to calculate GHG at various process levels at stage B.2.

- B.3 Modelling of GHG emissions together with other business objectives in a business process:

  Once the emission figures were quantified at the business process level, the visual model with a formal underpinning for GHG emission was constructed. This formed the base of a tool and a methodology named *"Green Activity Based Management (ABM)"* that allows GHG, time, and cost modelling and further analysis at different process levels.

- B.4 GHG emissions reporting according to GHG Protocol scopes at corporate level:

  In Stage B.4, the emission sources were examined and a reporting tool was built to report GHG emissions according to *GHG Protocol*. This provided the management with a snapshot of current GHG emissions according to business processes, detailing answers to questions of how much, what, where, when, and why.

- B.5 Setting the criteria for selection of an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions:

  Stage B.5 produced a criterion for selection of an optimisation technique that can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions with other objectives.

- B.6 Multi-dimensional business process optimisation for GHG emission mitigation:

  Stage B.6, a two-way mapping between the derived formula (stage B.5) and the selected optimisation technique was built.

Thus, at the end of each sub-stages of Stage B, a constituent artefact was produced. These individual artefacts collectively formed a much large artefact: "*Green Multi-Objective Process Optimisation*" or "*Green MOPO*" framework.

3.7.2. Stage (C): Evaluation

According to March and Smith (1995), the *"Evaluation"* process constitutes the second process in design. Cole et al. (2005) evaluate the artefact from Stage B. In this evaluation stage field trials and simulation are among some means used to achieving this. Measures of success were determined prior to artefact implementation. Then, the artefact, which is the framework, was evaluated against these pre-defined measures of success. As part of this, the utility and the efficiency were evaluated (Hevner et al., 2010).

A quality design science research project should have clear positive answers for two very important questions. Hevner et al.(2010) state these two questions as follows:

1. *"Does the design artefact improve the environment"*
2. *"How can this improvement be measured?*

The output of the design science research has to be studied and the feedback from this is very valuable if future improvements are needed. Upon reflection of the field testing, if the researcher decides another iteration of the relevance cycle is needed, then, may do so by restating the research requirements according to the actual experience (Hevner et al., 2010).

An artefact has to be testable against all the pre-defined measures of success. The new artefact can provide far superior solutions to the identified problems. Thus, the design expertise gained in this exercise will be useful for future use (Rossi and Sein, 2003). To evaluate this aspect of the framework, a set of guidelines provided by Hevner et al.(2010) is used. Following table summarises this set of guidelines. These guidelines will be discussed again in Chapter 8 (page 218).

Table 3.2: Design-Science Research Guidelines adopted from Hevner et al. (2004)

Guideline	Description
Guideline 1: Design as an Artefact	Design-science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and valuation of the design artefact.
Guideline 6: Design as a Search Process	The search for an effective artefact requires utilising available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

The guidelines described in Table 3.2, are currently accepted as the norm to justify the requirements as a design science research project. It is not mandatory to use the guidelines. Although, if these are used, it will showcase the completeness of the process (Hevner et al., 2004).

The relevance cycle stated the design requirements. The artefact was built as a solution to these identified requirements. Each requirement addressed a particular need faced by many organisations when they tried to manage GHG emissions. As will be discussed in Chapter 8 and Chapter 9, the new artefact (the framework) introduced a change to the organisation. The change brought in some sort of an outcome within the organisation. By reflecting upon these, success and failure within the organisational setting was understood.

Therefore, the next stage will enable the abstraction of knowledge to make practical and theoretical contributions to the Information systems field.

3.8. The Rigor Cycle

The knowledge base, from which the design science can draw knowledge and gather the raw material from, is vast. It is composed of foundations and methodologies. Foundations include theories, frameworks, instruments, constructs, models, methods, and instantiations. Methodologies include data analysis, techniques, formalisms, measures, and validation criteria. To achieve rigor, exiting foundations and methodologies should be appropriately applied. In the rigor cycle of design science research, computational and mathematical methods are primarily used to evaluate the artefacts. In addition empirical methods can be applied (Hevner, 2007, Hevner et al., 2004).

With respect to the five stage research plan, the rigor cycle consists of Stage (D): Reflection and learning and the Stage (E), Thesis and publications.

3.8.1. Stage (D): Reflection and Learning

In this step knowledge is abstracted to make practical and theoretical contributions to the IS field. Reflection during a cyclical research process is of prime importance. Reflection help maintain focus on the relevant practical problem. Learning is essential in ensuring the advancement toward the goal of contributing to the knowledge base (Cole et al., 2005).

Another important point is to differentiate design science from routine design. In routine design existing knowledge is applied to existing problems in the organisation. Design science research on the other hand tries to solve important unsolved problems via innovative artefacts and adds new knowledge to the existing knowledge. Thus, the key differentiator between routine design and design science is proving the clear contribution to the knowledge base of foundations and methodologies (Hevner et al., 2004).

This research uses several theories and methods in the existing knowledgebase and extends them. It clearly contributes to the knowledge base in many folds. These theoretical contributions are detailed in the chapters 4, 5, 6, 7, 8 and 9.

3.8.2. Stage (E): Thesis and Publications

This final stage comprised of writing the thesis. It presented the findings and new knowledge as a result of research stages (A) through (D). Several publications were also produced as a result of this research. These will be shown in Chapter 9.

3.9. Chapter Conclusion

This chapter discussed the research methodology that was employed. The chapter gave an overview of the chosen research paradigm, from which the more detailed research plan was derived. The plan outlined the fundamental elements of the research methodology employed. The researcher used this research plan to systematically solve the research problem of how to perform multi-dimensional business process optimisation for several dimensions including GHG emission management.

Design science research is employed as the research paradigm to come up with an artefact to solve the main research questions. A high quality design science research has three cycles namely: Relevance, Design, and Rigor. In this research each of these cycles are clearly identifiable. To make this more prominent, in this chapter, a synthesised research plan containing five stages is employed. The comprehensive research plan embracing two research methods, *Action Research* and *Design Research*, achieved the research objectives.

The resultant artefact is a framework to perform multi-dimensional business process optimisation including GHG emission management to support and empower organisational middle level managers. Hence, the framework is capable of:

(1) Modelling, measuring, and calculating GHG emissions at process level (activity, sub process, and process) and report at corporate level;

(2) Analysing GHG emissions against other business objectives to arrive at an optimal solution in emission management.

Further, the chapter also provided references to other chapters where aspects like artefact building, evaluation, and discussion is carried out in a more detailed manner.

CHAPTER 4 : Descriptive Case Study

4.1 Chapter Introduction

This research study employs the *Design science research methodology*. Thus, domain knowledge and understanding was gained while building and deploying the artefact named *"Green Multi-Objective Process Optimisation (Green MOPO) framework"*. According to Hevner et al.(2004), a *"Case Study* is used to study an artefact in depth in a business environment.

The chapter is organised as follows. First the organisation background is discussed. Thereafter, the selected business process and machines involved in this manufacturing process is detailed. Finally, the chapter concludes with a summary of the chapter.

4.2 Organisation's Background

The selected organisation is in the Western Sydney Region, in New South Wales (NSW), Australia. In this study the location of the business organisation plays an important role as some data collected is context specific e.g. In Australia, electricity rates and fuel prices are related to the geographical location. Selected organisation is a plastic packaging company which specialises in a wide range of plastic closures and containers. The company provides packaging solutions for pharmaceutical, household, and food industries. This is a privately owned organisation. It is located at a single geographical location. For this organisation, predominant emission source was Scope 2 (WBCSD-WRI, 2004) emissions from consuming purchased electricity.

4.3 Selected business process

The study considers the *Injection Blow Moulding (IBM)* process in *Poly-Ethylene Terephthalate (PET)* package manufacturing of the above mentioned organisation. PET is a thermoplastic polymer resin of the polyester family. PET–based polymers are very versatile in their applications. It is a water and moisture barrier material. Its popularity is mostly due to the safety and convenience of PET products. PET production consumes a lot of energy. IBM combines injection moulding with blow moulding. Preforms or resins and die are raw materials used in IBM machines. In this process, IBM machines transform these raw materials in to plastic closures and containers. Even though, the process consumes a lot of energy, apart from the heat that is generated, very little goes to waste. IBM machines deal with a lot of heat, are very efficient, and the products can be very delicate. Thus, robotic technologies are used to handle the products (Belcher, 2007, Jones et al., 1995).

4.3.1. Machines involved in manufacturing

IBM machines require specially trained employees to work on them. Thus, collecting machine related data was handled by a team of specialists that work in this organisation. The researcher was provided with the final set of data related to machines. An IBM machine composes of several components working in concert to complete the PET manufacturing process. In this manufacturing process, there are four main machines: *PET Heat, PET Drive, Dryer,* and *Water Chiller* and *pumps*. The *Water Chiller* and *Pumps* are considered to be in one machine group while *PET Heat*, *PET Drive* and *Dryer* are in another group.

All four of these machine components were purchased in 2009. The *PET Heat, PET Drive,* and *Dryer* were purchased at AUstralian Dollars (AUD) 1.5 million. The *Water Chiller* and *Pumps* cost the organisation AUD 0.5 million.

These machines are serviced once a year. The organisation paid AUD 1000 each for the *PET Heat, PET Drive*, and *Dryer* as well as for the *Water Chiller and Pumps* for machine servicing.

A machine has certain measurable properties. A digital power meter is used to collect energy related data for a production cycle. A machine will have an electricity energy consumption rate, a power factor, apparent power (kVA), and a machine state:

- Electric energy consumption or wattage is the amount of power, especially electric power, and is expressed in watts or kilowatts. A machine will draw more power when it is initially switched on. This is usually known as the start-up power consumption. After a certain period, the machine will draw a lesser amount of power and this is known as the run-time consumption rate. The power supplier uses the total power that was consumed by the machine to bill for that particular time period.
- Apparent power is defined by Pajic (2006), p. 1787 as *"the maximum active power that can be delivered to the load while adjusting or maintaining unchanged certain equivalent values of load voltages and currents unchanged."* The unit of apparent power is kilo-volt-ampere or kVA. During the initial start-up phase a machine will have a higher kVA value. Thereafter, once it goes in to the running mode it will have a lower kVA value. The energy supplier bills monthly for the highest kVA value consumed by a particular single geographical site. It is important to note that if more than one machine is on at a particular time, the total instantaneous kVA values will add up. Higher kVA values are harmful to the power distribution grids. Thus, in NSW, Australia, there is a threshold for the amount of maximum kVA for an electricity energy consumer.
- Power Factor is defined as the ratio between the useful (true) power (kW) and the apparent power (kVA) consumed by an alternative current electrical equipment (Ware, 2006).

After analysing the machine power consumption, this research identified seven distinct states in power consumption during a single production cycle. It is a generic pattern observed for various components of the PET machine. The seven states include:

1. *Pre-Activity*: This time is used for the machine maintenance activity.
2. *Start-Up:* This has the highest rate of electricity consumption before it goes into its running mode.
3. *Pre-Production Fixed:* Machine is in the running mode for a fixed time to perform a certain activity. This activity completion may trigger another machine to start working.
4. *Pre-Production Variable:* Machine is in the idle running mode until the production state. This happens when several machines are also required for production or operators may need to inspect before starting the machines.
5. *Production Fixed:* Final products are manufactured during this fixed time period.
6. *Shutdown Variable:* Machine is in the idle running mode until the shutdown or until the operator is ready for the shut-down procedure.
7. *Shutdown Fixed:* Machine is in the running the mode for a fixed time to perform a certain activity prior to shutting down.

In this company machines are switched on during different times. However, in order for the manufacturing to commence, all four machines must be in their running mode. First, the *Dryer* is loaded with resins. In this *Dryer,* the *PET resins* are dehumidified. Thereafter, the colours are fed in to the resins. Subsequently, the extrusion begins. The resins are heated and melted. The melted resins are injected into moulds. Then, the heated material is cooled so that the newly formed plastic product can be handled by robotic arms. In this organisation, robotic arms place the finished products in to large containers and finally finished products are ready to be packed away.

4.3.2. PET Product characteristics

There are some special characteristics of a PET product: *Intrinsic Viscosity (IV)* is a measurement of the molecular weight of the polymers; *Acetaldehyde (AA)* value is considered as a measure of the tendency to generate acetaldehyde (Rule, 2006) by the product under certain conditions. In addition, other generic characteristics of any product are found. Some of these are: dimensional, weight, visual, waste type generated as a by-product, waste amount, odour, lustre, and texture. Even though, these characteristics are there in PET Products this study does not analyse them. This is a limitation of this study.

4.3.3. PET Manufacturing activity characteristics

In this manufacturing process, it is possible to automate certain activities. This creates three types of activities: manual, partially automated, and fully automated activities.

As mentioned earlier, herein this manufacturing process, for a particular machine there are seven distinct states in power consumption during a single production cycle. All four machines possess these states and each state is an activity.

4.4 Chapter Conclusion

This chapter detailed the main case study used in this research. The main case study was used to study the artefact in a real business environment. The cased study was based on a *"Poly-Ethylene Terephthalate (PET) package manufacturing process"*. This chapter first introduced the selected case study and then justified the selection of it as a suitable business process. Next, it discussed the machines involved in the study, PET product characteristics, and PET manufacturing activity characteristics. The next chapters will use the main case study as the study context and for design evaluation.

CHAPTER 5 : Main Artefact Description

Green Multi-Objective Process Optimisation (Green MOPO) framework

5.1. Chapter Introduction

Chapter 4 detailed the case study employed in this research. This chapter contains a concise description of the new and innovative artefact, named *"Green Multi-Objective Process Optimisation (Green MOPO) framework"*, built as an answer to the original research problem of *"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"* The chapter introduces the framework that would facilitate modelling, measuring, calculating, and reporting of GHG emissions management. Further, it shows how this framework enables organisational management to optimise their business processes for GHG emissions management, alongside other vital business objectives such as reducing cost of production and time to market. Moreover, the framework is derived from the GHG Protocol (WBCSD-WRI, 2004),

Many researches argue in an organisation, within the business processes the actual work take place (Davenport, 1993, Saxton et al., 2007, Harmon and Davenport, 2007). In an organisation, business processes are generally managed by the middle level management. Organisational middle management strives to meet day to day business objectives such as cost and turnaround time, amidst continuous business challenges. One such challenge is the lack of process level GHG emission related information. If they have this information, they can manage GHG emissions alongside other business objectives at the business process level. Moreover, they can take the necessary action at a micro level, leading up to the management of GHG emissions at a macro level. Middle management empowered decision making and action taking is much more practical and less tedious than top level decision making and action planning.

In order to support their decision making, the middle level organisational management is in need of a multi-dimensional decision support system. However, to the researcher's knowledge, a decision support system which would simultaneously look at dimensions like cost and time as well as GHG emissions is not found in literature or in practice. One other important factor is that these dimensions need to be looked at simultaneously as a change in one may have an impact on another. For example, in some organisations timing of business process activities can have an impact on both cost and associated GHGs (e.g. the time a truck takes to deliver goods between two locations during daytime high traffic hours as opposed to the same delivery during the night). Therefore, middle management needs a decision support system to model, measure, calculate, and report GHG emissions produced at business process level along with other business objectives.

Even if such a software tool exists, organisations need step by step guidance and support to make use of it. For an example GHG emission reporting has to happen according to national and international standards. In order to do this, organisations first need to identify organisational boundaries, ownership and be consistent with these decisions throughout the reporting. In addition, they may need to identify their other vital business objectives and quantify them, and model at business process level. Hence, a mere decision support system would not be adequate to the level of support the organisational middle management currently need.

As described in Chapter 3, this research adopts the *Design Science* paradigm. This is fundamentally a problem solving paradigm. An artefact extends the human problem solving boundaries and organisational capabilities by providing intellectual and computational tools

(Hevner et al., 2010). This research looks at the holistic problem faced by the middle level management and proposes a framework to perform multi-dimensional business process level optimisation including GHG emissions management. The decision support system would form a part of this framework. In addition, the framework would perform external reporting by creating a *GHG Inventory* for the organisation.

The framework consists of four major *"stages"*. These stages are sub-divided into steps. Each step carries out a particular function necessary to solve the research problem. The research investigated on theories related to each step and discovered gaps in knowledge that has to be addressed to complete each stage. Research produced six constituent artefacts as a result of filling the identified research gaps.

In this chapter, first it provides an overview of the framework with its four major stages. This is followed by a summarised discussion on each of the stages and steps of the proposed framework. First is the identification stage i.e. identification of organisational boundaries, processes, emission sources, and business objectives. Second stage is the business process modelling, data collection, and GHG emission calculation. In the third stage, data is rolled up to the corporate level for reporting. The fourth stage optimises a business process. Where applicable, the chapter uses targeted examples to explain a particular concept. Finally, it concludes with a chapter summary of what has been achieved.

5.2. An Overview of the Framework and Four Major Stages

The framework is derived from the GHG Protocol which is currently, the most widely accepted guide for accounting and reporting of GHG emissions from organisations (WBCSD-WRI, 2004). The GHG Protocol standards and guidelines for organisations serve several important objectives. These are: a) to help organisations to come up with an accurate and fair account of their emissions; b) to reduce the cost of preparing a GHG inventory; c) to enable organisations to build a strategy to reduce as well as manage emissions; d) to improve the transparency and consistency among various participating companies and GHG accounting and reporting programs (WBCSD-WRI, 2004).

According to the GHG Protocol, there is a business value in compiling an accurate GHG Inventory. This inventory is able to serve several business goals. These goals include: a) Identification of reduction opportunities and management of GHG emission risks; b) Reporting to the general public; c) Entitlement to Eco-labelling and GHG certification; d) Participation in mandatory reporting programs; e) Participation in GHG markets for trading; f) The potential to earn recognition by participating in early voluntary action. In addition, a GHG Inventory would increase the understanding of the company's own emission profile. Guidelines further state that once GHG emissions gets measured accurately, it paves the way towards GHG management (WBCSD-WRI, 2004). Hence, the preceding statement supports one of this research's aims to accurately model, measure, calculate, and report GHG emissions in order to manage GHG emissions. Therefore, it can be argued that the proposed framework fulfils this aim by being in accordance with the GHG Protocol.

In Figure 5.1 a rectangle represents a step which is a sub-division of a stage. The continuous arrows represent flow of information within the organisation from one step to another. These arrows provide the information required by the next step. The broken lines with arrow heads indicate that information is conveyed to an external party. As is depicted in Figure 5.1, the proposed framework is cyclical and this can be used to adapt to dynamic business environments. Following sections briefly discuss each step and Chapters 6 and 7 will provide finer details of each of the steps.

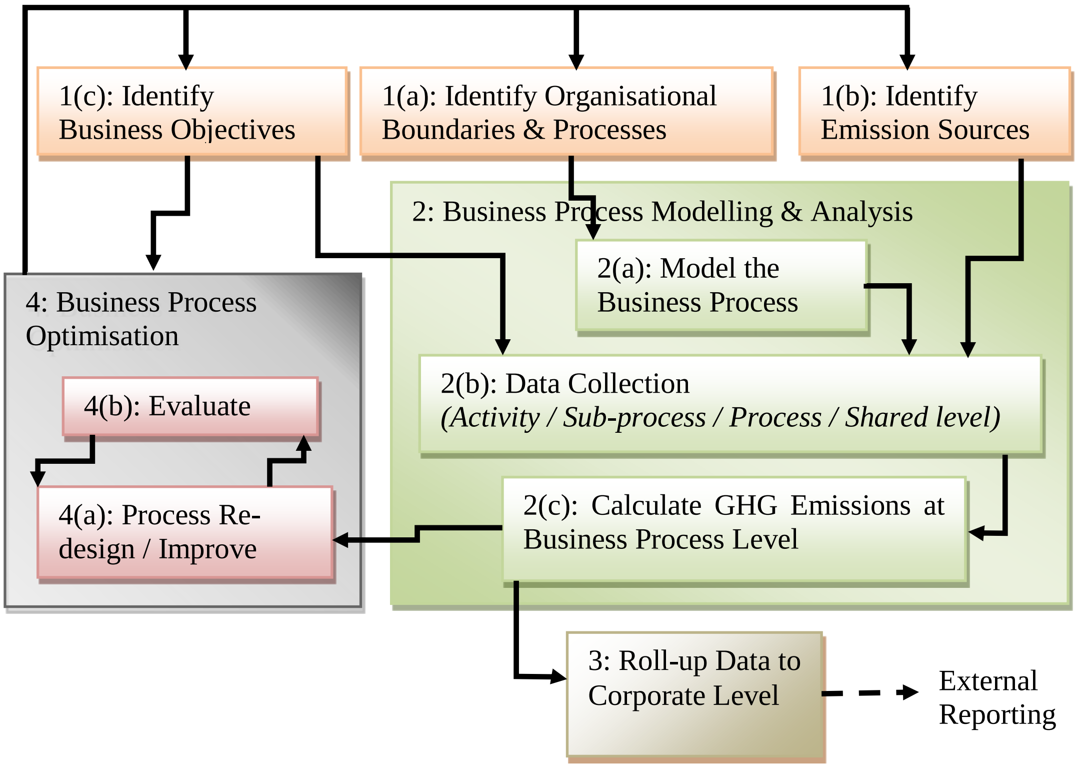

Figure 5.1: Green Multi-Objective Process Optimisation (Green MOPO) Framework

1. Identification Stage

Figure 5.2 illustrates the *Identification stage* with a red outline. This Identification stage, firstly, locates the organisational boundaries. Then, it breaks down into related processes. Once the business processes are identified, the framework stage can now identify related emission sources. Next, it identifies the business process level objectives.

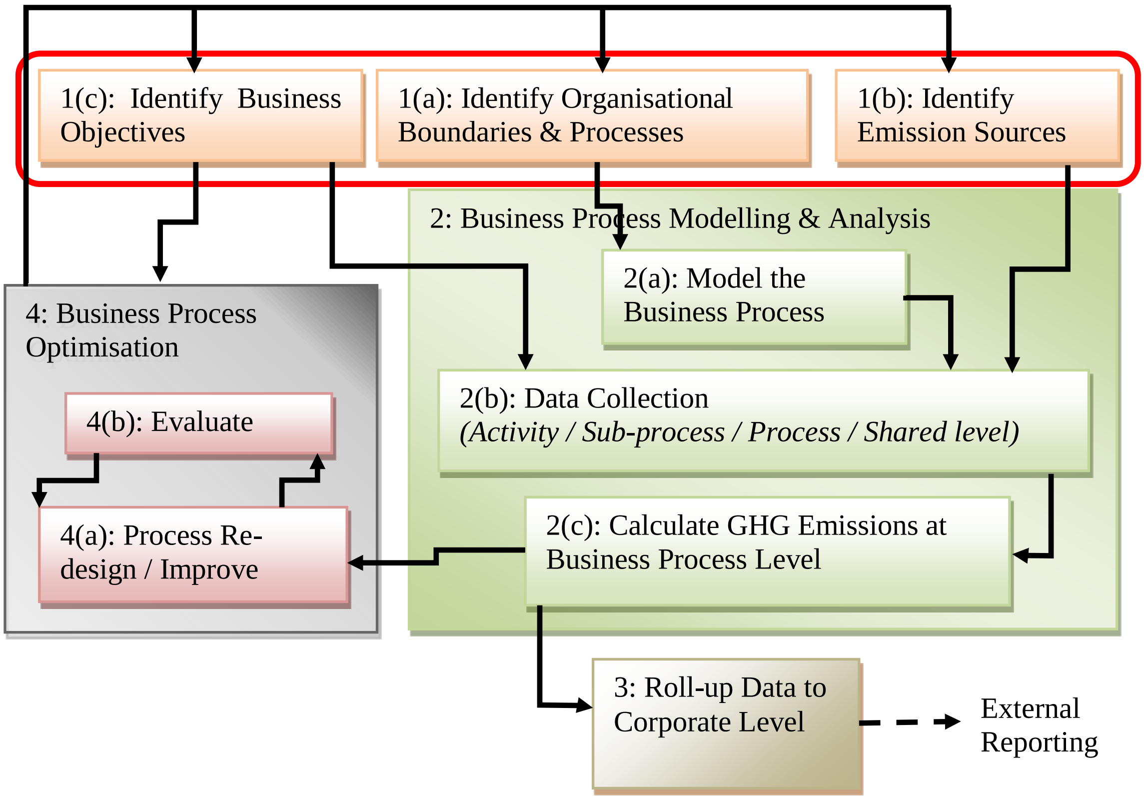

Figure 5.2: Green MOPO Framework – Identification stage outlined in red

1(a): Identify Organisational Boundaries and Processes

Today's businesses have different legal and organisational structures. Ownership of an organisation can differ from wholly owned, incorporated and non-incorporated joint ventures, subsidiaries, and others. Setting up of organisational boundaries is important for accounting and reporting. It defines facilities or entities that will be included in the final GHG inventory of the entire organisation. It links data with relevant operations, sites, geographic locations, business processes, and owners (Fransen et al., 2007, WBCSD-WRI, 2004).

Once the organisational boundaries are known, it is now possible to identify the business processes within these boundaries. As explained in the Chapter 2, an organisation will have several sub-divisions as processes and similarly these processes too will have their own sub divisions (Harmon and Davenport, 2007). Therefore, this study identifies the business processes with its own sub-divisions. Next step categorises GHG emission sources within the organisational boundary.

1(b): Identify Emission Sources

Once the organisational structure is clearly identified, then, the next step is to find out the activities, which would release a significant amount of GHG emissions into the atmosphere and associated sources of emissions (Pino et al., 2006). Emission sources are identified according to accounting and reporting scopes are defined by the GHG Protocol as Scope 1, Scope 2, and Scope 3 (WBCSD-WRI, 2004). As described in the Chapter 2, there are two broad categories of GHG emission sources; *Direct emissions* and *Indirect emissions*.

In Australia, National Greenhouse and Energy Reporting (Measurement) Technical Guidelines assist corporations by outlining calculation methods and the criteria for determining GHG emissions, energy production, and consumption. Emission source descriptions are based on IPCC Guidelines for National Greenhouse Gas Inventories, while estimation techniques are those that are used in National Inventory Report guidelines as required by UNFCCC (NGER, 2011).

This study uses the emission measurement and estimation technique termed *"Emission factors based approach"*, as it gives the most accurate estimate for carbon emissions. This technique and the other techniques were discussed in much more detail in the Chapter 2. Emission factor, which is a ratio, is published by relevant authorities. Using relevant activity data, GHG emissions are calculated (Daviet, 2006). Once the organisational boundaries, processes, and emission sources are known, the next step is to identify the business objectives.

1(c): Identify Business Objectives

According to Beatty (2010), a business objective is a measurable result a business desires to achieve when executing a project and would bring in a business value to the business. A business usually has a strategy to achieve a business objective. Every business will have business objectives, such as cost reduction, time reduction, and quality improvement (Tiwari et al., 2006). Businesses strive to meet these objectives and they are the driving force behind an organisation.

Generally these objectives are defined as business goals or targets. Even though, in literature business objectives and business goals are used interchangeably, they are basically different. A business goal is not as descriptive as a business objective (Beatty, 2010). For an example a business goal can be something like "to reduce the GHG emissions". In contrast, a business objective would be in a more descriptive form like "to reduce GHG emissions from the transport activity by 10% for this year".

2. Business Process Modelling, Data Collection and GHG Emission Calculation Stage

This stage looks after the business process modelling and business process analysis of an organisation. This is outlined in red in the Figure 5.3. Business process modelling precedes any business process analysis (Vergidis et al., 2008). Hence, data collection happens after modelling the business processes. Thereafter, according to the collected data, GHG emissions calculation takes place.

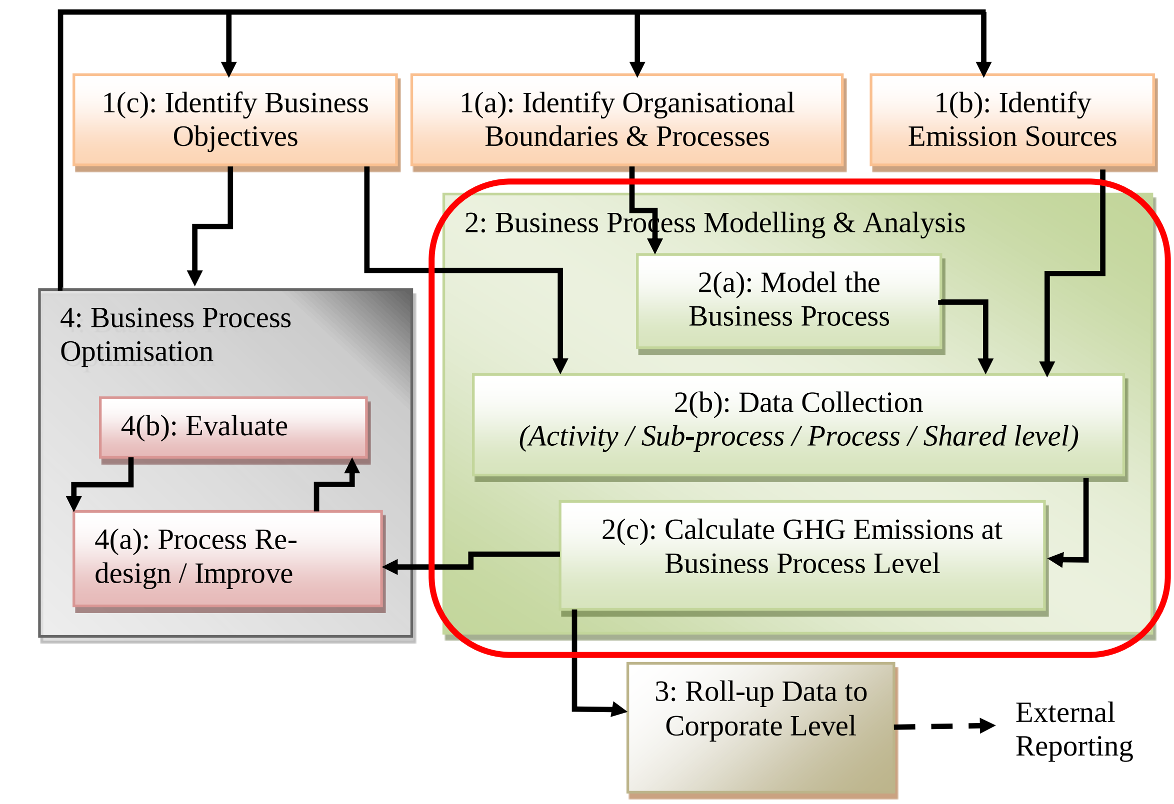

Figure 5.3: Green MOPO framework– Business process modelling, data collection and GHG emission calculation stage outlined in red

This business process modelling, data collection, and GHG emission calculation stage produces the following three constituent artefacts.

I. A set of guidelines to assist identification of a business process and its different abstraction levels i.e. activity level, sub-process level, process level and shared level.

II. A tool and a methodology named *"Green Activity Based Management (ABM)"* that allows GHG, time and cost modelling and further analysis at different process levels.

III. A set of formulas that allows GHG emissions to be calculated at different process levels.

The following sections give concise descriptions of the above mentioned artefacts. The next chapter goes in to details of each of them.

2(a): Model the Business Process

This step refers to visual modelling of the business processes identified in the previous step 1(a). The framework performs process modelling in two phases. During the first phase it identifies the business process and the constituent process elements. This is performed at a high level. Phase two of the process modelling is at the next step of *"2(b) Data Collection and Green ABM Modelling"*.

This research uses the widely accepted Business Process Modelling Notation (BPMN) technique. This modelling technique is an intuitive flow chart based modelling notation. The graphical representations of the business process being readily understood by the business user (White, 2006). This is an important benefit considered by the researcher in selecting the modelling technique(White, 2006). As a result of this step a business process model is visually represented. This is useful in data collection.

2(b): Data Collection and Green ABM Modelling

This step first collects data and thereafter models the GHG emissions along with, time and costs. While attempting to collect data related to GHG emissions for the *"Pilot Case Study"*, the research identifies the following data collection levels: activity level, sub-process level, business process level, and shared or organisational level. Chapter 4 detailed the pilot case study design. The rationale behind the selection of these particular levels is based on *"What is the most practical and sensible way to collect organisational or process elements' related GHG emissions?"* The researcher designed and built a web-based tool to collect data from corresponding levels including GHG emissions, cost, and time. *"Appendix - A: Online tool to collect organisational data"* presents the website developed to collect data from the participating organisations.

Once the data collection is finished, the second phase of the business process modelling commences. The first phase was carried out at the step 2(a) of the framework. The second phase models *"stable"* business processes. A business process is considered as *"stable"* if the core processes do not change comparatively with time but only the business decision rules within them will change (Taylor, 2009).

The research proposes a novel modelling approach called, *Green Activity Based Management (ABM), a tool and a methodology that allows GHG, time, and cost modelling and further analysis at different process levels*. This forms the second constituent artefact. *Green ABM* is a bottom-up approach for environmentally sustainable business process management. In *Green ABM*, the other two business process objectives i.e. time and costs are modelled against GHG emissions. Thus, this provides a holistic picture of these inter-dependent dimensions to the organisational manager for decision making.

Once the GHG emissions are modelled and data collected with relation to their emissions, time, and costs, the next step calculates GHG emissions at various business process levels.

2(c): GHG Emission Calculation at Business Process Level

As explained in the previous section, the empirical investigation revealed that GHG emissions result at various business process levels: activity level, sub-process level, business process level, and shared or organisational level. This step of the framework calculates the emissions at each of the above mentioned steps. The GHG emission frequency patterns are also taken into consideration in summing up the total emissions per annum.

This study extends the current emission calculation formulas, specified by WBCSD and WRI (2004), by introducing emission calculation at various process levels. This forms the third artefact the research produces: *"A set of formulas that allows GHG emissions to be* *calculated at different process levels".* Chapter 8 discusses these calculation formulas in detail with relation to how they are formed and how and when to apply. With regard to the emission calculations, special emphasis is given to electricity consumption related emissions at various process levels. This is to aid the process managers to get a clear understanding of the breakdown of the total electricity consumed within their processes.

Once the business process is modelled, data collected, and the GHG emission figures are calculated.

3. Reporting stage: Roll-up Data to Corporate Level

The previous step 2(c) calculates GHG emissions at various process levels. It details what the calculated emissions are. It helps to roll-up to the corporate level to arrive at a consolidated GHG emissions inventory based on Scopes 1, 2, and 3. Thus, the management gets a bird's eye view of what is happening within the organisation. Moreover, to be in line with GHG Protocol reporting standards, reporting according to Scopes 1, 2 and 3(optional) is required. This step is outlined in red in Figure 5.4. This forms the fourth constituent artefact, *"a reporting tool that allows reporting of GHG emissions according to the scopes defined by the GHG Protocol",* produced by this thesis.

The reporting tool follows a bottom-up approach for calculating and collating GHG emissions. Thus, reporting begins at the *Activity level* of the considered business process. Next, it calculates emissions at the *Sub-process level* followed by the *Process level* and finally it calculates emissions at the *Shared level*. Chapter 6 of this thesis explains the artefact in detail. As explained earlier, stages 3 and 4 of the framework form separate branches.

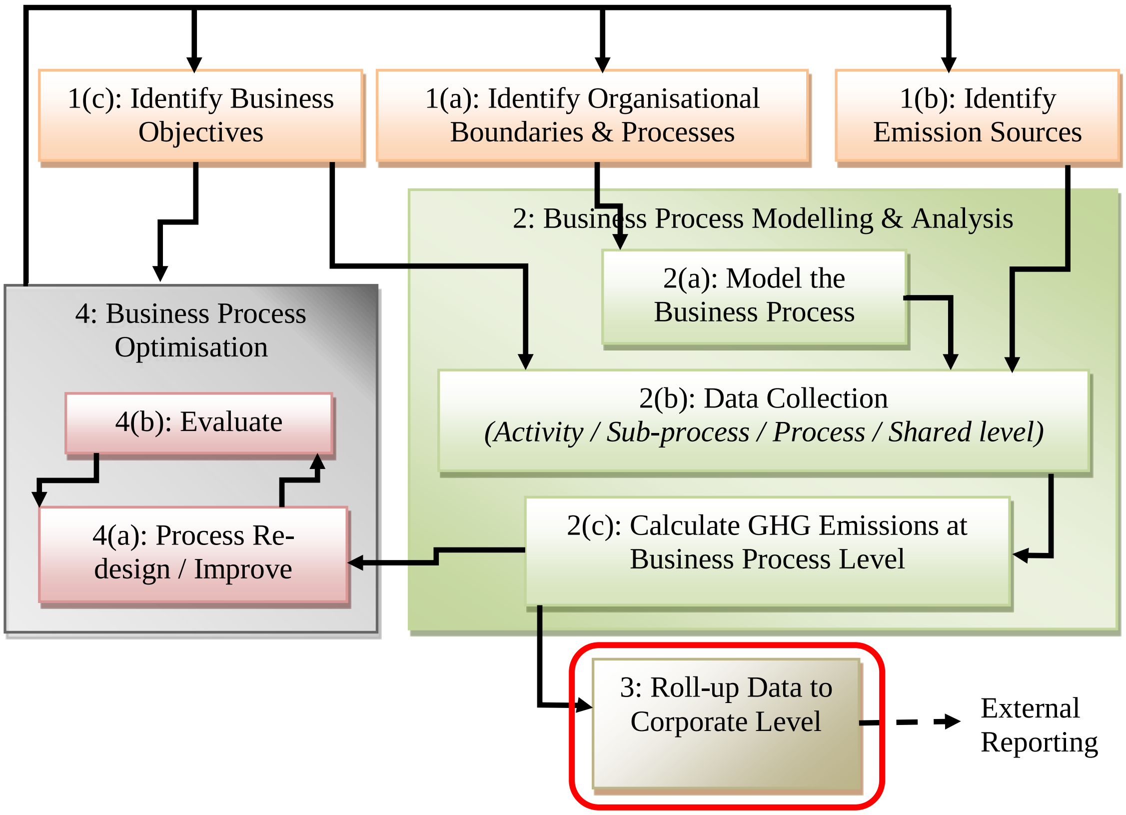

Figure 5.4: Green MOP framework – External Reporting stage outlined in red

4. Multi-dimensional Business Process Optimisation Stage

This section introduces the fourth stage, which is the multi-dimensional business process optimisation. The stage is outlined in red in Figure 5.5. During the construction of this step of the framework, the following two artefacts were produced. Details of these two artefacts are discussed in Chapter 7 of this thesis.

- The criterion for selection of an optimisation technique that can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions with other process level business objectives.
- Two-way mapping between the derived formula and the Elitist Non-Dominated Sorting Genetic Algorithm (NSGA II/ NSGA2), which is the selected optimisation technique. The terms *"two-way mapping"* signifies that the artefact: 1). Comes up with a computer

program where NSGA2, works in conjunction with the proposed Green ABM to solve multi-dimensional business process optimisation problem to achieve a set of optimal solutions. 2). Uses simulation to relate the optimal solution set back to the business domain in terms of what are the parameters and their values are in a manner understood by the business managers.

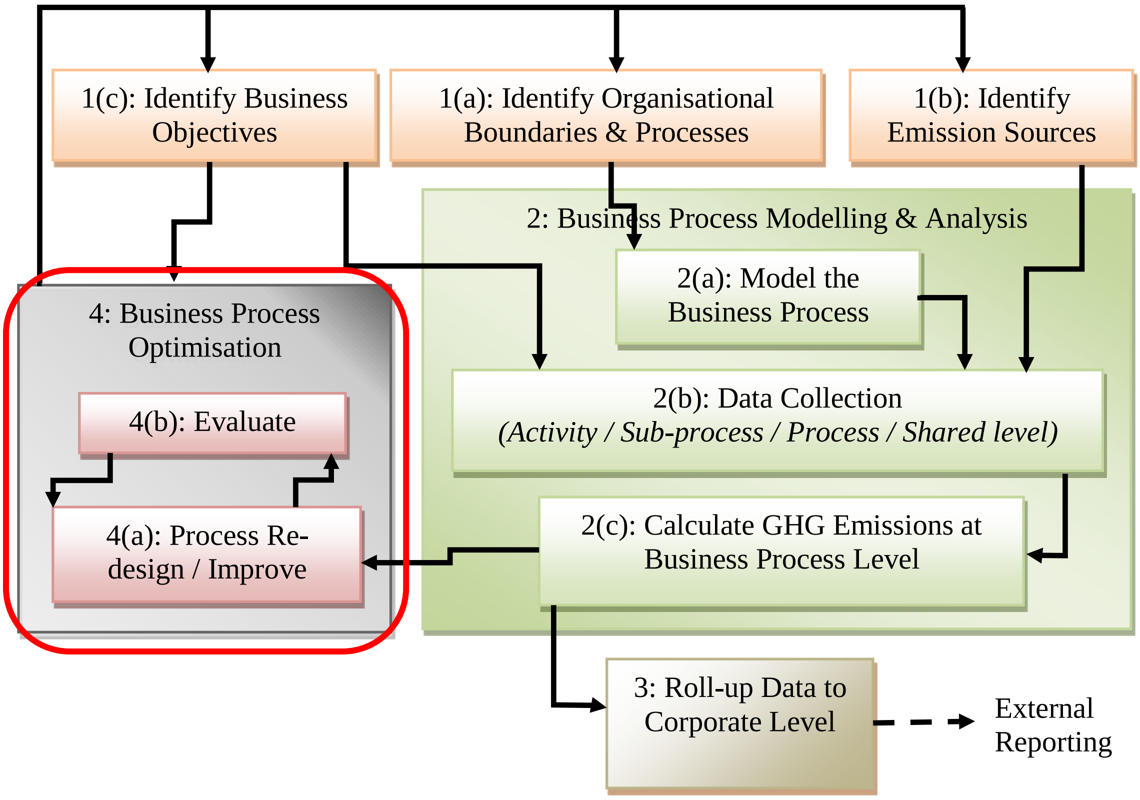

Figure 5.5: Green MOPO framework– Multi-dimensional business process optimisation stage outlined in red

As shown in Figure 5.5, the business process optimisation step is sub-divided into two lower level steps *1) Re-design / improve the business process* and *2) Evaluate* the resulting business process. These two steps are discussed in detail in Chapter 8.

4(a): Process Redesign / Improve

Today, business requirements change rapidly. Businesses constantly need to adjust their business processes to face the changing business requirements. What was suited a year ago may not be suitable in the present dynamic business world due to changes. As a result, business processes constantly get fine-tuned, value-added, and down-sized. Business process redesign is necessary due to this changing nature of business processes (Hee and Reijers, 2000). Some business processes are dynamic with changes happening frequently and other business processes are relatively stable as the frequency of the changes is less. Even stable business processes generally need to be redesigned or improved with time.

Business process redesign looks at how to articulate a process in terms of resources and interdependent tasks (Mansar and Reijers, 2007). Usually a business process redesign is a challenge with two facets. It is a technical challenge on the one hand and a socio-cultural challenge on the other hand. The technical challenge stems due to the fact that designing a new process can be a radical improvement on the current process design which may require some added technological innovations. The social-cultural challenge arises with the potential impact on the people involved and their opposition to changes (Reijers and Mansar, 2005).

There are many business process redesigning firms with their own proprietary redesigning methods. Main drawback in these methods is that they only address a part of the challenges. Mostly these address organisational issues and project management issues regarding the process redesign. They seldom look at the technical challenges involved in radically improving a current process design. Business process redesign practitioners realising this tend fall back on best practices. According to Mansar and Reijers (2007, p.193),

> *"A best practice may be seen as a successful way to treat a particular problem that may need to be adapted in skilful ways in response to prevailing conditions".*

Further, Mansar and Reijers (2007) discuss most popular best practices in this context. These are:

- Task elimination (Eliminates unnecessary tasks in a business process);
- Task composition (Combines smaller tasks in to a composite task or divides larger tasks in to smaller manageable and workable tasks);
- Integral technology (With the application of new technology, tries to elevate physical constraints)
- Empower (Reduction of middle management by empowering the workers by giving workers the authority to make decisions)
- Order assignment (Lets workers do as many steps as possible for a particular order);
- Re-sequencing (Relocate tasks to most appropriate places);
- Specialist-generalist (Making resources either more specific or more general);
- Integration (Integrate organisational business processes with the customer or the supplier);
- Parallelism (If possible execution of several tasks in parallel);
- Numerical involvement (Tries to reduce the number of departments, groups, people involved in a business process)

In the redesign / improve stage many different actions such as identification and removal of process performance bottlenecks (Vergidis et al., 2008) are possible to optimise a business process in addition to the actions stated above. In relation to GHG emissions, instead of burning fossil fuel to generate power, organisations can switch to green energy sources.

This step improves GHG emissions management against other objectives to arrive at an optimal solution in emission management. Other business objectives can be cost reduction and time reduction, as identified in the *"Identify the business objectives"* step. In literature, there are many attempts at optimising for a single objective (Dewan et al., 1998, Fitzgerald et al., 2008, Kock, 2003). According to Chong and Zak (2008), business objectives usually are competitive or in conflict against one another. Therefore, no single or unique solution can be found. When, an optimisation problem involves more than one objective function, the task of finding one or more optimum solutions is called "*multi-objective optimisation"* (Deb, 2001). So, organisational management needs to be empowered to make timely decisions and consider several optimised solutions before selecting the most suitable one.

Changes happen in business process elements. It is important to observe which characteristics of the process elements are likely to change to optimise for GHG emissions together with other process level objectives. According to Ginige (2008), there are several attributes which characterise a business process element and these attributes can be further categorised. She further states that three types of changes (*Addition*, *Modification*, and *Deletion*) can take place in these process elements. Based on the Ginige (2008) characterising of process elements, the researcher constructed a taxonomy of business process element changes that will help to derive a mathematical formula which captures these changes. Then, with reference to the constructed taxonomy, a formal model of the optimisation problem is derived as a mathematical formula. Thereafter, the researcher sets the criteria to select a suitable optimisation technique. Setting the criteria that helped to search for the best suited technique for this optimisation problem. Thus, the research creates the fifth constituent artefact of *"a criterion for selection of an optimisation technique that can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions with other objectives"*. A more detailed discussion of the fifth artefact is in Chapter 7 of this thesis.

As will be explained in Chapter 7, According to the selection criterion, a genetic algorithm i.e. Non-dominated Sorting Genetic Algorithm II (NSGA2) is selected to perform the optimisation. NSGA2 is a popular multi-objective evolutionary algorithm among genetic algorithms due to its robustness and performance (Vergidis et al., 2006).

The genetic algorithm needs to consider several parameters related to each dimension. Therefore, the formal/ mathematical model constructed in this section, support modelling of all these parameters. For an example GHG emissions calculated at various process levels form a part of the parametric formal model. This then can be used to perform optimisation. Therefore, this research proposes to apply a genetic algorithm to multi-dimensional business process optimisation for GHG emissions management and address a knowledge gap found in literature.

In parallel to this thesis, another study termed "Abnoba Framework" looks at business process design/re-design to support environmental sustainability. It aims to find alternative process designs that improve a process in terms of carbon emissions. This search space is constrained by number of possible alternative process designs. Abnoba makes an effort to extend its' search space to find more alternative process designs. This is attempted through generating a library that includes best practice process designs for a given domain to improve the sustainability profile while ensuring original process goals are achieved. In addition, the study takes the available organisational resources in to consideration. The end result is a semi-automatic process improvement which would potentially reduce the workload of the process analyst. However, this framework is not evaluated against a real business process which may present with some more process design constrains and resource compliances (Hoesch-Klohe and Ghose, 2011, Hoesch-Klohe and Ghose, 2010).

4(b): Evaluate

In order to use the formal model together with the selected optimisation technique, there has to be a mapping between the two. This mapping forms the sixth artefact, *"two-way mapping between the derived formula and the NSGA2, which is the selected optimisation technique"*. As result of deploying the sixth artefact, the framework will produce a set of optimal solutions.

This step evaluates the optimised solutions. A manager needs to take into consideration the dynamic environment and the multiple objectives in decision making. Therefore, simulation is a very useful tool for evaluation. Simulation is performed for several hypothetical optimal scenarios to see if they perform well (Figure 5.6). So, final optimised solution will again be analysed against the business objectives and justification of the reasons behind selection of that particular optimisation solution from the resulting suitable set of optimised solutions. If the evaluation suggests further changes, the feedback is taken from this instance and applied back to the previous step of process re-design / improve. The sixth artefact, two-way mapping between the derived formula and NSGA2, is useful to relate what each point in these simulation results mean to the organisational managers, who will then be empowered to make informed decisions.

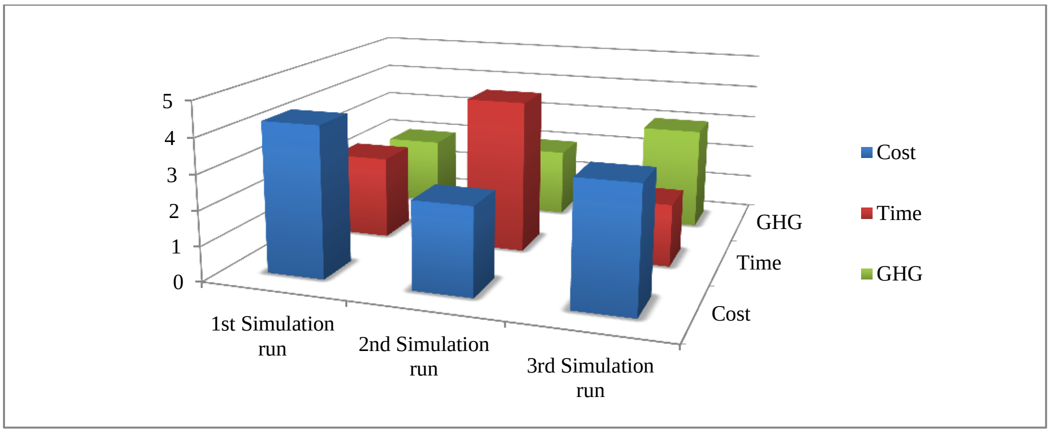

Figure 5.6: Relationship among time, cost, and GHG

Chapter 7 of this thesis further elaborates on the two-way mapping between the derived formula and NSGA2. This artefact is the final artefact produced by this framework. Thus, the next section concludes this chapter.

5.3. Chapter Conclusion

This chapter contained a concise description of the new and innovative artefact built as the answer to the research problem. The chapter introduced the framework named *Green*

Multi-Objective Process Optimisation (Green MOPO) framework, for multi-dimensional business process optimisation that facilitated in modelling, measuring, calculating, and reporting GHG emissions. Further, Chapter 5 showed how this framework, derived from the GHG Protocol, enabled organisational management to optimise their business processes for GHG emission management, alongside other vital business objectives.

CHAPTER 6 : Constituent Artefacts- for GHG Emission Management

Details and related investigative questions

6.1 Chapter Introduction

The previous chapter provided a concise description of the main artefact, *Green Multi-Objective Process Optimisation (Green MOPO) framework*, built in this research to answer the research problem. The proposed Green MOPO framework achieves this through completing four stages. These stages are: 1). Identification stage; 2). Business process modelling, data collection, and GHG emission calculation stage; 3). Reporting stage: Roll-up data to corporate level; and 4). Multi-dimensional business process optimisation stage.

The above mentioned stages are sub divided into steps. Each step carries out a function. As mentioned in Chapter 5, there are knowledge gaps that need to be filled to complete some steps. The search to fill the existing knowledge gaps led to the creation of six constituent artefacts. The first four artefacts are related to the management of GHG emissions, while the remaining two are related to business process optimisation for several objectives. This chapter details the *Constituent Artefact-I*, *II*, *III*, and *IV*. Following Table 6.1 presents the main research question, sub-research questions, investigative questions related to management of GHG emissions, *Constituent Artefact-I*, *II*, *III*, and *IV* and the relevant framework stage.

Table 6.1: A summary of the main artefact and constituent artefacts

Main Research Question	**How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?**
Main Artefact	**Green Multi-Objective Process Optimisation (Green MOPO) framework**

Sub Research Questions	**Investigative Questions**	**Output/ Constituent Artefact**	**Frame-work stage**
1. How can GHG emissions at a business process level be modelled, measured, calculated, and reported efficiently?	1.1 What are the levels of a business process, in which GHG emissions can be modelled?	**I**. A set of guidelines to assist identification of a business process and its different abstraction levels i.e. activity level, sub-process level, process level and shared level.	1
	1.2 How can GHG emission be modelled, measured, and calculated in above identified business process levels?	**II**. A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time, and cost modelling and further analysis at different business process levels.	2
		III. A set of formulas that allow GHG emissions to be calculated at different business process levels.	
	1.3. How can GHG emissions associated with a business process be reported in three emissions categories identified by the Greenhouse Gas (GHG) Protocol, namely Scope 1, Scope 2, and Scope 3?	**IV**. A reporting tool that allows reporting of GHG emissions according to the scopes defined by the GHG Protocol.	3
2. How can a set of multi-dimensional parameters including GHG emissions associated with a business process be optimised effectively?	2.1 How can other business objectives such as cost and time be modelled against GHG emissions in a business process?	**II**. A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time, and cost modelling and further analysis at different business process levels.	2
	2.2 What are the selection criteria of an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions?	**V**. The selection criteria of an optimisation technique that can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions with other objectives.	2,4
	2.3 How can a selected optimisation technique (based on the selection criteria set above) be applied for business process optimisation for GHG emission management alongside other business objectives?	**VI**. Two-way mapping between the derived formula and the Elitist Non-Dominated Sorting Genetic Algorithm (NSGA II/ NSGA2), which is the selected optimisation technique.	4

This chapter provides the detailed descriptions of *Constituent Artefact-I* to *IV* and shows how they answer the related investigative questions. Chapter 7 is a continuation of this chapter and it details *Constituent Artefact-V* and *VI*. These two chapters show how these artefacts would contribute to the knowledge base.

In *Design Science Research*, the artefact with its high utility contributes to the knowledge base. There are two related types of knowledge as *Descriptive* and *Prescriptive*. Descriptive knowledge provides the theoretical bases to design practical and useful artefacts. Prescriptive knowledge concerns artefacts built to improve the natural world by human beings. In other words it is about the *"how"* knowledge of artefacts built by humans (Gregor and Hevner, 2013). The prescriptive knowledge belongs to the sciences of the artificial (Simon, 1996). There are five prescriptive knowledge types. March and Smith defines four of these types as *constructs*, *models*, *methods*, *instantiations* (1995). *Design theory* makes up the fifth type (Gregor and Hevner, 2013). The *design theory* formalises knowledge in design science research and it tells *"How to do something"*. This can include other kinds of knowledge defined by March and Smith (1995).

The main artefact built in this thesis answers the research question of *"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"* This main artefact is a combination of a model, a method, and an instantiation. Chapter 8, which is the evaluation and discussion chapter, justifies this claim.

This chapter is organised as follows. First, it provides an introduction to knowledge types. Thereafter, the chapter first goes in to details of *Constituent Artefact-I*, *II*, *III*, and *IV* produced in this thesis. Finally, the chapter will conclude with a summary of the discussed artefacts.

6.2 Constituent Artefact-I:

A set of guidelines to assist identification of a business process and its different abstraction levels i.e. activity level, sub-process level, process level, and shared level for business process level GHG emission modelling.

As shown in the Table 6.1, this artefact provides a solution to the investigative question of *"1.1. What are the levels of a business process, in which GHG emissions can be modelled?"* To answer this question, the study modifies and extends a set of steps for identifying and calculating GHG emissions originally developed by the Greenhouse Gas Protocol (WBCSD-WRI, 2004) into a set of guidelines. Chapter 2 lists the GHG Protocol recommended steps for calculating GHG emissions and reporting at corporate level. This section introduces each of the seven proposed guidelines (Figure 6.1).

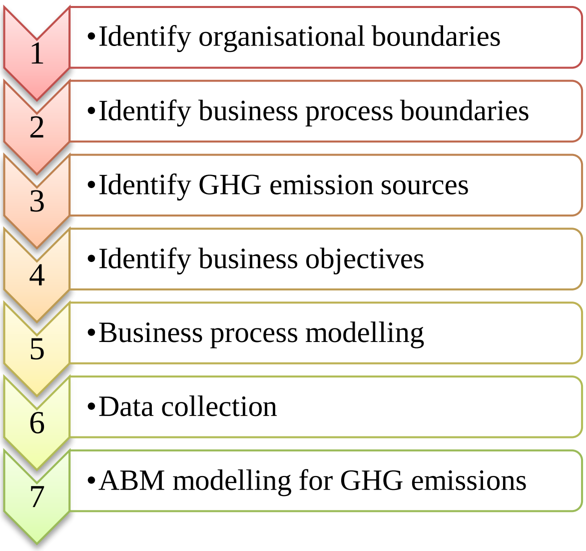

Figure 6.1: Guidelines to assist identification of a business process and its abstraction levels for GHG emissions

6.2.1. Guideline 1: Identify organisational boundaries

GHG Protocol (2004) points out that an organisational GHG inventory should be relevant, complete, consistent, transparent, accurate, specific, and non-ambiguous to ensure the inventory is a true and fair representation of the organisation’s GHG emissions. Business operations have varying legal and organisational structures. Organisational ownership may differ from group companies / subsidiaries, associated / affiliated companies, non-incorporated joint ventures / partnerships / operations where partners have joint financial control, fixed asset investments, and franchises. For the purpose of accounting and reporting GHG emissions, setting up of organisational boundaries is important to consolidate GHG emissions according to relevant categories (WBCSD-WRI, 2004).

In order to account GHG emissions of a company's operations, data needs to be linked with relevant operations, sites, geographic locations, business processes, and owners (Fransen et al., 2007). Organisational boundary defines facilities or entities that will be included in the final GHG inventory of the entire organisation (Fransen et al., 2007).The organisation can consolidate its GHG emissions within these identified organisational boundaries. This will avoid another organisation from owning up to the same emissions and this is termed as avoiding of *“double counting”* of GHG emissions (WBCSD-WRI, 2004).

There are two distinct approaches to consolidating GHG emissions of an organisation as equity share approach and control approach. However, if the reporting organisation has the total ownership of operations then the organisational boundary would not be dependent on the approach it chooses (WBCSD-WRI, 2004). In the equity share approach, GHG accounting is in accordance to the organisation’s share of equity in the operation. The equity share reflects the economic interest of the company (Carbon_Glossary, 2012, Pino et al., 2006). The control share is often defined in terms of financial control criterion or operational control criterion. Therefore, a company must choose which criterion it is going to use to consolidate its GHG emissions. With the control share approach, a company has to report emissions according to the percentage of control it has (WBCSD-WRI, 2004).

6.2.2. Guideline 2: Identify business process boundaries

Once the organisational boundaries are known, this second guideline identifies the business processes. Today, organisations are commonly identified as a set of business processes (Melão and Pidd, 2000). Chapter 2 discussed a business process in detail.

An organisation consists of several sub-divisions as processes. Likewise these processes too have their own sub-divisions (Harmon and Davenport, 2007). These sub-divisions found in a process can be either atomic activities or sub-processes themselves. Sub-processes can be recursively refined by activities and these activities are the basic elements in a process (List and Korherr, 2006). In Guideline 5, it identifies sub-processes and activities, also known as business process elements.

Identification of the business process and its boundaries is subjective. It depends on the business analyst's skill level. As Davenport (1993, p.27) suggests:

> *"Like an anthropologist exploring a distinct culture, the analyst should act as an observer of the business process"*

Davenport's (1993) statement implies that the business process analysts should draw knowledge from many facets, i.e. functional, behavioural, organisational, and informational (Curtis et al., 1992), present in a business process. Thereafter, use this knowledge to build an abstracted representation of the business process. Therefore, the role a business process analyst plays is crucial in this study.

Identifying the process boundaries may not be straight forward all the time. There may even be instances where boundaries of two processes appear as if they overlap. In such a situation, digging deep into process element levels, i.e. activities, may hold the key to resolving such an issue. It is important to remember the logical flow of the finite interdependent activities which transforms the process inputs into output/s. The logical flow of the activities will help to determine what is included and what is excluded in a particular process. This clear identification of process boundaries and the activities assist in identifying the GHG emission sources of the process activities (Guideline 3). Moreover, setting the organisational and process boundaries helps in modelling GHG emissions. The next guideline is the identification of the GHG emission sources.

6.2.3. Guideline 3: Identify GHG emission sources

This guideline categorises GHG emission sources within the organisational process boundary. Emissions happen due to some sort of an activity. Once the activities are known, an investigation into what type of GHG emission source is involved would help to gather and quantify activity related data of that activity (e.g. Litres of fuel consumed, Kilowatt-hours of electricity consumed, Kilograms of material consumed, Kilometres of distance travelled). According to the emission calculation technique selected for this study, the activity data together with relevant emission factors (e.g. kg CO_2 emitted per litre of fuel consumed, kg CO_2 emitted per kWh of electricity consumed, kg PFC emitted per kg of material consumed, t CO_2 emitted per kilometres travelled) will provide the amount of GHG emissions released (WRI-WBCSD, 2011a). In addition, the GHG Protocol stresses that, if a certain company derives an economic profit from an activity, it is important to take the ownership of that particular activity (WBCSD-WRI, 2004, Pino et al., 2006).

Identification of emission sources is essential in this study. Thus, the Chapter 2 provided a detailed discussion of these emission sources and accounting as well as reporting *Scopes*. Typically emissions happen from four main categories: stationary combustion; mobile combustion; process emissions; and fugitive emissions. These emissions are further categorised as Scope 1, Scope 2, and Scope 3 for accounting and reporting purposes

(WBCSD-WRI, 2004). Thus, the study identifies emission sources according to accounting and reporting *Scopes*.

According to GHG Protocol standard principles, *completeness* is one principle that enforces a reporting organisation to enclose all GHG emission sources within a chosen inventory boundary. If for some reason the reporting organisation excludes a particular emission source within the inventory boundary, they need to clearly justify the reasons for doing so (Fransen et al., 2007).

6.2.4. Guideline 4: Identify business objectives

Once the emission sources are identified, it is important to find out the process level business objectives. Every business will have business objectives, such as cost reduction, time reduction, and quality improvement (Tiwari et al., 2006). Businesses strive to meet these objectives and they are the driving forces behind an organisation.

Business objectives are defined at various levels of a business. Depending on the level of management, i.e. top level, middle level, the objectives being focussed may be different. A strategy of a business is defined in mission, vision, aims or goals, and objectives. A mission tells the overall mission of the business. The vision talks about the overall aspiration of the business. Aims or goals are general statements which tell what the business intends to achieve (Riley, 2012). However, a business goal is not as descriptive as a business objective (Beatty, 2010). On the other hand business objectives are comparatively more precise and are detailed statements of goals and aims (Riley, 2012). As explained in the Chapter 5, generally in literature business objectives and business goals are used interchangeably. However, they are basically different (Beatty, 2010).

Business objectives are often constructed to conform to a criteria defined by the acronym SMART (Turner and Müller, 2003, Riley, 2012). This criterion is:

- **S**pecific: Objective stating what needs to be achieved.

- **M**easurable: An objective has to be quantifiable to determine the extent how far it is achieved.
- **A**chievable: An objective should be realistic considering the resources, knowledge and time available to achieve it.
- **R**elevant: In order to achieve an objective, it needs to be relevant to the people responsible in achieving them.
- **T**ime bound: An objective has to be set within a certain time frame with deadlines that are achievable (MacLeod, 2012).

In this guideline the business objectives are set so that they conform to the popular SMART business objective framework. This thesis introduces GHG emission management (e.g. mitigating GHG emissions by 10% by 2015) as another objective into the set of business process level objectives (e.g. cost and time reduction). Moreover, this guideline enforces all the business process level objectives to be stated in quantifiable terms.

6.2.5. Guideline 5: Business process modelling

As explained in the Chapter 5, only comparatively stable business processes are selected to optimise for this research project. The first phase is the generic business process modelling using the Business Process Modelling Notation (BPMN) technique. This high level business process modelling will identify business process elements (e.g. mostly at a sub-process level). This will capture the ordered sequence of activities and supporting information. The graphical representation of the business process is very effective in communicating with and is readily understood by business user. As BPMN is simple and easy perceived by the business user, at this step BPMN plays an important role in verifying the business process. This makes sure that the mental model within the business analyst's mind is in line with the physical model of the actual business process.

In the business process modelling, the gateway element is used to split and join patterns. This pattern represents common programming control structures like “if-then-else”, “all” and “switch”. A gateway would split/branch out and then join/merge paths in a process. The Exclusive OR (XOR) gateway, uses “if-then-else” and “switch” to exclusively select only one path. In a business process model where XOR branches are available, the frequency of that path getting selected would have an impact in determining the GHG emissions related to that particular process(Havey, 2009). To determine the frequency of a particular branch being selected, there should be data available over a period of time. However, for the descriptive case study of this thesis, no such historical data to identify XOR branches nor the frequency of the process flow through that branch was available. If such data was available, this study could have identified XOR paths and calculated the accurate GHG emissions using the emission frequency pattern.

6.2.6. Guideline 6: Data collection

The most challenging and time consuming part of compiling a GHG emission inventory is the data collection. Data collection design needs to be adequate enough to obtain the most accurate and reliable data possible (Pino et al., 2006). Further, it is also important to design the data collection that can be used for several years without significant changes to the design (WBCSD-WRI, 2004).

This guideline assists to collect data against the business process model developed according to the earlier guideline. Chapter 4 provided details about the case study and the data collection. The following guideline will use the data collected to model the GHG emissions. Further, it uses a set of formulas introduced in this study (*Constituent Artefact-III*), to calculate GHG emissions related to a business process and its related process levels. *Constituent Artefact-III* is presented later on in the Chapter.

6.2.7. Guideline 7: Green ABM modelling for GHG emissions

In this 7th guideline, *Green ABM* approach is used to do modelling, measuring, and calculation of GHG emissions. *Green ABM* is a bottom-up approach for environmentally sustainable business process management. This approach extends Activity Based Costing (ABC) and Critical Path Management (CPM) principles for the purpose of modelling, measuring, calculating, and reporting GHG emissions.

The approach provides the solution to the investigative question of *"1.2. How can GHG emission be modelled, measured, and calculated in above identified business process levels?" Green ABM* not only looks at GHG emissions but also considers cost and time as well. Thus, this provides a holistic picture of these inter-dependent dimensions to the organisational manager for decision making. Therefore, it also provides an answer to the investigative question of *"2.1. How can other business objectives such as cost and time be modelled against GHG emissions in a business process?"*

Green ABM approach is the second artefact produced by this thesis. As a detailed description of *Green ABM* is given under the *Constituent Artefact-II*, this section does not go into details of GHG modelling according to Green ABM. However, this section will discuss how it identifies a business process and its different abstraction levels i.e. activity, sub-process, process, and shared levels of a business process for business process level GHG emission modelling.

This process level GHG modelling aims to achieve fine grain control over capturing GHG emissions at the lowest possible level. At the same time the practicality of capturing GHG emissions at that level is considered with equal importance. GHG emission modelling levels of a business process needs to give management the full picture of what is happening, yet it should not be a burden for organisational workers to update the required data alongside performing their day to day activities. Hence, extending popular business process techniques like CPM and ABC into the GHG emission management arena reduces the learning curve of the proposed *Green ABM*.

ABC is a cost modelling approach focused on activities. Thus, it is important to study this activity based technique to get insights as to how it is done. In ABC, each activity has various resource consumption levels (Walther, 2010):

1. Unit level activities
2. Batch level activities
3. Product line activities
4. Facility / customer support activities

These levels allow cost modelling at activity level and this leads the way to process costing. Similarly GHG emissions happen at various process levels. After a close inspection into all the emission sources identified in Guideline 2, business process modelling techniques, and data collection, the researcher identified various business process levels to model GHG emissions through refinement and at the same time through abstraction. Namely:

1. Activity level;
2. Sub-process level;
3. Process level and
4. Shared level emissions.

Activity level emissions are from emissions that can be quantified at activity level. For an example in a warehouse, a shrink wrapping machine can perform a task of wrapping pallets full of A4 sheet bundles for 8 hours. Machines wattage gives a definite figure to find the electricity consumption. Electricity consumption will result in Scope 2 emissions.

Sub process level emissions are not practical in capturing at activity level, yet it is meaningful in capturing at sub-process level due to the level of abstraction. If we take the same warehouse example in the previous paragraph, a team of employees will be receiving goods at the warehouse. They may perform several activities within this goods receiving sub-process. However, all of them will commute to work from home daily. Therefore, Scope 3 emissions due to employee commuting can be quantified at the sub-process level.

Process level emissions are captured at business process level. In the above mentioned example, *Warehouse management* is considered as a process and it contains several sub-processes and activities. A warehouse disposes of its waste, which results in Scope 3 emissions. In this scenario, the organisation measures its waste at process level.

In an organisation, some emissions are shared emissions. These emissions are not directly related to a value adding activity. For an example, emissions due to heating and lighting may fall in to this category. If two or more business processes happen within the same building floor space, both these processes will share the ownership of these emissions.

Like ABC, CPM too is a well-known business process management technique. Currently, CPM is applied in isolation mostly to manage time. Today, there are many applications of CPM in projects of different sectors such as construction, manufacturing, and aerospace (Santiago and Magallon, 2009). CPM is extremely useful in planning, scheduling, and controlling of projects for on time delivery as well as keeping within budget. Very often, projects encounter events like scarcity of resources such as labour and material that adversely affect the execution of the original plan. CPM has proved its worth on small, medium and large projects by highlighting the organisation, activities, processes, procedures, inter-relationships, and inter-dependencies (Galloway, 2006, Santiago and Magallon, 2009).

CPM constructs a model of the project that includes: a list of activities needed to complete that particular project, the time (duration) each activity will take to complete, and the dependencies between the activities (Galloway, 2006). There are four kinds of dependencies between activities (Microsoft, 2014) . These are:

- *Finish-to-Start (FS):* Dependent task waits to begin until the preceding task is finished.

- *Start-to-Start (SS):* Dependent task waits to begin until the preceding task begins.
- *Finish-to-Finish (FF):* Dependent task waits to be completed any time after the preceding task is completed.
- *Start-to-finish (SF):* Dependent task can be completed any time after the preceding task begins.

This leads towards the development of a network / model of activities that enables the identification of the critical path. The critical path is the longest activity path in the project from start to finish. If an activity is not on the critical path it will have a *float / slack.* A float/slack is the amount of time an activity can be delayed without any adversity to the project as possible. If an activity on the critical path experiences a delay, that delay will result in a delay to the project completion date (Galloway, 2006). There are two ways to identify the critical path i.e. the forward-pass and the backward-pass. The forward pass calculates the earliest start time and the earliest finish time for each activity in the model. The backward pass calculates the latest start time and the latest finish time for each activity in the model (Wei et al., 2002).

CPM constructs a visual process model with a formal under-pinning. Formal parameters capture activity related data that can be used to form a mathematical model of the business process. CPM can also take activity costs into consideration. This allows it to build a time-cost relationship and to provide time-cost estimates (Stelth and LeRoy, 2009). In this study this relationship is used to bridge the gap between CPM and the ABC models.

A business process is a collection of activities (Hammer and Champy, 1993). Thus, a node in *Green ABM* can represent an activity, a sub-process or a process. Selecting which process level a particular node represents will depend on where the GHG emissions happen and where it is practical to measure it. The next section discusses in detail the GHG emissions, energy, and cost tabs. The second, detailed business process modelling phase begins with the drawing of the CPM for the process. Thereafter, it can model other dimensions that include GHG emissions, cost, and energy.

This guideline is the final one in this set of guidelines which identifies a business process and its different abstraction levels i.e. activity level, sub-process level, process level, and shared level. This clearly shows the levels of a business process, in which GHG emissions can be modelled.

6.3 Constituent Artefact-II:

A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time, and cost modelling and further analysis at different business process levels.

The second constituent artefact and the third constituent artefact, i.e. a set of formulas that allows GHG emissions to be calculated at different process levels, answer the following investigative question of *"How can GHG emissions be modelled, measured, and calculated in business process levels identified by the first artefact?"* This section details the second constituent artefact. The artefact shows how to model GHG emissions at different process levels identified by the seventh guideline in the set of guidelines which identifies a business process and its different abstraction levels.

Green ABM goes beyond visual and formal modelling of GHG emissions and models other process level objectives like time and cost as well. Thus, this artefact provides a solution to the investigative question *"2.1. How can other business objectives such as cost and time be modelled against GHG emissions in a business process?"* The previous section provided a brief explanation of *Green ABM* artefact. Next, the section details the Green ABM artefact.

The proposed *Green ABM* is a bottom-up approach for environmentally sustainable business process management. As stated under Guideline 7, *Green ABM* extends the ABC and CPM principles and considers GHG emissions, along with time and cost of production. The results show that by using *Green ABM*, organisational managers can easily model, measure, and calculate emissions at various process levels (i.e. activity, sub-process, process and shared). The holistic approach taken by the Green Information System reported here is distinct from previous studies as it contributes to the existing body of research.

First, it is essential to look at the theoretical background behind *Green ABM*. Environmental sustainability requires equally sustainable business practices. Today, Information Systems (IS) are becoming an integral part of doing business (Esty, 2006). Moreover, Green IS are designed and implemented to contribute to sustainable business processes (Boudreau et al., 2008). In the emerging Green IS literature, the bottom-up approaches look at the application of IS and the usefulness of IS to reduce the carbon footprint in a cost effective and socially acceptable way. These bottom-up approaches either create theory based-frameworks or come up with Information Technology (IT) based practical and localised activities which may influence an individual or a group behaviours (Hasan and Dwyer, 2010). In this regard, this research is a bottom-up Green IS as it creates a theory-based framework, which is *Green ABM* methodology. Thus, *Green ABM* enables environmentally sustainable business process management practices. Green ABM methodology extends ABC and CPM, two well-known business process management techniques. Currently, these are applied in isolation mostly to manage cost with ABC and to manage time with CPM. Therefore, the next sub-section looks at ABC followed by CPM.

6.3.1. Activity Based Costing (ABC)

Traditional costing systems assume that a cost object (e.g. a product or a service) will directly consume resources (Emblemsvåg and Bras, 2001) and they do not pay attention to the activities which consume these resources. As they are relatively simple to use, traditional costing systems are the most widely used cost accounting systems. Traditional costing systems use volume/unit-level allocation bases like direct labour (Kaplan and Cooper, 1992). A major problem with this type of costing is they rely on direct labour as the allocation base for overhead/indirect cost allocation. However, today overhead/indirect costs are much higher and production costs are not directly proportional to direct labour (Emblemsvåg and Bras, 2001). Thus, the product costs generated by the traditional systems are inaccurate and as they do not give the managers the correct information. This inaccuracy hindered decision making.

On the other hand, ABC solves the problems in traditional cost accounting systems. ABC gives accurate and reliable cost information in representing financial data and allows for a more realistic view in profitability analysis (SAP 2001). The ABC view is critical when it comes down to understanding what resources are consumed and how to reduce costs. Currently, it is popular in the manufacturing sector. ABC assumes, a cost object will consume activities and in turn activities will consume resources. In ABC, resource and activity drivers are used to trace costs from resources to activities and then from activities to cost objects in a causal, directly proportional manner (Emblemsvåg and Bras, 2001, Turney, 2008, Kaplan and Cooper, 1992, Sedgley and Jackiw, 2001).

Raffish et al. (1991, p. 2) defines an activity driver as a

> *"Measure of frequency and intensity of demands placed on activities by cost objects"*

This is used to assign costs to cost-objects. According to Raffish et al. (1991, p. 10), a resource driver is defined as,

> *"A measure of the quantity of resources consumed by an activity"*

It is a multi-stage costing system as cost tracing is done in three ways:

- Direct attribution: resources directly match activities and cost-objects. E.g. The fuel (i.e. cost-object) consumed by a car while driving (i.e. activity) to a particular destination.
- Allocation: costs are traced in an arbitrary manner. E.g. Production planning costs are allocated using the number of units of a product that was produced.
- Causal assignment using resource and activity drivers: A driver is an attribute of the cost-object which is a *measure* or amount of consumption.

ABC provides a systematic approach to cost accounting. First, ABC identifies activities within an organisation. Then, it assigns each activity's resource costs to products or services, according to their resource consumption (Turney, 2008).

If taken an example from the manufacturing sector, first manufacturing costs of the organisation is analysed and evaluated by converting them in to three major pools: *direct material, direct labour*, and *factory overhead*.

Each activity has got various resource consumption levels. Therefore, these activities are divided into categories according to their levels of resource consumption as: *Unit level activities, Batch level activities, Product line activities, and Facility / customer support activities* (Walther, 2010).

Successful ABC implementation involves several steps: 1. Study of processes and costs; 2. Identification of activities at different levels; 3. Identification of traceable costs; 4. Assignment of remaining costs to activities; 5. Determination of per activity allocation rates; 6. Application of costs to cost objects (Walther 2010); In this study ABC is analysed in depth to understand the cost modelling at activity levels leading to process costing.

By extending the ABC method to include GHGs, managers can easily trace GHGs to the resources and activities. Thereafter, ABC method is further extended to include CPM. In literature some similar approaches to the proposed architecture were found (Emblemsvåg and Bras, 2001, Recker et al., 2011). These approaches address GHG emission measurement of a business process aspect of this thesis's research objective.

6.3.2. Extension of the ABC method to include GHG emissions management

The following Figure 6.3 illustrates the Extended ABC method to include GHG emissions management. In ABC, the underlying concept is that activities (e.g. maintenance) consume resources (e.g. material, labour) and cost objects consume activities (Kaplan and Cooper, 1992). As shown in Figure 6.3, costs are traced in three ways: direct attribution, allocation, causal assignment using resource and activity drivers. In causal assignment, ABC uses drivers.

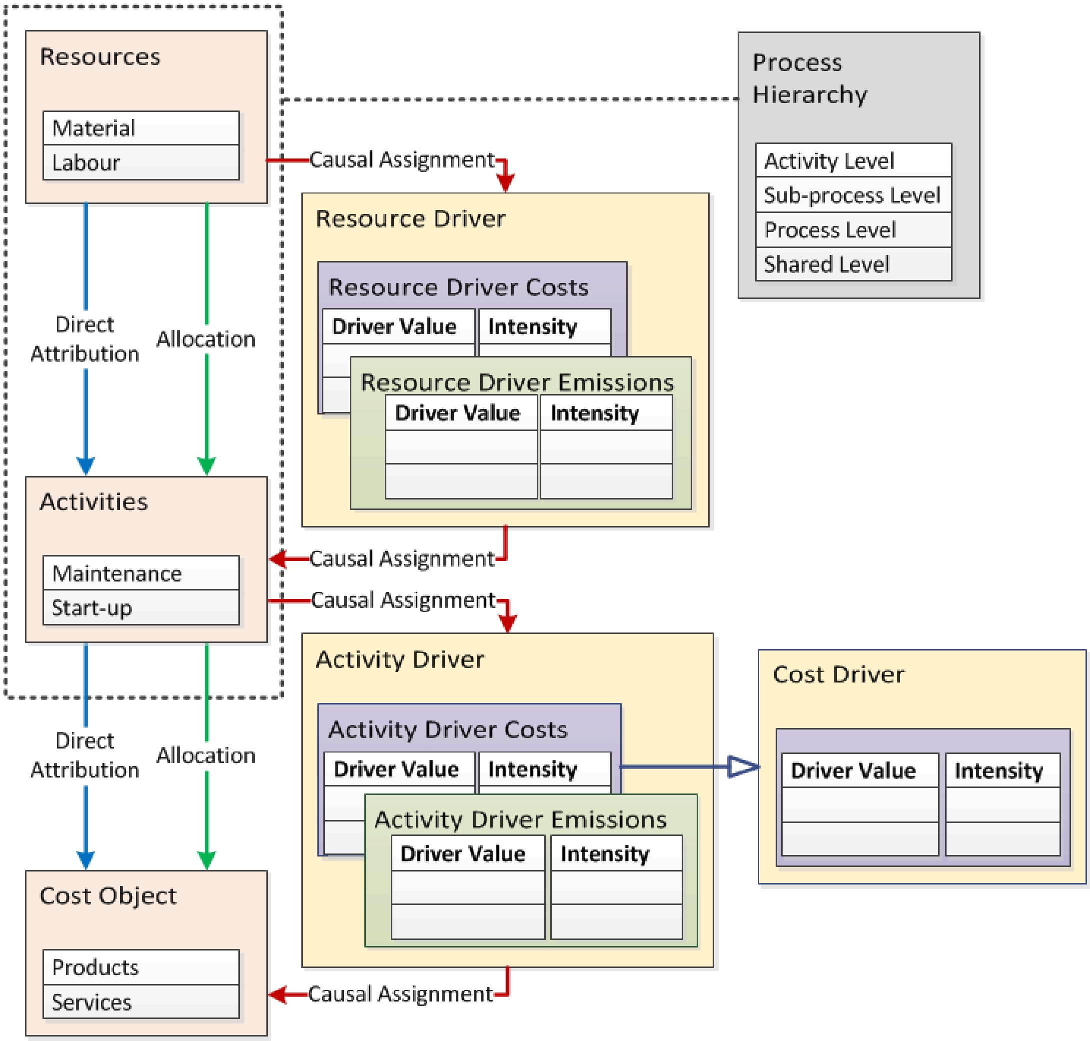

Figure 6.2: Extended ABC method to include GHG emission management.

The driver cost is calculated by multiplying *Driver Value* by *Driver Intensity*. The driver value is the amount of the resource or the activity in units (e.g. 5 direct labour hours) and the driver intensity is the corresponding consumption rate (e.g. direct labour charges are $20/hour). This research sub-divides the drivers into two categories as *costs* and *emissions*. Therefore, the resource driver will have two components. The *Resource Driver Costs* corresponding to the cost accounting aspect and the *Resource Driver Emissions* corresponding to the emissions accounting aspect of management. Similar to *Resource Driver Costs*, *Resource Driver Emissions* will contain a driver value (e.g. 5 liters of fuel) and driver intensity (e.g. energy consumption rate is 50 MJ/liter). By multiplying the driver value by the corresponding driver intensity, it will give the resource driver emissions (e.g. energy consumption 250MJ).

As can be depicted by Figure 6.3, the *Cost Driver* has a broader measure than activity or resource drivers as it will indicate the root cause of a change in the activity's cost (e.g. a factory worker spends 20 mins painting a particular toy and spends 30 mins painting a different type of a toy). A cost driver (e.g. product design complexity) is not easily measurable like a resource cost drive. However, these provide insights (Emblemsvåg and Bras, 2001) to the manager if they identify these cost drivers correctly.

This method links the activities and resources to the business process model. As explained in the Guideline 7, similar to ABC's various resource consumption levels, emissions can be measured at various process levels as *Activity level, Sub-process level, Process level* and *Shared level.* This extended ABC model for GHG emissions management will help to measure, calculate, model, and report emissions from an organisational process point of view. At the same time, as this model is activity based it has the potential to capture time related data as well. For any activity, duration is an important characteristic. Many manufacturing processes have activities of which the cost depends on timing. In some activities the timing of activities will have an impact on both cost and emissions. CPM is widely used in project management for scheduling and estimating costs. Therefore, this research further extends the extended ABC model by incorporating CPM.

6.3.3. *Extension of CPM to include the extended ABC*

In CPM, all the nodes are networked according the dependencies between the nodes with respect to time. As explained earlier in Guideline 7, time, cost, and emissions are correlated. In CPM, a node represents an activity with its time duration. The duration of an activity is just one of its characteristics. There are other characteristics like cost and related emissions of an activity. On this premise, the boundaries of a CPM node can be broadened to include the cost and GHG emissions of an activity. A business process is a collection of activities (Hammer and Champy, 1993), a node can represent an activity, a sub-process or a process. As explained in the previous section, this will depend on where the GHG emissions happen and where it is practical to measure it. A node as shown in Figure 6.3 contains four tabs: *Time*, *Energy*, *Cost*, and *GHG emissions*.

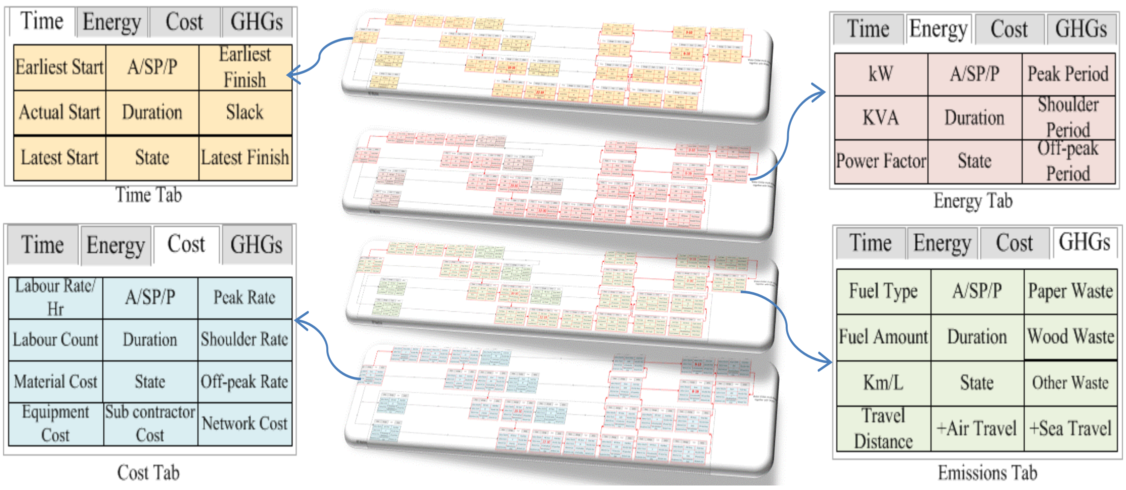

Figure 6.3: Green ABM to model time, energy, cost and GHG profiles of a business process and Time, Energy, Cost and Emissions tabs of a node

Related parameters are grouped into these four different tabs:

- Time Tab: This orange tab contains all the parameters required for applying CPM. Parameters include: Earliest start, Earliest finish, Latest start, Latest finish, Duration, Slack.

- Energy Tab: This purple tab contains parameters required to calculate the energy consumption of a particular action. Energy related parameters include: kW (Wattage of a machine used to perform a certain action / Useful power), KVA (total apparent power), Power Factor (the ratio between the useful (true) power (kW) to the total (apparent) power (KVA) consumed by a machine to perform a certain action.), and Different time periods (Peak, Shoulder, Off-peak).
- Cost Tab: This blue tab consists of parameters required to do costing. These are: Labour rate and Labour hours to calculate Labour costs, Equipment and sub-contractor costs to perform this action, Material costs incurred during this action, and Electricity rates (Peak rates, Shoulder rates, Off-peak rates, Network rates).
- Emission tab: This green tab comprises of GHG emission related parameters. Some of the parameters are: Fuel type, Fuel amount, Consumption rate (Km/L), Travel distance, Amount of paper waste, Amount of Wood waste, and Amount of other waste.

6.3.4. Green ABM Methodology

All the tabs share a set of common parameters: A/SP/P (Activity/ Sub Process/ Process), Duration (time to perform the action), and State (describe different states a particular machine would go through during production.) This is briefly explained in the Chapter 8. Even though, energy consumption results in GHGs, this research separately captures energy related parameters. This is mainly because energy management alone is a very important area that directly contributes to GHGs. Managers spend a great deal of time and effort in improving energy efficiency, reducing energy bills, correcting the power factor, and load management. Thus, energy is considered in a separate tab. The *Evaluation and Discussion* Chapter provides a detailed visual process model with the parameters captured to build the formal model.

In this extended model, if time tabs of all nodes are selected, they would show the CPM network of the process. As time, energy, cost, and GHG tabs are interconnected, similar to the CPM model, if selected, the energy tabs of all the nodes in this process will show the underlying energy model or the energy profile of the process. Similarly, all the cost tabs would model the associated cost parameters and the GHGs tabs would model the associated emission parameters. As can be depicted from Figure 6.3, for a particular process, the same type of tabs collectively model different dimensions i.e. time, energy, cost, GHGs of this activity based model.

This *Green ABM* will help organisational managers to look at several dimensions like time, cost, GHGs as well as energy. Though separated, it is easy to consolidate cost and GHG accounts at different process levels (e.g. activity, sub-process, process, shared) in a meaningful manner as emission sources are linked with the activities in the business process. This is very valuable in reporting and decision making.

Green ABM together with the third artefact was built to answer the investigative question of *"1.2. How can GHG emission be modelled and calculated in business process levels identified in the first guideline?"* The next section presents the third artefact, the set of formulas that allows GHG emissions to be calculated at different process levels. Green ABM not only looks at GHG emissions but also considers cost and time as well. Thus, this provides a holistic picture of these inter-dependent dimensions to the organisational manager for decision making. Green ABM has several functions and modelling GHG emissions according to different process levels is one aspect of this artefact. Therefore, this *Green ABM* answers the investigative question 2.1, *"How can other business objectives such as cost and time are modelled against GHG emissions in a business process?"* As stated earlier, the *Evaluation and Discussion* Chapter provides the visual and formal business process model with parameters captured with real values. The next section presents a set of formulas that allows GHG emissions calculation at a business process level.

6.4 Constituent Artefact-III:

A set of formulas that allows GHG emissions to be calculated at different process levels

This section details the third artefact. The artefact shows how to calculate GHG emissions at different process levels identified by the seventh guideline in the set of guidelines which identifies a business process abstraction levels i.e. activity level, sub-process level, process level, and shared level.

In order to consolidate GHG emissions at different process levels a set of formulas are needed. This set includes formulas to: calculate emissions at an activity level; consolidate GHGs at activity level; consolidate emissions at sub-process and process levels; and to allocate GHGs at shared level.

6.4.1. GHG emissions at task and activity levels

This research uses the *Emission factors–based* approach to measure GHG emissions (Daviet, 2006). Details of this emission measurement and estimation technique are in Chapter 2 of this thesis. As explained in Chapter 3, a business process is composed of a series of tasks and activities known as process elements (Wang et al., 2009). A task is a particularly ordered set of activities (Kueng et al., 1996). According to WBCSD and WRI (2004), two kinds of data will give the associated GHG emission figure. They are the *activity data* and *emission factor* which in turn help in calculating GHG emissions using the formula (6.1) given below. Activity data quantifies an activity in units. An emission factor is an activity specific figure. An emission factor converts activity data to emission values (Pino et al., 2006).

$$\text{GHG emissions from an activity} = \text{activity data} * \text{emission factor} \ldots\ldots\ldots\ldots(6.1)$$

6.4.2. *Consolidated GHG emissions at activity level*

The above formula (Formula 6.1) calculates the GHG emissions from a particular activity. For a business process there can be several such activities where it is practical to measure and calculate GHG emissions. Thus, total emissions from GHG emissions from all the activities that can be captured at activity level can be calculated using the formula (6.2). As can be noted from the formula given below, electricity consumption related values are summated separately to others.

$$\sum_{i=1}^{n} T_i + \sum_{j=1}^{m} T_j = A_{tot} \dots\dots(6.2)$$

A_{tot} = Total emissions captured at Activity level

T_i = Electricity consuming task level emissions

T_j = Non electricity consuming task level emissions;

n = 1,2,3,..,

m = 1,2,3,..,

I = 1,2,3....,

j = 1,2,3...

6.4.3. *Consolidated GHG emissions at sub-process level*

Sub process level emissions are consolidated from emissions that can be quantified at this level. Similarly, total emissions due to electricity consumption and non-electricity sources are calculated here. The sum of both emissions will give the total emissions that can be quantified at sub process level.

$$SP_{tot} = SP_{elec} + SP_{non} \dots\dots\dots\dots(6.3)$$

SP_{tot} = Total emissions due to emissions captured at sub process level;

SP_{elec} = Electricity consuming emissions due to emissions captured at sub process level;

SP_{non} = Non-electricity consuming emissions due to emissions captured at sub-process level.

6.4.4. Consolidated GHG emissions at process level

Similar to the sub process level, at a process level some emissions can be quantified for emissions from both electricity consumption and non-electricity consumption.

$$P_{tot} = P_{elec} + P_{non} \dots\dots\dots\dots (6.4)$$

P_{tot} = Total emissions due to emissions captured at process level;

P_{elec} = Electricity consuming emissions due to emissions captured at process level;

P_{non} = Non-electricity consuming emissions due to emissions captured at process level.

6.4.5. Consolidated shared level emissions

According to a formula shown by Pino, Levinson et al. (2006), approximate kWh consumed by an organisation sharing the same building with other organisations can be estimated. Similarly a derived formula from the above approximation formula is used to calculate emissions from a business process (which does not share the organisational floor space). Thus, the deduced formula would be:

$$\text{Approximate kWh used} = \text{Total building use of electricity} * \frac{\text{Area of process's space}}{\text{Total building area}} \dots\dots (6.5)$$

6.4.6. *Sum of Emissions at Process Level*

Total business process level emissions can be summed up using the following formula.

$$E_{proc} = A_{tot} + SP_{tot} + P_{tot} + SL_{proc} \dots\dots\dots\dots 6.6$$

E_{proc} = Total emissions captured at business process level

A_{tot} = Total emissions captured at activity level

SP_{tot} = Total emissions captured at sub process level

P_{tot} = Total emissions captured at process level

SL_{proc} = Total emissions captured at shared level

To answer the relevant investigative questions several artefacts use this set of formulas to calculate GHG emission at different process levels and the shared level. The second artefact, *Green ABM* uses these formulas to calculate emissions at different process levels. The fourth artefact which is the reporting tool, that allows reporting of GHG emissions according to the *scopes* defined by the GHG Protocol, also uses the formulas to calculate and consolidate the GHG emissions according to the reporting categories. The following section details this fourth artefact.

6.5 Constituent Artefact-IV:

A reporting tool that allows reporting of GHG emissions according to the Scopes defined by the GHG Protocol

This section explains the fourth artefact built as the solution to the investigative question of *"1.3. How can GHG emissions associated with a business process be reported in three emission categories identified by the Greenhouse Gas (GHG) Protocol, namely Scope 1, Scope 2 and Scope 3?"* Currently, GHG Protocol is the most widely accepted guide for accounting and reporting of GHG emissions from organisations. Details of this standard are given in Chapter 2 of this thesis.

This reporting tool helps to collate calculated GHG emissions figures according to Scopes. Guideline 3 of *Constituent Artefact-I* identifies the emission sources. The *"GHG emissions frequency patterns"* explained by Guideline 6 helps to determine the time period of the inventory i.e. annual. Guideline 7 tells what they are and the value. This reporting tool rolls-up the GHG emission figures, to the corporate level. The tool creates and consolidates a GHG emissions inventory, based on Scopes 1, 2, and 3. Thus, the management gets a bird's eye view of what is happening within the organisation. Even though, Scope 3 emission reporting is optional, this study considered and included it as well to give a holistic picture of all of the emissions.

As explained in *Green ABM* artefact, there are three ways for the emissions to be calculated i.e. direct attribution, allocation, causal assignment. Thus, this reporting tool calculates emissions using these three ways as well. With this tool, *Activity level, Sub-process level*, and *Process level* emission calculations use direct attribution and causal assignment. In order to calculate *Shared level emissions* the tool uses allocation at *Shared level*. In the context of this thesis, the tool calculates the *Activity level, Sub-process level*, *Process level,* and *Shared level* GHG emissions.

6.5.1. Activity Level GHG emission calculation

The reporting tool follows a bottom-up approach in calculating and collating GHG emissions. Thus, the reporting begins at the *Activity level* of the considered business process. By using the following formula (6.1) of *Constituent Artefact-III*, the tool can calculate the GHG emissions. With respect to Green ABM, the activity data represents the *driver value* and the emission factor represents the *consumption intensity*.

$$\text{GHG emissions from an activity} = \text{activity data} * \text{emission factor} \ldots\ldots\ldots\ldots(6.1)$$

In Green ABM artefact, the sub-section titled, *“Extension of the ABC method to include GHG emissions management”* talks about the assigned and attributed emissions. That section shows how to calculate the total assigned and attributed GHG emission figures at the activity level. It uses formula (6.2) of *Constituent Artefact-III*, to sum up the GHG emission figures of activity level emissions.

$$\sum_{i=1}^{n} T_i + \sum_{j=1}^{m} T_j = A_{tot} \ldots\ldots(6.2)$$

A_{tot} = Total emissions captured at activity level

T_i = Electricity consuming task level emissions

T_j = Non electricity consuming task level emissions;

n = 1,2,3,.., m = 1,2,3,.., I = 1,2,3...., j = 1,2,3...

Emissions calculation begins with Scope 1 emissions. Table 6.2 shows the parameters used to calculate GHG emissions from each activity. At this stage, the tool calculates emissions due to electricity consuming and emissions due to non-electricity consuming activities, according to the formula (6.2). It further adds up attributed and assigned for electricity consuming and non-electricity consuming activities. Scope 2 and Scope 3 emissions also follow a similar method to calculate Scope 2 and Scope 3 total assigned and attributed emissions. Table 6.3 and Table 6.4 show this for Scope 2 and 3.

Table 6.2: Scope 1 - Activity Level GHG emission calculation

Activity Level - Activity	**Directly Attributed Emissions Scope 1**						**Causally Assigned Emissions Scope 1**						**Total Emissions**
	Electricity Consuming			**Non-electricity Consuming**			**Electricity Consuming**			**Non-electricity Consuming**			
Name	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E =A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	
A1	S1EA1	EF11	S1EA1 * EF11										
A2				S1NEA 2	EF21	S1NEA2 * EF21							
A3							S1EA3	EF3	S1EA3 * EF31				
A4										S1NEA 4	EF41	S1NEA4 * EF41	
Total			Attribute d S1ETA			Attribute d S1NETA			Assigned S1ETA			Assigned S1NETA	Total Activity Level Attributed and Assigned Emissions

A = Activity Data, EF = Emission Factor, E = Emissions, A1..4, Activity Level Activity, S1EA1..4 = Scope 1 Activity Data, EF11..41 = Emission Factor, Attributed S1ETA = Scope 1 Total Directly Attributed Activity Level Emissions (Electricity Consuming), Attributed S1NETA = Scope 1 Total Directly Attributed Activity Level Emissions (Non-Electricity Consuming), Assigned S1ETA = Scope 1 Total Causally Assigned Activity Level Emissions (Electricity Consuming), Assigned S1NETA = Scope 1 Total Directly Assigned Activity Level Emissions (Non-Electricity Consuming)

Table 6.3: Scope 2 - Activity Level GHG emission calculation

Activity Level-Activity	**Directly Attributed Emissions Scope 2**						**Causally Assigned Emissions Scope 2**						**Total Emissions**
	Electricity Consuming			**Non-electricity Consuming**			**Electricity Consuming**			**Non-electricity Consuming**			
Name	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	
A1	S2EA1	EF11	S2EA1 * EF11										
A2				S2NEA 2	EF21	S2NEA2 * EF21							
A3							S2EA3	EF3	S2EA3 * EF31				
A4										S2EA4	EF41	S2EA4 * EF41	
Total			Attributed S2ETA			Attributed S2NETA			Assigned S2ETA			Assigned S2NETA	Total Activity Level Attributed and Assigned Emissions

A = Activity Data, EF = Emission Factor, E = Emissions, A1..4, Activity Level Activity, S2EA1..4 = Scope 2 Activity Data, EF11..41 = Emission Factor, Attributed S2ETA = Scope 2 Total Directly Attributed Activity Level Emissions (Electricity Consuming), Attributed S2NETA = Scope 2 Total Directly Attributed Activity Level Emissions (Non-Electricity Consuming), Assigned S2ETA = Scope 2 Total Causally Assigned Activity Level Emissions (Electricity Consuming), Assigned S2NETA = Scope 2 Total Directly Attributed Activity Level Emissions (Non-Electricity Consuming)

Table 6.4: Scope 3 - Activity Level GHG emission calculation

Activity Level-Activity	Directly Attributed Emissions Scope 3						Causally Assigned Emissions Scope 3						Total Emissions
	Electricity Consuming			Non-electricity Consuming			Electricity Consuming			Non-electricity Consuming			
Name	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E=A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E=A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	
A1	S3EA1	EF11	S3EA1 * EF11										
A2				S3NEA2	EF21	S3NEA2 * EF21							
A3							S3EA3	EF3	S3EA3 * EF31				
A4										S3EA4	EF41	S3EA4 * EF41	
Total			Attributed S3ETA			Attributed S3NETA			Assigned S3ETA			Assigned S3NETA	Total Activity Level Attributed and Assigned Emissions

A = Activity Data, EF = Emission Factor, E = Emissions, A1..4, Activity Level Activity, S3EA1..4 = Scope 3 Activity Data, EF11..41 = Emission Factor, Attributed S3ETA = Scope 3 Total Directly Attributed Activity Level Emissions (Electricity Consuming), Attributed S3NETA = Scope 3 Total Directly Attributed Activity Level Emissions (Non-Electricity Consuming), Assigned S3ETA = Scope 3 Total Causally Assigned Activity Level Emissions (Electricity Consuming), Assigned S3NETA = Scope 3 Total Directly Attributed Activity Level Emissions (Non-Electricity Consuming)

6.5.2. Sub-process Level GHG emission calculation

The reporting tool uses a similar approach to that of activity level GHG emission calculation to calculate the same for sub-process levels. Therefore, it uses the same formula (6.1) to calculate emissions at a sup-process level.

$$\text{GHG emissions from an activity} = \text{activity data} * \text{emission factor} \ldots\ldots\ldots (6.1)$$

Similarly, the *driver value* represents the activity data and the *consumption intensity* represents the emission factor. The tool calculates missions from electricity consuming and Non-electricity consuming sub-process level activities separately using the following formula (6.3). Further, it calculates the total assigned and attributed GHG emission figures at the sub-process level.

$$SP_{tot} = SP_{elec} + SP_{non} \ldots\ldots\ldots\ldots. (6.3)$$

SP_{tot} = Total emissions due to emissions captured at sub process level;

SP_{elec} = Electricity consuming emissions due to emissions captured at sub process level;

SP_{non} = Non-electricity consuming emissions due to emissions captured at sub-process level.

Table 6.5 shows the Scope 1 sub-process level emissions and the Tables 6.6 and 6.7 shows Scope 2 and Scope 3 emissions respectively.

Table 6.5: Scope 1 – Sub-process Level GHG emission calculation

Activity	Directly Attributed Emissions Scope 1						Causally Assigned Emissions Scope 1						Total Emissions
	Electricity Consuming			Non-electricity Consuming			Electricity Consuming			Non-electricity Consuming			
Name	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	**Activity Data (A)**	**Emission Factor (EF)**	**Emissions (E=A*EF)**	
SP1	S1E SP1	EF11	S1ESP1 * EF11										
SP2				S1NESP 2	EF21	S1NESP2 * EF21							
SP3							S1ESP3	EF3	S1ESP3 * EF31				
SP4										S1ESP4	EF41	S1NESP4 * EF41	
Total			Attributed S1ETSP			Attributed S1NETSP			Assigned S1ETSP			Assigned S1NETSP	Total Sub-process Level Attributed and Assigned Emissions

SP = Sub-process Level Activity Data, EF = Emission Factor, E = Emissions, SP1..4, Sub-process Level Activity, S1ESP1..4 = Scope 1 Activity Data, EF11..41 = Emission Factor, Attributed S1ETSP = Scope 1 Total Directly Attributed Sub-process Level Emissions (Electricity Consuming), Attributed S1NETSP = Scope 1 Total Directly Attributed Sub-process Level Emissions (Non-Electricity Consuming), Assigned S1ETSP = Scope 1 Total Causally Assigned Sub-process Level Emissions (Electricity Consuming), Assigned S1NETSP = Scope 1 Total Directly Assigned Sub-process Level Emissions (Non-Electricity Consuming)

Table 6.6: Scope 2 - Sub-process Level GHG emission calculation

Sub-process Level-Activity	Directly Attributed Emissions Scope 2						Causally Assigned Emissions Scope 2						Total Emissions
	Electricity Consuming			Non-electricity Consuming			Electricity Consuming			Non-electricity Consuming			
Name	Activity Data (A)	Emission Factor (EF)	Emissions (E= A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E=A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	
SP1	S2ESP 1	EF11	S2ESP1 * EF11										
SP2				S2NES P2	EF21	S2NESP2 * EF21							
SP3							S2ESP 3	EF3	S2ESP3 * EF31				
SP4										S2ESP 4	EF41	S2NESP 4 * EF41	
Total			Attributed S2ETSP			Attributed S2NETSP			Assigned S2ETSP			Assigned S2NETS P	Total Sub-process Level Attributed and Assigned Emissions

A = Sub-process Level Activity Data, EF = Emission Factor, E = Emissions, A1..4, Sub-process Level Activity, S2ESP1..4 = Scope 2 Activity Data, EF11..41 = Emission Factor, Attributed S2ETSP = Scope 2 Total Directly Attributed Sub-process Level Emissions (Electricity Consuming), Attributed S2NETSP = Scope 2 Total Directly Attributed Sub-process Level Emissions (Non-Electricity Consuming), Assigned S2ETSP = Scope 2 Total Causally Assigned Sub-process Level Emissions (Electricity Consuming), Assigned S2NETSP = Scope 2 Total Directly Attributed Sub-process Level Emissions (Non-Electricity Consuming)

Table 6.7: Scope 3 – Sub-process Level GHG emission calculation

Sub-process Level-Activity	Directly Attributed Emissions Scope 3						Causally Assigned Emissions Scope 3						Total Emissions
	Electricity Consuming			Non-electricity Consuming			Electricity Consuming			Non-electricity Consuming			
Name	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E=A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E=A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	
SP1	S3ESP1	EF11	S3ESP1 * EF11										
SP2				S3NESP 2	EF21	S3NESP2 * EF21							
SP3							S3ESP 3	EF3	S3ESP3 * EF31				
SP4										S3ESP 4	EF41	S3NESP4 * EF41	
Total			Attributed S3ETSP			Attributed S3NETSP			Assigned S3ETSP			Assigned S3NETSP	Total Sub-process Level Attributed and Assigned Emissions

A = Sub-process Level Activity Data, EF = Emission Factor, E = Emissions, A1..4, Sub-process Level Activity, S3ESP1..4 = Scope 3 Activity Data, EF11..41 = Emission Factor, Attributed S3ETSP = Scope 3 Total Directly Attributed Sub-process Level Emissions (Electricity Consuming), Attributed S3NETSP = Scope 3 Total Directly Attributed Sub-process Level Emissions (Non-Electricity Consuming), Assigned S3ETSP = Scope 3 Total Causally Assigned Sub-process Level Emissions (Electricity Consuming), Assigned S3NETSP = Scope 3 Total Directly Attributed Sub-process Level Emissions (Non-Electricity Consuming)

6.5.3. *Process Level GHG emission calculation*

The reporting tool uses a similar approach to that of activity level and sub-process level GHG emission calculations to calculate the same for process levels. Hence, it uses the same formula (6.1) to calculate emissions at a process level.

$$\text{GHG emissions from an activity} = \text{activity data} * \text{emission factor} \ldots\ldots\ldots\ldots(6.1)$$

The *driver value* represents the activity data and the *consumption intensity* represents the emission factor. The tool calculates missions from electricity consuming and Non-electricity consuming process level activities separately using the following formula (6.4). Further, it calculates the total assigned and attributed GHG emission figures at the process level.

$$P_{tot} = P_{elec} + P_{non} \ldots\ldots\ldots\ldots(6.4)$$

P_{tot} = Total emissions due to emissions captured at process level;

P_{elec} = Electricity consuming emissions due to emissions captured at process level;

P_{non} = Non-electricity consuming emissions due to emissions captured at process level.

The Table 6.8 shows the Scope 1 process level emissions and the Tables 6.9 and 6.10 shows Scope 2 and Scope 3process level emissions respectively.

Table 6.8: Scope 1 – Process Level GHG emission calculation

Process Level-Activity	Directly Attributed Emissions Scope 1						Causally Assigned Emissions Scope 1						Total Emissions
	Electricity Consuming			Non-electricity Consuming			Electricity Consuming			Non-electricity Consuming			
Name	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	
P1	S1EP1	EF11	S1EP1 * EF11										
P2				S1NEP 2	EF21	S1NEP2 * EF21							
P3							S1EP3	EF3	S1EP3 * EF31				
P4										S1EP4	EF41	S1NEP4 * EF41	
Total			Attributed S1ETP			Attribute d S1NETP			Assigned S1ETP			Assigned S1NETP	Total Process Level Attributed and Assigned Emissions

P = Process Level Activity Data, EF = Emission Factor, E = Emissions, P1..4, Process Level Activity, S1ESP1..4 = Scope 1 Activity Data, EF11..41 = Emission Factor, Attributed S1ETP = Scope 1 Total Directly Attributed Process Level Emissions (Electricity Consuming), Attributed S1NETP = Scope 1 Total Directly Attributed Process Level Emissions (Non-Electricity Consuming), Assigned S1ETP = Scope 1 Total Causally Assigned Process Level Emissions (Electricity Consuming), Assigned S1NETP = Scope 1 Total Directly Assigned Process Level Emissions (Non-Electricity Consuming)

Table 6.9: Scope 2 - Process Level GHG emission calculation

Process Level-Activity	Directly Attributed Emissions Scope 2						Causally Assigned Emissions Scope 2						Total Emissions
	Electricity Consuming			Non-electricity Consuming			Electricity Consuming			Non-electricity Consuming			
Name	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	
P1	S2EP1	EF11	S2EP1 * EF11										
P2				S2NEP2	EF21	S2NEP2 * EF21							
P3							S2EP3	EF3	S2EP3 * EF31				
P4										S2EP4	EF41	S2NEP4 * EF41	
Total			Attributed S2ETP			Attributed S2NETP			Assigned S2ETP			Assigned S2NETP	Total Process Level Attributed and Assigned Emissions

A = Process Level Activity Data, EF = Emission Factor, E = Emissions, A1..4, Process Level Activity, S2EP1..4 = Scope 2 Activity Data, EF11..41 = Emission Factor, Attributed S2ETP = Scope 2 Total Directly Attributed Process Level Emissions (Electricity Consuming), Attributed S2NETP = Scope 2 Total Directly Attributed Process Level Emissions (Non-Electricity Consuming), Assigned S2ETP = Scope 2 Total Causally Assigned Process Level Emissions (Electricity Consuming), Assigned S2NETP = Scope 2 Total Directly Attributed Process Level Emissions (Non-Electricity Consuming)

Table 6.10: Scope 3 –Process Level GHG emission calculation

Process Level-Activity	Directly Attributed Emissions Scope 3						Causally Assigned Emissions Scope 3						Total Emissions
	Electricity Consuming			Non-electricity Consuming			Electricity Consuming			Non-electricity Consuming			
Name	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E =A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E=A*EF)	Activity Data (A)	Emission Factor (EF)	Emissions (E=A*EF)	
P1	S3EP1	EF11	S3EP1 * EF11										
P2				S3NEP 2	EF21	S3NEP2 * EF21							
P3							S3EP3	EF3	S3EP3 * EF31				
P4										S3EP4	EF41	S3NEP4 * EF41	
Total			Attribute d S3ETP			Attribute d S3NETP			Assigned S3ETP			Assigned S3NETP	Total Process Level Attributed and Assigned Emissions

A = Process Level Activity Data, EF = Emission Factor, E = Emissions, A1..4, Process Level Activity, S3EP1..4 = Scope 3 Activity Data, EF11..41 = Emission Factor, Attributed S3ETP = Scope 3 Total Directly Attributed Process Level Emissions (Electricity Consuming), Attributed S3NETP = Scope 3 Total Directly Attributed Process Level Emissions (Non-Electricity Consuming), Assigned S3ETP = Scope 3 Total Causally Assigned Process Level Emissions (Electricity Consuming), Assigned S3NETP = Scope 3 Total Directly Attributed Process Level Emissions (Non-Electricity Consuming)

6.5.4. Shared Level Emissions

Emissions belonging to this level are due to activities that do not directly add value to a business process or the organisation e.g. lighting, heating activities. The tool uses formula (6.5) from the set of formulas presented in *Constituent Artefact-III*. This derived formula calculates emissions from a business process (which shares the organisational floor space). The formula given below considers an electricity consuming activity. If it is a non-electricity consuming activity which results in GHG emissions then total use of that utility will replace the electricity use and will give an approximate shared level emission value per process. It is also important to consider the emission frequency pattern. The derived formula for an electricity consuming activity is:

$$\text{Approximate process level kWh used} = \text{Total building use of electricity} * \frac{\text{Area of process's space}}{\text{Total building area}} \ldots\ldots\ldots\ldots \quad (6.5)$$

This approximate process level kWh used is divided by the number of production runs per month. Thus, the tool calculates the shared level GHG emissions per production run. However, it is important to note that in here the emission per production run is calculated as attributed and assigned emissions.

Table 6.11 shows how the GHG emission figures are calculated for shared level activities with allocation. This is performed for the Scope 1 emissions. Table 6.12 shows the emissions for Scope 2 shared level emissions. This is followed by Table 6.13, which shows the emissions figures for Scope 3 emissions.

Table 6.11: Scope 1 –Shared Level GHG emission calculation

Shared Level Activity	**Allocated Emissions - Scope 1**					
Site / Activity Name	**Floor space used for the process (F)**	**Total floor space of the site (TF)**	**Monthly Utility Bill (E.x. Fuel) (MB)**	**Monthly Allocated Emissions (MA =(F/TF * B)*EF)**	**Monthly - No. of production runs (PR)**	**Emissions per process production run (AE = MA/PR)**
Site1 / SLE1	Site1 PF1	Site1 PTF1	MB1	**S1**MA1 =(Site1 PF1 / Site1 PTF1 * MB1)*EF	PR1	**S1**AE1 = **S1**MA1 * PR1
Site1 / SLNE1						
Total Allocated Emissions						Allocated S1 TEPR + Allocated S1 TNEPR

Site1 = A single geographical location. E.x. A building, SLE = Shared level electricity consuming activity, SLNE = Shared level non-electricity consuming activity, Site1 PF1 = Process floor space of site 1, Site1 PTF1 = Total floor space of the site E.x. A building floor, MB = Monthly bill, S1MA1 = Scope 1 monthly allocated emissions for shared level activities, EF = Emission Factor, PR= Monthly - No. of production runs (PR), S1AE1 = Scope 1 monthly allocated emissions for shared level activities per production run (Electricity consuming), Allocated S1 TEPR = Total Scope 1 allocated emissions for shared level activities per production run (Electricity Consuming), Allocated S1 TEPR = Total Scope 1 allocated emissions for shared level activities per production run (Non-electricity Consuming)

Table 6.12: Scope 2 –Shared Level GHG emission calculation

Shared Level Activity	Allocated Emissions - Scope 2					
Site / Activity Name	**Floor space used for the process (F)**	**Total floor space of the site (TF)**	**Monthly Utility Bill (E.x. Electricity) (MB)**	**Monthly Allocated Emissions (MA =(F/TF * B)*EF)**	**Monthly - No. of production runs (PR)**	**Emissions per process production run (AE = MA/PR)**
Site1 / SLE1	Site1 PF1	Site1 PTF1	MB1	**S2**MA1 =(Site1 PF1 / Site1 PTF1 * MB1)*EF	PR1	**S2**AE1 = **S2**MA1 * PR1
Site1 / SLNE1						
Total Allocated Emissions						Allocated S2 TEPR + Allocated S2 TNEPR

Site1 = A single geographical location. E.x. A building, SLE = Shared level electricity consuming activity, SLNE = Shared level non-electricity consuming activity, Site1 PF1 = Process floor space of site 1, Site1 PTF1 = Total floor space of the site E.x. A building floor, MB = Monthly bill, MA = Monthly allocated emissions, **S2**MAE1 = Scope 2 monthly allocated emissions for shared level activities, PR= Monthly - No. of production runs (PR), **S2**AE1 = Scope 2 monthly allocated emissions for shared level activities per production run (Electricity consuming), Allocated S2 TEPR = Total Scope 2 allocated emissions for shared level activities per production run (Electricity Consuming), Allocated S2 TEPR = Total Scope 2 allocated emissions for shared level activities per production run (Non-electricity Consuming).

Table 6.13: Scope 3 –Shared Level GHG emission calculation

Shared Level Activity	**Allocated Emissions – Scope3**					
Site / Activity Name	**Floor space used for the process (F)**	**Total floor space of the site (TF)**	**Monthly Utility Bill (E.x. Fuel) (MB)**	**Monthly Allocated Emissions (MA =(F/TF * B)*EF)**	**Monthly - No. of production runs (PR)**	**Emissions per process production run (AE = MA/PR)**
Site1 / SLE1	Site1 PF1	Site1 PTF1	MB1	**S3**MA1 =(Site1 PF1 / Site1 PTF1 * MB1)*EF	PR1	**S3**AE1 = **S3**MA1 * PR1
Site1 / SLNE1						
Total Allocated Emissions						Allocated S3 TEPR + Allocated S3 TNEPR

Site1 = A single geographical location. E.x. A building, SLE = Shared level electricity consuming activity, SLNE = Shared level non-electricity consuming activity, Site1 PF1 = Process floor space of site 1, Site1 PTF1 = Total floor space of the site E.x. A building floor, MB = Monthly bill, MA = Monthly allocated emissions, **S3**MAE1 = Scope 3 monthly allocated emissions for shared level activities, PR= Monthly - No. of production runs (PR), **S3**AE1 = Scope 3 monthly allocated emissions for shared level activities per production run (Electricity consuming), Allocated S3 TEPR = Total Scope 3 allocated emissions for shared level activities per production run (Electricity Consuming), Allocated S3 TEPR = Total Scope 3 allocated emissions for shared level activities per production run (Non-electricity Consuming)

6.5.5. *Sum of Emissions at Process Level*

The tool will calculate the sum of emissions for all four business process level emissions. Thus, it will have emission figures for *Activity level, Sub-process level*, *Process level,* and *Shared levels.* Moreover, it will have separate figures for electricity consuming and non-electricity consuming activities of a particular activity level. The tool uses the following formula to calculate the sum of all the process level emissions.

$$E_{proc} = A_{tot} + SP_{tot} + P_{tot} + SL_{proc} \ldots\ldots\ldots\ldots 6.6$$

E_{proc} = Total business process related emissions

SL_{proc} = Total shared level emissions

P_{tot} = Total sub process level emissions

SP_{tot} = Total process level emissions

A_{tot} = Total activity level emissions

As shown in Figure 6.4, in order to calculate the total business process level emissions, the reporting tool uses the above formula. First, it calculates the totals separately for scopes, electricity consuming activities, and non-electricity consuming activities. This *"Activity Based GHG emissions",* leads towards the summary of total business process level emissions. Figure 6.4 clearly shows the three scopes (scope1, Scope 2, and Scope 3) colour coded accordingly in three rows. Each row is again sub-divided as electricity consuming activities and non-electricity consuming activities. Further, it shows the emissions traced in three ways: direct attribution, allocation, and causal assignment.

This section clearly explained the tool developed and how it explained about reporting GHG emissions according to the Scopes defined by the GHG Protocol. It went into finer details of how reporting should be performed to get a birds-eye view of organisational business process level emissions.

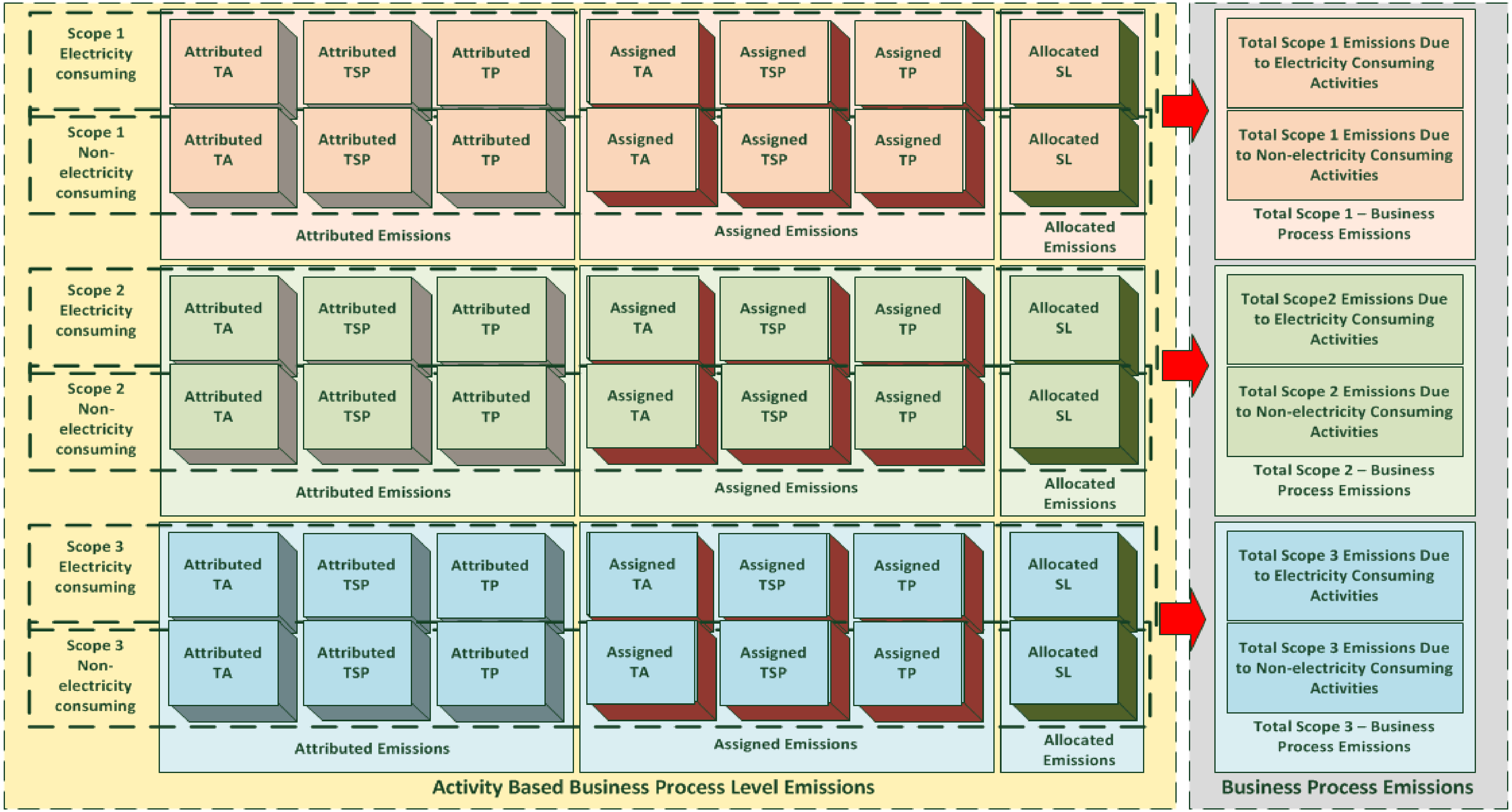

Figure 6.4: Summary of the total business process level emissions

6.6 Chapter Conclusion

This chapter explained the constructed artefacts that answered the investigative questions 1.1, 1.2, 1.3, and 2.1. The four artefacts help in GHG emissions management. These form an important part of the framework for multi-dimensional business process optimisation that facilitate in modelling, measuring, calculating, and reporting GHG emissions. The Chapter achieves its main aim by providing a detailed discussion of each of these artefacts that described the design search (development), that led to creation of the artefact (Gregor and Hevner, 2013).

The study modified and extended the set of steps for identifying and calculating GHG emissions as stipulated by the Greenhouse Gas Protocol (WBCSD-WRI, 2004) into a set of guidelines. This comprised the first artefact. The second artefact, *Green Activity Based Management (ABM)* which is a tool and a methodology, first models the GHG emissions and then goes beyond to form visual and formal modelling of GHG emissions and other process level objectives like time and cost. The third artefact shows how to calculate GHG emissions at different process levels identified by the seventh guideline. The fourth artefact, the reporting tool helps to collate calculated GHG emissions figures at different business process levels according to Scopes. Thus, this chapter showed four of the new and innovative constituent artefacts of the framework. The Chapter 7 discusses *Constituent Artefact-V* and *Constituent Artefact-VI*.

CHAPTER 7 : Constituent Artefacts- for Business Process Optimisation

Details and related investigative questions

7.1. Chapter Introduction

Chapter 6 provided detailed descriptions of four of the six constituent artefacts which were associated with GHG emission management. It showed how these answered the related investigative questions. This chapter provides the detailed descriptions of the remaining two constituent artefacts which are related to multi-dimensional business process optimisation. As shown in Table 7.1, the *Constituent Artefact*-*V* and *Constituent Artefact*-*VI* are "*The selection criteria for an optimisation technique that can optimise a multi*-*objective mathematical formula that captures possible process level changes of GHG emissions with other objectives* and "*Two*-*way mapping between the derived formula and the Elitist Non-Dominated Sorting Genetic Algorithm (NSGA II/ NSGA2), which is the selected optimisation technique."* respectively. The chapter shows how these answer the related investigative questions.

Following Table 7.1 presents the main research question, second sub-research question, and two investigative questions related to the optimisation stage (This table was presented in Chapter 6. In Chapter 7, the grey colour is used to symbolise the areas related to *Constituent Artefact*-*I, II, III,* and *IV*.).

Table 7.1: A summary of the main artefact and its constituent artefacts

Main Research Question	How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?		
Main Artefact	Green Multi-Objective Process Optimisation (Green MOPO) framework		
Sub Research Questions	**Investigative Questions**	**Output/ Constituent Artefact**	**Frame-work stage**
1. How can GHG emissions at a business process level be modelled, measured, calculated, and reported efficiently?	**1.1** What are the levels of a business process, in which GHG emissions can be modelled?	**I**. A set of guidelines to assist identification of a business process and its different abstraction levels i.e. activity level, sub-process level, process level and shared level.	1
	1.2 How can GHG emission be modelled, measured, and calculated in above identified business process levels?	**II**. A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time, and cost modelling and further analysis at different business process levels.	2
		III. A set of formulas that allows GHG emissions to be calculated at different business process levels.	
	1.3 How can GHG emissions associated with a business process be reported in three emissions categories identified by the Greenhouse Gas (GHG) Protocol, namely Scope 1, Scope 2, and Scope 3?	**IV**. A reporting tool that allows reporting of GHG emissions according to the scopes defined by the GHG Protocol.	3
2. How can a set of multi-dimensional parameters including GHG emissions associated with a business process be optimised effectively?	**2.1** How can other business objectives such as cost and time be modelled against GHG emissions in a business process?	**II.** A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time, and cost modelling and further analysis at different business process levels.	2
	2.2 What are the selection criteria of an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions?	**V.** The selection criteria for an optimisation technique that can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions with other objectives.	2,4
	2.3 How can a selected optimisation technique (based on the selection criteria set above) be applied for business process optimisation for GHG emission management alongside other business objectives?	**VI**. Two-way mapping between the derived formula and the Elitist Non-Dominated Sorting Genetic Algorithm (NSGA II/ NSGA2), which is the selected optimisation technique.	4

This chapter is organised as follows. First, this section provided a summary of the *Constituent Artefact-V* and *Constituent Artefact-VI* and the relevant investigative questions. Next, the chapter details the two artefacts. Lastly, the chapter will conclude with a summary of the discussed artefacts.

7.2. Constituent Artefact-V:

The selection criteria for an optimisation technique that can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions with other objectives.

As stated earlier in the Chapter Introduction, *Constituent Artefact-V* is a construction block of the framework. The artefact provides the answer to the following investigative question. *"2.2. What are the selection criteria for an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions?"* The utility of the artefact is not to provide a function in the framework. Instead it is to act as the selection criteria for an optimisation technique which can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions along with other objectives. Therefore, it is important to look at the context this derived formula will ultimately be used in.

7.2.1. A taxonomy to derive a mathematical formula to capture possible process level changes

In the investigative question 2.2, the research focus is on *Optimisation* aspect of the framework. As stated in Chapter 2, this study defines business process optimisation as:

> *"A continuous simulated business process improvement to meet a set of pre-defined business objectives to achieve greater efficiency and effectiveness of the business process and its' interactions, within the organisation"*

The researcher sub-divides the business process optimisation stage of the framework into two steps 3(a): Process redesign/improve and 3(b): Evaluation. In the *Process redesign/improve* stage, many different actions are possible to optimise a business process (Reijers and Mansar, 2005, Vergidis et al., 2008) to manage GHG emissions. As an example, these actions may include some unnecessary tasks elimination, combination of small tasks to form a larger task or decomposition of large tasks in to workable smaller tasks, execution of several tasks in parallel if possible, empowering the employees to make decisions to reduce middle management, task automating (Reijers and Mansar 2005), identification and removal of process performance bottlenecks (Vergidis et al. 2008). In relation to GHG emissions, organisations can switch to green energy sources instead of burning fossil fuel to generate power. In addition to these steps formal/mathematical optimisation techniques can be used. However, applying a formal/ mathematical technique is not simple.

Today, optimisation actions are introduced without a proper evaluation of the impact they may have. More importantly, the impact of these actions on other process level objectives is not considered. Currently, there is no proper methodology to perform optimisation simultaneously for several dimensions including GHGs. Thus, to introduce such an optimisation, possible process level changes need to be captured.

Changes happen in business process elements. It is important to observe which characteristics of the process elements are likely to change when optimising for GHG emissions together with other process level objectives. According to Vergidis (2008), basic structural elements of a business process are *actors*, *activities*, and *resources*. Actors are sometimes looked upon as external elements. Activities are the central elements and vital in executing business process steps that would transform inputs in to desirable outputs. Resources are business process inputs. In this study, the result of the process is also considered. In the manufacturing study context, the result is generally a product. Thus, the study considers activities, resources, actors, and products as basic business process elements.

According to Ginige (2008), there are several attributes which characterise a business process element. These attributes are further categorised as *Identification attributes, Categorisation attributes*, *Descriptive attributes,* and *Associative attributes.* In addition, three types of changes can take place in these process elements. These are *Addition, Modification*, and *Deletion*. Following describes each of the attribute categories.

- Identification attributes: Unique identification name or ID which helps to distinguish them from other elements of similar type.
- Categorisation attributes: This type of attributes categorise elements into several groups. Ex. Manual, partially automated, fully automated or, value-adding activities (important to the customers), work flow activities (these move work flow across functional, departmental, or organisational boundaries, control activities (these control the value-adding and work flow activities) (Vergidis, 2008). These categories are extendable to include other categories as required by the business process (Ginige, 2008).
- Descriptive attributes: Based on some other features of a particular element, these elements further describe process elements. Ex. Odour, Luster, Texture
- Associative attributes: This type of attributes signify the kind of relationship a particular process element will have with another. Ex. Put-away activity performed by the fork lift operator.

Based on the Ginige (2008) characterising of process elements, the following table provides a taxonomy of business process element changes that will help to derive a mathematical formula which captures these changes. In this table, the case study, *Poly-Ethylene Terephthalate (PET) package manufacturing process*, discussed in Chapter 4 is used.

Table 7.2: Process elements and their characterisation attributes

Process Element / Type of Attribute	Activity	Actors	Resource	Product
Identification attributes	• Name	• Role played by the actor	• Name of the resource	• Resulting output of the process
Categorisation attributes	• Automation – Manual Partially automated Fully automated • Machine State – Pre-Activity Start-Up Pre-Production Fixed Pre-ProductionVariable Production Shutdown Variable Shutdown Fixed • Slack time- Critical activity Non-critical activity	• Human , Machine • Internal, External	• Labour - Direct and indirect labour • Direct energy consumptions • Other services - Maintenance Process planning Industrial engineering activities Accounting and finance Administration Marketing • Fuel type • Consumption period- Peak Off-peak Shoulder	• Dimensional • Weight • Measurements of IV (Intrinsic Viscosity) and AA (Acetaldehyde levels) values • Visual • Waste type
Descriptive attributes	• Activity duration	• Skill level of a labour	• Labour rate / Hour • Material cost • Equipment cost • Sub-contractor cost • Network cost • Peak electricity cost • Off-peak electricity • Shoulder electricity cost	• No. of products • Waste amount • Odour • Luster • Texture

Process Element / Type of Attribute	Activity	Actors	Resource	Product
			• kW (Wattage) • KVA • Power factor • Fuel amount • Fuel consumption rate (km/L) • Travel distance • Peak electricity period • Shoulder electricity period • Off-peak electricity period • Material amount	
Associative attributes	• Earliest start • Earliest finish • Latest start • Latest finish	• Only a skilled labour can perform a certain production activity	• Activities will consume resources • Activities will consume resources at a rate • Resources will have a cost associated with it	• State of the material (e.g. preform) before performing an activity • State of the material (e.g. preform) after an activity is performed • Physical Changes that happen as a result of an activity. (e.g. melting)

7.2.2. Derivation of a multi-objective mathematical formula

This section shows how to derive a formal/ mathematical model of the process. This formal model will capture the possible business process element changes (Table 7.2) as well as the business objectives. A general multi objective optimisation problem can be stated as follows (Deb, 2001):

Minimize/ Maximize $f_m(x)$, $m = 1,2,3,\ldots M$; ….(7.1)

Subject to the g inequality constraints and the h equality constraints:

$g_j(x) \geq 0$, j = 1,2,3, …..J; …….. (7.2)

$h_k(x) = 0$, k = 1,2,3, …..K;

$x_i^{(L)} \leq x_i \leq x_i^{(U)}$, i = 1,2,3, …..n.

A solution vector $x \in R^n$ is composed of n decision variables: $x = (x_1, x_2, \ldots x_n)^T$. The solution, which satisfies the constraints and the variable bounds constitute a feasible variable bound space $S \subset R^n$. The variable bounds are denoted by $x_i^{(L)} \leq x_i \leq x_i^{(U)}$ and restricts each decision variable x_i to take a value within this given region. As shown in Figure 7.1, these decision variable bounds create the *decision variable space*. Objective functions create an M-dimensional space (Z) and this is named the *objective space* $Z \subset R^m$. Every solution (x) in the decision variable space is assigned a corresponding point (z) in the objective space ($z \subset R^m$). This point $f(x)$, is denoted by $f(x)= (x_1, x_2, \ldots x_m)^T$.

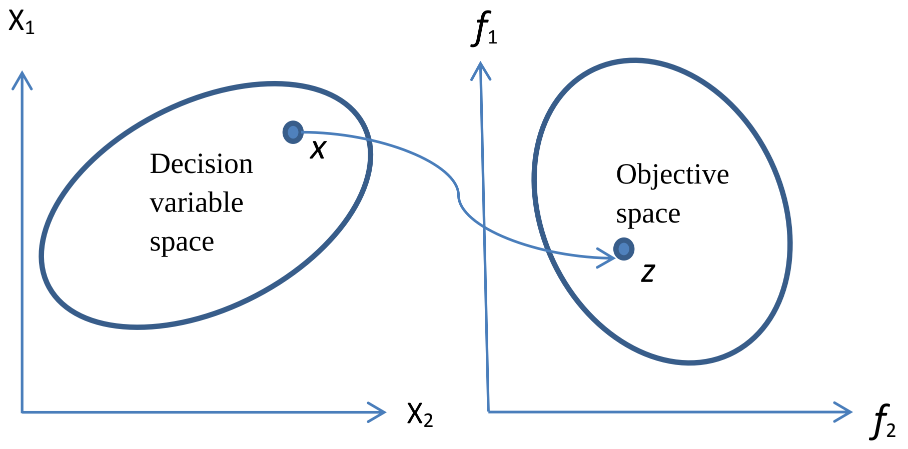

Figure 7.1: Mapping between the decision variable space and the related objective space

In *"Table 7.2: Process elements and their characterisation attributes"*, contains all the attributes of a particular process element that can be considered. The formal multi-objective model was constructed with reference to this. Formal model for GHG emissions, time, electricity consumption, and cost is formulated as a four-objective optimisation problem.

Objective 1: Minimise for time (f_1)

The first objective aims to optimise the critical path duration. The study employs the CPM to identify the critical activities. There may be activities where the activity duration can be a variable value. If these activities are in the critical path, these might affect the critical path duration. Each variable activity will have a lower and upper boundary for duration. However, the objective is to minimise the critical path duration.

$$f_1 = min\ (CD)$$

CD = Critical path duration

f_1 = Objective function for time

Objective 2: Minimise for electricity consumption (f_2)

The second objective aims at modelling the electricity consumption of a particular activity. Electricity consumption can be calculated by multiplying the wattage of a machine with the duration it was in operation. As the business process was modelled using the CPM, for PET manufacturing activities go through seven stages as identified in Chapter 4. In the CPM network for this manufacturing process there are identifiable rows for each machine along with activity stages as seven columns. Thus, this function calculates the total electricity consumption row and column wise for all the process activities.

$$f_2 = min(\sum_{i=1}^{m} \sum_{i=1}^{n} (kW * D_{mn}))$$

kW = Consumption

D = Activity Duration

f_2 = Objective function for electricity consumption

Objective 3: Minimise for cost of production (f_3)

The third objective is in regards to the costs associated with a particular activity. There are separate costs associated with electricity consumption, labour, material, and electricity supply network. This relationship forms the third objective function.

$$f_3 = min((f_2 * R) + (f_1 * l * W) + (M_c + M_m + M_{rc}) + (kVA * N_{nw})))$$

R = Electricity Rates (This will depend on the time of the day)

l = Number of labourers

W = Wages Rate

M_{rc} = Cost of raw materials

M_c= Machine cost

M_m =Machine maintenance cost

kVA = Kilovolts ampere value

N_{nw}= Network costs

f_3 = Objective function for electricity consumption

Objective 4: Minimise for GHG emissions (f_4)

The fourth objective function describes the GHG emissions from an activity. Emissions are calculated by multiplying activity data with the emission factor. In this formula the emission factor is divided by 1000 to have the units balance.

$$f_4 = \min(f_2 * Ef/1000)$$

Ef = Emission factor

f_4 = Objective function for GHG emissions

In addition to having the four objective functions, the multi-objective formula contains constraints as well. The constraints relates to activity durations of particular activities.

- Minimisation for GHG emissions is subject to these activity durations. Exact activities with duration changes are discussed in Chapter 8, where the evaluation takes place.
- There are constraints with respect to slack time of particular activities. These too are shown in Chapter 8 of the thesis.
- There are constraints with respect to the start time and end time of the process as well. Machine scheduling is not performed for the weekend due to resource unavailability (e.g. labour). Hence, this is another constraint on the whole process initiation.

In summary, the formal model for GHG emissions, time, electricity consumption and cost is formulated as a four-objective optimisation problem as follows:

$$f_1 = min\ (CD)$$

$$f_2 = min(\sum_{i=1}^{m} \sum_{i=1}^{n} (kW * D_{mn}))$$

$$f_3 = min((f_2 * R) + (f_1 * l * W) + (M_c + M_m + M_{rc}) + (kVA * N_{nw})))$$

$$f_4 = min(f_2 * Ef/1000)$$

f_1, f_2 ,f_3, f_4= Objective functions for time, electricity consumption, cost, and GHG emissions

The next, section details how the selection criteria are set for choosing a suitable optimisation technique.

7.2.3. Setting the criteria to select a suitable optimisation technique

As explained in Chapter 2, the first step in process optimisation is business process modelling (Vergidis et al., 2008). Therefore, it is important to model GHG emissions with other business objectives like cost reduction and time reduction at business process level. According to Vergidis et al. (2008) process modelling is predominantly done in three ways.

- Visual modelling: diagrams which contain a visual sketch of the process.
- Business process language modelling: software-based languages that support business process modelling.
- Formal or mathematical modelling: all the elements having a mathematical or a formal underpinning.

A mathematical model ensures formal correctness, consistency, and rigor. A formal business process model consists of a series of mathematical constraints and a set of objective functions (Koubarakis and Plexousakis, 2002). The constraints define the feasibility of this particular business process and objective functions represent various business objectives

(Pedrinaci and Domingue, 2007). A formal model can be optimised to provide a set of optimised solutions. This kind of optimisation is termed as Multi-objective optimisation (Deb, 2001).

In literature, multi-objective optimisation is used to optimise for time and cost (Vergidis et al., 2006). This technique can capture the possible changes and results can show the impact of the process improvement actions. Hence, a business process will contain several variables and optimised as a vector of objectives and decision variables (Chong and Zak, 2008). This technique will result in a set of optimised solutions. Thus, this study selects a multi-objective optimisation technique in order to optimise GHG emissions together with other process level objectives. Single objective optimisation will not consider conflicting objectives as in multiple objectives and thus are more straightforward. This thesis does not look in to single objective optimisation techniques.

It is difficult to optimise for all the objectives at the same time. There are a number of such optimisation techniques available today. As various optimisation techniques are best suited for particular optimisation contexts, it is important to look at characteristics of the optimisation techniques against the application context.

In situations like multi-dimensional business process optimisation, there are a number of important criteria to consider. Hence, it is evident that whichever the selected optimisation technique, it has to satisfy certain criteria. In this study, the researcher considers a set of criterion as the best suited in this context. The criteria consist of an optimisation technique that's suitable for: optimising for multiple objectives instead of a single objective; the ability to handle constraints; one that considers a vector of objectives instead of a single objective; capability to provide a set of trade-offs among objectives; and the ability to optimise nonlinear objective functions and constraints. The sub-section "*Criteria to Select a Suitable Optimisation Technique"*, will detail the above mentioned criteria while justifying the reasons for selecting these as criteria. However, in order to illuminate the techniques, first, the following sections will explain some important general concepts.

In multi-objective optimisation, *Dominance* (Deb, 2001) and *Pareto optimality* (Chong and Zak, 2008) are two important concepts. These concepts are important to describe multi-objective optimisation. Thus, the section briefly explains the concepts before further discussing multi-objective optimisation techniques.

7.2.3.1. Dominance

To determine *Dominance*, two solutions are compared against one another based on whether one dominates the other solution or not. This important concept helps to decide which solution is better than the other in terms of a given set of objectives. Multi-objective optimisation algorithms use this concept to search for non-dominated solutions. Only a non-dominated solution can become *Pareto optimal* (Deb, 2001).

7.2.3.2. Pareto optimality

According to Chong, E. and Zak, S., (2008) in 1881 Francis Y. Edgewood proposed a formal definition of a certain optimal point for a multi-objective optimisation problem. They further claim that later on in 1896, Vilfredo Pareto generalised this concept. As a norm, an optimal point of a multi-objective optimisation problem is known as a Pareto minimiser. Chong (2013), p. 429 state,

> *"the point x* is a Pareto minimiser, or a nondominated solution, if there exists no other feasible decision variable x that would decrease some objectives without causing simultaneous increase in at least one other variable".*

Hence, a Pareto front is a set of Pareto minimisers or optimisers.

The next sub-section describes various techniques available to perform multi-objective optimisation. First, the sub-section describes some of the popular multi-objective optimisation techniques according to a classification by Deb (2001). Then, it narrows down according to their applicability in optimising for several process level objectives that includes GHG emissions.

7.2.3.3. Multi-objective optimisation technique classification

Over the last two decades, there has been a considerable increase in multi-objective optimisation techniques. As a result, there are a number of techniques available today to perform multi-objective optimisation. Thus, it is important to classify all these techniques. According to a classification by Deb(2001), predominantly there are two classes of multi-objective optimisation techniques named *Classical* and *Ideal*.

1) Classical techniques:

Some of the classical techniques in handling multi-objective optimisation problems include: Weighted sum method; ε-Constraint method; Weighted metric method; Benson's method; Value function method; Goal programming method; and Interactive methods. These classical search and optimisation approaches perform, single solution update in every iteration (Deb, 2001). In addition, every classical multi-objective optimisation algorithm is designed to solve specific types of problems. This limited the applicability and was a major drawback for general application. In order to overcome these, *Ideal* multi-objective optimisation methods were developed.

2) Ideal techniques:

In the *Ideal* multi-objective optimisation sphere, Evolutionary Algorithms (EAs) are rapidly gaining popularity. This is mainly due to EAs versatility in applicability. EAs use the principles of evolution to guide the optimisation process (Vergidis et al., 2008). EAs include:

- Genetic Algorithms (GA);
- Evolution Strategies (ES);
- Evolutionary Programming (EP);
- Genetic Programming (GP).

When compared to other evolutionary algorithms, GAs are extensively used. They are by far the most popular and this is mainly due to its applicability in many domains. Practical multi-objective optimisation problems are more complex than others. Some decision variables can only take certain values or in other words discrete values. This puts an additional constraint on the already complex multi-objective problem. Thus, solving multi-objective optimisation problems with discrete decision variables is more complicated than solving one with continuous decision variables. In this regard GA is better at converging towards an optimal front (Deb, 2001).

A GA imitates the natural genetics and natural selection found in nature to find an optimal solution. The algorithm processes a large number of solutions in parallel. Each solution is regarded as an individual in a population. A genome of each solution is represented by a matching coded string. Natural evolution techniques include: *inheritance, mutation, selection* or *reproduction,* and *crossover.*

- A *mutation* operator changes values in some positions of the coded string and these positions are chosen randomly. Then, these mutated individuals or new offsprings are selected as parents in the next population generation or in other words get placed into the mating pool (Deb, 2001). This operator helps to search a broader space (Mathworks, 2014). Further, the mutation operator helps to maintain the diversity of the population.
- A *crossover* operator exchanges coded string values between two randomly chosen individuals and two new offsprings are generated. In order to preserve

some good offsprings who were generated during the *Selection*, only a set of solutions is used to perform crossover. Therefore, prior to execution of the algorithm it is important to set a cross over probability. This is mainly responsible for the search aspect of the algorithm when compared to the mutation operator.

- A *selection* operator randomly selects superior solutions to form the next generation. This random selection probability is dependent on the objective function values. Thereafter, it makes several copies of the same solution and at the same time eliminates the inferior solutions to make way for superior solutions as well as to keep the population size constant. However, this operator is incapable of creating any new solutions in the population.

These GA operators are over the time expected to create better offsprings form a population. This may not be possible all the time. However, the selection operator will eliminate the inferior offsprings in subsequent generations.

Next, a predefined termination criterion evaluates the population. A fitness value is assigned to the solution in terms of how close it has come to solving the problem. If the problem remains unsolved, the evolution process continues (Chande and Sinha, 2008, Hofacker and Vetschera, 2001, Deb, 2001).

In literature there is a plethora of GA techniques. This research selects one out of these for the optimisation stage of the framework. This is achieved by setting the criteria that would help the researcher to search for the best suited technique for the optimisation problem. The next section describes these criteria and then applies them against a selected set of GAs.

7.2.3.4. Criteria to Select a Suitable Optimisation Technique

First, the sub-section lists the selection criteria used to select an optimisation technique and then briefly describes each criterion. The criteria to select a multi-objective optimisation technique are:

- Multi-objectivity
- Sustain solution diversity
- Constraint handling
- Trade-offs among objectives
- Non-linearity
- Elitism
- Efficiency
- Implementation

Multi-objectivity:

In the context of the study, there is a need to optimise for several objectives at the same time. A single objective optimisation problem consist of a single objective function (Chong and Zak, 2008), whereas in multi objective optimisation, as the name suggests, there can be more than one objective function. These objective functions may include reduction of production costs, reduction of time to market, and reduction of GHG emission management. In the past many multi objective optimisation problems were solved by converting them in to a single objective optimisation problem based on some user defined variables. However, Deb (2001), argues that multi objective optimisation cannot be regarded as a simplified extension of the single objective optimisation. He further states that single objective optimisation is a degenerated scenario of the multi objective optimisation problem. In this scenario, a selected algorithm must handle multiple objective functions. Thus, multi-objectivity is one important criterion when selecting an optimisation technique.

Sustain solution diversity:

In multi-objective optimisation it is essential to maintain a diverse set of solutions in the non-dominated front. If a diverse population is maintained, then it will prevent premature convergence and will allow a well distributed trade-off front. There are techniques e.g. elitism, available that make sure a diverse population is maintained (Deb, 2001, Zitzler et al., 2000). Since all objective functions are equally important, a diverse set will provide variety and different trade-offs between objectives. Thus, the ability of an algorithm to produce a diverse set of solutions is an important criterion.

Constraint handling:

In real world scenarios, constraints may arise in the form of a business rule or a boundary limit for a certain parameter involved. Unconstrained optimisation does not have any such rules governing it. As a result their applicability in a real world scenario decreases. A constraint can divide the search space in to two areas as the feasible region and the infeasible region. (Fonseca and Fleming, 1998).

Trade-offs among objectives:

It is impossible to optimise for all the objectives at the same time. Therefore in situations like these various trade-offs or compromises between objectives are inevitable. Thus, another important criterion is that the optimisation technique should be able to provide a set of trade-of solutions (Lucas, 2006).

Non-linearity:

Linear optimisation is a specific case of mathematical optimisation, where it determines the best solution of a given mathematical function for some objectives represented as linear relationships. Linear multi-objective optimisation problem consists of linear objective functions as well as linear constraint functions. Thus, they are called Multi-Objective Linear Program (MOLP) (Deb, 2001). If any objective function or a constraint function is nonlinear the resulting multi objective optimisation problem becomes a nonlinear multi-objective optimisation problem. Real world optimisation problems rarely adhere to MOLP theoretical properties. Thus, the ability to handle non-linear optimisation problems is an important aspect.

Elitism:

In evolutionary algorithms, the *Elite Preserving Operator* is very important. In order to preserve and use previously found best solutions in subsequent generations, an elite preserving operator is used. Elites of a population are straightway carried over to the next generation. Some argue that elitism helps a GA to converge towards a global optimum solution. Also the probability of creating better offsprings is enhanced (Tiwari et al., 2006). If the selected algorithm has an elite preserving operator, it will make sure the fitness of the population-best solution does not deteriorate (Deb, 2001).

Efficiency:

Multi-objective optimisation algorithms handle a number of parameters simultaneously. The efficiency of these algorithms is the processing time required to perform calculations (Back, 1996). Furthermore, the true computational efficiency of an algorithm is revealed when it is applied to challenging test problems rather than simple ones

(Deb, 2001). Therefore, computational efficiency has to be considered especially in complex real world applications.

Implementation:

Each multi-objective optimisation algorithm requires a different implementation. Even though the objective functions and constraints may look the same, each algorithm is coded differently. Hence it is important to consider how easy it is to implement an algorithm in a real world scenario.

Currently, genetic algorithms are applied to solve real world problems such as: robot trajectory generation, acoustics, aerospace engineering, medical, scheduling, musical composition, and finance (Chande and Sinha, 2008).Some of the very popular genetic algorithms include: Vector Evaluated GA (VEGA); Multiple Objective GA (MOGA); Non Dominated Sorting GA (NSGA); Niched-Pareto GA (NPGA); Strength Pareto EA (SPEA); Strength Pareto (SPEA2); and Elitist Non-Dominated Sorting GA (NSGA II/ NSGA2). Table 7.3, briefly describes the above mentioned popular genetic algorithms.

Table 7.3: Evolutionary optimisation techniques

MOEA	Discussion
Vector Evaluated GA (VEGA)	VEGA randomly divides the entire parent population in to equal sub populations. Then, each sub population is assigned a fitness value based on different objective functions. A selection operator works on subpopulations and then shuffles together to obtain a new population (Fonseca and Fleming, 1993). This is efficient and easy to use. However it is noted that eventually VEGA converges towards individual champion solutions (Deb, 2001).
Multiple Objective GA (MOGA)	This algorithms begins by checking each solution for its domination in the considering population. Then a rank is assigned. Next, based on this assigned rank a fitness value is assigned to each solution. Thereafter the fitness of each solution is averaged in a rank wise basis. The niche count is used as a measure of crowding near a particular solution. Niching is performed among solutions of each rank to maintain diversity in the non-dominated set. Then selection, cross over, and mutation operators are applied to create a population (Fonseca and Fleming, 1993). This algorithm too is easy to implement and is efficient to execute.
Non Dominated Sorting GA (NSGA)	According to Deb (2001), there are two goals that should be met in MOO. First goal is to find a set of solutions which are the closest to the Pareto optimal front. The second goal requires this set of solutions to be diverse to enable attainment of a good set of trade-off solutions. In NSGA these two goals are met with the use of a fitness assignment. This fitness assignment has a preference towards non dominated solutions and another sharing strategy which preserves the solution diversity of each non dominated front. The NSGA begins with sorting the population in to non-dominated sets or fronts according to non-domination. Two members of the same front cannot be superior with respect to all objectives. Once this classification of solutions in to fronts is finished, all the solutions in the first front will become the best non-dominated

MOEA	Discussion
	front/set in the population. The second front will become the next best set of solutions in the population and so on. The highest fitness is assigned to the best front and consequently other fronts are assigned a fitness value as well. Diversity of solutions in a front is maintained by the sharing function. This function ensures diversity by getting more copies of solutions in less crowded regions of a front in to the mating pool. Thereafter, crossover and mutation are applied to the entire population (Srinivas and Deb, 1994).
Niched-Pareto GA (NPGA)	Horn et al. (1994) introduced NPGA, which uses niching pressure in order to get a good spread of solutions in the Pareto front. NPGA uses a binary tournament selection operator based on Pareto dominance. Whereas algorithms like VEGA, MOGA and NSGA use the proportionate selection operator which works with the sharing function. Two individuals from the population are picked up randomly compared against a sub set of the entire population and winner of the tournament selection, based on non-domination, is selected. The tournament selection operator selects non dominated solutions in a stochastic manner. When both of the competitors are non-dominated or both are dominated (a tie), fitness sharing is used to select the winner or in other words a niche count is found for all the individuals in the population (Rekiek and Delchambre, 2006).
Strength Pareto EA (SPEA)	SPEA maintains an external population based on elitism. It preserves a set number of non-dominated solutions. Each generation will find a set of new non-dominated solutions and these are compared with the external population. The resulting non dominated solutions of the population are preserved. Then, these elites are used along with the present population in genetic operations. This helps in steering towards better regions in the search space. Clustering techniques control the size of the elite population and maintain the diversity among elite members. Clustering enables achievement of a better spread among non-dominated solutions (Zitzler and Thiele, 1999).

MOEA	Discussion
Strength Pareto (SPEA2)	The goal of SPEA2 was to eliminate weaknesses of SPEA. This technique has a fine grained fitness assignment strategy and has improved the fitness assignment scheme. It takes each individual in to account and looks at how many other individuals dominate this individual and how many more are dominated by this individual. With the use of a nearest neighbour density technique, algorithm allows more precise guidance of the search process. Furthermore, this algorithm introduces an archive truncation method which ensures the preservation of boundary solutions (Zitzler et al., 2003).
Elitist Non-Dominated Sorting GA (NSGA II/ NSGA2)	This algorithm makes use of two mechanisms: elite preserving strategy and explicit diversity preserving strategy. NSGA2 begins by creating an offspring population by using the parent population. Then both of these populations are merged and non-dominated sorting is applied to classify the entire population. The new population is then filled up gradually starting from best non-dominated front and then by the next best front and so on. Whichever front that cannot be accommodated in this population is simply deleted. Crowded tournament selection, cross over, and mutation operators are used to create a new offspring population. Diversity among solutions is made sure by niching. NSGA2 introduces a new concept called crowded distance metric, which enhances the scalability of the number of objectives and making it faster (Deb, 2001, Deb et al., 2002).

In Table 7.3, only a selected set of optimisation techniques are briefly discussed. The selection of this particular set was based on their popularity, characteristics, and past applications of the technique in a similar scenario found in literature. This research selects one out of these many available to use in the optimisation stage of the framework. Therefore, this is achieved by setting the criteria that would help to search for the best suited technique for this optimisation problem. This is an important internal design evaluation of the artefact from the *Design Science Research* perspective that uses literature review. Multi-objective optimisation techniques are compared and contrasted to select the best suited technique. The next section describes these criteria and then applies them against a selected set of GAs.

The following Table 7.4 evaluates above discussed multi-objective optimisation techniques against the chosen criteria. Notations used include: (+) Fully supported without requiring any modifications; (<) Some support is provided in the current form; (>) With certain known extensions some support can be provided; (-) Not supported in the current form with known modifications or extensions; (?)Though mentioned, enough details not available or unclear

Table 7.4: Selection of a suitable multi-objective optimisation technique

Criterion	VEGA	MOGA	NSGA	NPGA	SPEA	SPEA2	NSGA2
Multi-objectivity	+ [1, 2]	+ [1]	+ [3, 4]	+ [5]	+ [3, 6]	+ [7, 8]	+ [3, 9]
Sustain solution diversity	-	+ [3]	+ [3, 10]	+ [5]	+ [6]	+ [7, 8]	+ [3, 9]
Constraint handling	> [2, 10]	+ [3]	+ [3, 10]	+ [5]	+ [3, 6]	+ [7]	+ [3, 9]
Trade-offs among objectives	+ [1, 2, 10]	+ [1]	+ [3, 10]	+ [5]	+ [11]	+ [7]	+ [3, 9]
Non-linear	+ [3]	+ [1]	+ [3, 10]	+ [5]	+ [6]	+ [7]	+ [3, 9]
Elitism	-	-	-	-	< [4]	+ [7, 8]	+ [3, 9]
Efficiency	+ [3, 11]	+ [1, 11]	> [3, 8]	+ [11]	+ [6]	+ [7, 8]	+ [3, 9]
Implementation	+ [3, 10, 11]	+ [3, 11]	+ [3, 10, 11]	+ [11]	+ [6]	+ [7, 8]	+ [3, 9]

Following is a list of references used to build the table 7.4.

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According to the literature review conducted SPEA2 and NSGA2 showed promising results for the research context considered here. Therefore, at this stage both of these are suitable candidates to perform multi-dimensional business process optimisation. However, it is important to look at how well they have performed when applied against a particular scenario. The next section looks at some successful applications and comparisons of the above mentioned two algorithms.

7.2.4. NSGA2 vs. SPEA2

According to the evaluation conducted in the Section *"Criteria to Select a Suitable Optimisation Technique"*, SPEA2 and NSGA2 both showed equal potential in being the best candidate to perform multi-dimensional business process optimisation including GHG emissions. Thus, in here the researcher looks at previous studies which applied or compared SPEA2 and NSGA2. The researcher will select a single technique based the number of recommendations and similarity to the application context. In the field of business process optimisation, there are a few studies that have successfully applied GAs with in a similar context and then compared the results. This type of comparing and contrasting evaluation falls under the internal design evaluation using literature review detailed in the "*Design Science Research* "section of Chapter 3.

Vergidis et al. (2007) reported a study which optimised a composite business process. Their trial included testing for bi-objectives and tri-objectives separately. They used three popular evolutionary algorithms i.e. NSGA2, SPEA2, and Multi-Objective Particle Swarm Optimisation (MOPSO). NSGA2 and SPEA2 came up with near Pareto optimal solutions. From the overall performance, they concluded that NSGA2 is the most robust in this optimisation instance. They strongly state that application of evolutionary algorithms in this context is far better than any other optimisation techniques (Tiwari et al., 2006, Vergidis et al., 2007).

In a separate study, Sag˘ and Çunkas (2009) develop a software tool named Multi Objective Evolutionary Algorithms Tool (MOEAT) for development, application, simulation, visualisation and analysis of multi objective evolutionary algorithms. This tool includes VEGA, MOGA, NPGA, NSGA, SPEA, SPEA2, Pareto Envelope-based Algorithm (PESA) and NSGA2 algorithms. Test results show that NSGA2, SPEA2 and PESA are better and VEGA and MOGA are poorer in their convergence towards a Pareto optimal front. They recommend NSGA2 as the best out of the considered EAs. They state, that evolutionary algorithms are superior and faster to gradient based algorithms in solving real world multiple objective problems.

Belgasmi et al. (2009), conducted an experiment using two elitist EAs, SPEA2 and NSGA2 in terms of hypervolume, spread and running time. Hypervolume metric is the quality indicator which computes the volume covered by the non-dominated set of solutions. In here NSGA2 performs better than SPEA2. The Spread metric is the diversity indicator which measures the degree of spread achieved among the solutions. SPEA2 proved to be better than NSGA2. However, in terms of running time NSGA2 performs better than SPEA2.

According to the conclusions of these studies, NSGA2 technique had the highest number of recommendations. Moreover, a multi-objective optimisation algorithm needs to meet two goals successfully. According to Deb (2001) these two are:

- Better Convergence near the Pareto-optimal front.
- Maintain as diverse a distribution as possible or in other words achieve a better spread of solutions.

When compared with the other multi-objective optimisation techniques, it is proven that NSGA2 comes up with a better spread of solutions as well as convergence near the Pareto-optimal front even for complex real world optimisation problems (Deb et al., 2002). Therefore, at this stage of the study the researcher selects and uses NSGA2 as the multi-objective optimisation technique.

7.3. Constituent Artefact-VI:

Two-way mapping between the derived formula and the Elitist Non-Dominated Sorting Genetic Algorithm (NSGA II/ NSGA2), which is the selected optimisation technique.

The Chapter Introduction stated that *Constituent Artefact-VI* is a construction block of the framework (main artefact). Similar to *Constituent Artefact-V*, this artefact too does not form a functional aspect of the framework. *Constituent Artefact-VI* provides a solution to the investigative question *'2.3. How can a selected optimisation technique (based on the criteria set above) be applied for business process optimisation for GHG emission management alongside other business objectives?'*

In order to answer the above mentioned investigative question, the researcher implements the selected algorithm, i.e. NSGA2 as a computer program, to solve the multi-dimensional business process optimisation problem. This study does not do any modifications to the NSGA2 algorithm itself, except during the population generation. This is explained in the section, *"GA in conjunction with the Green ABM".* The study used a Matlab program provided by the Matlab Central File Exchange. Lin (2011) coded this program based on the NSGA2 algorithms by Deb et al.(2002). The redistribution and use in source and binary forms, with or without modification of this code is permitted by the owner (programmer), subjected to two conditions and these two conditions were met by the researcher.

Once the NSGA2 code was implemented, the researcher mapped the multi-objective optimisation formula into the format required by the optimisation algorithm. Moreover, along with the formula the associated set of parameters are fed in to the algorithm to process them. The formula derived in *Constituent Artefact-V* captured the multi-dimensional business process optimisation problem as a formal/mathematical model. This formal model captured the business objectives that included GHG emission management alongside other business objectives (time and cost). The selected algorithm solves the optimisation problem and achieves a set of optimised solutions.

As the name suggests, *Constituent Artefact-VI* does the *two-way mapping* between the derived formula and the NSGA2. The terms *"two-way mapping"* signifies that the artefact:

1. Comes up with a computer program where NSGA2, works in conjunction with the proposed Green ABM to solve multi-dimensional business process optimisation problem to achieve a set of optimal solutions.
2. Uses simulation to relate the Pareto-optimal solution set back to the business domain in terms of what are the parameters and their values are in a manner understood by the business managers.

7.3.1. GA in conjunction with Green ABM

In the complex multi-objective optimisation problem considered here, some variables can only take certain discrete values. This aspect further constrains the optimisation problem. In the manufacturing scenario, this constraint needs to be addressed. The researcher achieved this by modifying the GA to work in conjunction with the extended CPM. *Constituent Artefact-II* showed how the researcher further extended the ABC model by incorporating the CPM. Rest of this sub section explains how the GA works in conjunction with the extended CPM.

CPM identifies the critical activities in the process. There can be activities where the task duration can be a variable value. If these tasks are in the critical path, these might affect the critical path duration. Thus, in terms of the time durations, apart from the slack times, the critical activity durations can have a variable value. More importantly, activity durations can only take certain discrete values.

In the manufacturing context, electricity rates for peak, shoulder, and off-peak have different monetary values. These values depend on the time of the day a particular activity is conducted. Every time a new generation is created, it is important to consider the above mentioned variations.

As illustrated in Figure 7.2, the proposed Green ABM methodology provides an opportunity to capture these values in the extended CPM nodes. Time tab (Earliest start, Earliest finish, Latest start, Latest finish, Duration, Actual start), Cost tab (Peak rate, Shoulder rate, Off-peak rate), GHG emission tab, and Energy tab (Peak period, Shoulder period, Off-peak period) captured the related variables.

Figure 7.2: Green ABM to model time, energy, cost and GHG profiles of a business process and Time, Energy, Cost and Emissions tabs of a node

In order to cater for the above mentioned variable value requirement, the genetic algorithm flow needed an adjustment (Figure 7.3). This section explains the functionality of a GA. In here, each variable activity will have a lower and upper bound for the duration. The extended CPM will provide the activity durations as well as the boundaries of variable activities required by the GA to come up with a new generation.

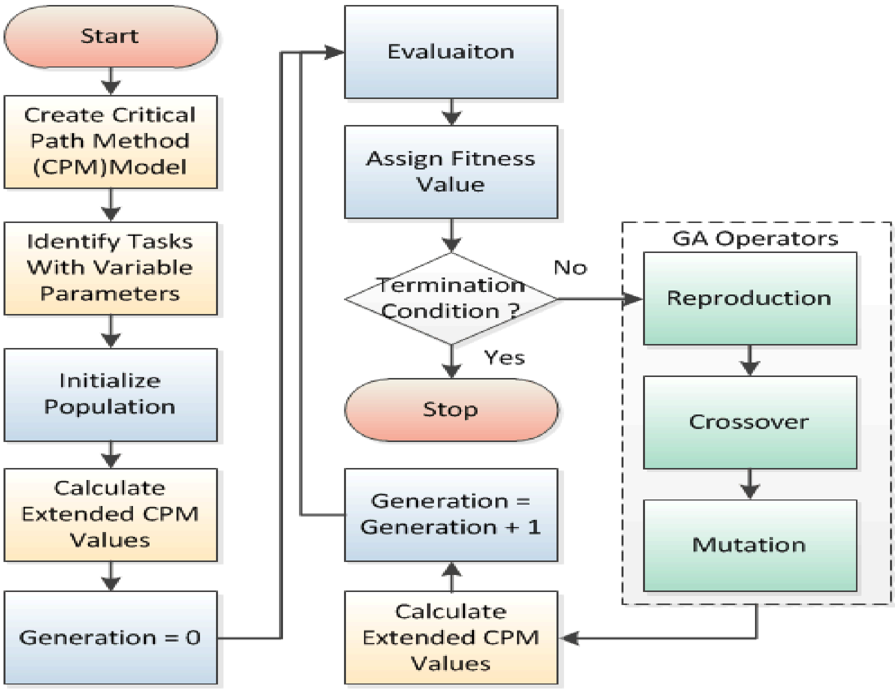


Figure 7.3: A flowchart of working of a GA in conjunction with the extended CPM

As shown in Figure 7.3, genetic algorithm steps are shown in blue colour, while GA operators are shown in green. The steps where the CPM intervenes in the GA flow are illustrated in orange colour. Start and termination are displayed in red.

Once the algorithm starts, the first step creates the extended CPM model. Then, the second step identifies the activities with variable parameters and takes into consideration their upper and lower boundary values. Thereafter, the population is initialised. The GA starts the search for an optimised solution with a random set of solutions. Then, the next step calculates the extended CPM values. The random set of solutions is evaluated in the context of the multi-objective optimisation problem. In order to assign a relative merit to the solution, during the evaluation it calculates the four objective function values and constraint violations for each and every solution in the population. This relative merit is termed as the *fitness*. Thereafter, the next step checks the termination condition. If the solution does not satisfy the termination condition, the population gets modified by the *Reproduction (Selection), Crossover,* and *Mutation* GA operators. As stated in the section *"Setting the criteria to select a suitable optimisation technique"*, the reproduction operator randomly selects superior solutions to form the new generation. However, prior to executing, crossover and mutation operators need to be initialised. Application of GA operators results in a new population generation. Thereafter, it will calculate the critical path of the new population. The generation counter gets incremented by one, indicating the completion of successful execution of one generation as well as the formation of a new generation. It starts the loop again by evaluating each and every solution in the population (Deb, 2001). If the solution satisfies the termination condition then the execution will stop.

The GA will solve the multi-objective optimisation problem and result in a set of trade-off solutions. The resultant solution set may look like the *"Figure 7.4: Non-dominated optimisation results from Matlab with NSGA2"*. Each solution in the Pareto front has a set of corresponding variables. The next sub-section shows how this relationship is used to relate the results back to the business world.

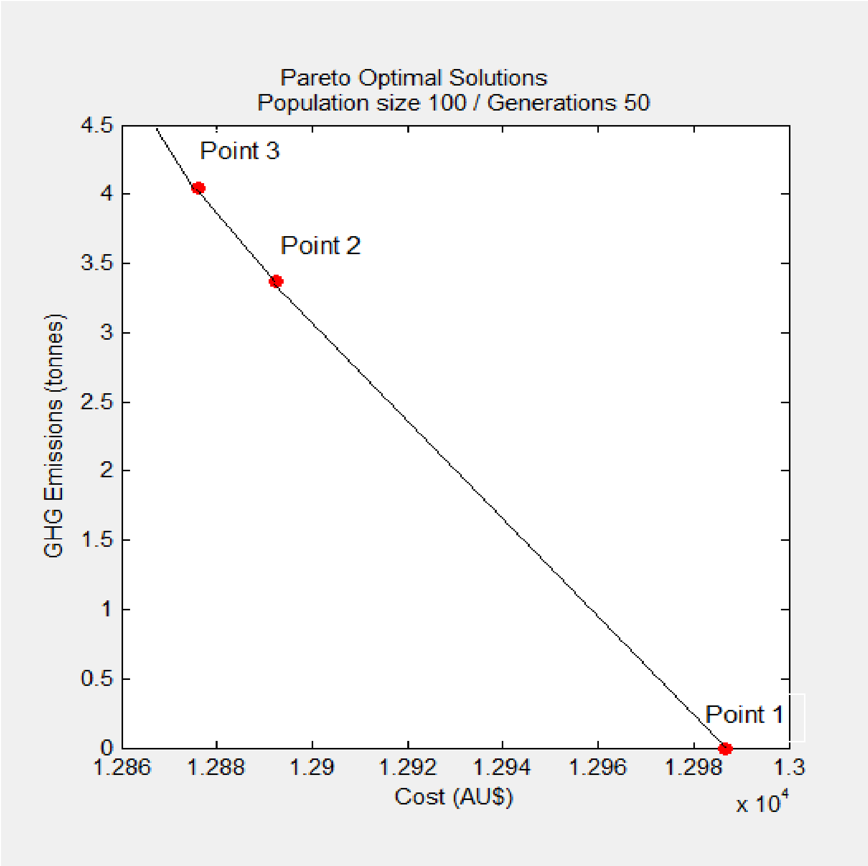


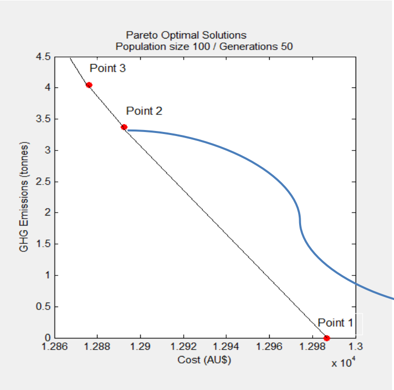
Figure 7.4: Non-dominated optimisation results from Matlab with NSGA2

7.3.2. Simulation to relate the Pareto-optimal solution set back to the business domain

The previous sub section showed how to use a GA in conjunction with the extended CPM to perform multi-objective optimisation to achieve a set of solutions which are Pareto optimal. This section shows how the researcher used simulation to relate the Pareto-optimal points back to the business objectives and the corresponding parametric values, to make sense out of each optimal point to the organisational middle level management.

When the organisational middle management views this simulation they are able to make a decision based on the information presented to them. They have the necessary process level information to perform their task and activities to achieve business process optimisation for several objectives. These objectives included not just GHG emission management but reduction of cost of production and reduction of time to market as well. As all the points in the Pareto front are optimal, decision makers can use the higher level information about the problem to select one. The kind of higher level information may relate to the current dynamic business environment.

In order to choose one out of the optimal set requires detailed information regarding the optimal points. In this NSGA2 program, a database table stores all the parametric values for each solution of the population for all the generations. The optimal solutions from the last generation are used for the simulation.



Time	Green Energy	Cost	Emissions	Critical Path	Consumption
3010.36	4.02749	13054.3	0	2447	5015.78
1236.84	2.46829	12932.9	3.38308	2451.85	5011.97
2734.07	2.28988	12932.8	3.38213	2446.45	5010.56
53.7809	2.90935	12945.2	3.38532	2442.02	5015.29
1711.88	2.18302	12950.5	3.38525	2444.57	5015.18
4688.27	2.76492	12943.1	3.38351	2439.02	5012.6
3917.23	4.9018	13009.4	0	2444.01	5018.26
239.278	2.29381	12949.9	3.38355	2443.34	5012.67
4213.34	3.18826	12970.1	2.25472	2447.01	5010.48
107.272	3.45746	12984.2	2.25482	2445.98	5010.71

Figure 7.5: Optimisation non-dominated results from Matlab with NSGA2 and corresponding variables for a particular point in the Pareto front

As shown in Figure 7.5, each optimal point has a corresponding set of parametric values. These values correspond to the parameters captured in the extended CMP. Figure 7.2 (The Green ABM to model time, energy, cost and GHG profiles of a business process and Time, Energy, Cost and Emissions tabs of a node), contains possible activity based parameters. However, all these parameters may not contain a value E.g. A manual activity may not need electricity.

Constituent Artefact-V derived a multi-objective mathematical formula for GHG emissions, time, electricity consumption, and cost objectives. The formulated four-objective optimization problem is as follows:

$$f_1 = min\ (CD)$$

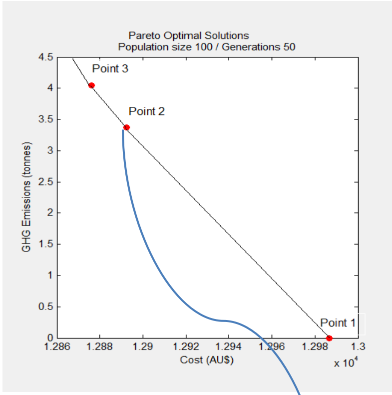
$$f_2 = min(\sum_{i=1}^{m} \sum_{i=1}^{n} (kW * D_{mn}))$$

$$f_3 = min((f_2 * R) + (f_1 * l * W) + (M_c + M_m + M_{rc}) + (kVA * N_{nw})))$$

$$f_4 = min(f_2 * Ef/1000)$$

f_1, f_2, f_3, f_4= Objective functions for time, electricity consumption, cost, GHG emissions.

The f_1, f_2, f_3, f_4 values can be calculated by using the relationships in the above mathematical formula along with the values from the database table which contain all the optimal solution parameter values. This is used in simulations. Thus, the simulations are generated as shown in Figure 7.6.



Time	Green Energy	Cost	Emissions	Critical Path	Consumption
3010.36	4.02749	13054.3	0	2447	5015.78
1236.84	2.46829	12932.9	3.38308	2451.85	5011.97
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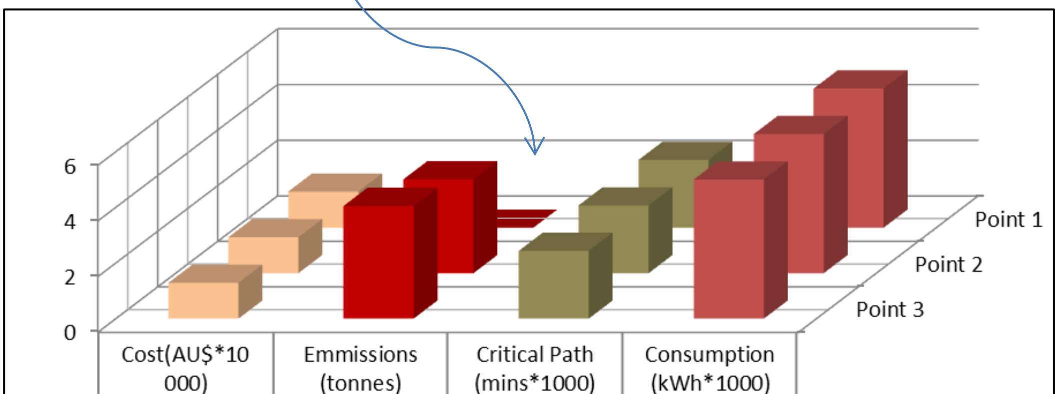
53.7809	2.90935	12945.2	3.38532	2442.02	5015.29
1711.88	2.18302	12950.5	3.38525	2444.57	5015.18
4688.27	2.76492	12943.1	3.38351	2439.02	5012.6
3917.23	4.9018	13009.4	0	2444.01	5018.26
239.278	2.29381	12949.9	3.38355	2443.34	5012.67
4213.34	3.18826	12970.1	2.25472	2447.01	5010.48
107.272	3.45746	12984.2	2.25482	2445.98	5010.71

$$f_1 = min\ (CD)$$

$$f_2 = min(\sum_{i=1}^{m} \sum_{i=1}^{n} (kW * D_{mn}))$$

$$f_3 = min((f_2 * R) + (f_1 * l * W) + (M_c + M_m + M_{rc}) + (kVA * N_{nw})))$$

$$f_4 = min(f_2 * Ef/1000)$$



	Cost(AU$*10 000)	Emissions (tonnes)	Critical Path (mins*1000)	Consumption (kWh*1000)
Point 1	1.29866	0	2.435	4.99933
Point 2	1.28922	3.37455	2.435	4.99933
Point 3	1.2876	4.04946	2.435	4.99933

Figure 7.6: Relationship among time, cost, energy, and GHG

As shown in the Figure 7.6, the GA working in conjunction with the extended CPM solved the multi-objective optimisation problem which included GHG emissions, cost, time, and energy as its objectives. The solution was a set of Pareto optimal points. These optimal points each had corresponding parameter values stored in a database table. For the simulation, the formal multi-objective problem relationships and the corresponding database table vales are used to get the simulated result. The visualisation of the simulated result can be customised to suite the decision maker or the organisation middle level management's preference. These managers can use high level multi-objective problem related information to choose one out of the optimal set of solutions.

7.4. Chapter Conclusion

This chapter explained the *Constituent Artefact-V* and *Constituent Artefact-VI*. These two artefacts helped to build the Multi-dimensional business process optimisation stage of the framework. These are essential to perform multi-dimensional business process optimisation for GHG emissions and other process level objectives like reducing the cost of production and reducing the time to market. The chapter provided a detailed discussion on how the artefacts were formed and how they answered the corresponding investigative questions.

Constituent Artefact-V acts as the selection criteria for an optimisation technique that can optimise a multi-objective mathematical formula which captures possible process level changes of GHG emissions with other objectives. The *Constituent Artefact-V* provided the answer to the investigative question *"2.2. What are the selection criteria of an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions?"*

Constituent Artefact-VI does the *two-way mapping* between the derived formula and NSGA2. The terms *"two-way mapping"* means that the artefact:

1. Comes up with a computer program where NSGA2, a GA works in conjunction with the extended CPM to solve multi-dimensional business process optimisation problem to achieve a set of optimal solutions.
2. Uses simulation to relate the Pareto-optimal solution set back to the business domain in terms of the parameters and their values in a manner understood by the business managers.

Constituent Artefact-VI provided the answer to the investigative question *"2.3. How can a selected optimisation technique (based on the criteria set in the investigative question 2.2) be applied for business process optimisation for GHG emission management alongside other business objectives?"*

This concludes the detailed discussions on constituent artefacts. Chapter 6 detailed the *Constituent Artefacts I to IV*. The *Constituent Artefacts I to IV* facilitated modelling, measuring, analysing, and reporting GHG emissions. This chapter discussed *Constituent Artefact-V* and *Constituent Artefact-VI*, which formed the construction blocks of the framework to build the Multi-dimensional business process optimisation stage. The next chapter provides the evaluation and discussion of the framework.

CHAPTER 8 : Evaluation and discussion of the framework

8.1 Chapter Introduction

Chapter 1 introduced the study background and outlined the research problem. Thereafter, Chapter 2 set out to review the prior work that is relevant to the study. Chapter 3 detailed the employed research approach. Chapter 4 detailed the main case study used in this research. Chapter 5 gave a concise description of the main artefact which was built using the six constituent artefacts. Thereafter, Chapters 6 and 7 detailed these six constituent artefacts.

This chapter strives to showcase that the main artefact is useful for the specific purpose it was built for by providing relevant evidence. Therefore, the chapter relates the performance to the intended use of the artefact. The intended use can span across a range of tasks (March and Smith, 1995). The chapter exhibits how the research process (i.e. activities) together with product (i.e. output) constitutes a design science project. Further, the chapter demonstrates how the artefact rigorously demonstrates utility, quality, and efficacy by using well executed evaluation methods. Further, it draws upon the guidelines published by Hevner et al. (2004) to evaluate the research.

The following section, *"8.2 Evaluation in Design Science"*, briefly discusses evaluation with in the Design Science Research context. The section, *"8.3.Evaluation of the framework for multi-dimensional business process optimisation for GHG emissions management"*, provides the evaluation of each of the major areas of the framework along with their sub-areas. The section *"8.4"* focusses on the discussion aspect of the theses and justifies how the research fulfils the requirements of an effective design science research. In this section the researcher integrates the results of this study with the existing body of knowledge. Finally, this chapter concludes by providing a summary of this evaluation and discussion chapter.

8.2 Evaluation in Design Science

The distinction of *Design Science Research* from *Behavioural Science Research* is the pursuit of utility as opposed to the truth. Chapter 3 justified that the framework build was within the boundaries of design science research.

As explained earlier in the Chapter 3, an artefact has to be testable against all the pre-defined measures of success to determine if it is the best solution to the identified problems (Rossi and Sein, 2003). To evaluate this aspect of the framework, the research uses a set of guidelines provided by Hevner et al.(2010). Following table summarises this set of guidelines.

Table 8.1: Design-Science Research Guidelines adopted from Hevner et al. (2004)

Guideline	Description
Guideline 1: Design as an Artefact	Design-science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and valuation of the design artefact.
Guideline 6: Design as a	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the

Guideline	Description
Search Process	problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

At present, the guidelines described in Table 8.1, are considered the standard to justifying the requirements as a design science research project. Though, it is not mandatory to use the guidelines, if these were tested, it will showcase the completeness of the process (Hevner et al., 2004).

There are a number of evaluation methodologies available in the knowledge base to evaluate the design artefact. This forms Guideline 3 of the set of "*Design Science Research Guidelines*". Following Table 8.2 shows some of the typically used methodologies to evaluate the artefact.

Table 8.2: Design Evaluation Methods adopted from Hevner et al. (2004)

Design Evaluation Method	Description
1. Observational	Case Study: Study artefact in depth in business environment
	Field Study: Monitor use of artefact in multiple projects
2. Analytical	Static Analysis: Examine structure of artefact for static qualities (e.g., complexity)
	Architecture Analysis: Study fit of artefact into technical IS architecture
	Optimization: Demonstrate inherent optimal properties of artefact or provide optimality bounds on artefact behavior
	Dynamic Analysis: Study artefact in use for dynamic qualities (e.g., performance)
3. Experimental	Controlled Experiment: Study artefact in controlled environment for qualities (e.g., usability)

Design Evaluation Method	Description
	Simulation. Execute artefact with artificial data
4. Testing	Functional (Black Box) Testing: Execute artefact interfaces to discover failures and identify defects
	Structural (White Box) Testing: Perform coverage testing of some metric (e.g., execution paths) in the artefact implementation
5. Descriptive	Informed Argument: Use information from the knowledge base (e.g., relevant research) to build a convincing argument for the artefact's utility
	Scenarios: Construct detailed scenarios around the artefact to demonstrate its utility

This research uses some of the selected evaluation methodologies shown in Table 8.2. The selection was performed based on the artefact and the evaluation criteria. This study used observational, analytical, testing, and descriptive design evaluation methods. Design evaluation methods were not used for the main artefact in general. As the framework composed of several major stages, the appropriateness of design evaluation methods changed from one stage to another. The following section, presents the conducted evaluation relating to each major framework stage.

8.3 *Evaluation of the framework for multi-dimensional business process optimisation for GHG emissions management*

As shown in Figure 8.1, the framework for multi-dimensional business process optimisation for GHG emissions management contains four distinctive areas. The first stage is the identification and this is the initial entry point of this framework i.e. identification of organisational boundaries, processes, emission sources, and business objectives. The second stage is the business process modelling, data collection, and GHG emission calculation. The third stage rolls-up data to the corporate level for reporting and fourth stage does the business process optimisation.

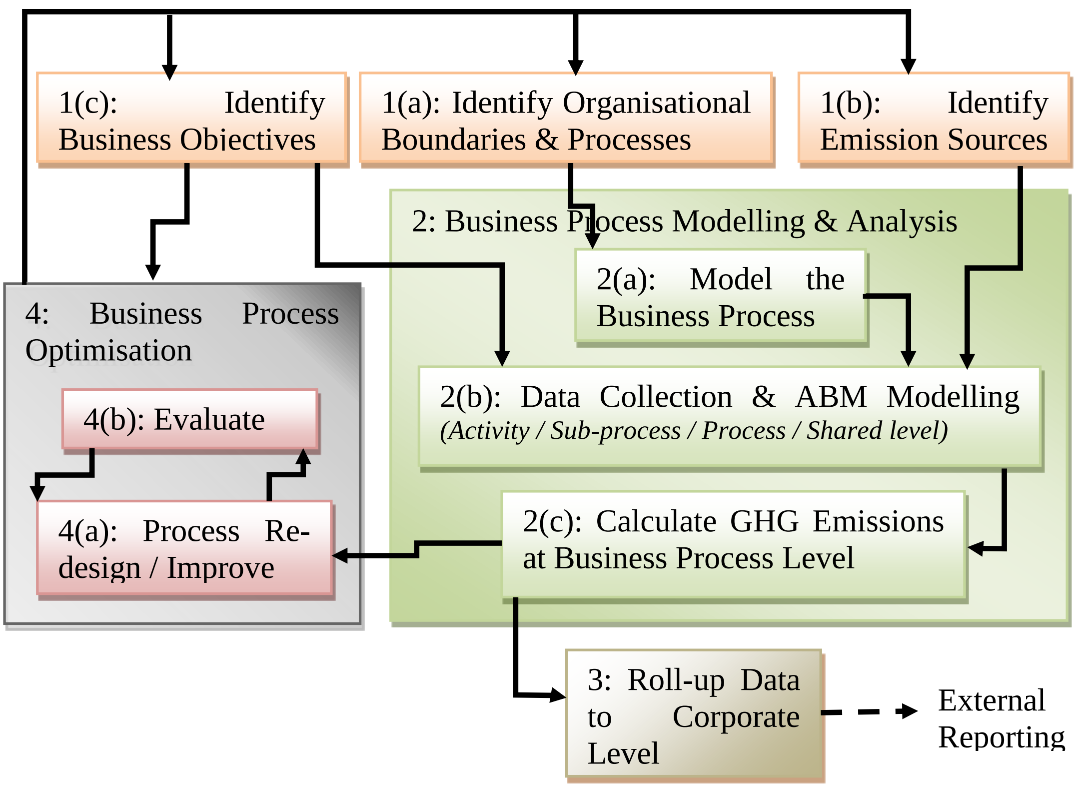


Figure 8.1 : Green Multi-Objective Process Optimisation (Green MOPO) framework

It is important to note that this evaluation is based on framework stages rather than on individual constituent artefacts. As explained in the Chapter 5, 6, and 7, the *Constituent Artefact-I*, *II*, *III*, and *IV* form functional parts of the framework. Therefore, the functional utility of these artefacts match that of the framework stages each one belongs to. Others, *Constituent Artefact-V* and *Constituent Artefact-VI*, form construction blocks of the framework. Therefore, functional utility of these artefacts are different to that of the framework stage they belong to.

1. Identification Area

"Identification stage" first identified the organisational boundaries. Then, it identified the related processes. Thereafter, the area identified the emission sources related to the business processes. Next, the business process level objectives are identified. The next three sub-sections evaluate first stage of the main artefact to demonstrate its utility with evidence.

1(a): Identify Organizational Boundaries and Processes

The researcher studied the manufacturing company's ownership, organisational structure, geographical location, sites, and the processes. Thereafter, the researcher selected a Polyethylene terephthalate (PET) package manufacturing process for detailed examination.

The evaluation was performed with a plastic packaging company which specialises in a wide range of plastic closures and containers. The company provides packaging solutions for pharmaceutical, household, and food industries. The company is 100% privately owned. As the reporting organisation has the total ownership of its operations, the organisational boundary does not depend on either of the GHG emission consolidating approaches namely, equity share approach and control approach. These approaches are explained in Chapter 2 of this thesis. As explained in Chapter 4, the organisation is in the Western Sydney Region of

NSW, Australia. The considered company is located in a single geographical site. Thus, as far as consolidating GHG emissions are concerned, it is straight forward. This study considered the Injection Blow Molding (IBM) process in PET package manufacturing of the above mentioned company. (Belcher, 2007, Jones et al., 1995)

1(b): Identify Emission Sources

For this company, the energy consumed comes from electricity. In addition to paying high prices for electricity, the previous Australian government's carbon tax implementation (this was abolished by the present government) has led this type of manufacturing organisations to seek better GHG management and optimisation techniques alongside meeting their other business objectives like reducing time to market, improving quality and reducing the cost of manufacturing.

All GHG emission sources were identified according to various scopes and emission categories. For GHG accounting and reporting purposes, three Scopes are defined by the GHG Protocol as Scope 1, Scope 2, and Scope 3(WBCSD-WRI, 2004). In this process, for this company, predominant emission source was the Scope 2 emissions from consuming purchased electricity. This study uses the emission measurement and estimation technique termed *"Emission factors based approach"*, as it gives the most accurate estimate for carbon emissions. Details of this technique are in the Chapter 2 of this thesis.

1(c): Identify Business Objectives

As explained in Chapter 5, business objectives are the driving force behind every business. However, there should be a strategy to meet these business objectives. If there is not a strategy, achieving business objectives is not very straightforward. Business managers or decision makers within the company need to have a clear idea about where the changes are needed and how to improve the business to achieve them.

Keeping in mind the business strategy to achieve business objective, at this stage of the framework, the business objectives are stated in quantitative terms. Organisations' business objectives were recorded in terms of GHG emission management, cost reduction, and time reduction. Following are the business process objectives for this evaluation.

- Mitigate GHG emissions, for the value to be less than 20% of the current year's value by next year.
- Reduce the time to market, for the value to be less than 5% of the current year's value by next year.
- Reduce the cost of production, for the value to be less than 5% of the current year's value by next year

The framework identification stage completes with the statement of the business process objective identification step. The next section evaluates the business process modelling, data collection, and GHG emission calculation aspects of the framework.

2. Business Process Modelling, Data Collection and GHG Emission Calculation Area

This stage looks after the business process modelling and analysis of an organisational process for GHG emissions. Business process modelling precedes any business process analysis (Vergidis et al., 2008). Hence, data collection happens after modelling the business processes. Thereafter, according to the collected data, GHG emissions calculation takes place.

2(a): Model the Business Process

The PET package manufacturing process selected for this study is in the manufacturing and logistics sector. The complete set of business processes were first modelled using BPMN as the modelling tool. The following shows the key business process models of the selected organisation.

The Demand Process

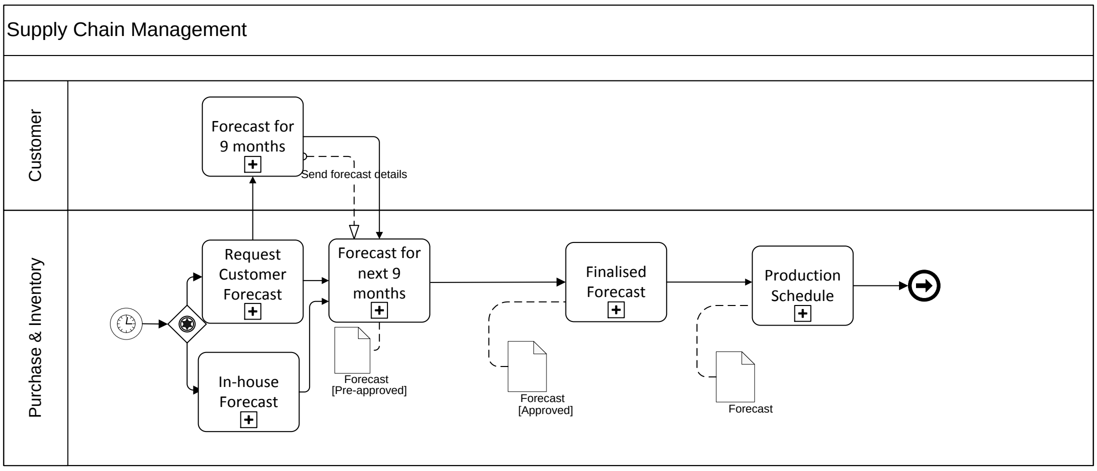


Figure 8.2: Business Process Modelling of the Demand Process

Order Plan Process

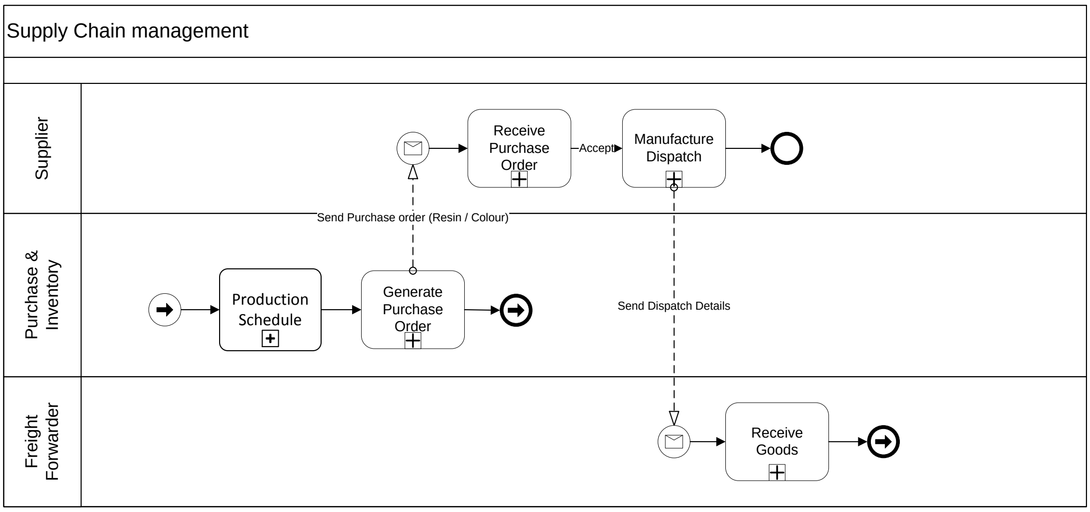


Figure 8.3: Business Process Modelling of the Order Plan Process

Order Processing Process

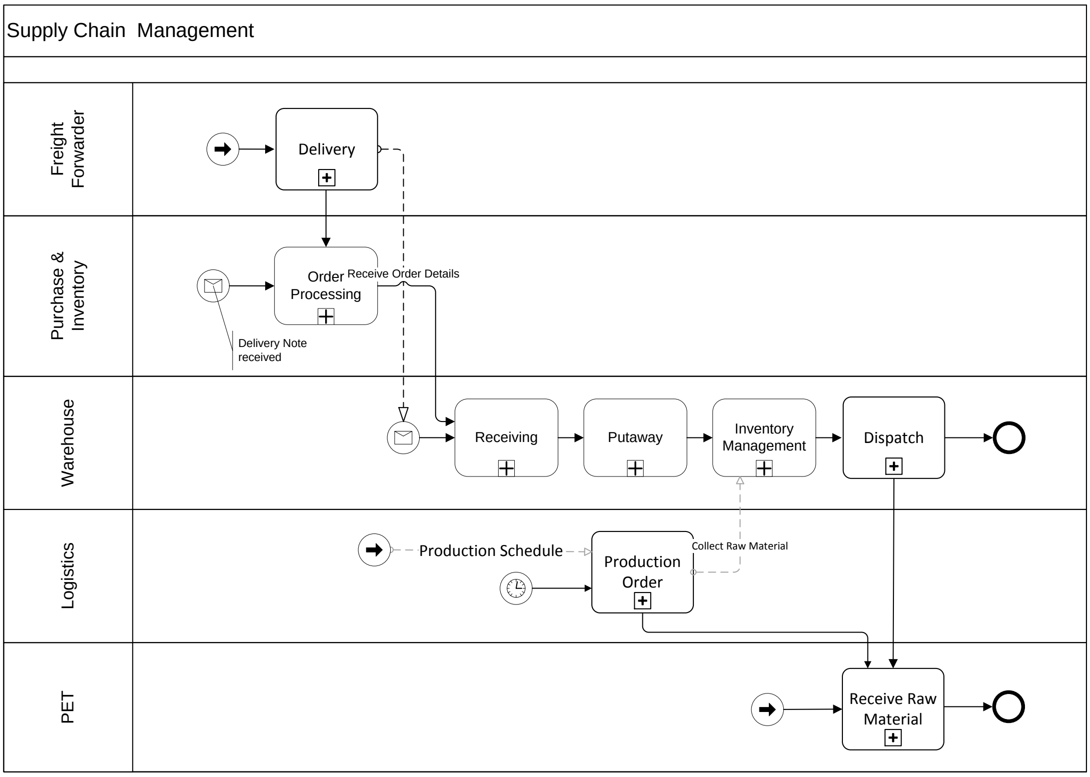


Figure 8.4: Business Process Modelling of the Order Processing Process

PET Manufacture and Dispatch Processes

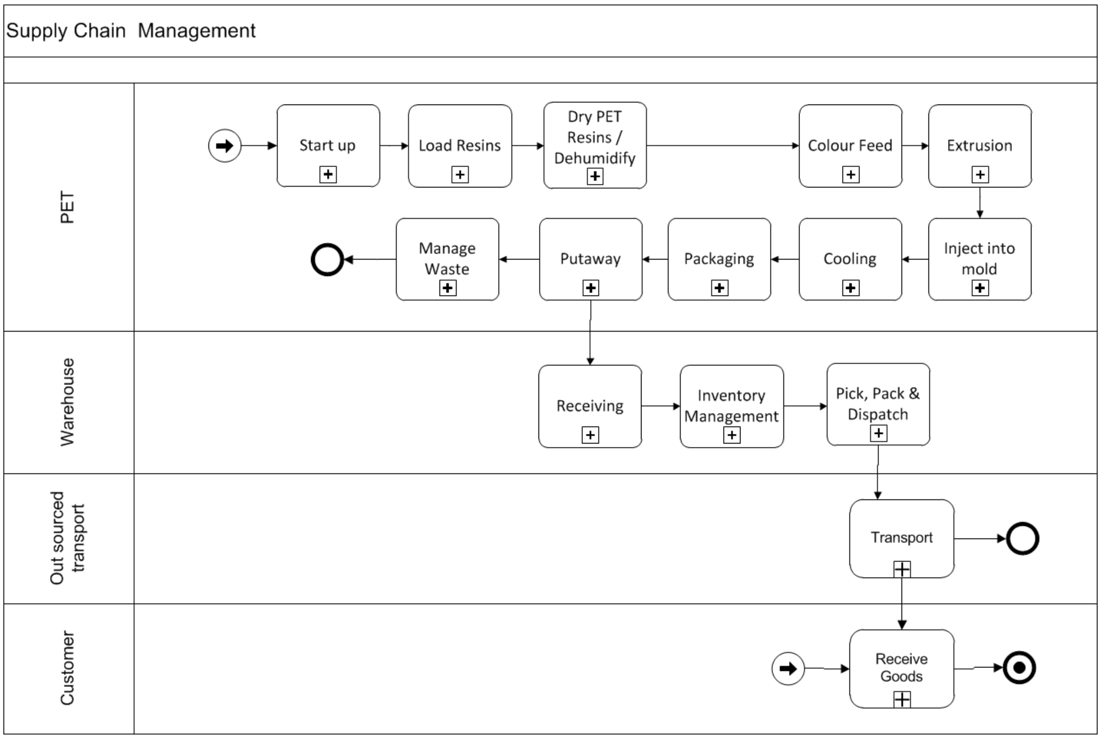


Figure 8.5: Business Process Modelling of the PET Manufacture and Dispatch Process

2(b): Data Collection and ABM Modelling

This step collects the data required by the framework. The researcher collected data from the company identified in the *"Identification Stage"*. The researcher used a web-based tool to collect data from this company. Details of this web-based tool to collect organisational data are provided in the Appendix A of this thesis.

The data collected was used to model the stable business process, i.e. PET manufacturing process, using the proposed novel modelling approach called, Green Activity Based Management (ABM). Green ABM is a bottom-up approach for environmentally sustainable business process management. It identified the business process and the constituent process elements. This is performed at a lower detailed level. In the framework this low level business process modelling extended the modelling carried out in the sub-stage 2(a).

Green ABM first built the visual process model. Secondly, alongside the visual process models it developed the formal process models. Formal model construction required two types of parameters. These are static configuration parameters and dynamic configuration parameters. The static configuration parameters describe attributes of process elements that hold fixed (relatively) values. The dynamic configuration parameters hold attributes of process elements that can change (Wang et al., 2009).

The fundamental building block of the Green ABM visual modelling is a node. As shown in Figure 8.6, a node contains four tabs: Time, Energy, Cost, and Emissions. The four different tabs group these related parameters.

Time	Energy	Cost	GHGs
ES	Process	EF	
AS	Duration	Slack	
LS	State	LF	

Time Tab

Time	Energy	Cost	GHGs
kW	Process	Peak	
kVA	Duration	Shoulder	
Power Factor	State	Off-peak	

Energy Tab

Time	Energy	Cost	GHGs
Labour Rate/Hr	Process	Peak Rate	
Labour Count	Duration	Shoulder Rate	
Material	State	Off-peak Rate	
Equipment	Sub contractor	Network Rate	

Cost Tab

Time	Energy	Cost	GHGs
Fuel Type	Process	Paper Waste	
Fuel Amount	Duration	Wood Waste	
Km/L	State	Other Waste	
Travel Distance	+Air Travel	+Sea Travel	

Emissions Tab

Figure 8.6: Green AMB node tabs prior to inserting data

As described in Chapter 4, within this process, the four machines that make up the PET machine, PET Heat, PET Drive, Water Chiller, and Dryer run simultaneously. Switching on of these four separate machines (i.e. PET Heat, PET Drive, Water Chiller, and Dryer) is staggered according to the production process.

Green ABM at activity level

The digital power meter measured several parameters related to electrical power consumption. These included running load and maximum demand occurrences of the various components of the PET machine. As explained in Chapter 4, after analysing the machine power consumption, this research identified seven distinct states in power consumption during a single production cycle. It is a generic pattern observed for various components of the PET machine.

The following diagrams illustrate the Green ABM business process model at an activity level. As can be depicted from the Figures 8.7-10, for a particular process, Green ABM modelled different dimensions i.e. time, energy, cost, and GHGs.

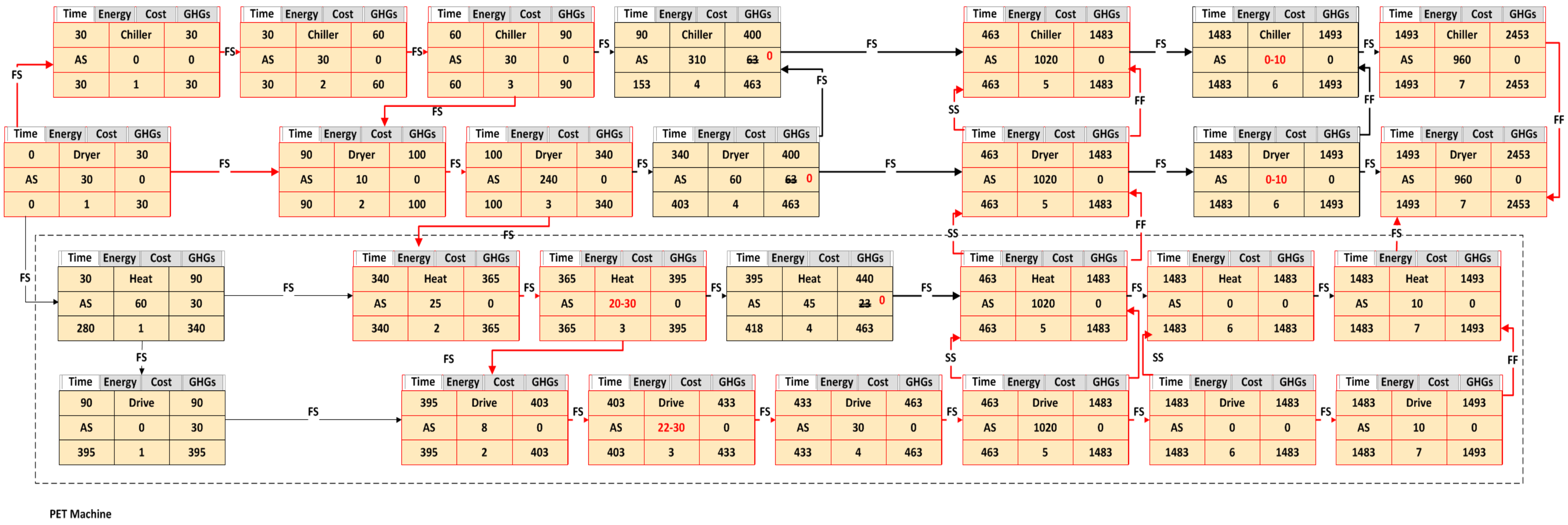


Figure 8.7: The Activity Level Time Profile of the Green ABM architecture.

Legend

Time	Energy	Cost	GHGs

Earliest Start	A/SP/P	Earliest Finish
Actual Start	Duration	Slack
Latest Start	State	Latest Finish

A	= Activity	SS	= Start-to-Start
SP	= Sub process	FF	= Finish-to-Finish
P	= Process	SF	= Start-to-finish
FS	= Finish-to-Start	GHG	= Greenhouse Gas

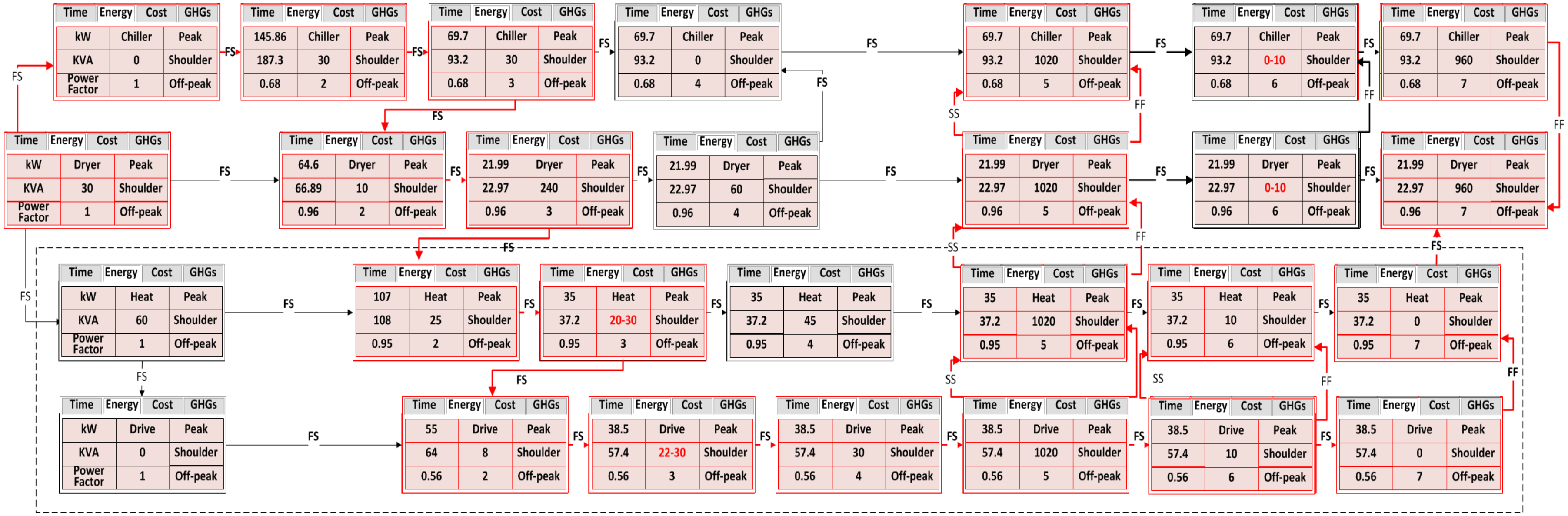


Figure 8.8: The Activity Level Energy Profile of the Green ABM architecture.

Legend

Time	Energy	Cost	GHGs
kW	A/SP/P	Peak Period	
KVA	Duration	Shoulder Period	
Power Factor	State	Off-peak Period	

A = Activity
SP = Sub process
P = Process
FS = Finish-to-Start

SS = Start-to-Start
FF = Finish-to-Finish
SF = Start-to-finish
GHG = Greenhouse Gas

KW = Kilowatt
KVA = Total apparent power

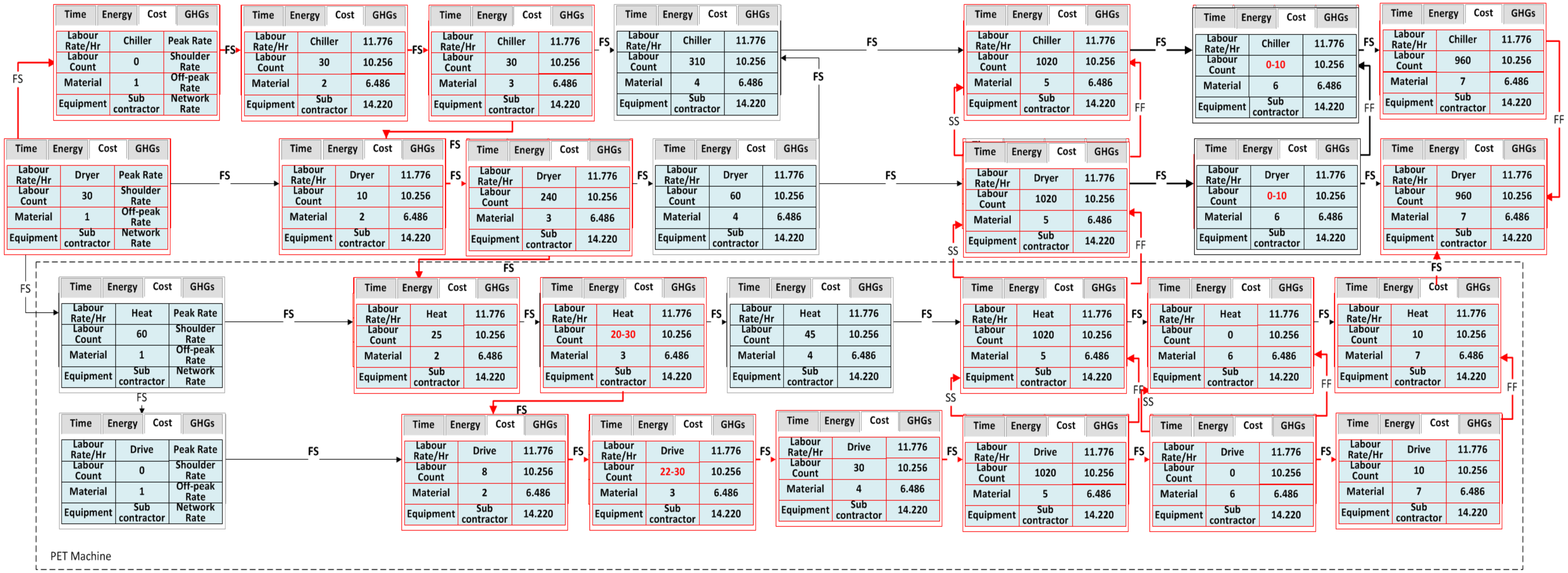


Figure 8.9: The Activity Level Cost Profile of the Green ABM architecture

Legend

Time	Energy	Cost	GHGs
Labour Rate/ Hr	A/SP/P		Peak Rate
Labour Count	Duration		Shoulder Rate
Material Cost	State		Off-peak Rate
Equipment Cost	Sub contractor Cost		Network Cost

A = Activity
SP = Sub process
P = Process
FS = Finish-to-Start
SS = Start-to-Start
FF = Finish-to-Finish
SF = Start-to-finish
GHG = Greenhouse Gas

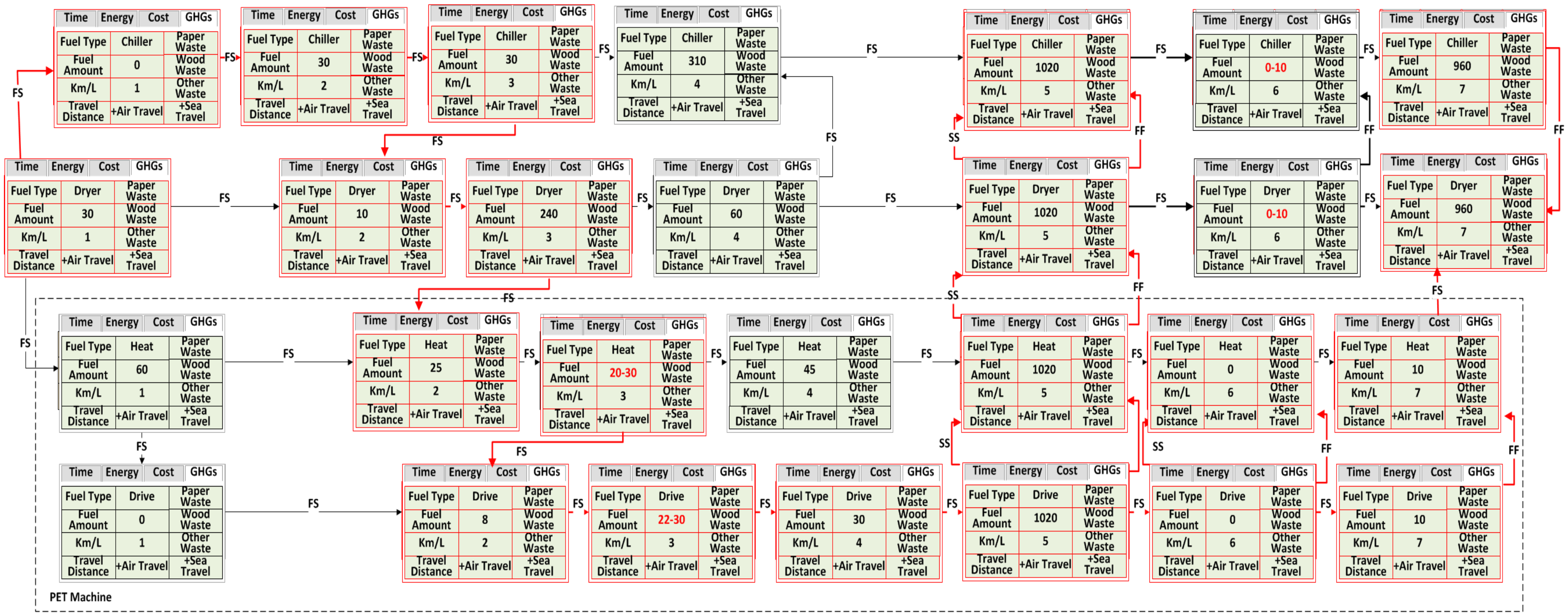


Figure 8.10: The Activity Level Emission Profile of the Green ABM architecture

Legend

Time	Energy	Cost	GHGs
Fuel Type	A/SP/P	Paper Waste	
Fuel Amount	Duration	Wood Waste	
Km/L	State	Other Waste	
Travel Distance	+Air Travel	+Sea Travel	

A = Activity
SP = Sub process
P = Process
FS = Finish-to-Start

SS = Start-to-Start
FF = Finish-to-Finish
SF = Start-to-finish
GHG = Greenhouse Gas

As can be seen by the activity levels profiles of the Green AMB architecture, in this research, GHG emission related data is collected at an activity level in the energy tab.

Green ABM at sub-process level

1. *Direct attributed parameters (time, cost, and GHG emissions)*

   Direct attributed parameters are not found for this level of the process.

2. *Causally assigned parameters (time, cost, and GHG emissions)*

   Causally assigned parameters are not found for this level of the process.

3. *Allocated parameters (time, cost, and GHG emissions)*

   Allocated parameters are not found for this level of the process.

Green ABM at business process level

Chapter 7 explained the extended ABC method to include GHG emissions management. It showed how the driver cost and emissions are calculated by multiplying *Driver Value* by *Driver Intensity*. Further, it argued the boundaries of a CPM node can be broadened to include cost and GHG emissions of an activity. Thus, it creates the Green ABM node to capture time, cost, energy, and GHG emission figures.

The following sections show process level data and calculations including time and cost related figures. However, the business process level GHG emission calculations are carried out in 2(c): GHG Emission Calculation at Business Process Level.

1. *Direct attributed parameters (time, cost, and GHG emissions)*

Cost and time related figures can be calculated by direct attribution at process level. It is important to note that though the duration is 2453 mins, the number of employees is counted as 1.5. Hence, labour costs are for 1.5 employees at the rate of AU$ 25 per hour.

Table 8.3: – Direct attributed costs of the PET process

Cost object	Driver value	Consumption Intensity		Cost	
		Rate unit	AU $		AU $
Material 1/ Resin (kg)	5000	Unit price / kg	1.66	Material costs	8300.00
Material 2 / Colour (kg)	7.5	Unit price / kg	55	Material costs	412.50
				Total (Material)	**8712.50**
Labour hours	2453min/60	Labour rate / hr	25	Labour Costs	1533.12

2. *Causally assigned parameters (time, cost, and GHG emissions)*

Causally assigned parameters are not found for this level of the process.

3. *Allocated parameters (time, cost, and GHG emissions)*

A machine depreciates with every use of it. Thus, it is important to consider the depreciation costs of the machines as well. This will form the equipment costs of the cost tab. The following formula is used to calculate the machine depreciation. Machine depreciation calculations and formulas are in Appendix C of this thesis.

$$\text{Depreciation costs per production run} = \text{Machine or Equipment depreciation per year} \div \text{No. of production runs per year} \ldots\ldots\ldots\ldots. (8.1)$$

Table 8.4: Equipment Costs for machine groups of the PET process

Machine group	Machine Depreciation per year (AU $)	No. of production runs per year	Depreciation costs per production run (AU $)
Water Chiller & Pumps	40,426.00	72	561.47
PET(Heat& Drive) & Dryer	102,630.60	72	1441.01
		Machine cost	**2002.49**

PET machines require maintenance once a year. It can be argued that as machine maintenance is not related to just one production run, the cost has to be allocated to each production run. The following formula is used to allocate the machine maintenance costs for a production run.

$$\text{Maintenance costs per production run}$$
$$= \text{Machine or Equipment depreciation per year}$$
$$\div \text{ No. of production runs per year} \ldots\ldots\ldots\ldots (8.2)$$

Table 8.5: Maintenance Costs of the PET process

Machine group	Machine maintenance cost per year	No. of production runs per year	Maintenance costs per production run
Water Chiller & Pumps	1,000.00	72	13.89
PET (Heat& Drive) & Dryer	1,000.00	72	13.89
		Maintenance cost	**27.78**

As can be seen in the Table 8.5, maintenance is performed for machine groups by out sourcing labour. The Water Chiller and Pumps are considered to be in one machine group while PET (Heat and Drive) and Dryer are in another group. As this cost calculation is at process level, allocating the maintenance cost per each machine is not required. Therefore, maintenance is calculated for each production run.

Time | Energy | Cost | GHGs

ES	PET Process	EF
AS	Duration	Slack
LS	State	LF

Time Tab

Time | Energy | Cost | GHGs

kW	PET Process	Peak
kVA	Duration	Shoulder
Power Factor	State	Off-peak

Energy Tab

Time | Energy | Cost | GHGs

$25/hr	PET Process	Peak Rate
1.5	2453/60	Shoulder Rate
8712.50	State	Off-peak Rate
2002.49	Sub contractor	Network Rate

Cost Tab

Time | Energy | Cost | GHGs

Fuel Type	PET Process	Paper Waste
Fuel Amount	Duration	Wood Waste
Km/L	State	Other Waste
Travel Distance	+Air Travel	+Sea Travel

Emissions Tab

Figure 8.11: Process tabs after inserting data

Green ABM at shared level

Green ABM at a shared level provided the means to collect data for time and cost related parameters as long as they are practical to calculate at this level.

1. *Direct attributed parameters (time, cost, and GHG emissions)*

   Direct attributed costs are not found for this level of the process.

2. *Causally assigned parameters (time, cost, and GHG emissions)*

   Causally assigned costs are not found for this level of the process.

3. *Allocated parameters (time, cost, and GHG emissions)*

   Allocated parameters are not found for this level of the process.

This section showed how the data was collected and what data was collected. Thereafter, it showed how to perform Green ABM modelling and calculations for time and cost related parameters. However, the section did not calculate GHG emissions. The following section shows how the calculations were performed at the process level for GHG emissions.

2(c): GHG Emission Calculation at Business Process Level

Constituent Artefact-III, named "*A set of formulas that allows GHG emissions to be calculated at different process levels*", allows for the calculation of GHG emissions at various process levels. These formulas are discussed in Chapter 6 of this thesis.

Activity Level GHG emission calculation

By using formula (8.2) of *Constituent Artefact-III*, the tool can calculate the GHG emissions for a particular activity. Then this sub-section shows how to calculate the total assigned and attributed GHG emission figures at the activity level. It uses formula (2) of *Constituent Artefact-III*, to sum up the GHG emission figures of activity level emissions.

$$\text{GHG emissions from an activity} = \text{activity data} * \text{emission factor} \ldots\ldots\ldots\ldots(8.2)$$

Consolidated GHG emissions at activity level:

$$\sum_{i=1}^{n} T_i + \sum_{j=1}^{m} T_j = A_{tot} \ldots\ldots(8.3)$$

In this study, the organisation gets its power needs from an external energy provider. Purchased electricity is a cleaner energy source with no pollution at the point of consumption. This kind of purchased energy belongs to Scope 2 Activity Level GHG emissions.

As can be seen in the Table 8.6, the activity data needs to be in kWh unit format. The digital power meter used measures the power in kW. According to Beiser (2012), power is "the rate at which work is done by a force." Then, it further states, "A kilowatthour is the work done in 1 h by an agency whose power output is 1 kW". Table 8.6 shows how this research calculates the relevant activity data in kWh. According to the Department of Climate Change and Energy Efficiency (2012), Indirect (Scope 2) emission factors for the consumption of purchased electricity from the grid for New South Wales and Australian Capital Territory is 0.90 (kg CO2-e/kWh). Thus, in this study, from this point forward, the Scope 2 emission factor for electricity consumption is considered as 0.90 (kg CO2-e/kWh). This falls under the directly attributed emissions. Thus, in the following Table 8.6, only directly attributed emissions are shown.

Table 8.6: Scope 2 - Activity Level GHG emission calculations for the PET manufacturing process

	Activity Level-Activity	Directly Attributed Emissions Scope 2 (Metric Tonnes)				
		Electricity Consuming				
Machine	**State**	**Power (kW)**	**Duration (min)**	**Activity Data (A) (kWh)**	**Emission Factor (EF)**	**Emissions (E =A*EF)**
Chiller	Start-Up	145.86	30	72.930	0.9	0.066
Chiller	Pre-Production Fixed	69.7	30	34.850	0.9	0.031
Chiller	Pre-Production Variable	69.7	310	360.117	0.9	0.324
Chiller	Production	69.7	1020	1184.900	0.9	1.066
Chiller	Shutdown Variable	69.7	10	11.617	0.9	0.010
Chiller	Shutdown Fixed	69.7	960	1115.200	0.9	1.004
Dryer	Start-Up	64.6	10	10.767	0.9	0.010
Dryer	Pre-Production Fixed	21.99	240	87.960	0.9	0.079
Dryer	Pre-Production Variable	21.99	60	21.990	0.9	0.020
Dryer	Production	21.99	1020	373.830	0.9	0.336
Dryer	Shutdown Variable	21.99	10	3.665	0.9	0.003
Dryer	Shutdown Fixed	21.99	960	351.840	0.9	0.317
PET Heat	Start-Up	107	25	44.583	0.9	0.040
PET Heat	Pre-Production Fixed	35	30	17.500	0.9	0.016
PET Heat	Pre-Production Variable	35	45	26.250	0.9	0.024
PET Heat	Production	35	1020	595.000	0.9	0.536
PET Heat	Shutdown Variable	35	0	0.000	0.9	0.000
PET Heat	Shutdown Fixed	35	10	5.833	0.9	0.005
PET Drive	Start-Up	55	8	7.333	0.9	0.007
PET Drive	Pre-Production Fixed	38.5	30	19.250	0.9	0.017
PET Drive	Pre-Production Variable	38.5	30	19.250	0.9	0.017
PET Drive	Production	38.5	1020	654.500	0.9	0.589
PET Drive	Shutdown Variable	38.5	0	0.000	0.9	0.000
PET Drive	Shutdown Fixed	38.5	10	6.417	0.9	0.006
	Total Emissions (kg CO2-e/kWh)					4.523

Table 8.6, uses several abbreviations, A = Activity Data, EF = Emission Factor, E = Emissions.

Sub-process Level GHG emission calculation

The reporting tool uses a similar approach to that of activity level GHG emission calculation to calculate the emissions for sub-process levels. Therefore, it uses the same formula (8.2) to calculate emissions at sup-process level.

Similarly, the driver value represents the activity data and the consumption intensity represents the emission factor. The tool calculates missions from electricity consuming and Non-electricity consuming sub-process level activities separately using the following formula (8.4). Further, it calculates the total assigned and attributed GHG emission figures at the sub-process level.

$$SP_{tot} = SP_{elec} + SP_{non} \dots\dots\dots\dots (8.4)$$

SP_{tot} = Total emissions due to emissions captured at sub process level;

SP_{elec} = Electricity consuming emissions due to emissions captured at sub process level;

SP_{non} = Non-electricity consuming emissions due to emissions captured at sub-process level.

GHG emission calculations:

1. *Direct attributed emissions*

   Direct attributed emissions are not found for this level of the process.

2. *Causally assigned emissions*

   Causally assigned emissions are not found for this level of the process.

3. *Allocated emissions*

   Allocated emissions are not found for this level of the process.

Process Level GHG emission calculation

The reporting tool uses a similar approach to that of activity level and sub-process level GHG emission calculations to calculate emissions for process levels. Hence, it uses the same formula (8.2) to calculate emissions at process level.

The driver value represents the activity data and the consumption intensity represents the emission factor. The tool calculates emissions from electricity consuming and Non-electricity consuming process level activities separately using the following formula (8.5). Further, it calculates the total assigned and attributed GHG emission figures at the process level.

$$P_{tot} = P_{elec} + P_{non} \dots \dots \dots \dots (8.5)$$

P_{tot} = Total emissions due to emissions captured at process level;

P_{elec} = Electricity consuming emissions due to emissions captured at process level;

P_{non} = Non-electricity consuming emissions due to emissions captured at process level.

GHG emission calculations:

1. *Direct attributed emissions*

   Direct attributed emissions are not found for this level of the process.

2. *Causally assigned emissions*

   Employees who work for this manufacturing process commute daily to work. Though, this falls under Scope 3 emissions, this study considered this type of causal emissions as well to give a holistic picture of all of the emissions. It takes about 41 hours or in other words 2 days for a production run. This particular company has 8-hour shifts. Thus, there were 6 employees working on this process per day. In the data collection, daily commute related data was gathered using a survey. This survey queried about the, distance travelled, fuel economy of the employee's car, number of people in the car, number of working days, and emissions factor.

The following combined formula was formed by the researcher to calculate the daily commuting emissions according to GHG Protocol (Pino and Bhatia, 2002). The distance travelled, fuel economy of the employee's car, number of people in the car, and the number of working days represents the *driver value*. The emissions factor represents the *consumption intensity*.

$$\text{Emissions due to commute} = \text{distance travelled} \div \text{fuel economy of car} \div \text{number of people in car} * \text{number of working days} * \text{Emission factor} \ \ldots\ldots\ldots\ldots. (8.6)$$

Fuel efficiency and fuel type differs for each vehicle. Therefore, calculations were performed for each employee who drove to work. In this company due to the nature of work (e.g. shifts, location), employees need to travel by their own vehicles. Fuel economy of each car was obtained from FuelMileage.com.au (2014). Emission factors were obtained from the GHG Protocol (Pino and Bhatia, 2002). A total of 0.000877918 (0.0009) tonnes of Scope 3 emissions were reported from the employee commute to work. However, it is important to note that this emission is not due to electricity consumption from the grid.

3. *Allocated emissions*

Emissions belonging to this level are due to activities that do not directly add value to a business process or the organisation e.g. lighting, heating. The tool uses formula (8.7) of the set of formulas presented in the *Constituent Artefact-III*. This derived formula calculates emissions from a business process (which shares the organisational floor space). The formula given below considers an electricity consuming activity. Table 8.7 shows the electricity consumption of the PET process per month.

$$\text{Approximate kWh used} = \text{Total building use of electricity} * \frac{\text{Area of process's space}}{\text{Total building area}} \ldots\ldots (8.7)$$

Table 8.7: Monthly electricity consumption of the PET process

Monthly facility electricity bill (kWh)	Floor space used for the process	Monthly allocated process electricity consumption (kWh)
253335	200/1400	36190.71429

For a month there are approximately 6 production runs planned for the PET process. Thus, the following table shows how it calculates the electricity consumption and related emissions per production run.

Table 8.8: Electricity consumption per production run of the PET process

Monthly allocated process electricity consumption (kWh)	No. of production runs per month	Allocated electricity consumption per process (kWh)
36190.71429	6	6031.785714

As shown in the above table, allocated electricity consumption per process is 6031.785714 kWh. In order to calculate the emissions due to allocated electricity consumption per process, this figure is multiplied by the emission factor which is 0.90 (kg CO2-e/kWh). Thus, the process level allocated emissions are calculated as 5.4286 tonnes.

Shared Level of Emissions at Process Level

The tool will calculate the sum of all four business process level emissions. Thus, it will have emission figures for Activity level, Sub-process level, Process level, and Shared levels. Moreover, it will have separate figures for electricity consuming and non-electricity consuming activities of a particular activity level. The tool uses the following formula (8.8) to calculate the sum of all the process level emissions.

$$E_{proc} = A_{tot} + SP_{tot} + P_{tot} + SL_{proc} \ldots\ldots\ldots\ldots 8.8$$

Eproc = Total business process related allocated emissions

SLproc = Total shared level emissions

Ptot = Total process level emissions

SPtot = Total sub process level emissions

Atot = Total activity level emissions

Electricity consuming shared level emissions:

SLproc = Eproc – (Ptot + SPtot + Atot)

= 5.4286 – (0 + 0 + 4.5230) = 0.9056 tonnes

This concludes the utility of *Constituent Artefact-III*, a set of formulas that allows GHG emissions to be calculated at different process levels. It demonstrated how to use a set of formulas to calculate GHG emissions at activity level, sub-process level, process level, and shared level. These GHG emission figures are used by *Constituent Artefact-IV* i.e. *"A reporting tool that allows reporting of GHG emissions according to the scopes defined by the GHG Protocol"*. This is in the third area of the framework and it rolls-up data to corporate level reporting.

3. Roll-up Data to Corporate Level Stage

This third stage of the framework uses the artefact, "*A reporting tool that allows reporting of GHG emissions according to the scopes defined by the GHG Protocol"*. The second section shows how to calculate the total causally assigned, directly attributed, and allocated GHG emission figures at the process level. The reporting tool uses the Activity level, Sub-process level, Process level, and Shared level emissions to arrive at a consolidated GHG emissions inventory, based on scopes 1, 2, and 3. This gives the management a bird's eye view of what is happening within a particular process in the organisation. The cumulated GHG emission figure was obtained according to Scope 1, Scope 2 and Scope 3. Even though Scope 3 emission reporting is optional, this study considered it as well as to give a holistic picture of all of the emissions.

As shown in Figure 8.12, in order to calculate the total business process level emissions, the reporting tool uses formula (8.8). First, it calculates the totals separately for scopes, electricity consuming activities, and non-electricity consuming activities. This is clearly shown in the '*Activity Based GHG emissions'* leading towards the summary of total business process level emissions.

Figure 8.12: Summary of the total business process level emissions

This sub-section, *"3. Roll-up Data to Corporate Level"*, explained the developed tool that allows reporting of GHG emissions according to the scopes defined by the GHG Protocol. It goes in to finer details of how reporting should be performed to get a birds-eye view of organisational business process level emissions.

Process level emission calculation formulas proposed by this study were used to calculate at process levels. The section showed the GHG emission figures related to the processes. These figures are calculated for a particular production run. Then, GHG emission figures are rolled up to the corporate level for reporting for this production run instance which is the third stage of the overall framework.

Within the manufacturing process, GHG emissions change with activity duration changes. There can be different duration values for different instances of the same process. Thus, in Green ABM, the durations of activities in the critical path can change. It is a difficult task to calculate GHG emission figures manually. Hence, this set of formulas is programmed and implemented using Matlab. According to Mathworks (2014), Matlab is a *"high-level language and interactive environment for numerical computation, visualization, and programming"*. Due to these characteristics, the researcher selected Matlab as the programming tool.

The next section discusses the fourth stage of the framework named *"Multi-dimensional business process optimisation"*. It shows how the framework use a genetic algorithm named *"Elitist Non-Dominated Sorting GA (NSGA II/ NSGA2)"* in conjunction with the proposed Green ABM to solve multi-dimensional business process optimisation problem to achieve a set of optimal solutions.

4. Multi-dimensional Business Process Optimisation Stage

In the framework, this fourth stage performs the business process optimisation. This is further divided in to two sub steps. These are *"4(a): Business Process Re-designing / Improvement"* and *"4(b): Evaluate"*.

4(a): Business Process Re-designing / Improvement

In this organisation, one of the major business process changes in relation to managing GHG emissions that was considered was using electricity generated via green energy sources. The energy provider of this company provided a set on green energy solutions. In addition to these steps formal/mathematical optimisation techniques can be used.

Formal model for GHG emissions, time, electricity consumption and cost is formulated as a four-objective optimisation problem (This is discussed in Chapter 7 of this thesis):

$$f_1 = min \ (CD)$$

$$f_2 = min(\sum_{i=1}^{m} \sum_{i=1}^{n} (kW * D_{mn}))$$

$$f_3 = min((f_2 * R) + (f_1 * l * W) + (M_c + M_m + M_{rc}) + (kVA * N_{nw})))$$

$$f_4 = min(f_2 * Ef/1000)$$

f_1, f_2, f_3, f_4= Objective functions for time, electricity consumption, cost, GHG emissions

CD = Critical path duration	W = Wages Rate
m = Machine number	M c = Machine costs

n = Machine state | M m = Maintenance costs

D = Activity duration | M rc = Material costs

kW = Consumption | Nnw = Network costs

R = Electricity Rates | kVA = Kilovolts ampere value

l = Number of labourers | Ef = Emission factor

Minimise

$$f_1, f_2, f_3, f_4$$

Subject to:

$S_{14} = 0;$

$S_{24} = 0;$

$S_{34} = 0;$

$20 \leq D_{33} \leq 30$

$22 \leq D_{43} \leq 30$

$0 \leq D_{16} \leq 10$

$0 \leq D_{26} \leq 10$

$CD \leq 7200$

D_{33}, D_{43}, D_{16}, D_{26} = D_{mn} =Duration of a particular activity;

S_{12}, S_{24}, S_{34} = S_{mn} = Slack

Parameter specification for the genetic algorithm consisted of:

- Population of size = 100
- Generations = 100
- Crossover probability = 0.8
- Mutation probability = 0.2

The output from the Matlab consisted of a set of optimised trade-off solutions. In here, for the ease of visualisation, f_3 (cost) and f_4 (GHG emissions) is used to plot the graph in a 2-D plane. The first two objectives are not shown in this plot. The following Figure 8.13 shows the set of optimal points achieved for this optimisation run.

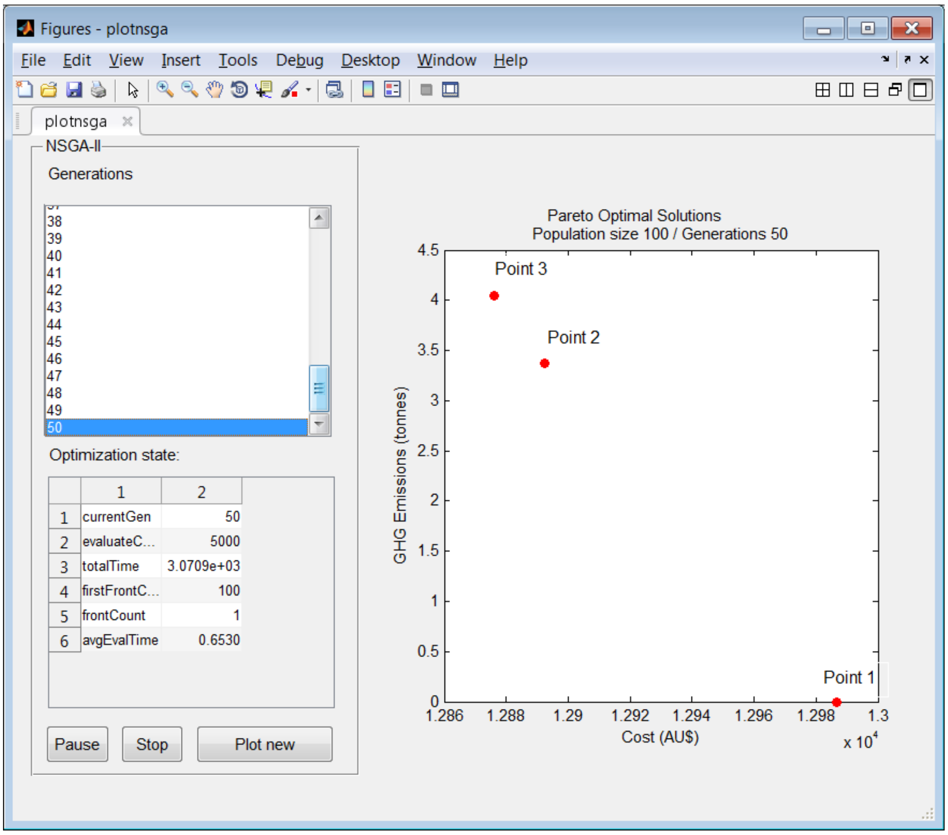


Figure 8.13: Non-dominated optimisation results using Matlab with NSGA2 together with Extended CPM

The first part of *"two-way mapping"* of the *Constituent Artefact-VI*, signifies that the artefact:

> *"Comes up with a computer program where NSGA2, a GA works in conjunction with the proposed Green ABM to solve multi-dimensional business process optimisation problem to achieve a set of optimal solutions"*

Therefore, the parameters captures through *Green ABM* is employed in the NSGA2 to solve the multi-dimensional business process optimisation problem. This NSGA2 program stores the values of each of the program variables in a database table for each and every member of the population for every generation. This table can be used to find out the related parameter values of the optimal points.

Following Table 8.9 shows the results of the optimisation run. According to the optimisation algorithm, optimal points are:

Table 8.9: Results from the optimisation run

Objective	Pareto-optimal points		
	Point 1 (P1)	**Point 2 (P2)**	**Point 3 (P3)**
f_1 = *time(min)*	2435	2435	2435
f_2 = *electricity (KWh)*	4999.33	4999.9	4999.33
f_3 = *cost(AU$)*	12986.6	12892.2	12876
f_4 = *GHGs (tonnes)*	0	3.37493	4.04946

(It is important to note that for the Point 1 (P1), the value "0" for GHGs does not mean that there is "zero" emissions. The algorithm has offset the emissions by switching to green energy sources.)

All these Pareto-optimal points have related variable values stored in the program database corresponding to each generation. Thus, the next section evaluates the optimal points against the business objectives mentioned in stage 1(c) of the framework. It simulates the Pareto-optimal points in a meaningful manner to the business users of this framework. Simulations can be performed according to the user preferences. As a result, the process manager or the decision maker has a choice and can use some higher level qualitative information to select one solution out of this set. In particularly the organisational decision maker can look at various possibilities. As the business environments are very dynamic, the ability to visualise along with the corresponding values adds a tremendous value to the business user.

4(b): Evaluate

The sixth artefact is the two-way mapping between the derived mathematical formula and NSGA2. The previous section showed how *Constituent Artefact-VI* came up with a computer program where NSGA2, a GA worked in conjunction with the extended CPM, to solve the multi-dimensional business process optimisation problem to achieve a set of optimal solutions. This is the first part of *"two-way mapping"* of *Constituent Artefact-VI*. The second part of *"Constituent Artefact-VI"* used *"simulation and related the Pareto-optimal solution set back to the business domain in terms of what are the parameters and their values in a manner understood by the business managers."* This section shows how the framework performed part 2 of this artefact.

Section 1(c) identified business objectives as:

- Mitigate GHG emissions, for the value to be less than 20% of the current year's value by next year.
- Reduce the time to market, for the value to be less than 1% of the current year's value by next year.
- Reduce the cost of production, for the value to be less than 2% of the current year's value by next year

The business objective is to reduce this PET process's GHG emissions, time, and cost values. GHG emission related figures are calculated in the stage 2(c) of the framework. Stage 2(b), modelled other business process level objectives like time and cost alongside GHG emissions. The following sub-section uses this data to confirm if the results have achieved the stated objectives and where if any compromises have been made.

The stated objectives are calculated as given below:

- f_1 *= time (min):* This is the critical path duration where the maximum duration values were considered for the activities with variable figures. As considered in *"Figure 8.7: The Activity*

Level Time Profile of the Green ABM architecture.", the maximum figure for the critical path duration is 2453 mins. Business objective is to reduce 1% by next year, thus, the target value considered is 2428.47 mins.

- *f_2 = consumption (KWh):* This is the allocated electricity consumption per process (KWh). As demonstrated in *"Process Level GHG emission calculation"*, page 242, the allocated value is 6031.7857 KWh. Business objective is to reduce the emissions by 5% by next year. Thus, to achieve this target, the target process level emission is 4825.4286 KWh.
- *f_3 = cost (AU\$):* This figure is a combination of the cost of electricity consumption, labour, material and KVA. The cost for electricity consumption is calculated by allocating the electricity bill cost. (This is calculated in the sub section*" Process Level GHG emission calculation"*, page 242). Monthly electricity bill is AU$ 39291.11. As the floor space used is 200/1400, the monthly allocated process electricity cost is AU$ 5613.02. Since, there are 6 production runs per month, the allocated electricity cost per production run is AU$ 935.50. As shown in the "*Green ABM at business process level*", page 234, sub section, the cost of raisins and colour dye is AU$ 8712.50. Machine maintenance costs are AU$ 27.78. Labour costs are AU$ 1533.12. The sum of all these figures is considered as the cost. This is AU$ 13211.39. As the business objective is to reduce the cost of production by 2%, the target cost should be AU$ 12947.16.
- *f_4 = GHGs:* Total GHG emissions is reported in the third stage, *"3. Roll-up Data to Corporate Level Area"*, page 246, of the framework. According to this, the total Scope 2 Emissions Due to Electricity Consuming Activities is 5.4286 tonnes. Total Scope 3 Emissions Due to Non-electricity Consuming Activities is 0.0009 tonnes. By summing-up the both figures the total GHG emissions per production run is 5.4295 tonnes. However, in mathematical formulation, only the attributed or assigned figures are considered, as allocated figures do not add value to the process. As explained in Chapter 5, the taxonomy of business process element changes was used to derive the mathematical formula. As shared emissions (e.g. lighting and heating) may change due to factors beyond this business process, it is

logical only to disregard it for the optimisation of this process. Hence, process level GHG emissions are considered as 5.4286 tonnes for optimisation purposes. If the desired values are to be less than 20% of this figure then it has to be below 4.3429 tonnes. The following table compares the business objectives against the results obtained.

Table 8.10: Business objectives vs. the results obtained

Objective		**Pareto-optimal points and success**					
Result	**Stated objective**	**Point 1**	**Objective Reached? Y / N**	**Point 2**	**Objective Reached? Y / N**	**Point 3**	**Objective Reached? Y / N**
f_1 = *time(min)*	2428.47	2435	N	2435	N	2435	N
f_2 = *electricity (KWh)*	6031.79	4999.33	Y	4999.9	Y	4999.33	Y
f_3 = *cost(AU$)*	12947.16	12986.6	Y	12892.2	Y	12876	Y
f_4=*GHGs (tonnes)*	4.3429	0	Y	3.37493	Y	4.04946	Y

As can be seen in Table 8.10, there are compromises for the achieved objectives. In general the results have converged towards the optimal front. The results show that f_2 *(consumption)*, f_3 *(costs),* and f_4 *(GHGs)* have achieved the set business objective. Whereas f_1 *(time)* shows a compromise. However, the difference between the objective and the optimal point is very small.

The results achieved in this section needs to be related back to the business domain in terms of what the parameters are and their values in a manner understood by the business managers. In order to do this, the multi-objective formula below is used.

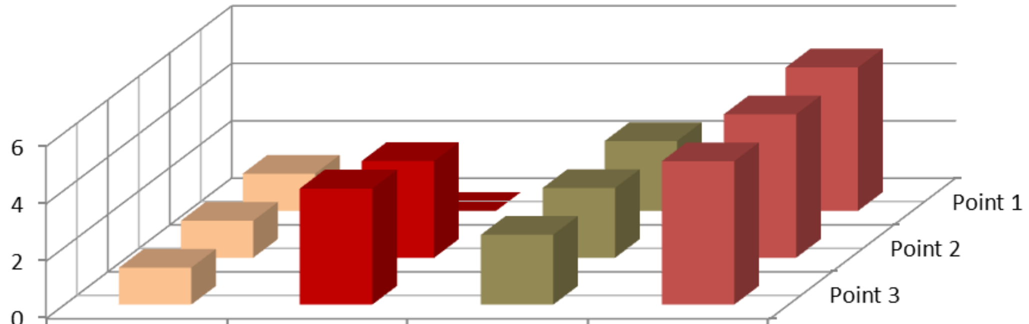
$$f_1 = min\ (CD)$$

$$f_2 = min(\sum_{i=1}^{m} \sum_{i=1}^{n} (kW * D_{mn}))$$

$$f_3 = min((f_2 * R) + (f_1 * l * W) + (M_c + M_m + M_{rc}) + (kVA * N_{nw})))$$

$$f_4 = min(f_2 * Ef/1000)$$

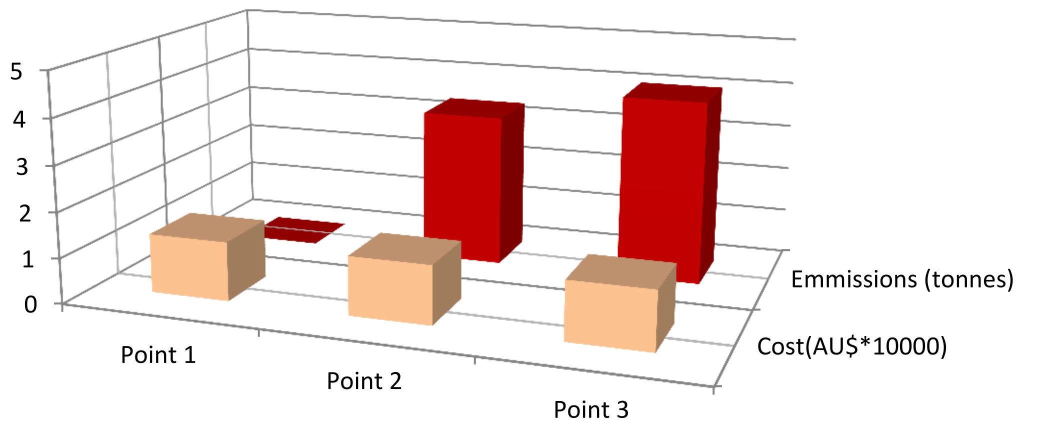
In $f_1$critical path is given. f_2 gave the electricity consumption of the process per production run. f_3 gave the related cost figure, while f_4 gave the GHG emission figure. Optimal points in this Pareto front have the same time and consumption figures. Hence, it can be inferred that 2435 minutes for the entire process time duration and 4999.33 KWh for the consumption are the singular optimal values for the process. The following graph shows the simulated figures for f_2, f_3, andf_4 .



	Cost(AU$*10 000)	Emmissions (tonnes)	Critical Path (mins*1000)	Consumption (kWh*1000)
Point 1	1.29866	0	2.435	4.99933
Point 2	1.28922	3.37455	2.435	4.99933
Point 3	1.2876	4.04946	2.435	4.99933

Figure 8.14: Relationship among time, cost, and GHG

Generally, organisational managers are mostly concerned about the impact on cost if the GHG emissions are mitigated. The following shows the relationship between cost and emissions.



	Point 1	Point 2	Point 3
Cost(AU$*10000)	1.29866	1.28922	1.2876
Emmissions (tonnes)	0	3.37455	4.04946

Figure 8.15: Relationship among time, cost, quality and GHG

Supposing a manager decides to select Point 3 to be the most suitable optimal point under prevailing conditions, the summarised view of the machine schedule is as shown in Figure 8.16. This clearly shows the process start time as 3:00 PM on the third day and the finishing time as 6:40 AM on the fifth day as the finishing time. As can be depicted from Figure 8.16, four machines, PET Heat, PET Drive, Water Chiller, and Dryer run simultaneously. Switching on of these four separate machines (i.e. PET Heat, PET Drive, Water Chiller, and Dryer) is staggered.

Figure 8.16 is a 2-dimensional graph and according to this, the total area under the curve of each of the machine will provide the energy consumption by each machine. Therefore, the total area will provide with the total energy consumption of the process.

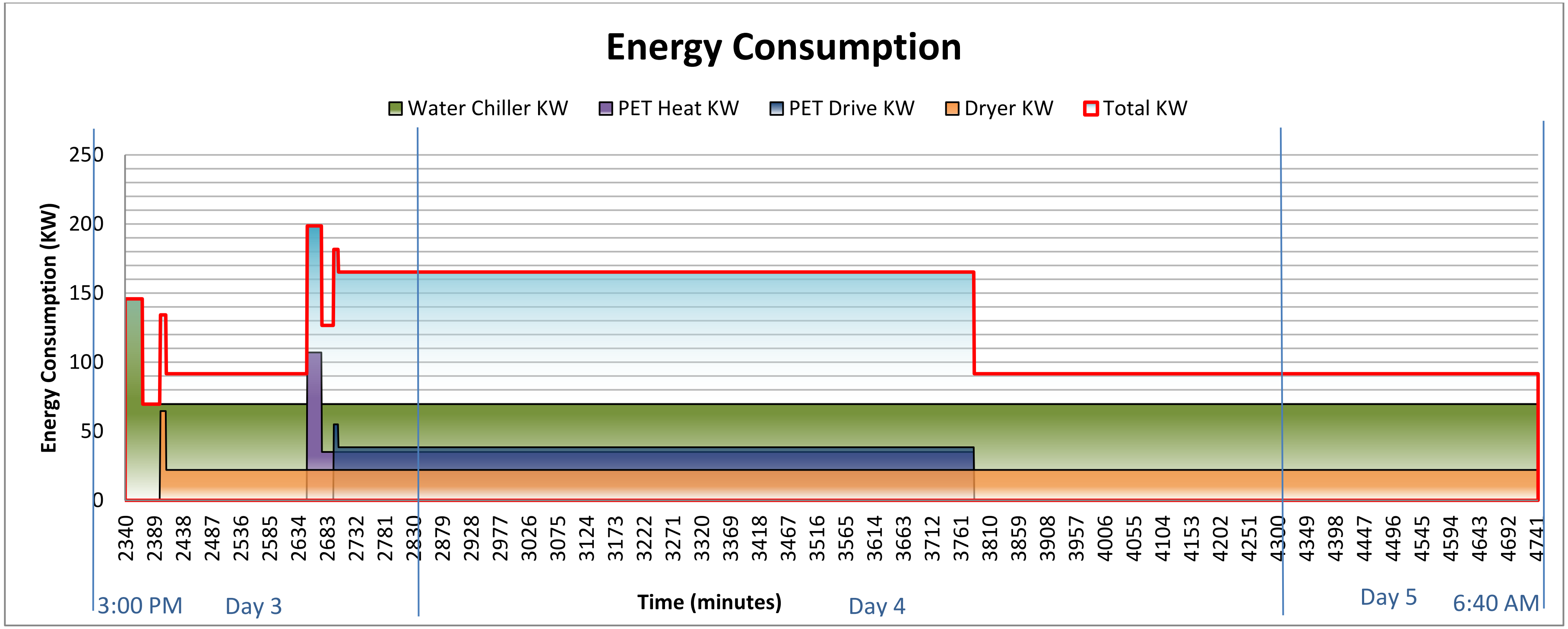


Figure 8.16: Energy consumption profile for the production run

Figure 8.17 illustrates the variations in the kVA value as different machines start. As explained earlier, during the initial start-up phase, a machine has a higher kVA value. Thereafter, once it goes into the running mode it has a lower kVA value. Further, graph clearly shows how the kVA values add up to make the highest kVA figure for this production run. The energy supplier bills monthly for the highest kVA value consumed by a particular single geographical site. Higher kVA values are harmful to the power distribution grids. Thus, in NSW, Australia there is a threshold for the amount of maximum kVA for an electricity energy consumer.

As explained in the section "7.2.3. Setting the criteria to select a suitable optimisation technique", it is difficult to optimise for all the objectives, some of which may conflict with each other, at the same time. Multi-objective optimisation algorithms in particularly search for non-dominated solutions and obtain a set of trade-offs among objectives or a "Pareto" optimal set. Optimising for several objectives simultaneously result in a set of solutions rather than a single solution. Each objective is considered as a function that the algorithm will then seek to optimise through changes in the problem variables while satisfying the constraints. Thus, the term "Optimise" implies that finding solutions that would provide all acceptable objective function values to the decision maker. Now, the decision maker does not need to find the most suitable solution in a large search space but rather select the preferred solution from the finite Pareto optimal set for the problem at hand. As discussed in this section, the framework evaluated this finite set of solutions to help the organisational decision maker select the best solution after considering present business requirements.

This concludes the evaluation and discussion aspect of the framework. The following section addresses a set of guidelines to justify the requirements of a design science research project. Each guideline is discussed to demonstrate that the research project satisfies the design science requirements (Hevner et al., 2004).

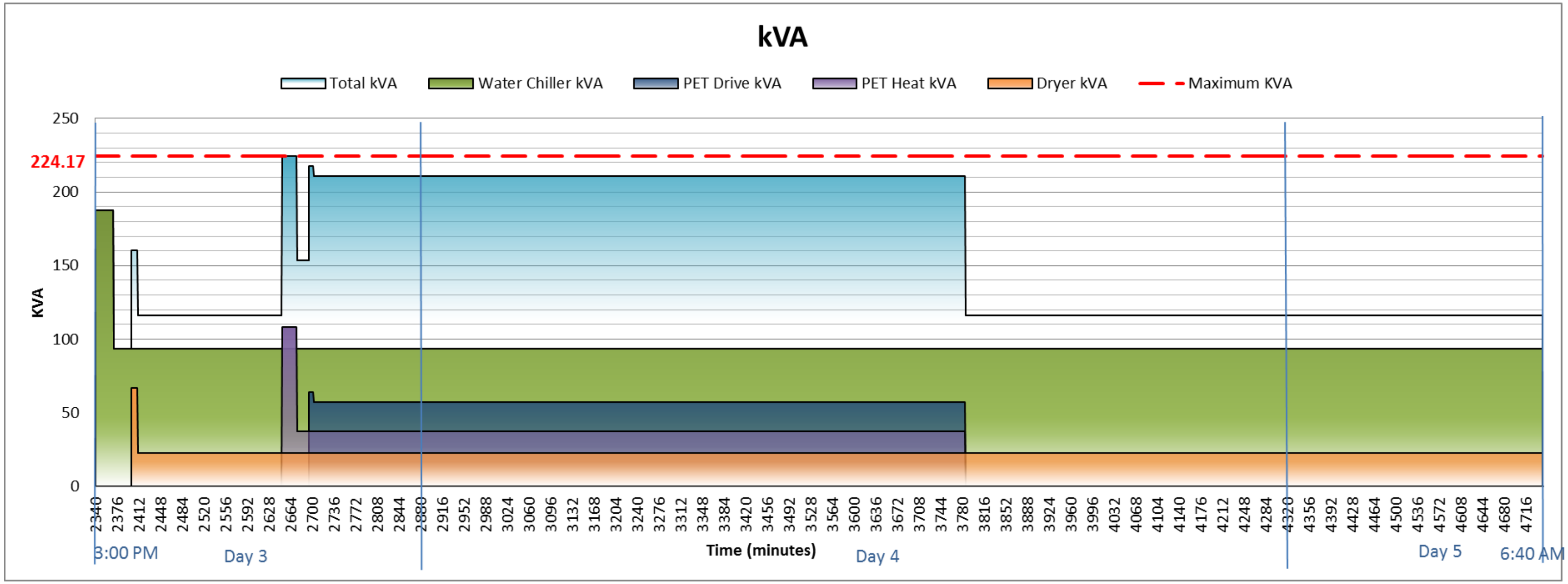


Figure 8.17: Apparent power (kVA) profile for the production run

8.4 Requirements for effective Design Science research

Hevner et al.(2010) provide with a set of guidelines as the norm to justify the requirements of a design science research project.

Guideline 1: Design as an Artefact

The main artefact built is *"A framework for multi-dimensional business process optimisation for GHG emissions management*" This framework incorporates models, methods and an instantiation. Chapters 5, 6, and 7 explain these.

Guideline 2: Problem Relevance

This research successfully solves the research problem of *"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"* The *Green MOPO framework* help support the organisational middle level management. This framework successfully achieves its research objectives and this chapter showcased this in the previous section.

Guideline 3: Design Evaluation

This research rigorously demonstrates utility, quality, and efficacy of the framework via well executed evaluation methods. Each area in the framework was iteratively evaluated prior to assessing against the IBM process within PET package manufacturing company. This prior evaluation included: an initial pilot study with a logistics company for functional testing to discover failures and defects; experimental simulation by executing the framework with test data; and descriptive evaluation using hypothetical detailed scenarios around the framework to showcase its utility.

Guideline 4: Research Contributions

This research outputs several new and innovative contributions to solve the business problem mentioned in the Problem Relevance guideline. Foremost contribution is the main artefact, *"Green MOPO framework"*. Following chapter goes in to details of this section, under the *"9.3.1 Contributions for Research"* section.

Guideline 5: Research Rigor

Research rigor is gained through the way the research was conducted in both construction and evaluation of the designed artefact. This research successfully developed the framework (Chapters 5, 6, and 7) and evaluated the artefact (Chapter 8).

Guideline 6: Design as a Search Process

Design Science often captures the knowledge through abstraction which decomposes problem into simplified sub-sets. In this research, each main stage in the framework sub-divided the research problem as: identification, GHG emission calculation and analysis, GHG emission reporting, and optimisation. Again these stages are decomposed in to further steps. This simplified an otherwise much more complex organisational problem. Thus, different areas resulted in constituent artefacts which addressed important aspects in-depth. Through iterations each became more refined in nature and in its application.

Guideline 7: Communication of Research

This research and the framework were presented to several audiences which included both academics and industry practitioners. The researcher clearly articulated the design process (the set of activities) employed in this research to build the framework. This research produced the following publications.

- WESUMPERUMA, A., GINIGE, J. A., GINIGE, A. & HOL, A. Framework for Multi-dimensional Business Process Optimization for GHG Emission Mitigation. 22nd Australasian Conference on Information Systems ACIS 2011 - Paper 91, 2011. AIS Electronic Library.
- WESUMPERUMA, A., GINIGE, A., GINIGE, J. A. & HOL, A. Green Activity Based Management (ABM) for Organisations. 24th Australasian Conference on Information Systems (ACIS), 2013 Melbourne, Australia. Melbourne: RMIT Library Research Repository, 11.
- WESUMPERUMA, A., GINIGE, A., GINIGE, J. A. & HOL, A. Green Activity Based Reporting for Organizational Business Process Management. 10th Asia Pacific Conference on Sustainable Energy & Environmental Technologies (APCSEET 2015), 2015 Korea. 4.

8.5 Chapter Conclusion

This research was pursued to find an answer to an important and a pragmatic problem faced by businesses. The research undertook a qualitative and quantitative examination of GHG emission management and other business objectives of a business to perform multi-dimensional business process optimisation. The researcher articulated this problem in the form of a research question as *"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"* The research goal was realised as a framework named *"Green MOPO framework"* The design process, a sequence of expert activities, produced this innovative framework. Moreover, a set of six constituent artefacts were produced and these collectively helped to build both functional and construction aspects of the framework. In *Design Science Research* two fundamental questions asked are: *"What utility does the new artefact provide?"* and "*What demonstrates that utility?"* This Chapter addressed this aspect of the *Design Science Research Methodology* and successfully provided evidence according to the framework stages. This proved that the research delivered satisfactory answers to the research question to address the problem currently faced by businesses. This concludes the validation and discussion of this research. The next chapter is the *"Conclusion, Limitations, and Future Research Directions"*. The chapter will restate the important findings, limitations, and the main highlights of this research.

CHAPTER 9 : Conclusion, Limitations, and Future Research Directions

9.1. Chapter Introduction

Chapter 1 introduced the study background and highlighted the real world problems faced by businesses. It stated that businesses need to manage and optimise their business processes not just for objectives like costs and time but for GHG emissions as well. Further, Chapter 1 specified the research aim which would address the identified research problem. This chapter presents how this research fulfilled the aim stated in the introductory chapter. The chapter will show how the conclusions were drawn from relating the performance to the intended use of the framework as argued in the evaluation and discussion chapter. It briefly examines the contributions to research community and practitioners by research findings. Further, the chapter makes suggestions on additional work this research investigation left incomplete. It concludes with indicating avenues where future researchers can pursue related goals for academic merit.

9.2. Major Conclusions

As stated in Chapter 1 of this thesis, the main aim of this research was to *"develop a framework to perform multi-dimensional business process optimisation including GHG* *emission management to support and empower organisational middle level managers"*. In order to achieve this, the framework had to attain two goals. The two goals were:

(1) Model, analyse, and calculate GHG emissions at a business process level and report at corporate level as required by the GHG Protocol standard;

(2) Analyse GHG emissions against other business objectives to arrive at an optimal solution in GHG emission management.

This research successfully achieved the stated aim by developing the framework named, *"Green MOPO framework".* The framework answered the research question of *"How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?"* This answer was systematically developed by using the *Design Science Research* methodology.

The major conclusions indicated that:

- Measuring, modelling, and calculating had to be conducted at various process levels and apportioned for shared or overhead emissions e.g. lighting and heating.
- Activity based reporting of GHG emissions empowered the organisational middle level managers by providing a detailed bird's eye view of emissions and their sources.
- The selection criteria that gave the most suitable optimisation technique to solve the optimisation problem had to be determined.
- The computer based simulation had to relate the optimal solutions back to the business domain, and specify the optimisation parameters and their values in a manner that is clearer and concise to business managers.

9.3. Contributions of Research Findings to Research Community and Practitioners

The main artefact constituted of six related components. Table 9.1 provides a summary of each component and indicates the research question it solved. As explained in Chapter 8, each main stage in the framework sub-divided the research problem. These sub-divisions helped to tackle the complex research problem which spanned across many disciplines i.e. environmental science, mathematics, information systems, business management. This allowed the researcher to conduct in-depth investigations and fulfil the requirements of each problem area. This research provides significant research contributions and new possibilities to the research community and to practitioners. Thus, the following two sub-sections point out these research contributions.

Table 9.1: A summary of the main artefact, its constituent artefacts and contributions to the knowledge base

Main Research Question	**How can multi-dimensional business process optimisation be performed to support the management of GHG emissions?”**
Main Artefact	**A framework for multi-dimensional business process optimisation for GHG emissions management**

Sub Research Questions	**Investigative Questions**	**Output/ Constituent Artefact**	**Frame -work Stage**	**Contribution to knowledge base**		
				Extension or Addition?	**New**	**Publicatio n**
1. How can GHG emissions at a business process level be modelled, measured, calculated, and reported efficiently?	1.1 What are the levels of a business process, in which GHG emissions can be modelled?	I. A set of guidelines to assist identification of a business process and its different abstraction levels i.e. activity level, sub-process level, process level, and shared level.	2	✓		[1]
	1.2 How can GHG emission be modelled, measured, and calculated in above identified business process levels?	II. A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time, and cost modelling and further analysis at different business process levels.	2	✓	✓	[2]
		III. A set of formulas that allow GHG emissions to be calculated at different business process levels.	2	✓	✓	[1]
	1.3. How can GHG emissions associated with a business process be reported in three emissions categories identified by the *Greenhouse Gas (GHG) Protocol*, namely Scope 1, Scope 2, and Scope 3?	IV. A reporting tool that allows reporting of GHG emissions according to the scopes defined by the *GHG Protocol*.	3		✓	[3]

Sub Research Questions	Investigative Questions	Output/ Constituent Artefact	Frame -work area	Contribution to knowledge base		
				Extension or Addition?	**New**	**Publication**
2. How can a set of multi-dimensional parameters including GHG emissions associated with a business process be optimised effectively?	2.1 How can other business objectives such as cost and time be modelled against GHG emissions in a business process?	II. A tool and a methodology named Green Activity Based Management (ABM) that allows GHG, time and cost modelling and further analysis at different business process levels.	2			[2]
	2.2 What is the criterion for selection of an optimisation technique to support business process optimisation against a set of multidimensional parameters, including GHG emissions?	V. A criterion for selection of an optimisation technique that can optimise a multi-objective mathematical formula that captures possible process level changes of GHG emissions with other objectives.	2,4			
	2.3 How can a selected optimisation technique (based on the criteria set above) be applied for business process optimisation for GHG emission management alongside other business objectives?	VI. Two-way mapping between the derived formula and the NSGA2, which is the selected optimisation technique.	4			

Following is the list of publications:

1. Wesumperuma, A., et al. Framework for Multi-dimensional Business Process Optimization for GHG Emission Mitigation. in 22nd Australasian Conference on Information Systems ACIS 2011 - Paper 91. 2011. Sydney, Australia: AIS Electronic Library.
2. Wesumperuma, A., et al. Green Activity Based Management (ABM) for Organisations. in 24th Australasian Conference on Information Systems (ACIS). 2013. Melbourne, Australia: RMIT Library Research Repository.
3. Wesumperuma, A., et al. Green Activity Based Reporting for Organizational Business Process Management. in 10th Asia Pacific Conference on Sustainable Energy & Environmental Technologies (APCSEET 2015). 2015. Korea.

9.3.1. Contributions for Research

As shown in the Table 9.1, research produced artefacts that extended or added to the existing theories as well as new contributions to the knowledge base. Some of these contributions are published as conference papers. As described in Chapter 8, the evaluation that was performed demonstrated every artefact served its intended purpose rigorously in terms of utility, quality, and efficacy. Collectively these constituent artefacts contributed in varying degree to build the main, new, and innovative artefact.

This main artefact is the major contribution of this research to the knowledge base. Further, the framework is innovative as it came up with a new solution to a contemporary and new research problem. The framework provides systematic business process optimisation for several quantitative dimensions. To date, quantitative dimensions like cost reduction, turnaround time, and quality of product have materialised as business objectives for business process optimisation. However, GHG emission management has never been considered as one objective. Therefore, this study brings together new knowledge in how to multi-dimensionally optimise a business process including GHG emissions. As discussed in Chapter 3, the research approach combined both inductive and deductive reasoning to come up with results. The research was more inductive in nature with some deductive characteristics.

9.3.2. Contributions for Practitioners

The research developed the main artefact to help and support organisational middle management. Generally, organisations function as a set of processes under the supervision and control of the middle management. The main artefact empowers and provides the management with much needed opportunities to manage and optimise for GHG emissions together with other process level objectives. Further, analytical simulations of optimised solutions provided the opportunity to look at not just one option but a few, so that the decision maker or the manager can use some higher level qualitative information to select one solution out of this set. As the business environments are very dynamic, the ability to visualise the process along with the parameters and corresponding values involved added a tremendous value to the business user. Finally, multi-dimensional business process optimisation is difficult to perform manually. As there are many variables involved, manual calculations are difficult to include all these variations. This framework uses Matlab to implement the optimisation aspect of the framework. Thus, it provides with several options to visualise the optimised results. Analytical simulations provide the managers with visual models and thus, increase their perception of the business process and impact of the process level changes.

9.4. Research Limitations

During the course of this research several limitations became apparent. Limitations arose due to reasons like time frame available for a PhD research project, available resources, and nature of the manufacturing organisation. Though, these limitations did not hinder the output of this research, it is important to state them as these limits will pave ways to future research directions. These limitations are:

- The final evaluation was conducted using a Polyethylene terephthalate (PET) package manufacturing process. The predominant emission source was the Scope 2 emissions from consuming purchased electricity. As explained in Chapter 5, only comparatively stable business processes are selected to optimise for this research project. Thus, *"Green ABM"* was developed and evaluated only for stable business processes.

- The research only considered two other business process level objectives. These were reducing time to market and reducing the cost of production. These two objectives were selected as these are quantifiable. However, in a business there are objectives like quality. Improving quality of a product can be both quantitative and qualitative, or either one of them. If quality is quantifiable the framework can very easily incorporate it. However, if quality is described in a qualitative manner this framework cannot cater for it. Thus, this framework only considers the quantifiable objectives of a business process.
- The "*Criterion to Select a Suitable Optimisation Technique*" was applied against a selected set of genetic algorithms. According to the literature review conducted, SPEA2 and NSGA2 both showed promising results for the research context considered in this research. Thus, both were suitable candidates to perform multi-dimensional business process optimisation. According to an internal design validation, the researcher selected NSGA2 as the multi-objective optimisation technique. Ideally, if both optimisation techniques were implemented this would have given an opportunity to compare the performance of the two techniques.
- Currently, major stages of framework are implemented in isolation. Identification stage, business process modelling, data collection and GHG emission calculation stage, reporting stage, and business process optimisation stage all have underlying computer programs. However, these are not integrated. Therefore, required data inputs from one stage to the other were transferred manually. Thus, this framework is not yet a fully-fledged automated information system.
- As shown in the section, "6.3.2. Extension of the Activity Based Costing (ABC) method to include GHG emissions management", activities consume resources like material and labour. The "Figure 6.2" illustrated that in this research a

"Resource Driver" is sub-divided in to two categories as *costs* and *emissions.* By extending the ABC method to include GHG emissions, the research linked the activities and resources to the business process model. As explained in the Guideline 7, similar to ABC's various resource consumption levels, emissions can be measured at various process levels as *Activity level, Sub-process level, Process level* and *Shared level.* The section "6.3.3. Extension of CPM to include the extended ABC", showed how Green ABM modelled time, energy, cost and GHG profiles of a business process in Time, Energy, Cost and Emissions tabs of a node. In particularly, it elaborated on how a resource such as a *machine* is modelled by taking in to consideration parameters like kW (Wattage of a machine used to perform a certain action / Useful power), KVA (total apparent power), Power Factor (the ratio between the useful (true) power (kW) to the total (apparent) power (KVA) consumed by a machine to perform a certain action.) In context of this research, the framework is to support and empower the organisational middle managers and provide a tool they can use to manage GHG emission alongside other process level objectives. In addition, further resource level modelling like product life cycle emissions, would fall under the Scope 3 emissions. Hence, it would be difficult for the middle level managers to consider such emissions on a day to day basis. Thus, this research does not further elaborate on resource models.

The framework that achieved the research aim of *"performing multi-dimensional business process optimisation including GHG emission management to support and empower organisational middle level managers"* has implications for future research directions.

9.5. *Future Research Directions*

This research contributed towards a very important and current business need that is not limited to a specific country. As this research is based on *GHG Protocol* (WBCSD-WRI, 2004) which provides international standards for GHG accounting and reporting, this framework has great potential as the application domain is global. Managing GHG emissions to help combat climate change helps to tackle the major global challenge of the present generation. The threat from climate change is serious, it is growing and urgent. Hence, any future implications from this research will help this generation to better respond to this major global challenge that shows no boundaries. In the previous section it listed some of the limitations in this study. Most of these limitations may open up very important future research possibilities.

This research extended the BPMN notation to capture GHG emissions at the business process level. These extensions allow GHG emissions modelling at a business process level. These are shown in Appendix B of the thesis. However, this research did not pursue this beyond these visual process modelling. Business Process Modelling Language (BPML) is the counterpart of BMPN (Vergidis et al., 2008). BPML is a XML-based language which encodes the process flow in an executable form. Each of the BPML processes consists of a name, a set of activities, and a handler. Smith (2003) states that BPML presents a metalanguage which is process-centric as well as an executional model for business systems. This aspect is an important future research avenue. It has great potential as BPMN and BPML together can model, analyse, and improve business processes. However, recently the focus on pairing up BPMN with BPML shifted towards BPMN with Business Process Execution Language (BPEL). This too bridges the gap between business process design and business process implementation (White, 2005). Thus, creating executable processes from process models is a very important and interesting avenue.

This research bridges the gap between the formal process model and process optimisation using the two-way mapping between the derived formula and the selected optimisation technique, the NSGA2. This two-way mapping currently supports NSGA2 only. This can be extended to include other optimisation evolutionary algorithms like Strength Pareto (SPEA2); Vector Evaluated GA (VEGA); Multiple Objective GA (MOGA); Non Dominated Sorting GA (NSGA); Niched-Pareto GA (NPGA); Strength Pareto EA (SPEA). As explained in the Chapter 7, performances of evolutionary algorithms vary depending on the application domain. In different contexts, some algorithms converge towards a Pareto-optimal front better than others (Sag˘ and Çunkas, 2009).

In the framework, only quantifiable business process level objectives are considered. Objectives with a more qualitative nature are not considered. Hence, the formal model only considered GHG emissions, time, and cost. Quantifying a more qualitative process level objective such as product quality is a challenging and interesting possibility. This will offer many more options to the organisational management for decision making.

9.6. Chapter Conclusion

The purpose of this thesis was to undertake a qualitative and quantitative examination of managing GHG emissions to achieve multi-dimensional business process optimisation while considering other process level objectives like cost and time, to support and empower organisational middle level managers in decision making. This study developed a framework that organisational middle level managers can use to achieve this stated purpose. This concluding chapter stated the significance of the research findings of this study.

In conclusion, it is clear that this research has fulfilled its aim that was stated in Chapter 1 by developing a framework that is innovative, useful, effective, and efficient in successfully solving the important and pragmatic research problem.

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Appendix - A: Online tool to collect organisational data

Concise Descriptions and Screenshot

An online tool offers several advantages. This online tool was designed taking several such advantageous factors into consideration. Factors such as: environmentally-friendliness, cost-effectiveness, accessibility, convenience, and data quality were some of those considered.

The main artefact, “Green Multi-Objective Process Optimisation (Green MOPO) Framework”, requires data inputs starting from activity level leading up to organisational level in a bottom up manner. This online tool to collect organisational data was designed by taking generic organisational structures in to consideration as employees would need to furnish data according to the role they play within the selected business process. Therefore, prior to collecting data, one particular energy intensive process would be chosen to perform the business process level optimisation.

This tool allows for four types of users. A system administrator, Top level managers, middle level managers, and staff. All these users must relate to the selected business process. This tool collects data at four organizational levels. These include organizational level, business process level, sub process level, and individual level. Organizational data would be collected from the top level management. Process level and sub process level data would be collected from the middle level management. Individual data would be collected from individuals involved in the selected process.

All users can gain access to the online tool by identifying and authenticating themselves. This is the entry point to the online tool. The following section describes the login screen.

Login Screen

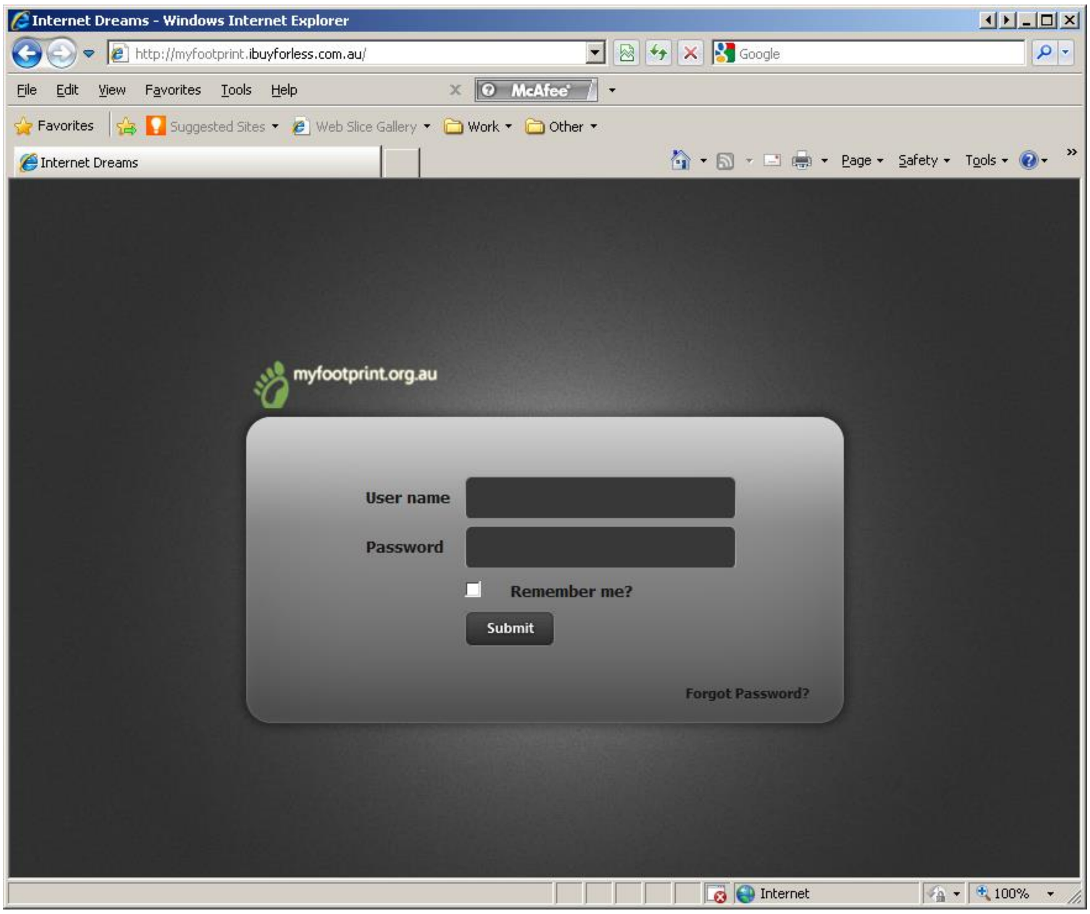

Figure A.1: Login Screen

This screen prompts the user to input a username and the password. Depending on the credentials they will be guided towards one of the three types of screens related to each employee's role. If a user forgets their password, they can use the forgot password page to reset the password.

Organisation list screen

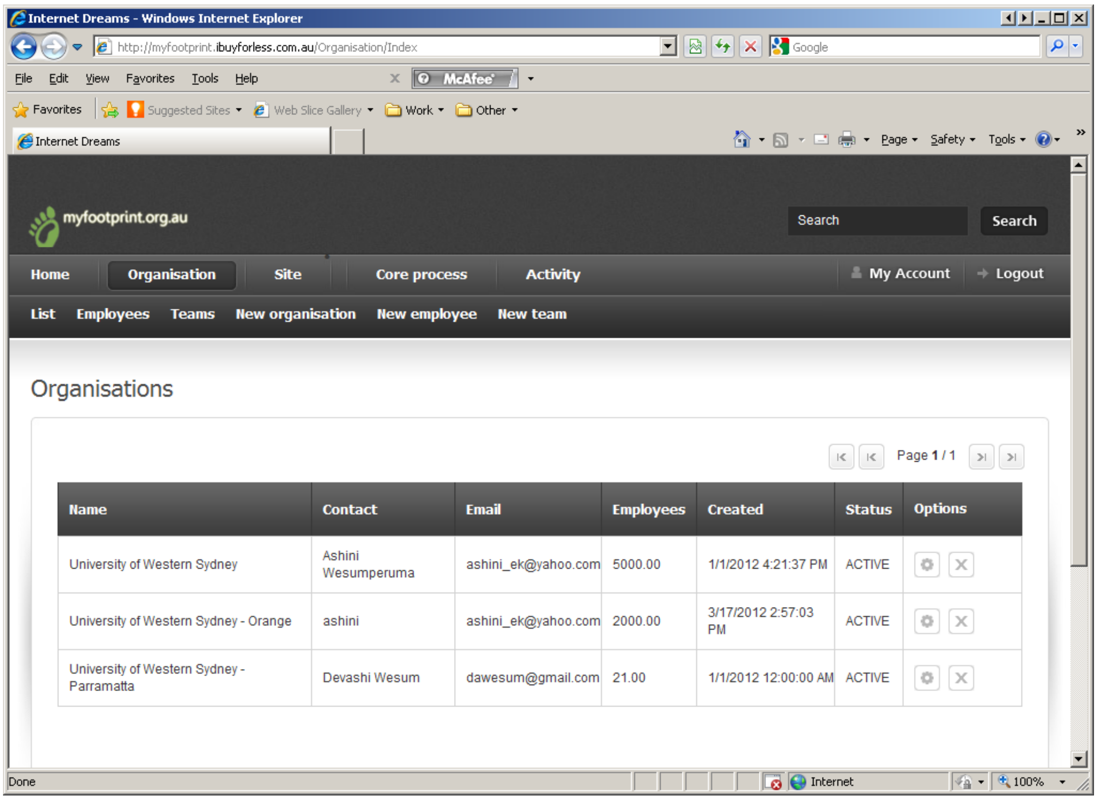

Figure A.2: Organisation creation screen.

This is the organisation list screen that will display all the organisations currently in the system. This screen is only visible to the system administrator and they can create an organisation, initial logins and temporary passwords.

Organisation edit screen

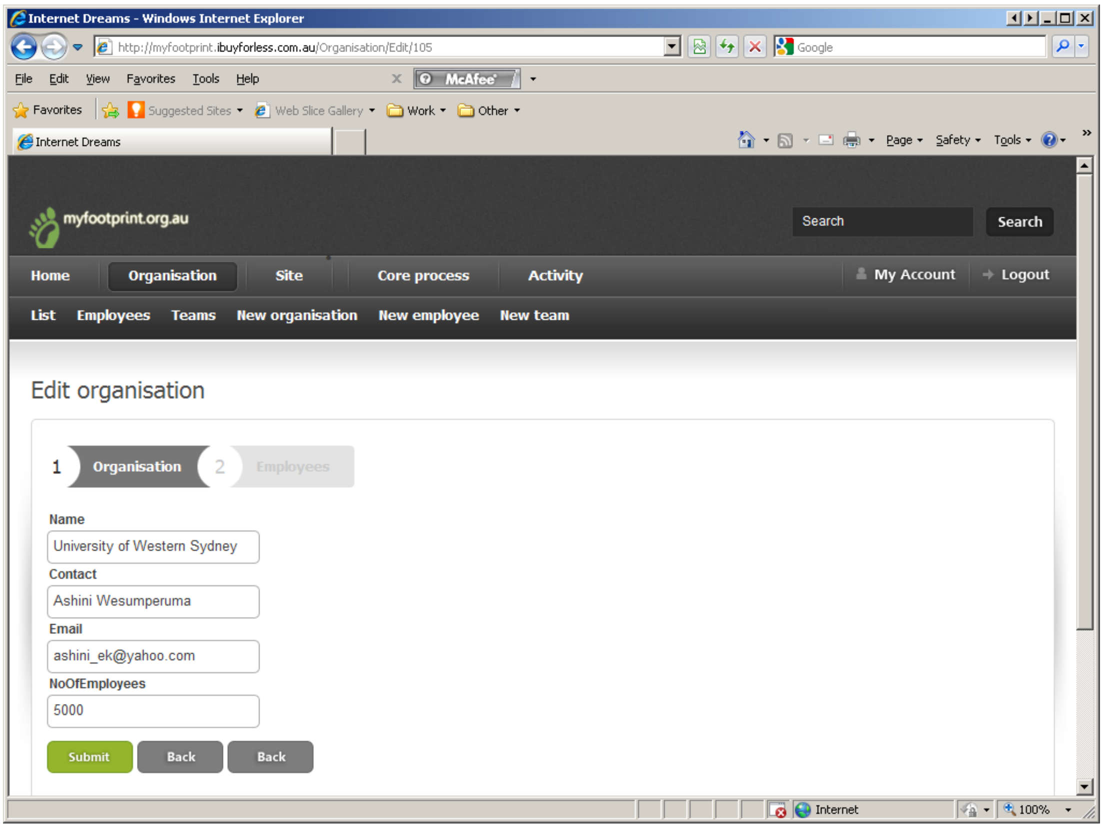

Figure A.3: Organisation management screen.

There may be occasions when details about an organisation may have changed. This screen will allow organisational data to be edited. This is only visible to the administrator.

Sites list screen

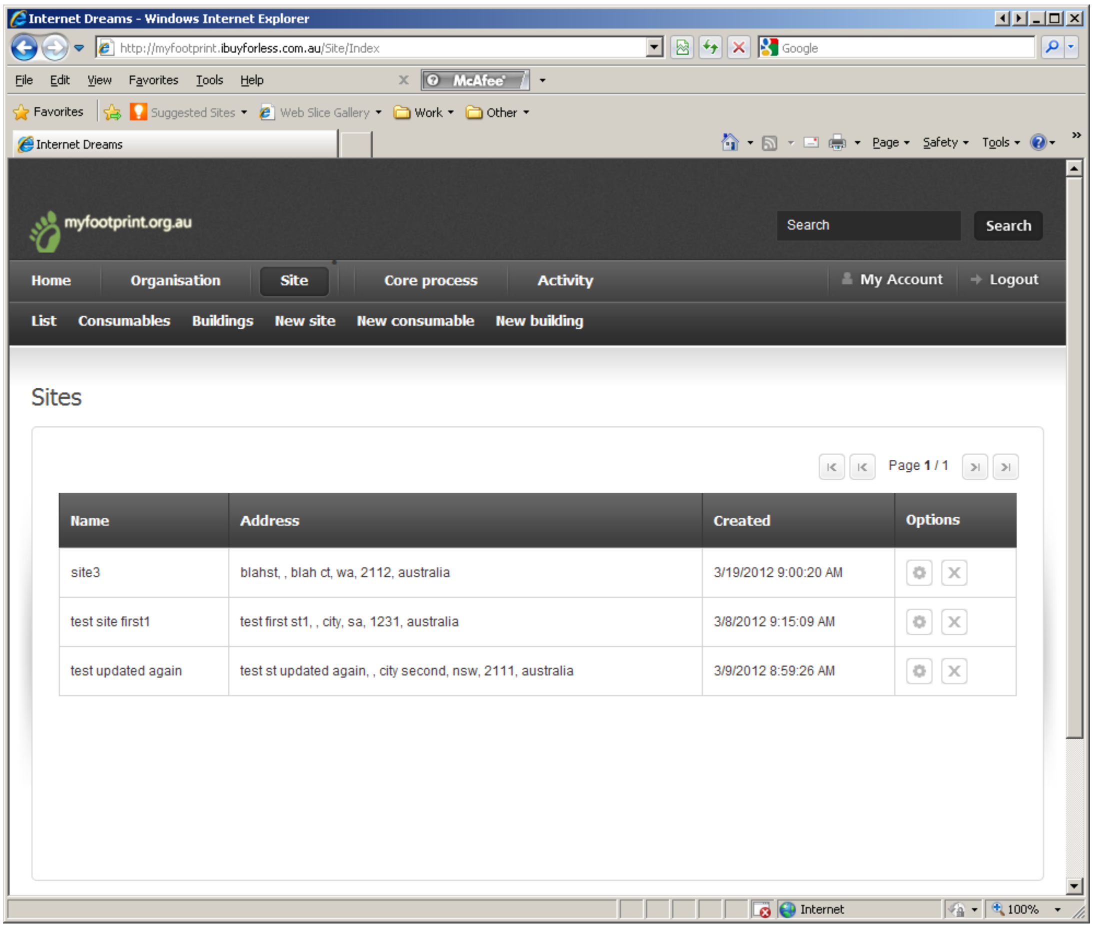

Figure A.4: Organisational site list screen

An organisation may not be located at a single geographical location. An organisational may have several sites instead of just one. Thus, the system needs to keep track of all the sites. This screen will list all the sites related to a particular organisation. This is accessible to the organisational top level management.

Site consumable type selection screen

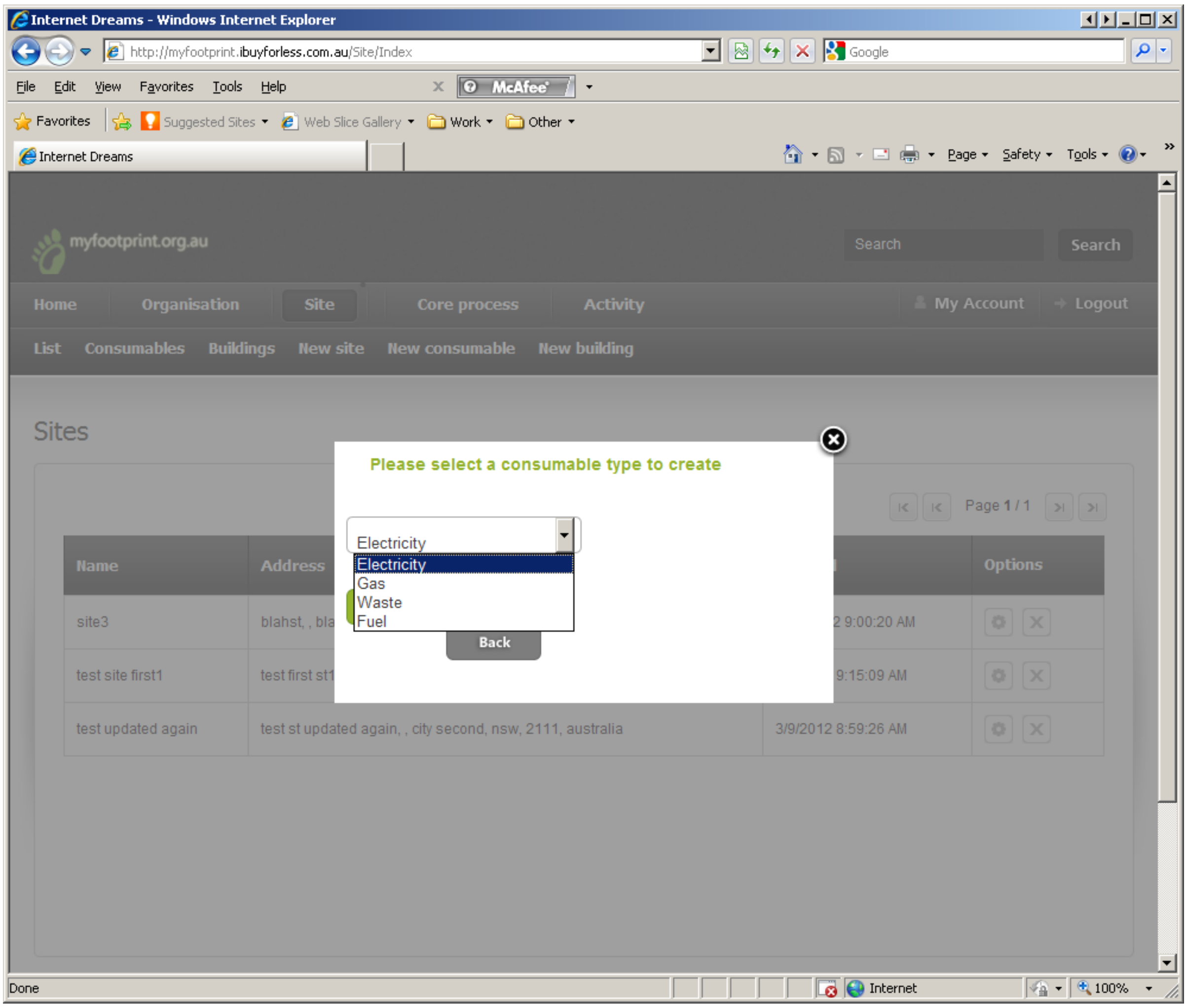

Figure A.5: Organisational site consumables

Consumables are those resources that may be spent, wasted, dissipated or destroyed during a business process. This screen will allow the organisational top or middle level managers to input consumables related to a particular site. For an example there may be Electricity, Gas, or Fuel bills. Using this screen organisational top or middle level managers will be able to record all the significant consumables related to a site.

Add an electricity bill for a site

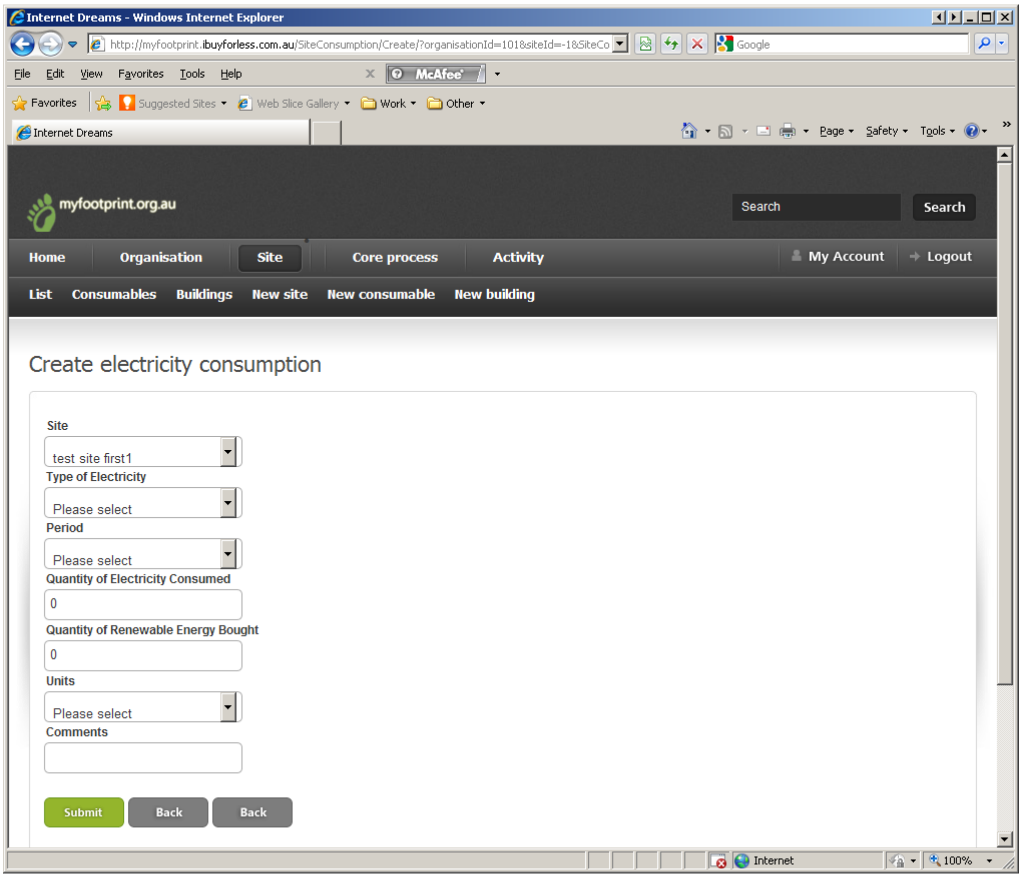

Figure A.6: Site electricity consumption.

This screen will allow electricity consumption details to be input. An electricity consumption is related to a single geographical location. Thus, if the organisation has several sites registered with this tool, it will allow the electricity consumption related data to be put in for each site. This is accessible to the organisational top management and the organisational middle level managers.

Hierarchical list of teams

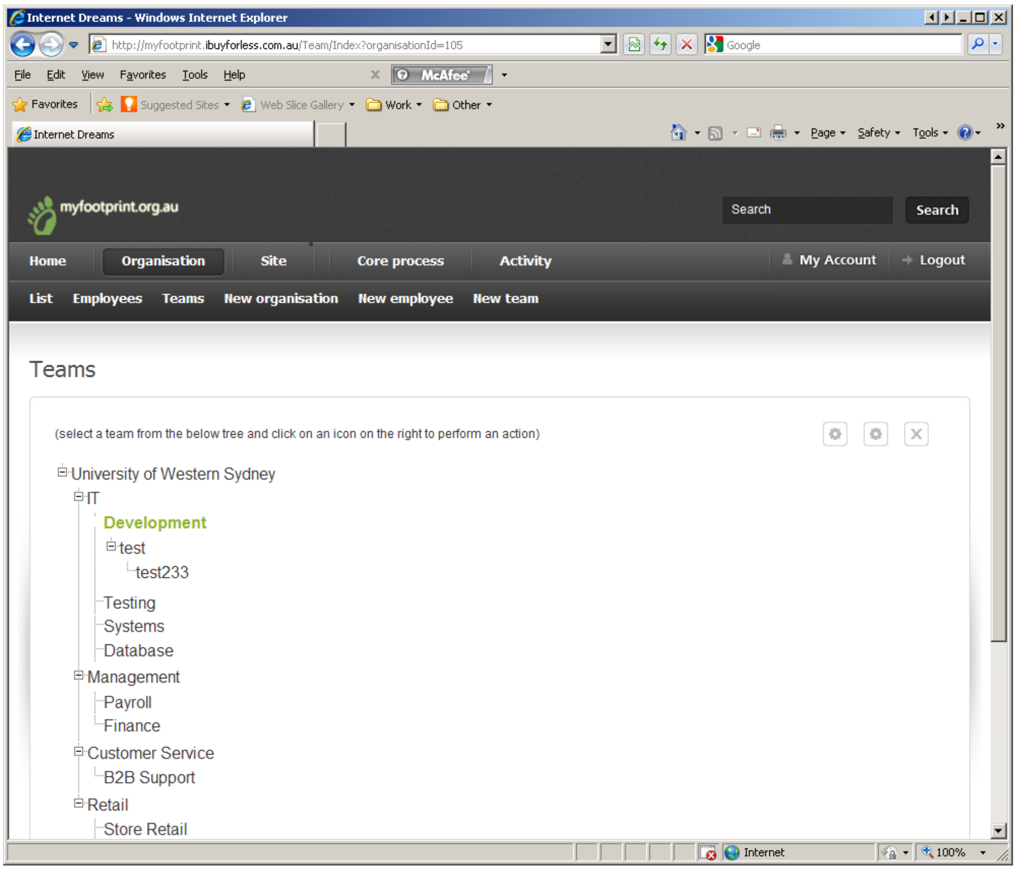

Figure A.7: Organisational teams.

This screen allows the organisational top or middle level managers to input the teams in the organisation. For each process, there can be several ways a team may perform the actual work: a dedicated team of employees for each process; a single team for several processes; or several teams that will work in sub process and activities within a process. This screen allows for the creation of flexible team hierarchical structures to mimic those used in organisations.

Edit team details

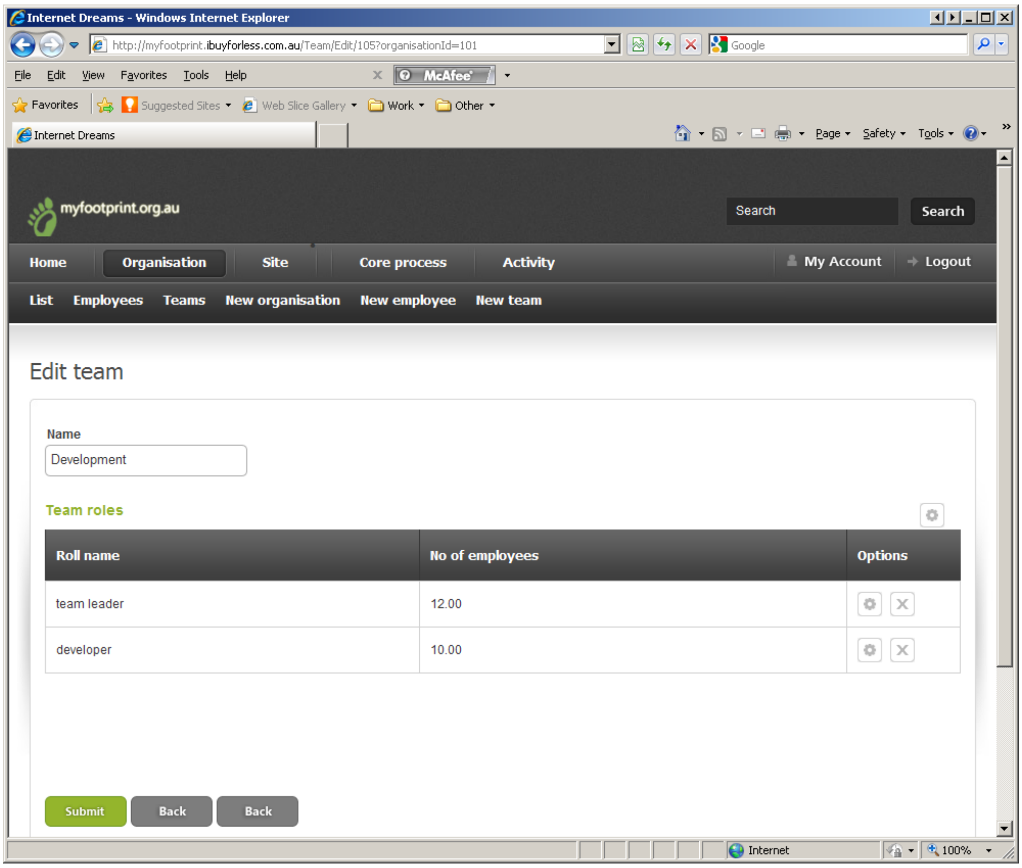

Figure A.8: Team detail management screen

It is natural for an organisation to re-structure teams or change the members in the teams. Thus, this screen allows the team details to be edited. This is accessible to the organisational top management and the middle level management.

Core processes

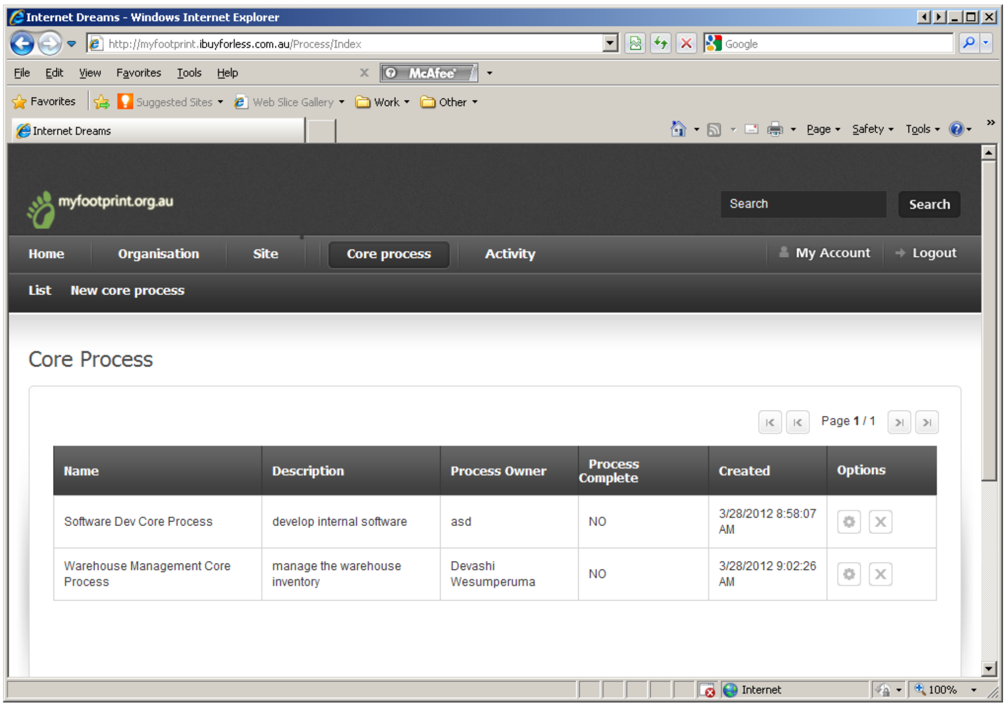

Figure A.9: Organisational core processes

Every organisation can have a set of processes. This screen lists all the core processes of the organisation. It will allow the core processes to be created, edited or deleted. Every process will have a process owner. A core process can have several sub-processes and/or activities. Once the details of all the sub-processes are complete the "Process Complete" status would be set to "YES".

Hierarchical list of sub processes and activities for a given core process

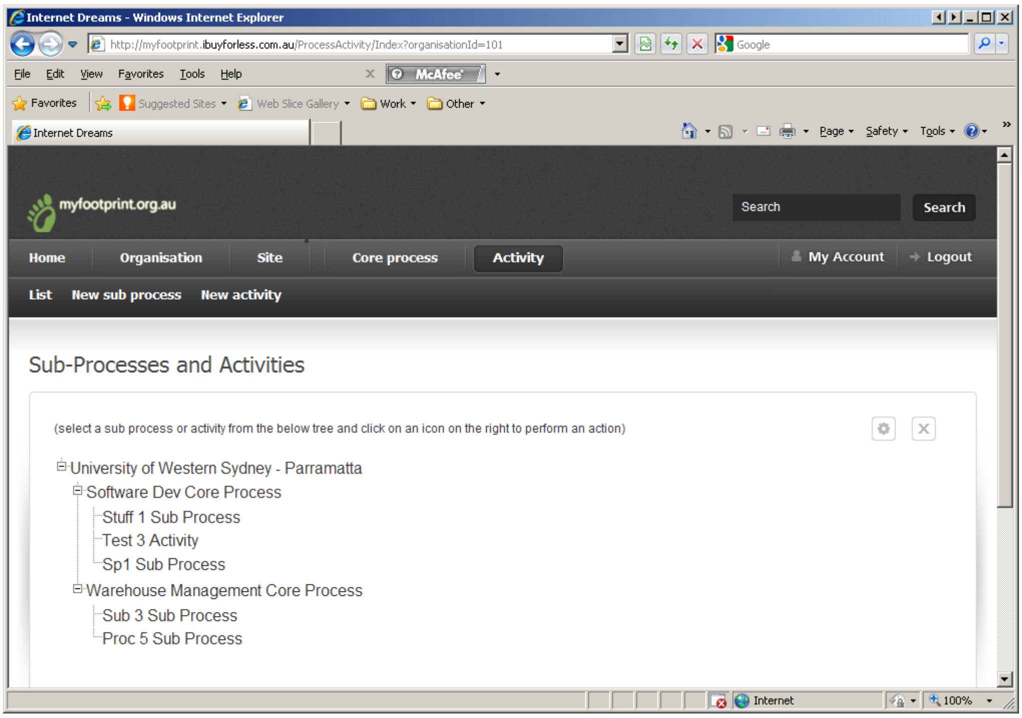

Figure A.10: Sub-processes and activities related to a particular core process

This screen provides a hierarchical list of sub processes and activities for a given core process. Using this screen, for each core process, new sub-processes or activities can be added. This is accessible to the organisational top and middle level management.

Activity edit screen

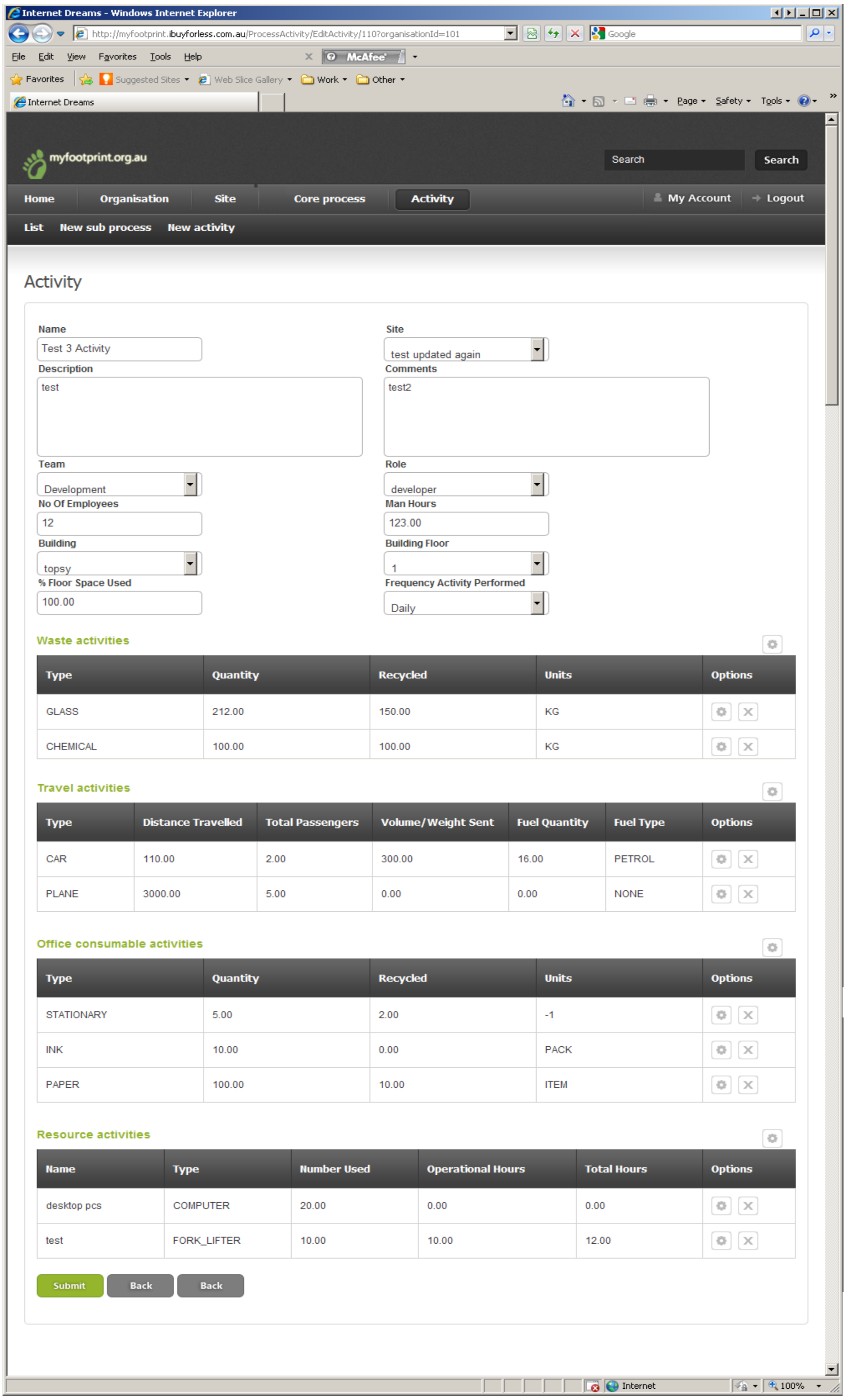

Figure A.11: Activity edit screen

Activities that were added using “Sub-processes and activities” screen can now be selected to add more details using this activity edit screen. In here, each activity will be linked to a role within a selected team. All the roles and the number of man hours required to complete the activity per role are collected here as well. Data regarding waste, travel, office consumables, and resources can be added here. Once the users clicks on the create button for waste or travel or office consumables or resources, they will be guided to a screen such as that in “Figure A.12”, which is described in the following section.

Create a "Waste details" related to an activity

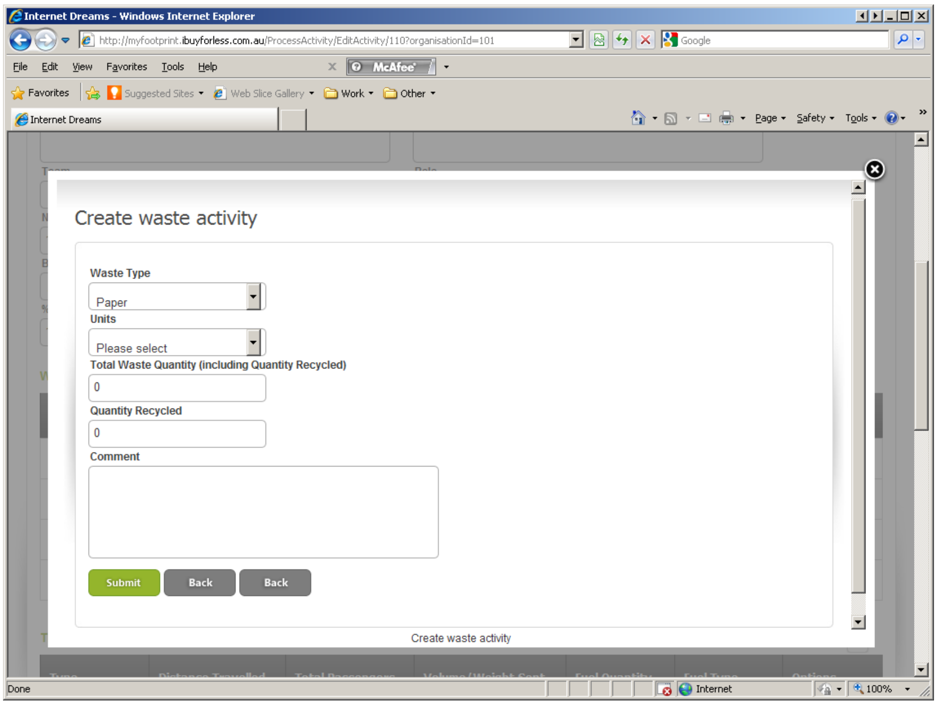

Figure A.12: Waste details related to an activity

This screen collects data related to waste generation within an activity. The user can input data regarding the type of waste, the units of measure, total waste quantity and the quantity that was recycled. Users can include an additional comment as well.

Appendix - B: Extended BPMN Notation to model GHG emissions at a business process level

Concise Descriptions and Notations

The research proposes set of notations to model GHG emissions form a process point of view. This set of notations work in conjunction with the BPMN notations. These are similar to BPMN shapes in Visio 2010. Following is the set of notations. As can be seen, every notation contains a "+" symbol. This indicated that additional information is captured at a more detailed level. Each shape has its own detailed view. The "+" sign implies expansion is required to enter data.

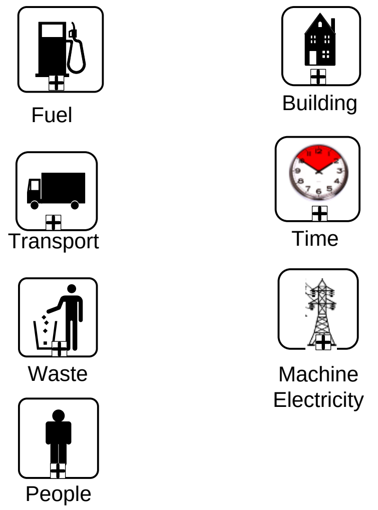

Figure B.1 Extended BPMN notation to model GHG emissions

Following sections go into details of the proposed BPMN notations to model GHG emissions. Lower detail level information helps to categorise and quantify GHG emissions related to process level.

Fuel Consumption

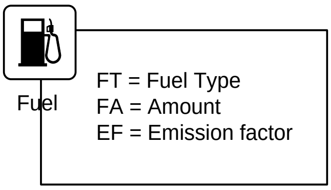

Figure B.2 Fuel consumption

This shape captures the information related to fuel consumption. Thus, this shape captures the type of fuel used and the amount consumed.

Transportation

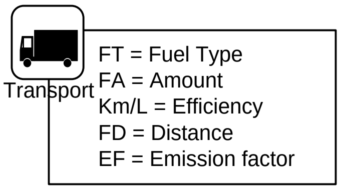

Figure B.3 Transportation

This shape captures information related to transport fuel consumption. There are two ways to capture GHG emissions related to transportation. One way is by using the amount of fuel consumed and the other way is by using the distance travelled (WBCSD-WRI, 2004). Depending on the data available one can select the best way to capture and model GHG emissions.

Waste

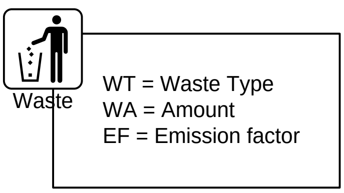

Figure B.4 Waste related information

There are many types of waste. The emissions factor depends on the type of waste. This shape considers the municipal waste.

People

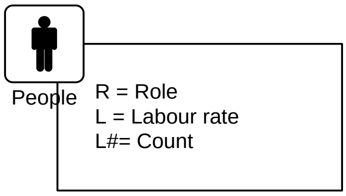

Figure B.5 People related information

In a business organisation there can be a number of people. Each person plays one or more roles within this organisation. There can be more than one person playing the same role.

Building

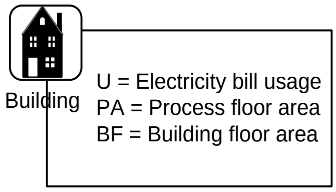

Figure B.6 Building related information

A business process may take up a floor space. At the same time it can share the same floor with another process. A utility bill is issued for a site Ex. Electricity bill. This shape captures the total floor space that was considered in the electricity bill.

Electricity consumption

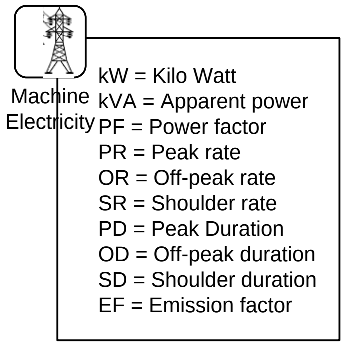

Figure B.7 Electricity consumption related information

In a business process there can be machines that perform a certain task. These machines may consume electricity. This shape captures the GHG emissions related to electricity consumption of those machines.

Time duration

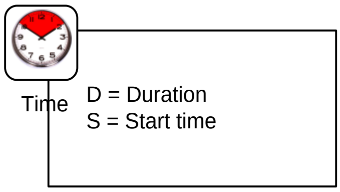

Figure B.8 Time duration

There is a time associated with any task, activity, sub-process or a process. This shape captures the time duration. This time duration is important when modelling GHG emissions from various sources. The shape capture the actual start time of a task or an activity as well.

Following is a sample model of a business process with GHG emissions. In here, organization's "Supply Chain" stream of processes was studied, starting from the demand forecasting, customer ordering, and ultimate goods delivery. Especially the warehouse management process was analysed in great detail. First, all the business processes along the supply chain were modelled by using BPMN as the modelling technique. Thereafter, data collection at various business process levels was conducted. Data collection at activity level, sub-process level, process level and shared level were meticulously performed. For the warehouse management process, the newly introduced BPMN visual and formal extensions were used as shown in the following figure.

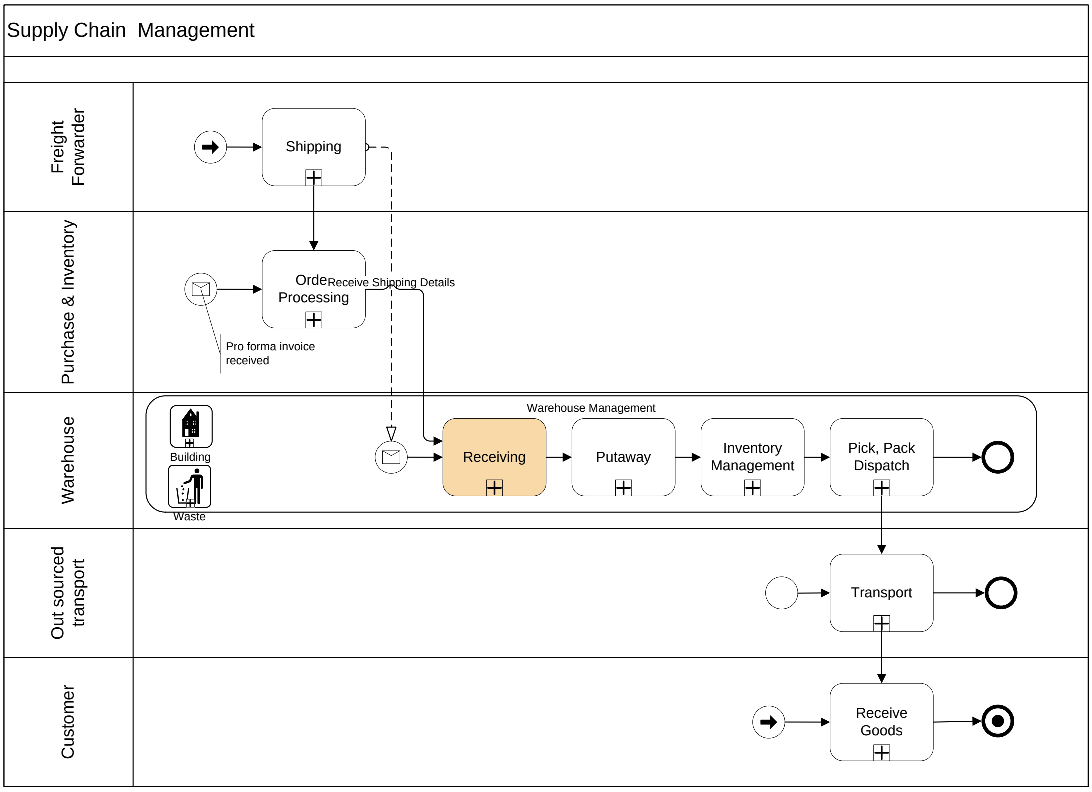

Figure B.9: BPMN extensions for modelling GHG emissions at various business process levels.

As can be depicted from the following figure the receiving sub-process was studied in detail. Following figure shows the "Receiving" process's GHG emission related information.

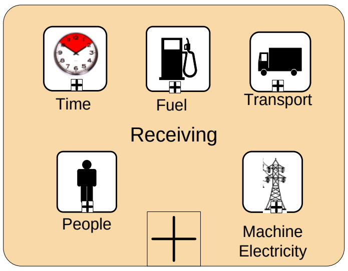

Figure B.10: BPMN extensions for modelling GHG emissions at “Receiving” sub-process

Appendix - C: Activity Based Costing

A machine will depreciate in value over time due to wear and tear. There several ways of calculating machine depreciation. Out of these, Declining Balance Depreciation in particularly considers that during the planned life time of a machine, it depreciates more at the beginning than towards the end of its life time. Further a machine is more productive at the beginning than it is at the end of its life span due to machine degradation (Al-Chalabi, 2014). In order to calculate following inputs are required (Furey, 2013).

- Machine cost: Original value of the machine
- Useful life: The length of time the machine will be productive
- Scrap value: Machine value towards the end of its useful life
- Year bought: Year the machine was purchased

The following formula (C.1) calculates the depreciation rate (Al-Chalabi, 2014). Table C.1 uses this formula to calculate the depreciation rate for the two sets of machines in the PET process.

Depreciation Rate = 1 - [(Scrap value / Machine cost)$^{(1 / \text{useful life})}$]…… (C.1)

Table C.1: Machine depreciation rate calculation

Machine	Cost	Year Brought	Useful Life as of year bought	Scrap Value	Depreciation Rate
Water Chiller & Pumps	$500,000	2009	15	$10,000	0.23
PET (Heat& Drive) & Dryer	$1,500,000	2009	15	$5,000	0.32

The following table C.2 and table C.3 calculates the depreciation schedule for the machines. These two tables consider the value of the machines when they were bought to initiate the calculations. In order to calculate the new base value, the depreciation value is deducted from the previous base value. The accumulated depreciation column keeps a tab of the total machine depreciation over the years.

Table C.2: Machine depreciation calculations for Water Chiller and Pumps

Year	Base value	Depreciation Calculation	Depreciation Value	Accumulated Depreciation
2009	$500,000	500000*.23	$115,000	$115,000
2010	$385,000	385000*.23	$88,550	$203,550
2011	$296,450	296450*.23	$68,184	$271,734
2012	$228,267	228266.5*23	$52,501	$324,235
2013	$175,765	175765.20 *.23	$40,426.00	$364,660.79

Table C.3: Machine depreciation calculations for PET (Heat and Drive) and Dryer

Year	Base value	Depreciation Calculation	Depreciation Value	Accumulated Depreciation
2009	$1,500,000	1500000*.32	$480,000	$480,000
2010	$1,020,000	1020000*.32	$326,400	$806,400
2011	$693,600	693600*.32	$221,952	$1,028,352
2012	$471,648	228266.5*32	$150,927	$1,179,279
2013	$320,721	175765.20 *.32	$102,630.60	$1,281,909.96

As shown in the previous tables, Water Chiller and Pumps have a depreciation value of $40,426.00 and PET (Heat and Drive) and Dryer have a depreciation value of $102,630.60.