Integrated Carbon Emission Management for the United Arab Emirates Construction Industry

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ABSTRACT

Awareness of sustainable building construction and its benefits is growing in the United Arab Emirates (UAE), to safeguard the interests of future generations. Although there is a wide range of sustainable building standards and assessment tools available, the application of Carbon Emissions management (CEM) in building projects is still less. This research provides an Integrated CEM framework to increase the environmental efficiency of building projects by estimating, monitoring and controlling the Embodied carbon emissions during the Tendering and construction stages.

This research interprets the related literature and uses opinion of green building experts, through surveys to gather data on sustainable construction practices in the UAE. The approach also analyses the preferences and challenges of the UAE construction industry with current sustainable practices such as environmental performance evaluation, standards, tendering methods, rating tools and software used. It identifies the need for enhancing the environmental efficiency of buildings through an integrated CEM framework. It also performs two in-depth case-studies to practically test the CEM Model and conducted a focus group to validate the proposed Integrated CEM framework.

Emphasis on Operational carbon emissions, prevalence of low-cost-bid-award criteria, Lack of awareness on CEM, unavailability of standard common-unit-of-measure and complexity of existing carbon estimation tools makes CEM very challenging. The proposed Integrated CEM framework addresses the challenges through a rigorous selection of contractors based on cost and carbon emissions as criteria, quantification of carbon emissions of project activities, and then to monitor and control the emissions during the construction stage. The research finds that Carbon Emissions, time and cost can be integrated into a framework with use of Earned Value analysis and simple in use tools, to provide a holistic evaluation of environmental efficiency in building construction. Findings include that the Construction industry can apply the Integrated CEM Framework and associated models in real-life practices without the requirement of additional software or processes.

Finally, this research found that the implementation rate for CEM will increase through the use of a proposed Integrated CEM framework which includes the carbon cost(COCO2) tendering Model, Carbon Emissions Estimation Model(CE-EM) and Carbon emissions control and monitoring model(CE-MCM). The methodology and CEM

framework, while geared toward the UAE construction industry, excel and Primavera; can be easily adapted to other countries and software.

The integrated CEM framework will assist contractors, consultants and clients in making informed decisions about the carbon emissions in the UAE. It also promotes a proactive, environmentally conscious construction approach to enhance sustainable performance. The research suggests the use of CO_2e as a unit of measure for accounting to give visibility to carbon emission management in addressing the impacts of climate change.

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LIST OF ABBREVIATIONS

ACE	Actual carbon emissions
ADIPEC	Abu Dhabi International Petroleum Exhibition and Conference
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATHENA	Advanced technologies for interoperability of heterogeneous enterprise networks and their applications
BCIS	Building cost information services
BIM	Building information modelling
BOQ	Bill of quantity
BREEAM	Building Research Establishment Environmental Assessment Method
CE-EM	Carbon émissions estimation model
CEM	Carbon emissions management
CE-MCM	Carbon emissions monitoring and control model
CEV	Carbon emissions variance
CO2e	Carbon dioxide equivalent
CLF	Carbon Leadership Forum
CPSAS	Construction Project Sustainability Assessing System
COCO2	Cost and carbon emissions
CPI	Cost Performance Index
DEFRA	Department for Environment, Food and Rural Affairs
ECO2e	Embodied carbon emissions equivalent factor
EE	Embodied energy
EIA	Environmental impact assessment
EPC	Engineering procurement and construction
EVA	Earned value analysis

FEED	Front end engineering design
GGBS	Ground granulated blast furnace slag
GHG	Greenhouse gases
GWP	Global warming potential
HVAC	Heating, ventilation and air conditioning
ICE	Inventory of Carbon and Energy
IEA	International Energy Agency
IESVE	Integrated Environmental Solutions of VE
I-O	Input-output
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KM	Kilometre
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LED	Light emitting diode
LEED	Leadership in Energy and Environmental Design
MDF	Medium density fibre board
PCC	Plain cement concrete
PMI	Project Management Institute
PVC	Polyvinylchloride
PCC	Plain cement concrete
RCC	Reinforced cement concrete
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SEV	Sustainability earned value
SIUT	Simple-in-use tools

SPV	Sustainability planned value
SSPI	Sustainability Performance Index
UAE	United Arab Emirates
USGBC	United States Green Building Council
WBS	Work breakdown structure
WCED	World Commission on Environment and Development
WRAP	Waste and Resources Action Programme
WRI	World Resources Institute
SPI	Schedule Performance Index

LIST OF PUBLICATIONS BY THE CANDIDATE

International conferences: The following has been presented to peers in an international conference and published in conference proceedings.

> Azharuddin, M., Al-Hajj, A. (2014) 'A way forward to effective implementation of carbon emission management in the UAE building construction industry', 1st International Conference of the CIB Middle East & North Africa Research Network, 14-16 December 2014, United Arab Emirates.

Poster Presentations: The following is a poster presentation at the Abu Dhabi International Petroleum Exhibition and Conference (ADIPEC) 2014.

> Azharuddin, M., Maskari, N. (2014) '*Sustainable (LEED-certified) buildings and their role in reducing the reliance on conventional resources and reduction of emissions'*, Abu Dhabi International Petroleum Exhibition and Conference, UAE.

Excellence Forum: The following was presented and published at the Abu Dhabi National Oil Company Excellence Forum in 2018.

> Azharuddin, M., Saud, S. (2018) '*Smart project management system (SPMS) – an integrated and predictive solution to manage oil and gas projects'*, Abu Dhabi National Oil Company Excellence Forum, Abu Dhabi, 2018.

International Journals: The following manuscripts are ready to be submitted to international journals and will be under review by the time of submission.

> Azharuddin, M., ElHag, T., Saud, S. (2019) 'Managing carbon emissions using Primavera – a case study of a building project in the United Arab Emirates' (Draft)

Chapter One: Introduction

1.1 Research Background

Earth's average temperature has increased by approximately 2°F or 1.1°C, mainly driven by increase in greenhouse gas emissions (GHGs) into the atmosphere (Agung Wibowo, Uda and Zhabrinna, 2018). Ironically, the poorly performing construction industry provides a unique opportunity to play a vital role in minimising the negative impacts of GHG emissions, thereby improving global sustainability (Yu et al., 2014). Various studies (Carmen et al., 2012; Lin, 2016; Vijayraghavan, 2016; Woszuk and Franus, 2017; Yu et al., 2017; Organisation for Economic Co-operation and Development [OECD], 2018) offer different approaches to improving the sustainability of the construction industry, such as green innovation of construction methods, promotion of green building technologies, low-emissions asphalt technology, waste reduction and implementation techniques for GHG emission reduction. In summary, current efforts focus on improving the technology or process levels, affecting only a few activities in a construction project; therefore, their improvements or impacts on the overall project are limited (Yu, Cheng, Ho and Chang, 2018). A collaborative effort at the global level is required to increase the carbon-efficient sustainable industry. However, disputes in developing and developed countries are disturbing the result-oriented initiatives.

After the Kyoto summit (1997), the United-Nations climate change conferences of Cancún (2010) summit is considered a turning point in international climate negotiations, recognising that climate change is an urgent and irreversible threat to humans and planet (UNFCC, 2011). But on the other hand, the message for the common man was that climate change is being politicised and treated as an arms deal rather than a necessity for existence. The world can no longer wait until the damage is irreversible to stabilise the climate. As Figure 1.1 shows, CO_2 emissions levels have been increasing since 1880, which in turn has elevated global temperatures, leading to climate change (Climate Central, 2018). Rather than countries and politicians deciding on and agreeing on emissions factors and levels, a revolution is required within various industry sectors to align themselves in reducing CO_2 emissions.

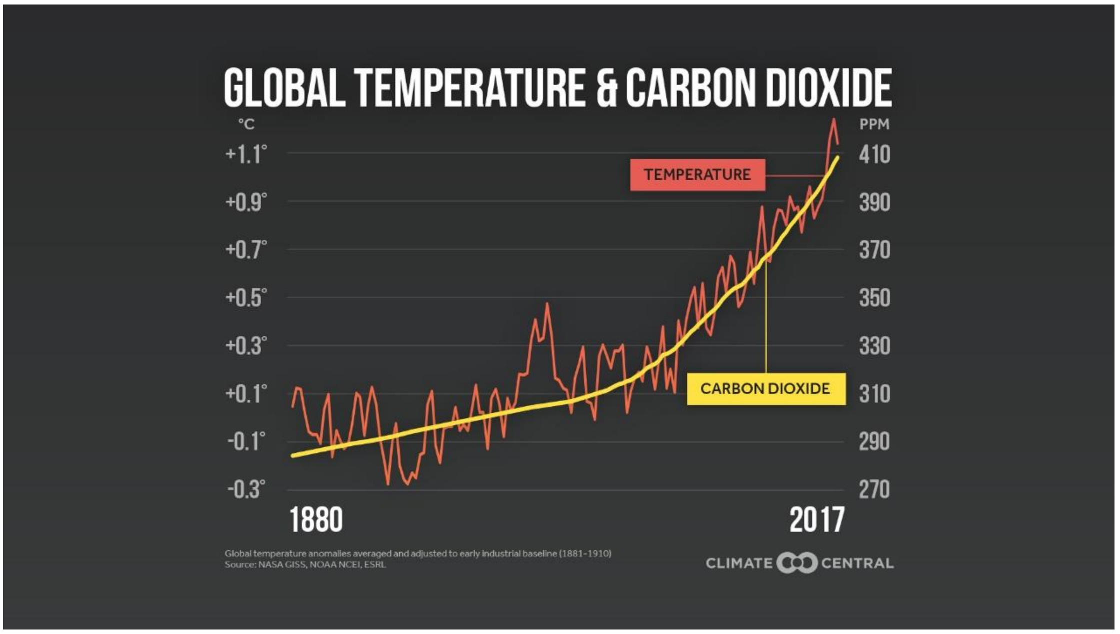


Figure 1.1 Rising Global Temperatures and CO_2 Emissions
(Source: Climate Central, 2017)

Collaborative efforts from all sectors of the industry reduces the Global warming impacts, instead of waiting for countries to resolve conflicts. Paul Morrell states this fact in the 'emerging findings' report, which included recommendations to measure and count embodied carbon emissions (Morrell, 2010). If these measures are instituted, it remains to be seen whether the construction industry is ready for the change. To understand the state of readiness of the industry, the following section shows the carbon emissions in building construction followed by the description of two distinct types of carbon emissions in buildings.

In conventional project management, project performance is assessed in three dimensions: time, cost and quality. The current threat posed by emissions from construction activities has shifted the construction project management paradigm to include carbon emissions produced during the execution of construction processes. There is increasing pressure on the industry to integrate carbon emissions management in the design and construction of buildings to induce minimal or no impact on the environment (Abanda et al., 2013). Kumanayake and Luo (2018) state that as buildings have longer life spans, they should be planned, designed and managed for high energy efficiency and low carbon emissions over their entire life cycle. Life cycle analysis is a basis for assessing the environmental impact of products and services, but in reality, it's not a standard practice (Bohari, Skitmore, Xia and Teo, 2017).

The construction industry has progressed remarkably in recent years in providing low-energy sustainable buildings. The factors which helped achieve the present position is the environmental assessment methods and rating systems such as the Leadership in Energy and Environmental Design (LEED) rating system of USA, the Building Research Establishment Environmental Assessment Methodology (BREEAM) of U.K, Estidama of Abu Dhabi-U.A.E, Al Safat of Dubai-U.A.E and GREEN STAR of Australia. The other factors are building regulations, growing awareness, industry demand, research and development, etc. Considerable success is visible for the products related to energy, health and wellbeing areas of the buildings, which has resulted in reducing operational energy usage. Many energy-efficient products are being developed and made available because manufacturers are interested in increasing their market share or gaining competitive advantage over other products. In addition to the product's availability, there are also various tools and technologies available to estimate, calculate and regulate the energy consumption in a building during the operational phase. However, the importance of quantifying and reducing embodied carbon emissions generated during the construction phase is ignored by academia and industry alike (Saadah and Abu Hijleh, 2012) and (Nawarathna and Fernando, 2017). The embodied carbon emissions calculation models are available, but the majority of them focus on the early design stage for comparing alternate design options only (Victoria and Perera, 2018). This concept is supported by Kravari (2017), who argues that the critical phase during which sustainable decisions taken in the design phase when materials are specified. This led to restrictions on managing embodied carbon emissions only to the design phase.

1.1.1 Carbon emissions in buildings

The energy use and carbon emissions throughout the life cycle of a building are in two distinct stages (Ibn-Mohammed et al., 2013):

i. Embodied energy use/embodied carbon emissions, which is the energy associated with the construction of the building; and
ii. Operational energy use/operational carbon emissions, which is the energy used post-construction once the building is commissioned and occupied.

1.1.2 Operational carbon emissions

Operational CO_2 emissions are emitted due to consumption of energy during the life of a building, from commissioning to demolition. CO_2 emissions related to HVAC, lighting water heaters and any equipment used to maintain building operations. Page (2006) stated that operational CO_2 emissions contribute to 82% of the life cycle CO_2 emissions compared with 18% for embodied energy CO_2 emissions. However, Nicolas (2008) stated that if operating CO_2 emissions are reduced by 50%, embodied carbon emissions become more influential. Furthermore, the operational CO_2 emissions are released gradually over the life of a building, whereas the embodied CO_2 emissions release within a short period (i.e., during the construction period). Hence, the immediate impact of embodied energy is more significant than that of operating embodied energy.

1.1.3 Embodied carbon emissions

The definition of embodied energy proposed by Boustead and Hancock (as cited by Langston and Langston, 2008) is as follows: 'Embodied energy/carbon emissions is defined as the energy/CO_2 emissions demanded by the construction plus all the necessary upstream processes for materials such as mining, refining, manufacturing, transportation, erection and the like…'

Langston and Langston (2008) suggest that, while measuring operating energy is easy and less complicated (through BIM), determining embodied energy is more complex and time-consuming. Moreover, there is no generally accepted method for computing embodied energy accurately and consistently; therefore, wide variations in measurement figures are inevitable. To effectively analyse the embodied carbon emissions of buildings more efficiently, it is necessary to select building materials with the lowest embodied impacts. The construction of buildings includes, on average more than 1000 building materials, and the embodied carbon emissions analysis requires a great deal of time and labour (Roh, Tae and Kim, 2018).

Embodied carbon emissions have also been found to be significant by many researchers (Kumanayake and Luo, 2018; Nawarathna, Fernando and Alwan, 2018; Varun et al., 2012; Zhang et al., 2016). Despite acknowledgement of the need to consider embodied energy and CO_2 in building impact analysis, very few projects conduct the quantitative studies in the UAE.

Alwan and Jones (2014) stated that operational energy is more significant over the long term and emphasised not to ignore the embodied energy of key materials, which is likely to be a bigger proportion of the total carbon in a low-carbon building. Iddon and Firth (2013) concluded through a case study that cradle-to-gate embodied carbon represents 20–26% of the total 60-year carbon emissions, with operational carbon representing 74–80% of total emissions. Hence, with bigger reductions in operational carbon due to the initiatives of green building adaptation, a focus on reducing embodied carbon emissions is required (Khasreen, 2013). It raises questions regarding whether, carbon emissions are being managed in the building construction industry and, if they are, what the implementation levels are?.

1.1.4 Embodied carbon emissions management

The industry focus on operational impacts is justifiable by the assumption that they are dominant. However, case studies and the literature over the last decade show that embodied carbon emissions also, make up a significant portion of whole life impacts of buildings (Pomponi and Moncaster, 2018; Nawarathna et al., 2018). The percentage of Embodied carbon to whole life carbon emissions of buildings accounts for more than 50% (Crawford, 2011) and 70% for some cases in the UK (Ibn-Mohammed et al., 2013).

Carbon emissions management reflects and captures all possible changes in emissions levels caused by planning decisions at the project level and will allow a comparison of potential environmental impacts caused by different planning alternatives. It will also cover the mitigation opportunities for emissions during the construction phase (Ahn et al., 2013). As with any management technique, carbon emissions management includes estimations, monitoring, control and feedback.

The aim of estimating embodied carbon emissions is to make much more radical use of it at the design stage, tender stage, material procurement and construction stage, by providing real-time readings of embodied energy (Alwan and Jones, 2014). Quantifying the Embodied CO_2 emissions is vital for making early decisions and material substitutions by analysing the impact of materials, processes and methods. Estimation, monitoring and control presents the true impact in terms of the correlation between certain materials, resources, processes and carbon emissions during the entire life of the buildings.

1.2 Rationale

Emissions of three main contributors of GHGS, CO_2, methane and nitrous oxide, are predominantly due to emissions from fossil fuels to support the needs of the growing population (EPA, 2007). ‘Sustainability’, derived from the phrase ‘ability to sustain’, is becoming a key challenge in almost all industries (Mansah et al., 2012). Newell (2008) stated that this improvement in awareness made sustainability a top-priority factor or common concept for most of the community and business decisions around the world. Therefore, the United Nations Framework Convention on Climate Change has set up reporting requirements for countries based on the Intergovernmental Panel on Climate Change (IPCC). To reduce the impact of global warming and to attain the targets set by the IPCC, every sector, including the construction sector, is called on to concentrate on excessive carbon emissions challenges associated with their trade. Managing CO_2 emissions related to business would also fulfil the Corporate Accounting and Reporting Standard requirements as defined by the World Resources Institute (WRI, 2004).

The Kyoto Protocol was targeted at reducing 5% of global GHG emissions between 2008 and 2012 (Kim et al., 2013). Assessments of carbon emissions of buildings initiated as a result of introducing the Kyoto Protocol. Subsequently, the Copenhagen

(2009), Cancun (2010), Paris (2015) and Katowice (2018) summits considered as inflection points in international climate negotiations. The outcome of the Katowice summit was to initiate a new international climate regime under which all countries will report their emissions – and progress in cutting them – every two years from 2024 (Carbon Brief, 2019). But the future of these United-Nation climate change summits are at threat due to the changing political leaderships of America and other countries. Brazil pulled out for hosting the next summit (COP 25) of the year 2019, which shifted to Santiago, Chile (UNFCC, 2019). Rather than relying on these political leaders, industries shall realise the threat and reduce the emissions to save the planet.

Construction works and buildings illustrate the major challenges of providing for the needs of the growing population (International Council for Research and Innovation in Building and Construction[CIB], 1999). Building construction and operation is responsible for 40% of the world's total energy use, 30% of raw materials consumption, 55% of timber harvests, 16% of freshwater withdrawal, 35% of global CO_2 emissions and 40% of municipal solid waste sent to landfill (Worldwatch Institute, 2008; Al Horr et al, 2017; Sinha et al, 2016;). Webb (2000) states that 50% of all energy used worldwide is in construction work and building use, of which 25% is the construction phase comprising of embodied energy and transportation. Moreover, as identified by the IPCC in 2007, the building sector has considerable potential for energy-efficient improvements and GHG reductions without a significant increase in investment costs (IPCC, 2007). Due to such enormous impacts of the construction industry and the potential for efficiency, a substantial change in construction processes, design, procurement, delivery and maintenance is urgently needed.

The effective procurement of construction projects requires a balance of time, cost and qualities consistent with each client's requirements and budgetary constraints. Research is necessary to address the need for changing the procurement, monitoring and control strategies for a construction project from the cradle to the grave to capture the aspects of sustainability.

The construction industry adapts conventional practices with various aspects managed through supply chains (Heap-Yih and Christopher, 2014). A revolution in the approach to shift from a cost-based to a carbon emissions tendering approach is required. CO_2 emissions tendering approach helps to explain the impacts and sources of expenditure-related emissions. Similarly, if applied to a project during the tender stage, the tender submissions should state the impacts and the source of expenditure related to emissions based on elemental analysis (BCIS) for the project from inception to demolition.

Strategies to reduce emissions in all sectors and all regions is required, and, in fact, many countries already have policies to reduce emissions, but their application is lacking (Agung Wibowo et al., 2018). The construction industry has progressed remarkably in recent years in providing low-energy sustainable buildings, but only through sustainable tools (LEED, BREEAM, Estidama, Alsafat, Global Sustainable Assessment System (GSAS), GREEN STAR), building regulations, increasing awareness, creating industry demand, research and development. Most of the development is available in the energy and health and wellbeing sectors by reducing operational energy (Al Horr et al., 2017). Strategies to reduce the amount of carbon embodied in construction is vital, not only in economic terms but also to ensure that our planet remains habitable (Langston, Chan and Yung, 2018).

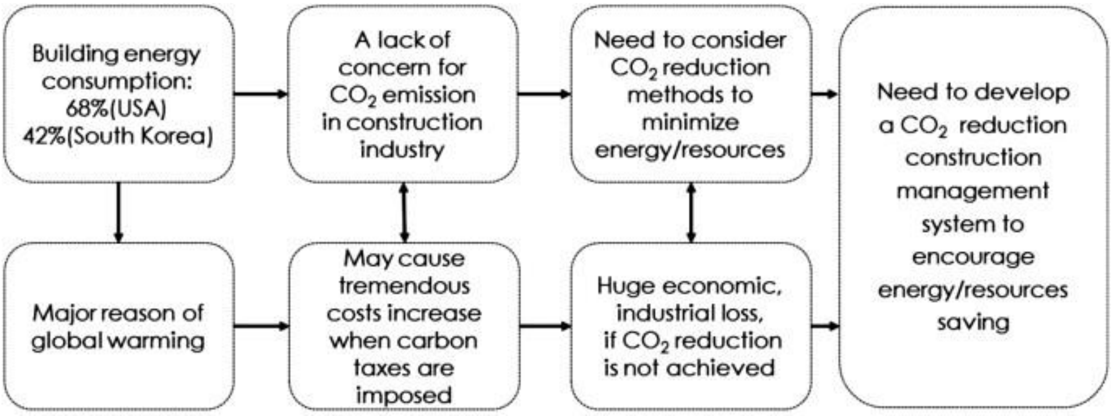


Figure 1.2 Need for carbon emissions management (Source: Kim et al., 2013)

As Figure 1.2 shows, industry realises the need to measure and track carbon emissions in a similar way as cost and time are being estimated, measured and monitored in the construction industry (Kim et al., 2013). For example, RICS has launched a tool called

‘Redefining Zero’, which helps designers cut embodied carbon (RICS, 2010). Also, the Waste and Resources Action Programme (WRAP) issued guidance to help identify basic, cost-effective actions in reducing the carbon impact of materials used in construction projects (WRAP, n.d.). The main criterion is that the embodied energy and operating energy shall be balanced to produce minimal whole life carbon emissions (WLCE). Due to the combined effect of regulations, consumer expectations and the optimisation of business costs, carbon management is slowly finding its place in corporate agendas (Czerniawska, 2007; Weinhofer and Hoffmann, 2010). To stay competitive, companies must deliver projects considering carbon exposure, i.e. CO_2 emissions, as a key factor rather than just environmental standards or rating tool compliance (Schultz and Williamson, 2005; Abdul-Azeez and Ho, 2015).

1.3 The gaps in theory and practice

To build upon, the knowledge gained from the literature review, a preliminary study is prudent rather than solely relying on research data. This research aims to propose an integrated framework for effective carbon emissions management with a shift from a cost-based procurement strategy to a cost and carbon- ($COCO_2$) based procurement of contracts, on which previous empirical studies seem rather limited. From the literature review conducted, the limitations of the work, highlights of the findings, and conclusions from the preliminary study identified, as follows.

- Carbon-emissions studies focus on either the design phase for choosing the design alternatives or on the operation phase for energy consumption (Khasreen, 2013; Al Horr et al., 2017). This practice has ignored the environmental impacts and the potential opportunity to reduce carbon emissions during the tendering and construction stage (Chhatwani, 2015). In the UAE, limited work has been done to estimate the carbon footprint of projects (Alzard et al., 2019)

- From an overview of the preliminary study, it was found that certain assessment parameters of existing tools in developed countries do not control and manage carbon emissions during construction due to the difficulties in quantifying environmental, socio-cultural and economic needs (Kumanayake et al., 2017).

- Non-availability of a standard measure or unit of sustainability with which to compare (Dobrovolskienė and Tamošiūnienė, 2016). Instead, the monitoring and controlling focus is mainly on descriptive means specified in sustainability certification requirements. Material selection, design approach, energy efficiency and water efficiency were found to be inconsistent in their methodologies as they comply with the requirements and priorities of the developer.

- Most building professionals still consider cost, time and quality as important factors, whereas environmental project priorities are the least considered unless mandated by regulatory requirements.

- There were clear indications that the resulting and consequent lack of implementation of embodied carbon emissions management is due to a lack of requisite knowledge among developers, clients, designers, constructors and the supply chain rather than poor regulatory framework, as has been hypothesised by previously reviewed studies (Abdi et al., 2018). Alzard et al. (2019) researched Carbon emissions of roads in the UAE and stated that effective management of GHG emissions and ensuring sustainable development is a challenge. Nonetheless, to ensure the development and successful implementation of appropriate GHG emissions reduction strategies, integrated efforts are needed with active participation and strong commitments from all stakeholders

- Recently, several studies have been conducted to estimate and report the total amount of GHG emissions in the construction phase of a project (Alzard et al., 2019; Chou and Yeh, 2015; Hong et al., 2016; Sandanayake et al., 2016; Wang et al., 2015; Yeo et al., 2016). The issue of GHG emissions control during project execution, however, has seldom been addressed in the literature. There was no demonstrable and compelling evidence of technical research on available resources which could better enable the integration of embodied carbon emissions management intent at the tendering stage of a project to benchmark the emissions and monitor and control the emissions during the construction phase (Chhatwani, 2015).

As may be interpreted from the above findings and the reviewed literature, many design and building professionals still do not have a clear idea of the issues, requirements, constraints and opportunities specific to the use of embodied carbon emissions management. The analysis of the preliminary study, thus reaffirms the identification of the knowledge gap in the reviewed literature, which brings this study to its key research question. Does Construction industry needs a model and framework to modify existing sustainable management practices?, Does industry requires a shift in existing procurement practices (tendering process) based on the carbon footprint of the building in addition to cost, time and quality?. Does the industry require a standard unit of sustainable measure to assist the decision-makers in quantifying strategies in the building sector? Are the complexity, lack of transparency of the carbon calculators and software, the barriers to implementing carbon emissions management?

1.4 Addressing the gaps through this research

This research will address the research questions and provide UAE construction industry, with carbon emissions management models and framework to estimate, monitor and manage carbon emissions.

- This research also identifies the need for the construction industry to adapt bid selection based on the integration and trade-off among cost, time, quality and carbon emission requirements. This arrangement will make designers, constructors, product manufacturers and suppliers rethink their strategies regarding the use of materials and construction methods and techniques.

- A $COCO_2$ tendering model will also be developed to recommend and modify existing procurement practices (tendering process) to consider carbon emissions in addition to cost, time and quality.

- The Carbon emissions estimation, control and monitoring model using SIUT and framework will assist decision-makers in quantifying the low carbon strategies.

- By applying an integrated framework in the building sector, provides policy developers data regarding emissions at the unit level, project level, city level and building sector level. In future, building approvals and construction can be regulated based on emissions levels.

- This research recommends the industry to adopt CO_2e as 'unit of measure' to assess the environmental efficiency of buildings construction.

1.5 Novelty of this study

An essential step is to adopt an effective carbon emissions management to enhance environmental efficiency of building construction using CO_2e as a 'unit of measure'. An Integrated CEM framework will assist in reducing the emissions by establishing detailed baseline conditions that serve as a reference for future enhancements (Alzard et al., 2019). Also, it helps to award the projects on 'technically acceptable lowest cost and carbon emissions' criteria.

This research associates benchmarking and controlling carbon emissions using simple-in-use tools without the need of additional software and new processes.

The Model and integrated CEM framework will be adopted by those primarily entrusted with the construction project and that the expended carbon emissions (CO_2e) will become a key performance indicator. Life-cycle assessment of the environmental impacts of buildings in UAE has not been done before using CEM framework, and this offers the possibility of answering important research questions.

1.6 Aim and Objectives

1.6.1 Aim

This research aims to develop an Integrated Carbon Emissions Management framework to enhance environmental efficiency of buildings in the UAE. Environmental efficiency is enhanced through managing embodied carbon emissions and operational carbon emissions at the tendering and construction phases.

1.6.2 Objectives

To achieve the research aim, the following are the objectives:

i. To review and investigate the current practices, tools and methods of carbon emissions assessment in building construction projects;

ii. To identify and evaluate the construction management methods involved in achieving efficient and low carbon buildings;

iii. To develop a Carbon emissions Management model(CEM) based on theory and expert recommendations from industry;

iv. To test and validate the developed CEM model using case studies and focus group; and

v. To develop and validate the integrated carbon emissions management framework for tendering and construction phase of building projects in the UAE.

1.7 Outline Methodology

1.7.1 Stage 1: Conceptual research framework development - literature review and survey 1

This study reviews relevant literature on the background of sustainable construction, current sustainability practices, impacts of rising carbon emissions, initiatives in various sectors, the role of the construction industry, global warming and the implementation of sustainable measures. It also emphasises carbon emissions of buildings and investigates the need for carbon emissions management (CEM) in a project's life cycle, in particular, the tendering and construction stage.

Furthermore, it investigates the current tools, standards, carbon emissions database, a comparison of cost management vs carbon emissions management, current and alternate procurement practices. Literature review identifies the gaps in current literature and practice and identifies a need to enhance the environmental efficiency of buildings using an Integrated CEM framework for the UAE construction industry.

Also, the industry awareness on Carbon emissions management, current sustainable practices, tools in use for estimation, time management, issues of stand-alone software and the preferences are investigated. Literature review and survey-1 findings helped to develop a conceptual research model to carry out the study to the next stage.

1.7.2 Stage 2: Methodological development stage – Research method, data analysis and CEM model development

Research methods and strategies are identified and collected the data through survey-2. The second questionnaire survey was carried out after the literature review to investigate the sustainable construction practices in UAE, tendering practices, awareness on carbon emission estimation and monitoring methods, factors hindering the implementation of CEM, prospective measures to increase CEM implementation and the willingness to participate in such projects. Literature review and survey responses helped in developing a Carbon emissions management model (CEM) comprising of tendering, estimating, monitoring and controlling the carbon emissions during Phase 4 & 5 of RIBA Plan of work.

An Integrated Carbon Emissions Management (CEM) framework is developed using the CEM model and the literature review findings, to enhance the environmental efficiency of building construction.

1.7.3 Stage 3: Empirical study stage – CEM model testing, validation of Integrated CEM framework and Conclusions

In Stage 3, the CEM model was applied and tested on two case study projects. Case studies also tested the means of estimating, monitoring and managing carbon emissions during construction using EVA analysis.

An Integrated CEM framework is developed using the CEM Model is validated by a focus group workshop comprising of UAE Construction industry practitioners to record the efficiency and ease of use. Feedback is collected to validate the role of the Integrated CEM framework in increasing the implementation levels of carbon emissions management in the UAE. Conclusion is derived from the research findings, with limitations, recommendations and suggestions for further research.

1.8 Thesis Structure

Chapter 1 – Introduction – Background information for the research

This chapter provides an overview of the research study, including the background issues related to the topic, justification for the study, research aim and objectives, research outline methodology, research scope, significance and contribution of the study and thesis structure.

Chapter 2 – Embodied Carbon Emissions and Evaluation Methods

This chapter introduces the theoretical background for the research through a critical review of the literature around building construction and carbon management. It identifies the changing context of the sustainability climate in which construction companies operate. The chapter will also critically examine the concept of embodied carbon management in building construction and to what extent carbon management is strategic. It provides a critical review of the literature related to the embodied carbon emissions and calculation methods; standards followed; current software and tools; and the available database for construction projects which forms the basis for the theoretical background of the research study.

Chapter 3 – Building Construction and Carbon Emissions Management in the UAE

This chapter provides a brief discussion about climate change, sources of CO_2 emissions, the meaning of sustainability and the role of the building construction industry. The chapter also provides a review of the United Arab Emirates, where the research is being carried out, the impacts faced due to CO_2 emissions, current practices of procurement, management and the need for an alternative approach to sustainable project management. Chapter 3 also presents a theoretical review of existing tendering frameworks currently used in the UAE for the awarding of projects. The argument establishes the need for a more robust carbon emissions management model and framework which takes into account carbon emissions as a unit and critical factor during the tendering award stage.

Chapter 4 – Research Methods

This chapter addresses the research methodology/strategy adopted for the study using the research onion such as ethical considerations, research philosophy, design, approaches, including justification for the chosen research methods and approaches. It provides an overview of various data collection, analysis and interpretation methodologies followed to achieve the research aim and objectives of the study.

Chapter 5 – CEM Model Development

This chapter focusses on identification and development of mathematical and process models for carbon emissions management from the literature review, to calculate, monitor and control the embodied carbon emissions of the building project. CEM Model includes Carbon emissions estimation model (CE-EM), carbon emissions monitoring and control model (CE-MCM) and Cost and carbon tendering model ($COCO_2$). The chapter covers the scope of the model, calculation principles for carbon emissions management and the step-wise model development.

Chapter 6 – Survey Results – Discussion and Analysis

In this chapter, the data gathered through the questionnaire survey are reviewed, analysed and summarised, mainly to investigate the current practices of sustainable management. Also, the chapter presents the details of awareness levels of carbon emissions management, barriers of CEM and the existing rating tools and methods fo sustainable construction. This chapter interprets the industry perceptions and utilises them for developing and refining the Carbon emissions model and framework.

Chapter 7 – Case Study Results – Discussion and Analysis

This chapter analyses the results of embodied carbon expenditure in the construction phase of a building project by applying and testing the carbon emissions management model on two case study projects. The chapter contains the steps taken for enhancing the environmental efficiency of building construction through the use of CEM. This chapter also compares the results achieved after implementation of CEM model with the base case of tendering stage as well as industry benchmarks.

Chapter 8 – Integrated Framework for CEM

This chapter focusses on the generation of integrated carbon emissions management framework based on findings from the literature review, survey findings and case study. This chapter shows the use of the Carbon emissions estimation Model (CE-EM), Carbon emissions Monitoring and control model (CE-MCM) and carbon cost tendering ($COCO_2$) in developing an integrated CEM framework. Sections of the chapter also includes the reporting and payment mechanism as part of the Integrated CEM framework.

Chapter 9 – Validation and Discussion

This chapter presents the results of the focus group discussions, carried out to refine and validate the Integrated CEM Framework including the CEM models, which was applied and tested on case studies of commercial building projects in the UAE. It also covers the validation on enhancement of environmental efficiency due to the use of Integrated CEM framework. This chapter explores and elaborates on the implications and inferences drawn from the focus group.

Chapter 10 – Conclusions and Recommendations

The concluding chapter of the thesis presents the key research findings. It summarises the overall research process adopted, to achieve the research objectives and the contribution to knowledge and practice. Chapter also includes the conclusions derived from the research findings, with limitations, recommendations and suggestions for further research.

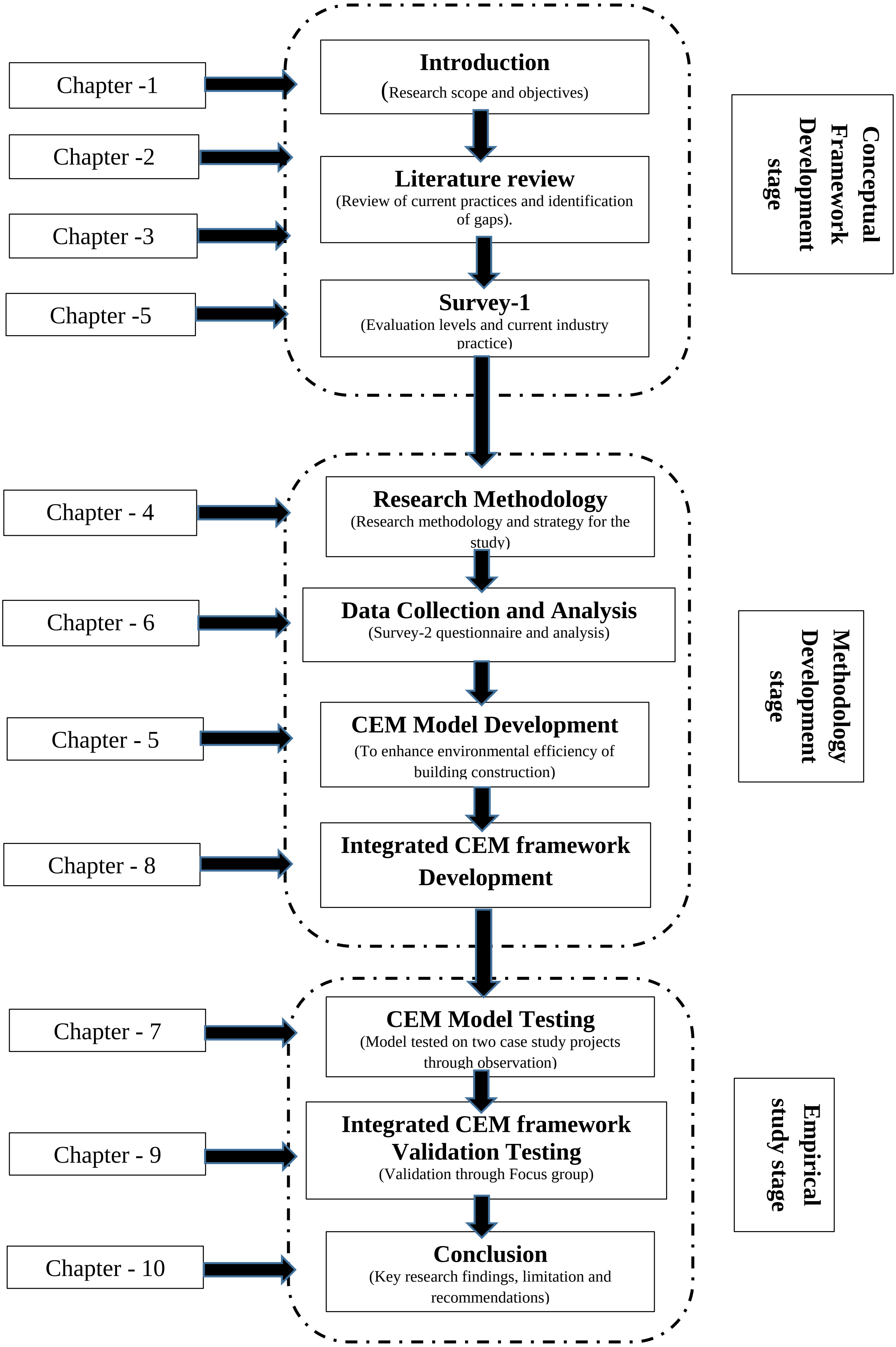


Figure 1.3 The Structure of Research

Chapter Two: Embodied Carbon Emissions and Evaluation Methods

2.1 Introduction

Embodied carbon research is not a new proposition but researched and discussed in the industry since the 1980s. However, the industry is lagging in the implementation of embodied carbon management in building projects. Lack of awareness, complicated calculations and lower percentages compared with operational carbon emissions have led the industry to neglect embodied carbon management (Ariyaratne and Moncaster, 2014). As the awareness and understanding of low carbon design improves within the construction industry, the need for life cycle assessments of buildings is increasing. Hence, operational carbon is no longer the only driving force in measuring sustainability in buildings (Alwan and Jones, 2014). Dixit et al. (2012), and Khasreen et al. (2009) asserted that the construction of zero-carbon buildings would reduce operational carbon emissions. As few efforts concentrated in the area of embodied carbon emissions, the share of embodied carbon emissions will increase comparatively (Hammond and Jones, 2011).

Although several methods and databases exist to calculate embodied carbon emissions in a building, they are most predominantly derived using guidelines set forth by the International Organization for Standardization (ISO) for life cycle assessment. This chapter presents the literature review of embodied carbon emissions, current carbon calculations methods, standards followed, current software, tools, available database/inventories and the building performance models.

2.2 Embodied Carbon Emissions – CapCarb

The embodied carbon emissions of a building component are emissions required to extract and process its raw materials, as well as the emissions from transport of the finished product to the job site and site activities (direct energy). There are also other recurring embodied carbon emissions in a building, which are the emissions required to maintain, replace, recycle and dispose of a building at the end of its useful life. Since

2013, an alternate terminology for embodied carbon has been preferred and also adopted by the industry, known as capital carbon (CapCarb) (HM Treasury, 2013).

The operational carbon emissions (OpCarb) of a building during its lifetime are much higher than the building embodied carbon due to prolonged use (approximately 50 years) of energy for heating, cooling, lighting and equipment. Dixit et al. (2012) and Sansom and Pope (2012) determined that previously embodied carbon in a building made up 20 to 30% of the total carbon footprint of the building. It led the respective governments and industry to concentrate on the operational stage for reductions in carbon emissions. As buildings become energy efficient through the government's ambitious and legally binding target to reduce national GHG emissions by at least 80% by 2050, embodied carbon percentages will increase proportionately (Sansom and Pope, 2012).

2.3 Challenges of Embodied Carbon Calculation

The reasons for the low implementation of carbon emissions management is due to the challenges, as shown in Table 2.1. Despite the various methodologies, tools, data and databases available, the construction industry is facing many challenges and barriers to estimating and monitoring embodied carbon emissions (Nawarathna et al., 2018). Davies et al. (2014) identified the challenges of embodied calculations as the programme of works, maintaining a plant register, implementation of onsite energy management procedures, maintaining tracking sheets, maintaining a resource database and other various forms of environmental reporting. Moncaster and Symons (2013) identified the unique/bespoke nature of buildings, a dearth of data, the use of sub-contractors for different packages and a culture of commercial confidentiality as the challenges of embodied carbon calculations on a building project. Dixit et al. (2012) identified multiple challenges in embodied energy calculations ranging from size, complexity, longer life spans of buildings. Also identified are the difficulties in collecting data, involvement of key players with different objectives, lack of reliable and accurate information, and limited awareness about environmental impacts of building materials. Correia et al. (2014) also identified similar methodological challenges of carbon quantification, such as the operational boundaries regarding the emissions, cut-off thresholds, availability and reliability of data, issues of uncertainty, the adoption of different analytical methodologies and assumptions of different standards.

Table 2.1 Challenges for estimating carbon emissions
(Source: Nawarathna et al., 2018)

S.No	Challenges/Barriers	Description	Authors
1	Lack of regulations mandating the Embodied Carbon estimation in buildings	There are no regulations yet announced to estimate and reduce Embodied Carbon emissions in most of the countries	• Moncaster and Song (2012) • Moncaster and Symons (2013)
2	Inconsistencies in the Embodied Carbon estimation methods	Multiple calculation methods exist but lack consistency and transparency	• Gavotsis and Moncaster (2015) • Fouche and Carwford (2015)
3	Difficulty in setting an estimation boundary for embodied carbon emissions	Cradle to gate, cradle to site, cradle to handover of construction, cradle to grave and cradle to cradle.	• Gavotsis and Moncaster (2015) • Fouche and Carwford (2015) • Anand and Amor (2017)
4	Lack of a standard for data collection and maintenance procedure	High level of uncertainty present in standards. Collection and maintenance of data, due to lack of a standard data collection and maintenance procedures.	• Gavotsis and Moncaster (2015) • Anand and Amor (2017)
5	Lack of national databases and knowledge sharing for carbon emission factors in developing countries	Despite the IPCC Emission Factor Database for global practice and EMEP/EEA Guidebook 2016 for European countries, etc., there is the scarcity of national specific carbon emission factor databases. Lack of national specific databases will reduce the implementation of carbon emissions management.	• WRAP (2011) • Geisekam et. al (2015) • Gavotsis and Moncaster (2015)
6	Lack of open source assessment tool, software and benchmarks	Lack of Open source assessment tools and software for calculating Embodied Carbon emissions. Also, the lack of Benchmarks for the comparisons to be drawn are the barriers.	• De Wolf (2017) • Fouche and Carwford (2015)
7	Lack of accurate and transparent data	Lack of and unavailability of published data on the embodied impact of components or materials, and Environment Product Declaration databases, unreliable, aged and incomplete data followed by access	• Giordano et al (2015) • Dixit et al (2012) • Davies et al (2014) • Lützkendorf et al (2015)

		restrictions and geographic variations is another major challenge in estimating Embodied carbon emissions.	
8	Complex and time-consuming nature of EC estimation	Data collection and analysis of a large quantity of data is complex, work-intensive and time-consuming. Therefore, it requires more additional cost and labour.	• Fouche and Carwford (2015) • Dixit et al. (2012)
9	Lack of skilled personnel and awareness	This is a major challenge, mainly in developing countries where the technology and the knowledge has not been disseminated or shared. Limited awareness of climate change and its impacts on developing countries has overlooked the significance of estimating Embodied Carbon emissions and implementing reduction strategies	• Ng et al. (2013)
10	Lack of interest in the embodied impacts by the industry stakeholders	Lack of interest on the EC reduction among all stakeholders (i.e. engineers, architects, facility managers, public, government authorities)	• Ibn-Mohammed et al. (2013) • Alzard et al. (2019)

The supply chain industry is concerned with the challenges of assessing embodied carbon for any particular material, as it is complex and involves many significant variables in addition to the extraction, processing and manufacturing activities. Factors such as travel distance to the site from the factory gate and the travel distances of personnel to and from the site during construction will affect levels of embodied carbon. Cabeza et al. (2013) also highlighted the difficulties of embodied energy quantification due to the lack of a generally accepted methodology for its measurement or calculation.

One of the barriers to lack of implementation of CEM is regulations. Currently, governments do not mandate carbon management for buildings. Instead, non-mandatory standards are available and form a baseline in building rating systems. Any enhancement over these baselines are awarded as credits under the rating tools. The other barrier for many developing countries is the lack of a national specific and agreed database for building materials (Nawarathna et al., 2018). Commonly used databases in Europe, such as Ecoinvent and Global Emissions Model for integrated Systems (GEMIS) (Berggren et al., 2013). To understand the challenges of CEM, the current methods of calculating embodied emissions are explored in the subsequent section.

2.4 Current Methods of Calculating Carbon Emissions

Input-output (I-O) analysis, process analysis and hybrid analysis are predominantly used for embodied energy and embodied carbon computations. Each method poses limitations, variable accuracy and errors, which results in different outcomes (Dixit et al., 2012).

2.4.1 Input-output analysis

Input-output analysis is one of a set of related methods which show how the parts of a system are affected by a change in one part of that system. The input-output method follows a top-down technique, concentrating on financial transactions through the use of input-output tables, to determine the energy intensity of economic sectors (Davies et al., 2014). Embodied energy studies performed using I-O analysis are subject to errors and are therefore considered inferior to those using more complex analysis methods (Crawford and Taylor, 2005). The I-O method is based on the assumption that the buildings are homogeneous and calculates the carbon emissions directly from the financial costs data, thus concealing the embodied carbon benefits of relatively high-cost materials (Moncaster and Symons, 2013). Figure 2.1 shows the details to explain input-output analysis at the building system level.

2.4.2 Process analysis

The process analysis method has the most significant limitations in terms of system completeness. The critical stage requires the quantification of the inputs to the product or system. Assumptions and boundaries are created for quantification of inputs to the product(s) being assessed due to difficulties in obtaining necessary data and the understanding of these data. Hence, inputs are neglected in the quantification of inputs to a product, and thus the system is incomplete. This is primarily due to the complexity of the upstream requirements for goods and services (Treloar, 2006). Crawford (2009) performed the embodied energy calculation using the process analysis method.

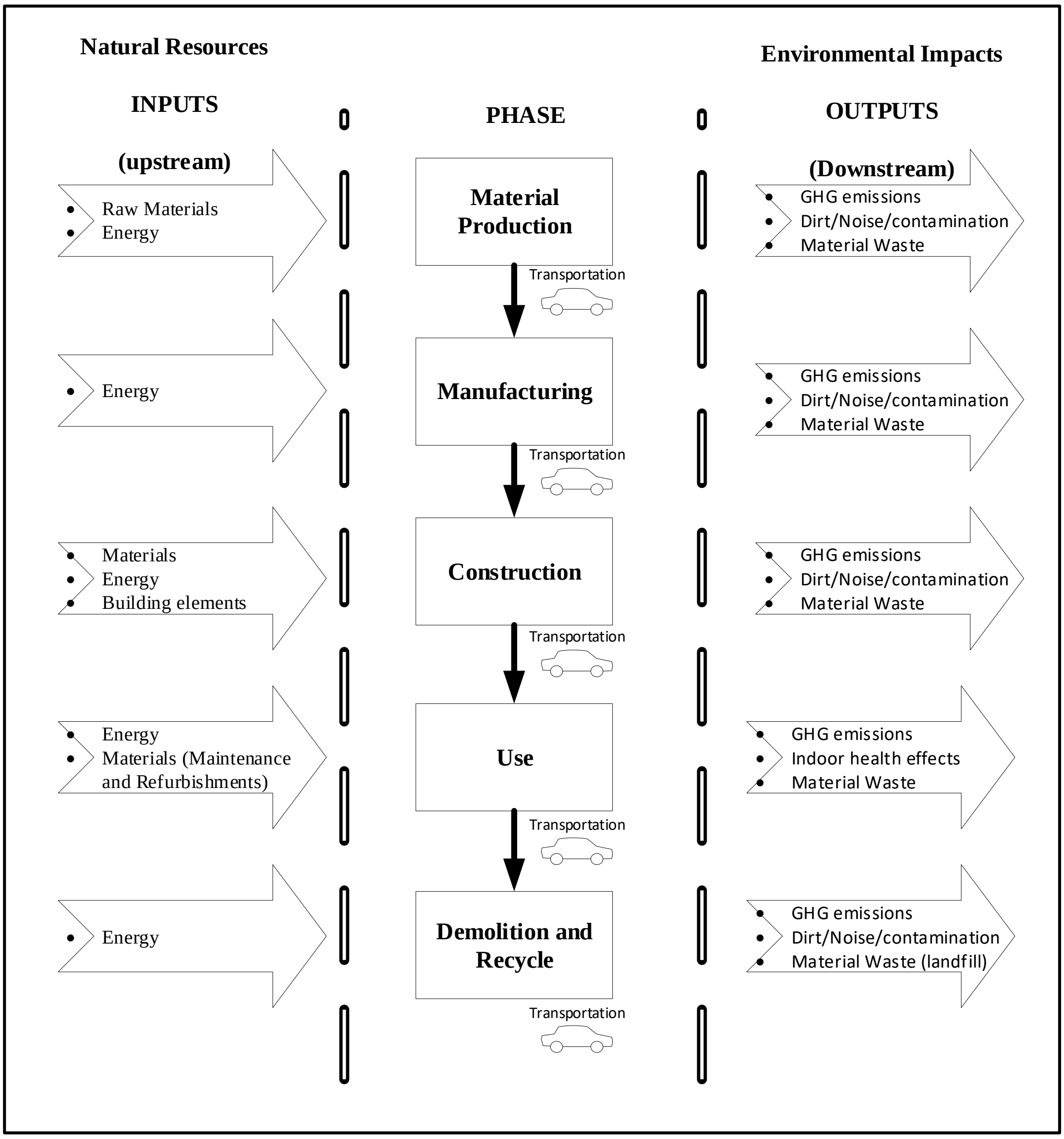


Figure 2.1 Input-output analysis for a building lifecycle

2.4.3 Hybrid analysis

The limitations of process analysis and I-O analysis and an aim to minimise errors led researchers to develop a hybrid method of analysis. The hybrid method utilises a combination of process data and I-O data, wherein a comprehensiveness of system boundaries of I-O data is used. Similarly, direct inputs to a specific product or process being studied are calculated using process analysis. Davies et al. (2014) explained that it uses the principles of a process-based method until gaps emerge within data which are filled by the use of an I-O based method. While process data is not usually easy to obtain, its use maximises the reliability of the analysis at this stage. Further upstream indirect processes are accounted for by I-O analysis when the process analysis data is unavailable or is considered too time-consuming (Alcorn et al., 1997). Bilec et al. (2010) further indicated that the hybrid LCA decreases reliance on the limited amount of public data and utilises available data within the context of the construction industry.

Table 2.2 Authors and their contributions to embodied carbon emissions and the approach

S. No	Authors	Description	Approach
1	Hammond and Jones (2008)	Established the most recent and up-to-date inventory list of embodied CO_2 emissions of building materials	Cradle to gate
2	Dixit et al. (2010)	Analysed the existing literature on embodied carbon emissions	Cradle to grave
3	Crishna et al. (2011)	Evaluated embodied CO_2 emissions of dimension stone in the UK	Cradle-to-site operations
4	Monahan and Powell (2011)	Compared embodied carbon – traditional vs modern methods of construction	Cradle to site+ waste production +transportation to disposal
5	Kara and Ibbotson (2011)	Investigated embodied energy of product life cycle manufactured under different supply chains using SimaPro LCA software	Cradle to gate
6	Moncaster and Symons (2013)	Presented a tool for whole life embodied carbon and energy of buildings (ECEB) complying with TC350 standards	Cradle to grave
7	Iddon and Firth (2013)	Identified that embodied carbon represents 20 to 26% of the total 60-year carbon emissions, with operational carbon representing 74 to 80% of total emissions	Cradle to gate
8	Bilec et al. (2010)	Chose hybrid LCA because it could improve the time and cost associated with the processes of LCA and developing an inclusive boundary. Environmental impacts due to the construction stage of a building	It included construction processes from site preparation to painting, as well as detailed modelling of construction equipment combustion.

Studies carried out so far have assessed the embodied energy or carbon in building construction based on the above methods through life cycle assessment (LCA). LCA relies on various standards, such as those of the ISO, the British Standards Institution (BSI), the World Resources Institute (WRI), the World Business Council for Sustainable Development (WBCSD), the French environmental product labelling initiative (PAS 2050), and the European Committee for Standardization's CEN TC 350 programme. LCA calculations also depend on which method is used, and may even end up with varying and, in some cases, conflicting results. However, Moncaster and Song (2012) highlighted that the inconsistencies in the methods are due to the boundary conditions applied, approaches such as cradle to gate, cradle to grave, etc. and the data used. Table 2.2 shows the contributions of recent authors to the embodied carbon assessment methods and data. The following section describes the life cycle assessment and the various standards briefly.

2.5 Life Cycle Assessment

LCA is ‘a technique for assessing the environmental aspects and potential impacts associated with a product, by; compiling an inventory of relevant inputs and outputs of a product system; evaluating the potential environmental impacts; and interpreting the results of the inventory analysis and impact assessment phases’ (ISO, 2015).

LCA use for building embodied carbon assessment is complicated for a variety of reasons, including larger building size and a complex and unique nature, which often involves a wide range of materials, products and efforts. It is also a method which is widely used to examine and analyse the carbon dioxide emissions during the life of a product or a building (Khasreen et al., 2009). Predominantly, LCA methodologies used in the industry are based on ISO 14040, which identifies four steps:

- Define goal and scope
- Create a life cycle inventory
- Assess impacts
- Interpret results

Adalberth (1996), Crawford and Treloar (2005), Dixit et al. (2010), Lenzen et al. (2004) and Pullen (2000) assert that carbon dioxide emissions play a noteworthy role in building materials. Previous LCA studies have focussed largely on assessing the environmental impacts and embodied coefficient of common materials used in the building construction industry. There is an insufficient amount of LCA work completed on evaluation, control and monitoring of the embodied carbon coefficient of construction activities and materials.

2.6 Standards of LCA for Carbon Emissions

The ISO 14000 family deals with environmental aspects. ISO's new standards of 2018 replacing the 2013 release, focus closely on the quantification of GHGs and guidance for organisations. ISO 14067 on the carbon footprint of products will provide requirements for the quantification and reporting of GHGs associated with products. It consists of two parts: quantifying the carbon footprint (Part 1) and harmonising methodologies for communicating the carbon footprint information and providing guidance for this communication (Part 2). Whereas ISO 14069 guides organisations to calculate the carbon footprint of their products, services and supply chain (ISO, 2009), Hammond and Jones used LCA standards – ISO 14040. ISO standards are used in conjunction with other procedures. Condeixa et al. (2014) used LCA standards – ISO 14040 series and the procedures of the Institute of Environmental Sciences at Leiden University (CML 2001) to study the life impact assessment of masonry systems. CML 2001 is a problem-oriented approach (midpoint approach) which evaluates impacts for a list of CML2001 characterisation factors, such as acidification potential, climate change, human toxicity, land use, and photochemical oxidation.

The TC350 standards measure the cradle-to-grave impacts, defining four life stages — product, construction process, use and end of life — in addition to other environmental impacts. TC350 standards omit the impacts of the designers' and contractors' offices and the finance-related to insurance, government administration and related office buildings. The Strategic Forum for Construction (SFfC) and the Carbon Trust state that the responsibility lies with the construction sector to reduce and manage carbon emissions, instead of estimating the emissions of individual construction projects (SFfC, 2012). The SFfC differs with TC350 in certain aspects; for example, carbon emissions associated with materials was left out of the scope and referred to the manufacturing sector share, whereas the impacts from off-site offices, employee commuting, water and waste treatment, construction plants and off-site assembly are included in LCAs (Moncaster and Symons, 2013). Table 2.3 shows the list of LCCE standards and scope coverage.

Table 2.3 List and scope of LCCE standards

S. no.	Standard	Scope
1	Greenhouse Gas Protocol	Standards and guidance to prepare GHG emissions inventory
2	PAS 2050	Specifies requirements for the assessment of life cycle GHG emissions of goods and services based on assessment techniques and principles
3	ISO 14064-1	Specifies requirements at the organisation level for quantification and reporting of GHG emissions
4	ISO 14064-2	Specifies requirements and guidance at the project level for quantification, monitoring and reporting of activities intended to cause GHG emissions reduction
5	ISO 14064-3	Specifies requirements and guidance for management, validation and verification of GHG statements

2.7 Guidelines, Tools and Database for LCA of Embodied Carbon Emissions

The above standards shown in Table 2.3 are leading the industry in publishing guidelines to promote and encourage management of embodied CO_2 emissions. The Institution of Structural Engineers (IStructE) published a short guide for members on measures for reducing embodied carbon emissions. The RICS included the environmental measures to be taken in reducing CO_2 emissions in its New Rules of Measurement (NRM), and further steps are in progress, such as inclusion of a detailed methodology and a database of embodied carbon emissions for estimation and monitoring purposes (RICS, 2012).

In addition to guidelines, there are various LCA tools for assessing embodied carbon emissions and management in the form of software, which also includes data related to the environmental impacts of building materials. These tools and calculators, such as ATHENA, Building for Environmental and Economic Sustainability (BEES) 4.0 software, Ecoinvent, Eco-Quantum, Envest-2 software, SimaPro software, Build Carbon Neutral, Faithful+Gould’s Construction Carbon Calculator, GaBi life cycle assessment software and NZ Wood, provide means to determine the life cycle impacts of a building (Dixit et al., 2012; Happio and Viitaniemi, 2008; Khasreen et al., 2009). However, most of these concentrate more on operational carbon emissions; they do not cover the construction stage of carbon emissions explicitly, they do not provide a framework for managing carbon emissions, and they do not integrate with other project objectives, such as time, cost and quality for an integrated management of carbon emissions (Ariyaratne and Moncaster, 2014).

With the advent of technology and to gain competitive advantage, design consultants are developing in-house tools. The consulting firm Atkins has developed a set of tools called Carbon Critical Design for assessing the climate impact of a variety of master planning projects. These tools include parameters for calculations of carbon emissions in the operational phase of residential buildings, which, for example, can help builders choose sustainable materials (Atkins, 2014). Building information modelling is helping significantly in its versatility and compatibility with any plug-in software. Skanska Finland also used BIM to provide a quick and cost-effective carbon analysis of construction materials which can also incorporate cost estimation to compare both economic and environmental impacts, which ultimately will promote the delivery of cost-efficient green buildings (Skanska, 2010).

Building information modelling is a multidisciplinary approach to building design and construction. BIM supports integration and provides an opportunity to simulate and validate project objectives in improving the performance of buildings. BIM is increasingly used in the building design process, such as in information control among project stakeholders (i.e., architects, structural and mechanical and electrical (M&E) engineers, cost consultants and, ultimately, contractors). BIM stores large amounts of data associated with a building, including plans, designs, materials, specifications, quantity information and cost details. Design consultants use Revit (an Autodesk software package) to develop basic information in BIM and to assist the design process of complex buildings. In conjunction with this, plug-ins will be added to allow the storage of embodied CO_2 data with building elements. Hence, BIM assists in calculating the total embodied CO_2 of a building (Knight and Addis, 2011). Alwan and Jones stated that an integrated BIM model with carbon rates could potentially simplify the process of carbon emissions calculations, comparisons and sharing information at the design stage, enabling greater transparency across the design team (Alwan and Jones, 2014). Memarzadeh and Golparavar-Fard (2012) and Shitehfar et al. (2010) proposed a visual method through the DnAR-N-dimensional augmented reality model (BIM) or using BIM to visualise at the elemental level the expected and released CO_2 emissions in a 3D environment, whereas Wand et al. (2011) evaluated the potential of using BIM to perform LCA using Autodesk Ecotect Analysis.

Table 2.4 Existing Excel-based carbon footprint calculators
(Source: Kravari, 2017)

Name	Use	Source	Type
AggRegain	Primary or recycled and secondary aggregates	WRAP	Excel
AsPECT	Asphalt	Highways Agency, Mineral Products Association, Refined Bitumen Association and TRL limited.	Excel
Build Carbon Neutral	Structures and sites	Mithun, Lady Bird Johnson Wildflower Center, University of Washington	Online
Environment Agency Carbon Calculator	Sustainability performance of design choices	Highways Agency	Excel
PAS 2050	Stoneworks	Forest Pennant, Natural stone specialist	Excel
Highways Agency Carbon Calculator	Highways	Highways Agency	Excel
Carbon Management System	Road and rail schemes	Transport Scotland	Excel
Kilmagassregnskap	GHG emissions of buildings	Statsbygg	IFC file, data input

Despite these tools, existing emissions visualisation and quantification models are in the early stages of development and are limited to regional applications. Existing research is limited to specific activities, such as concrete, earthwork, blockwork, reinforcement and metal works. A tool which provides a more holistic estimation of emissions from all of the construction activities in a project is still lacking (Wong et al., 2013). Hajibabai et al. (2011) also highlighted the need for a more comprehensive tool to analyse and visualise the carbon emissions from construction sites. In spite of the specialist tools available, Excel remains a preferred tool for carbon footprint calculation due to ease of use and familiarity, as shown in Table 2.4.

2.8 Database and Inventory Sources

Databases are an integral part of all life cycle assessment tools and software. Available databases follow similar methods, such as the input-output process or hybrid analysis. Life cycle assessments of materials from cradle to gate or cradle to grave are conducted based on the standards followed. Ideal criteria for choosing the database are compliance with approved methodologies/standards, clearly defined system boundaries, country of origin of data, free access to data and age of data source (Hammond and Jones, 2011). Table 2.5 shows the data sources available for life cycle assessment of embodied carbon.

The BRE also provides LCA data and tools such as EPDs, the Green Guide and IMPACT. EPDs, also known as BRE Environmental Profiles, which apply to construction products and materials. The EPD data generated by BRE is also used in other BRE resources and tools, including the Green Guide to Specification, Envest2 and IMPACT. The Green Guide to Specification provides environmental ratings (summaries and individual category ratings) and embodied carbon data for more than 1,200 common construction specifications used in various building types. IMPACT allows users to quantify the embodied environmental and cost implications on a whole-building basis. LCA and life cycle costing (LCC) data are provided by BRE and are coupled with other operational impact modules provided by IES (Steel Construction, 2018).

Of the available data sources, the Inventory of Carbon and Energy (ICE) database is specific to building construction and fulfils specialised criteria, such as availability of many different building materials and consistent system boundaries (i.e., cradle to gate; data is simple and can be used with relative ease (Dixit, Culp and Fernández-Solís, 2013; Hammond and Jones, 2011). Junnila et al. (2003) indicated that the database and

LCA should take into account all materials, especially the ones with very small quantities, but will have large impacts of carbon emissions such as lead.

Table 2.5 Third-party database showing type and geography
(Source: www.ghgprotocol.org; Navaratna, 2018)

Source	Data Type	Geography
Athena Institute	Process	USA, Canada
Australian National Life Cycle Inventory Database	Process, other	Australia
Bath Inventory of Carbon and Energy (ICE)	Process	UK
Building Research Establishment (BRE)	Process	UK
Canadian Raw Materials Database	Process	Canada
Carbon Calculations over the Life Cycle of Industrial Activities (CCaLC)	Process	Global
Centre for Sustainability Accounting (CenSA)	Input-output	UK
Department for Environmental, Food and Rural	Process, Input-Output, Other	Global
Ecoinvent	Process, other	Global
Encompass	Process, hybrid	Canada
Environmental product declarations (EPDs)	Process	Global
Footprint expert	Process	Global
Greenhouse Gas Protocol	Process	Global
Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model	Process	USA
International Energy Agency (IEA) GHG Programme	Process	Global
International Iron and Steel Institute (IISI)	Process	Global
International Stainless Steel Forum (ISSF)	Process	Global
Inventory Database for Environmental Analysis (IDEA)	Gate to cradle and cradle to gate	Global
IPCC Emissions Factor Database	Process	Global

The ICE database is widely used in calculating embodied carbon. Because the ICE database is prepared by using data figures not only from the UK but also from all over the world, it can be applied in countries where there is a lack of explicit local information (Kravari, 2017). Fu et al. (2014) used the ICE and IPCC databases to develop a system to assess and compare carbon emissions in building construction.

The Carbon Leadership Forum (CLF) has created the largest known database of building embodied carbon, containing more than one thousand buildings. It includes information on building parameters such as area and number of stories; the LCA methodology used to assess the building, such as included life cycle stages and LCA data sources; and the resulting embodied carbon, reported in units of $kgCO_2e/m^2$ (Rodriguez, Barrera and Huang, 2017).

Menzies et al. (2007) identified the accessibility of data, methodology adopted and selection of system boundaries as the parameters which govern data completeness, which in turn affects the reliability of the outcome of a life cycle assessment of embodied carbon. Reliance on various sources of data end with varying results; however, the emphasis should be on reducing embodied carbon emissions and the measures taken towards reducing global warming impacts to sustain the resources for the next generation.

2.9 Building sustainability Performance Models

Existing research on building sustainability performance modelling describes ways to establish a model to assess sustainable building performance and ways to choose the assessment criteria. These models measure the performance of a building life cycle based on the 'three pillars' (i.e., social, environmental and economic). However, as per Table 2.6, these models do not increase implementation levels and also do not cover monitoring and control. Instead, these models rely on descriptive and subjective parameters (Akadiri et al., 2013; Ali and Al Nsairat, 2009; Bilec et al., 2010;). Moreover, the models' available focus on comparing the early design stage and alternate design options (Victoria and Perera, 2018). Assessing three criteria is insufficient to reflect the building performance as energy and carbon emissions are also part of environmental aspects which are not included in the majority of models (Ding and Shen, 2010).

Abdi et al. (2018) assert that the implementation of a carbon emissions management model would be much easier if simple-in-use tools of planning, costing and reporting software such as Microsoft Project and Primavera are employed for project GHG management. This would also help to integrate the cost, time and carbon emissions information of a project into one measurement model, as shown in Figure 2.2.

Table 2.6 Previous research on building sustainability performance models

Authors	Building sustainability Performance Model
Gangolells et al. (2009)	Predicting and assessing the environmental impact of a building in the construction process. Developed the indicators of environmental aspects related to the construction process as well as the formulation of the significance limits. Model was based on the construction process and activities, and the impact is assessed by the duration, scale and probability of occurrence.
Bilec et al. (2010)	Presented a life-cycle assessment model of construction processes for commercial buildings. Examined the environmental impacts in the construction stage of a building. Used the hybrid LCA to model the construction phase, which combined the advantages of process LCA and EIO-LCA.
Ali and Al Nsairat (2009)	Three aspects — environmental, economic and social impacts — have been taken into consideration. The seven categories include site, energy efficiency, water efficiency, material, indoor environment quality, waste and pollution and cost and economics. The analytic hierarchy process (AHP) was adopted for dealing with multi-dimensional criteria for decision-making. Though this model addresses sustainability issues in all stages of a building life cycle, it has not integrated the assessment criteria into the building process. Moreover, there is no quantification for each category in this model, and the scores are based on the interview ranking.
Ding and Shen (2010)	A model to integrate the sustainability assessment into the building process and call it the sustainable development value (SDV). It measures the building sustainability in different stages of a building life cycle, including inception, construction, commissioning, operating and demolition. The SDV in each stage is amalgamated into the model of sustainable development ability (SDA).
Akadiri et al. (2013)	A multi-criteria evaluation model for the selection of sustainable materials for building projects. The sustainable assessment criteria are chosen based on the Triple Botton Line (TBL) and the needs of stakeholders. Four guidelines are used for selecting sustainable assessment criteria: comprehensiveness, applicability, transparency and practicability. Comprehensiveness means that the criteria chosen should cover all aspects of sustainability, including environmental, economic and social aspects.
Chen and Ng (2015)	Using existing BEA tools studied and the consolidated opinions from the interviews, a BEA integrated embodied GHG emissions assessment model was outlined. In this assessment model, the building materials are assessed according to three elements: i) product category, ii) GHG auditing framework, and iii) benchmark
Krantz et al. 2015	Study presents a model to assess embodied energy and associated GHG emissions, which is specifically adapted to address the dynamics of infrastructure construction projects.
Bohari et al., 2017	Study presents a model of green procurement for building projects and a list of factors and practices associated with green procurement affecting a project's environmental performance in Malaysia.
Resch and Andresen, 2018	Study presents a model for standardising the reporting and characterisation of embodied emissions in the built environment to help practitioners produce systematic data, leading to comparable results and reliable embodied emissions statistics.
Victoria and Perera, 2018	Study presents a model to facilitate easier and faster prediction of embodied carbon during the early stages of design and allow comparisons between alternative design solutions.
Abdi et al., 2018	Presents a GHG performance model for buildings based on an Earned Value Management (EVM) methodology, which includes monitoring and control during the construction phase. Figure 2.2 Greenhouse gas performance measurement model.

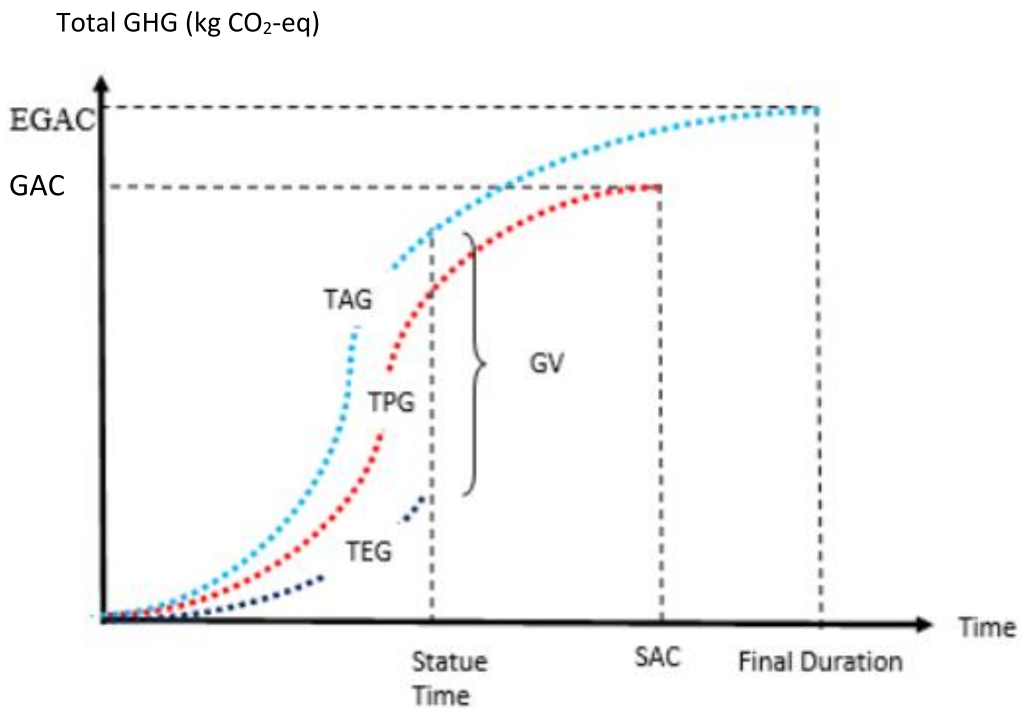


Figure 2.2 Greenhouse gas performance measurement model

(Source: Abdi et al., 2018)

2.10 Summary

The significance of embodied carbon is growing as more buildings are becoming energy efficient by reducing operational carbon emissions due to regulations and the efforts made by industry. Although neglected so far, embodied carbon is a genuine indicator of greenhouse gas emissions and should also be used to assess the environmental impacts of buildings. However, there is an improvement in data accuracy, and many international standards are concentrating on including standard methodologies for embodied carbon management.

This chapter emphasises the existing embodied carbon calculation methods, such as I-O analysis, process analysis, hybrid analysis and LCA standards. A review of the literature indicates a need to develop a consistent standard detailed methodology for calculating and managing embodied carbon across the life cycle of a project which could help reduce the errors and variances among the existing standards. Preliminary reviews suggest that the existing standards are unsuccessful in providing complete guidance on LCA studies. Furthermore, the LCA process, such as estimating and managing the embodied carbon emissions, should be simplified by providing a reliable source of inventory data.

As suggested by the literature review, calculators and tools currently available are complex, their databases hidden, databases not made accessible to all, and this is hampering implementation. With the use of freely accessible and reliable data such as the ICE database, industry can use simple-in-use tools such as Excel spreadsheets and Primavera to improve the implementation of carbon emissions management.

Chapter Three: Construction and Carbon Emissions Management in the UAE

3.1 Introduction

Buildings are one of the largest contributors of CO_2 emissions leading to global warming and climate change. Also, the building operation will be affected by global warming, due to the rise in the ambient air temperature. Global warming will increase the energy used for HVAC of buildings by 23.5%, CO_2 emissions to 7.6 million metric tonnes if the UAE warms by 5.9 °C (Radhi, 2010).

This chapter presents a brief discussion about climate change, sources of CO_2 emissions, the meaning of sustainability and the role of the building construction industry. It is imperative to review the United Arab Emirates, where the research is being carried out, the impact it is facing due to CO_2 emissions, current practices of procurement, management and the need for an alternative approach to improve implementation of sustainability in the construction industry.

3.2 Climate Change and Sources of CO_2 Emissions

Scientific literature suggests that limiting the average global temperature rise to 2°C above pre-industrial levels — the target internationally adopted in UN climate negotiations — is possible if cumulative emissions in between 2000 and 2050 do not exceed 1,000 to 1,500 billion tonnes CO_2 (Meinshausen et al., 2009). Current global increases in CO_2 emissions should be reduced to avoid cumulative emissions surpassing the limit within the next two decades (Living Planet, 2015). In 1990, the industrialised countries with a mitigation target for total greenhouse gas emissions under the Kyoto Protocol had a share in global CO_2 emissions of 68%, versus 29% for developing countries. A growth of 50% in global anthropogenic CO_2 emissions in the 20 years since 1992 was observed and reported during the UN Earth Summit held at Rio de Janeiro. The CO_2 concentration in the atmosphere also increased from 356 as reported at the Rio summit to 392 ppm in the year 2012. In Oct 2016, as shown in Figure 3.1, the Atmospheric CO_2 concentration was 401.01 ppm (CO_2.Earth, 2016).

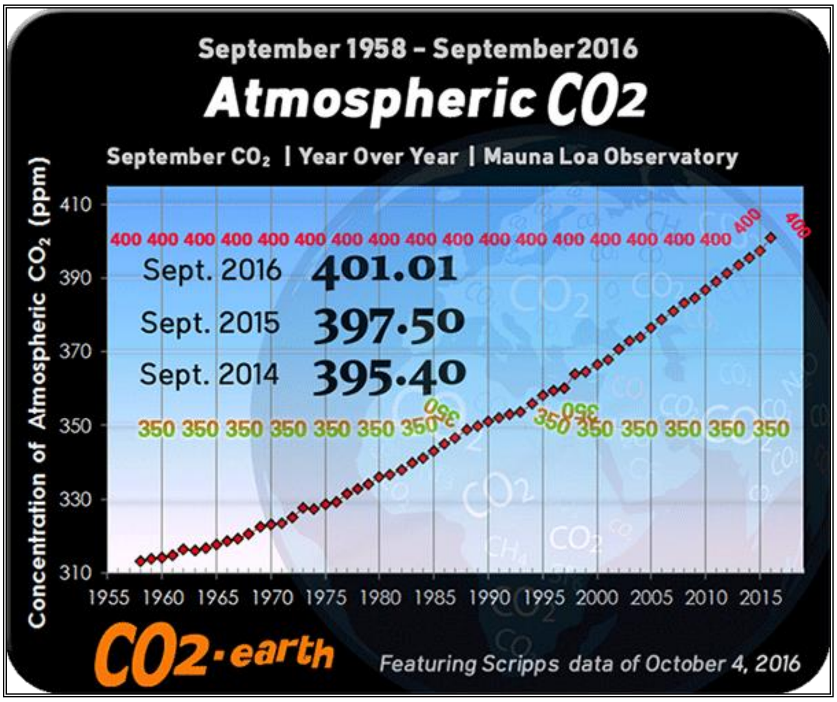


Figure 3.1 Atmospheric CO_2 levels – from the year 1958 to 2016

(Source CO_2.earth)

The increase in CO_2 emissions was mainly due to a continued high economic growth rate, with related increases in fossil fuel consumption. For example, the increase in fuel consumption in China in 2011 is due to the increase in building construction and the expansion of infrastructure, as indicated by the growth in cement and steel production (Trends in global CO_2 emissions; 2012 report). In the year 2018, the Atmospheric CO_2 concentration levels rose to 410.79 ppm, as shown in Figure 3.2. To stabilise the concentration levels, the sources shall be identified; and objectives shall be set with defined targets. The sources of CO_2 emissions broadly categorised as stated in Table 3.1.

One of the outcomes of the Cancún summit (2010) and Paris summit (2015) resulted in 191 parties signing the agreement and 83 countries ratifying, representing 61% of global emissions (World Economic Forum, 2016). These countries submitted quantified economy-wide emissions reduction targets for 2020, and 45 developing countries pledged mitigation action plans. Emissions levels are expected to be lower by 51 to 55 billion tonnes carbon equivalent (CO_2e) due to these pledged actions (Den Elzen et al., 2012).

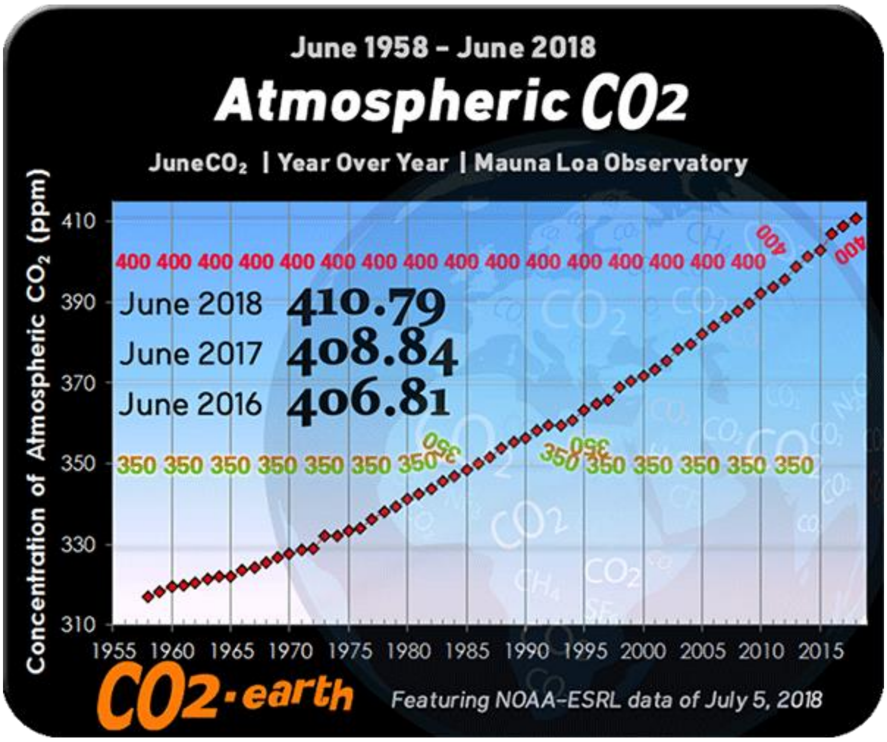


Figure 3.2 Atmospheric CO_2 levels – from the year 1958 to 2018

(Source CO_2.earth)

Climate change is being recognised as a key business issue through which companies can increase their competitive advantages by implementing carbon reduction strategies (Busch and Wolfensberger, 2011). Businesses are also under constant pressure due to changing government policies, competitors reducing their emissions, and the cost associated with non-compliance (Wittneben and Kiyar, 2009). Therefore, incorporating climate change initiatives into sustaining business through efficient carbon management strategies is vital in the current business environment, due also to increasing levels of awareness among stakeholders (Hoffman, 2007). Companies have begun viewing carbon management as a business opportunity more than a mere risk. Subramaniam et al. (2015) suggest the concept of integrating carbon emissions-related risks and opportunities into risk management systems, which are a part of overall business management.

In addition to these global trends, companies are facing pressures from five major forces to assess better, redefine and enact strategies to increase their climate resilience (see Figure 3.3).

Table 3.1 Sources of CO_2 emissions (Source: Trends in global CO_2 emissions report 2012)

Source	Description
Fuel combustion	Major fossil fuel type (coal, oil, gas, other) (IEA, 2011) used by the International Energy Agency (IEA) for fuel combustion to calculate the trend per country. BP Statistical Review of World Energy is used to calculate the trend of fuel consumption per main fossil fuel type: coal, oil and natural gas (BP, 2012).
Fugitive emissions from fuels	Fugitive emissions from solid fuel which for CO_2 refers mainly to coke production. Other fugitive emissions from oil and gas refer to leakage, flaring and venting.
Cement production and other carbonate uses	Cement production and other carbonate uses, such as lime production and limestone use, soda ash production and use. CO_2 emissions from cement production, which amount to more than 90% of this category.
Non-energy/feedstock uses of fuels	Ammonia, ethylene, carbon black, carbides production. Net losses in blast furnaces in the steel industry. Consumption of lubricants and paraffin waxes and indirect CO_2 emissions related to VOC emissions from solvent use. Urea used as fertiliser emits CO_2.
Other sources	Emissions from peat fires, waste incineration, underground coal fires and oil and gas fires.

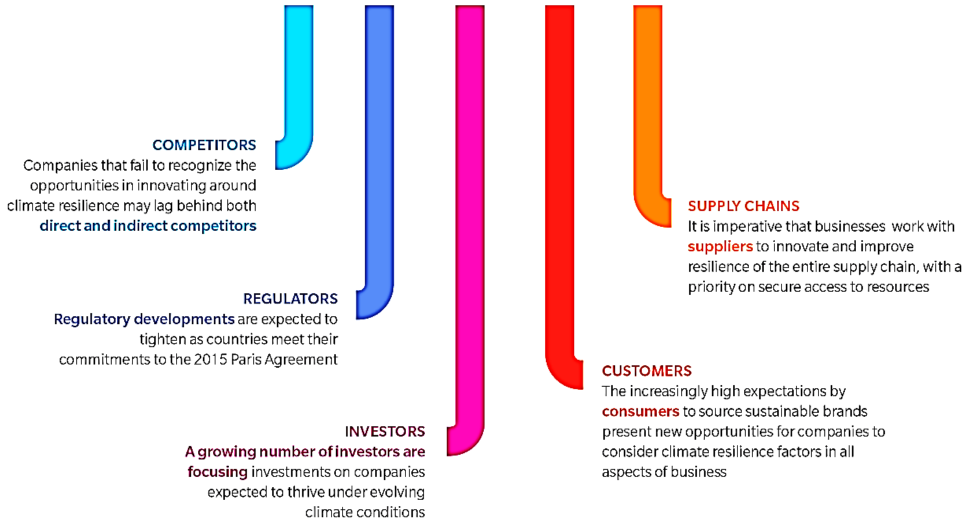


Figure 3.3 Five factors driving the focus on climate change

(Source: Marsh & McLennan Companies)

3.3 Sustainability

Sustainability is derived from the term *sustinere-eco*, which means holding or maintaining the environment or, more precisely, preserving Earth to preserve the human race (Mensah et al., 2012). Furthermore, the World Commission on Environment and Development (WCED), which is also known as the Brundtland Commission, created the definition of sustainability which is currently in use and widely accepted, in their report 'Our Common Future' (1987):

> ***An approach to progress which meets the needs of the present without compromising the ability of future generations to meet their own needs.***

The U.S. EPA further clarified the main principle behind sustainability, highlighting the direct or indirect connection between the environment and humans, because the natural environment is the ultimate source which can protect human survival and wellbeing. 'Both humans and nature shall survive in productive harmony and protect resources for present as well as future generations', including social, economic and other elements (U.S. EPA).

Sustainability practices are not new but rather have endured and developed across generations of history, such as the construction of igloos in the Central Arctic, the Native American tipi, and Cliff Palace at Mesa Verde National Park (Krygiel and Niles, 2008). However, the concept of sustainability was realised with the industrial growth, which began 40 years ago, according to the 1972 UN Conference on the Human Environment (Adams, 2006). This conference led to the founding in Nairobi, Kenya of the United Nations Environment Programme (UNEP), whose aim is to provide leadership to protect the environment and people (Mensah et al., 2012).

Krygiel and Niles (2008, p. 5) argued that this concept of sustainability was conceived in the 1960s with Rachel Carson's *Silent Spring* (1962), the first book exploring the price of environmental pollution caused by humans. Also highlighted as contributing to the awareness and actions of governments are the Wilderness Act of 1964 in the U.S. and the establishment of the U.S. EPA in 1970. The establishment of the World Wildlife Fund (WWF) in 1961 is also considered by many researchers to be an initial step towards the development of the concept of sustainability (Life Science Foundation, 2012).

John Elkington introduced the *Triple Bottom Line* concept in his book *Cannibals with Forks: The Triple Bottom Line of 21st Century Business* (1998), and these triple bottom line items ultimately became the pillars or dimensions of sustainability. Initially, the categorisations were People, Planet and Prosperity, but later modified to Social, Environmental and Economic and represent the needs which must be balanced for a sustainable outcome (Presley and Meade, 2010), as shown in Fig 3.4. To this date, pillars are being added and argued over. For example, a fourth pillar — technology — was introduced by Hill and Bowen in 1997 (Tan et al., 2011). Scholars differ in their views of the advantages of including new pillars to develop sustainability quality and performance (Adams, 2006; Mensah et al., 2012).

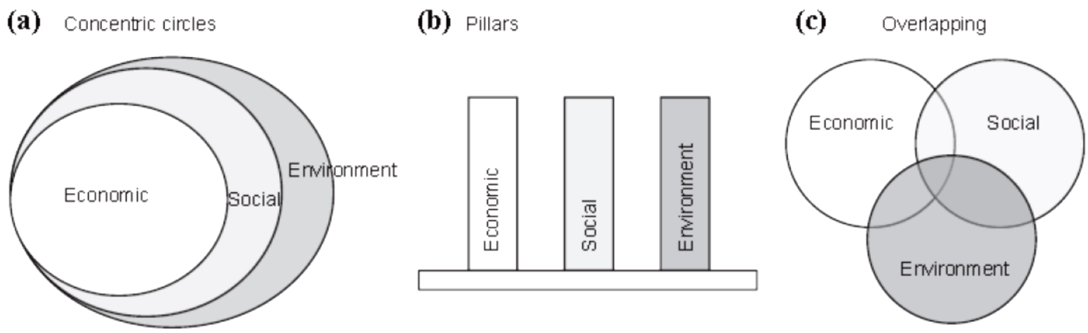


Fig 3.4 Sustainability Triple Bottom Line

(Source: Presley and Meade, 2010)

3.4 Role of Construction Industry

The construction industry and built environment are defined as human-made surroundings, their activities in those surroundings and environments in which people reside (Mensah et al., 2012; Presley and Meade, 2010). The construction industry directly impacts on a country's economy, society, resources and environment. Moreover, this industry fulfils the basic livelihood needs of humankind and contributes significantly to generating employment and investment (Mensah et al., 2012). The European Commission has cited the construction industry as Europe's largest industrial employer, i.e. 8.6% of Europe GDP, whereas the construction industry proportion in the U.S. is 4 to 5% of GDP and 10.6% of GDP for the UAE, which signifies impacts of the construction industry for any economy. (Buildingradar, 2018)

The built environment is one of the major emitters of GHGs and represents 50% of CO_2 emitters and 40% of energy consumers and is responsible for 16% of water usage, 40% of solid landfill waste, 50% of raw material use and 71% of electricity use. It represents 50% of the world's resources use and 30 to 40% of worldwide energy use (Lam et al., 2009; Low et al., 2009; Newell, 2008; Ortiz et al., 2009). In 2008, the United Kingdom's construction process released 48 tonnes CO_2/million pounds of project cost (Arup, 2010). Therefore, the concept of sustainable construction has become a priority around the world. Various sustainability certification rating systems and standards have been implemented, such as CEEQUAL (infrastructure projects), Al Safat, National Australian Built Environment Rating System (NABERS), BREEAM (buildings), LEED (buildings) and Estidama (infrastructure and buildings). These systems are gaining acceptance in all phases of the construction process (Guthrie et al., 2012), either through regulations or voluntary implementation by clients.

Table 3.2 Rating systems and standards addressing carbon emissions

Sustainability rating system	**Country**	**Type**	**Embodied carbon**	**Carbon reduction**	**Cap/Rating type**	**Carbon incentive**	**Product EPD Use**
LEED v4	International	Certification	Optional	Carbon comparison	Self-declared	Rating points	Buy low carbon
BREEAM international	International	Certification	Optional	Carbon reporting	-	Rating points	Documentation
Estidama	Abu Dhabi	Certification	No	-	-	-	-
ISO 14040	International	Standard	Required	Carbon reporting	-	-	Use in LCA
NABERS	Australia	Certification	No	-	-	-	-
Al Safat - Dubai Green Building Evaluation System	Dubai	Certification	No	-	-	-	-
CEEQUAL International	International	Standard	Required	Carbon comparison	Self-declared	Rating points	-

Table 3.2 shows the rating systems, which fall under the carbon reporting or carbon comparison types, the majority for the UAE being optional with rating points as incentives. The Embodied Carbon Review (2018) propose the measures in increasing order of efficiency, such as carbon reporting, comparison in design, carbon rating, carbon caps and de-carbonisation. These measures are estimated to lead to embodied carbon reductions in terms of percentage points or quantity of carbon emissions optimised. As per Table 3.3, United Kingdom tracked their carbon emissions from construction-related activities and presented the carbon emissions in 2008, which was 48 tonnes CO_2 per million pounds of contractors output. With continuous efforts, UK greenhouse gas (GHG) emissions fell 3% in 2017 to 456 $MtCO_2e$ and have fallen 43% since 1990 (Committee on Climate Change, 2018).

Table 3.3 Carbon emissions in the United Kingdom for 2008
(Source: Strategic Forum for Construction & Carbon Trust, 2010)

	England	**Wales**	**Scotland**	**Northern Island**	**Great Britain**	**UK**
Contractors Output (£ million)	106,579	4,633	10,751	3,249	123,584	125,513
Site activities (tonnes of CO_2)	1,710,000	86,300	196,000	-	2,010,000	-
Freight transportation (tonnes of CO_2)	1,620,000	77,300	165,000	-	1,860,000	-
Waste removals (tonnes of CO_2)	525,000	23,300	53,500	-	604,000	-
Offsite assembly	232,000	11,100	23,600	-	268,000	-
Offsite offices	233,000	11,800	26,600	-	274,000	-
Business travel	732,000	37,000	83,600	-	861,000	-
Total absolute emissions	5,050,000	247,000	547,000	154,000	2,870,000	5,990,000
Emissions per £ million contractors output (tonnes of CO_2/£ million)	47	53	51	48	48	48

The built environment is always slow to adapt to changes compared with other sectors, such as the automobile industry. The automotive industry was quick to adopt the sustainable tracking and monitoring of CO_2 emissions, which is evident from the reports being submitted by car manufacturers from 1995 to the present date. By way of comparison as shown in Table 3.4, the BMW Group reduced the CO_2 emissions of its newly sold vehicles in Europe by approximately 41% between 1995 and 2016 (BMW, Sustainable Value Report, 2016). It is remarkable to see how the car manufacturer is reporting CO_2 emissions from its operations, as outlined in the table below. Construction Industry too can adapt the good practices from the automobile industry to monitor, control and report the emissions. Doda et al. (2015) argue that companies need to explicitly discuss how the adoption of corporate management practices influences corporate greenhouse gas emissions.

Ideally, companies should explain how the sustainable practices adopted are influencing the carbon management actions they have taken and how these actions are contributing to lower GHG emissions (Doda et al., 2015).

Table 3.4 BMW Group CO_2 Footprint

(Source BMW, Sustainable Value Report, 2016)

in t CO_2	**2012**	**2013**	**2014**	**2015**	**2016**
Total emissions of BMW Group CO_2 footprint (T3.04)	61,603,503	64,019,874	66,913,264	68,991,955	70,818,970
Scope 1 - Direct Greenhouse gas emissions(CO_2, NO_2)	484,612	492,798	494,931	536,168	562,146
Scope 2 - Indirect Greenhouse gas emissions (Electricity/Heat purchased)	862,214	922,843	966,067	923,313	868,089
Scope 3 - Indirect Greenhouse gas emissions (Logistics, business trips, employee commute, disposals)	60,256,678	62,604,233	65,452,266	67,532,474	69,388,735

3.5 Carbon Emissions in the UK and Other Countries

In 2016, global CO_2 emissions from fuel combustion were 32.31 $GtCO_2$, closer to 2015 values (32.28 $GtCO_2$). However, emissions have doubled since the 1970s and have increased by approximately 40% since 2000, primarily due to increased economic output (IEA, 2018). Countries all over the world are making efforts to reduce emissions. However, as per Embodied Carbon Review reports, the lowest rates of adoption for embodied carbon are in the Middle East, South America and Asia. On the other hand, the most effective carbon reduction incentives are applied in Continental Europe, while overall the global process is still primarily applying for rating points in a certification system (The Embodied Carbon Review, 2018). Table 3.5 shows CO_2 emissions from fuel consumption by sector in the UK, the U.S., Australia, China, the UAE and Saudi Arabia.

In 2015, the United Kingdom signed the Paris Agreement along with 178 other countries to limit the global average temperature rise to 1.5°C above pre-industrial levels. An average temperature increase exceeding 1.5°C would affect weather patterns, and sea level rises, create food and water shortages and impact on human security and economic growth (Greater London Authority, 2018). The Paris Agreement and the United Kingdom's own subsequently instituted regulations will increase pressure on construction companies to manage carbon emissions on all projects. The guidance is already available from the RIBA and the RICS to enable the built environment industry to meet or exceed the set targets (Sturgis, 2018).

Table 3.5 CO_2 emissions from fuel consumption by sector in 2016 as per IEA (2018)

Country	Total CO2 emissions from fuel combustion	Electricity and heat production	Other energy industry	Manufacturing and construction industry	Transport	Residential	Commercial and public services
	Million tonnes of CO_2						
United Kingdom	371.1	99.4	25.8	36.4	120.5	65.8	18.9
USA	4833.1	1893.7	251.9	433.6	1711.2	281.8	214.7
Australia	392.4	194.5	41.1	38.7	96.1	9.3	5.4
China	9101.5	4386.4	285.8	2849.7	851.2	374.9	151.8
Saudi Arabia	527.2	246.1	28.6	110.8	136.9	4.9	-
United Arab Emirates	191.8	85.6	2.6	68.2	34.6	0.8	-

London also adapted measures to help businesses make London a zero-carbon city by 2050, as follows:

- Measure and report on greenhouse gas emissions and set long-term targets
- Adhere to Minimum Energy Efficiency Standard (MEES) building regulations
- Ensure that new buildings are energy-efficient and include measures to reduce cooling needs
- Optimise fleet movements and switch owned vehicles to electric vehicles
- Use procurement to encourage decarbonisation
- Increase awareness to drive behavioural changes which help reduce business emissions

Following the passage of legislation, the British construction industry is now legally obliged to reduce carbon emissions by 80% by 2050 (Sattary, 2017). Figure 3.5 demonstrates that values for GHGs in the UK are continuously improving and have been reduced to 37% from 1990 to 2017. However, in 2017, transport was the largest emitting sector of GHGs in the UK (Department for Business, Energy and Industrial Strategy [BEIS] UK, 2018).

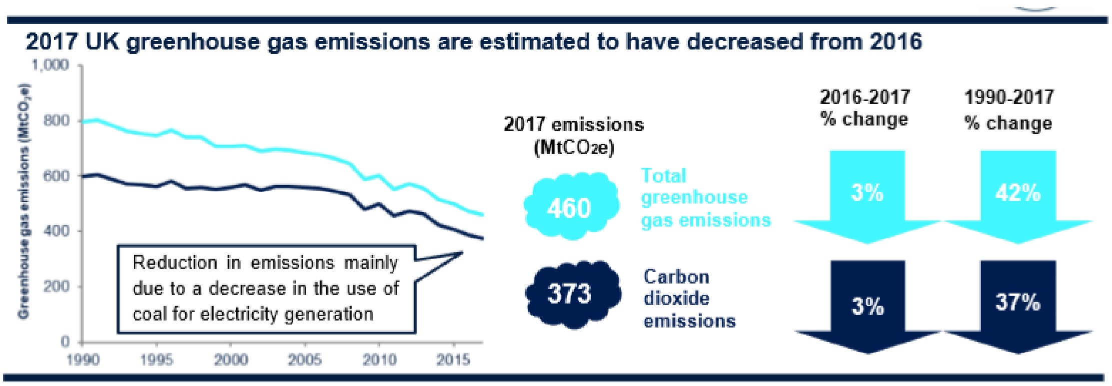


Figure 3.5 Greenhouse gas emissions of UK as per BEIS UK (2018)

In the UK, Network Rail prepared guidelines and a tool to implement carbon emissions monitoring on all projects with a value of £1 million or more from March 2019 (Network Rail, 2018). Similarly, the UK Green Building Council (UKGBC) prepared and issued guidelines to enable built environment clients to include embodied carbon measurements as part of the scope of work (Lewis, 2018).

The buildings sector is the driver of about one-fifth of Australia's greenhouse gas emissions, making it an important opportunity to reduce carbon emissions to limit warming to 1.5°C (ClimateWorks Australia, 2018). The estimated energy embodied in existing building stock in Australia is equivalent to approximately ten years of the nation's energy consumption (Sattary, 2017).

China, as the largest carbon emitter and the second-largest economy in the world, has proposed a series of policies and made great efforts to control the carbon emissions of buildings (Li, Cui and Lu, 2016). The Chinese government submitted four principal climate goals as part of its Intended Nationally Determined Contributions (INDC) under the UN Framework Convention on Climate Change in June 2015, which are as follows (Sandalow, 2018):

- Achieve the peaking of carbon dioxide emissions by approximately 2030, making best efforts to peak early.
- Lower carbon dioxide emissions per unit of GDP by 60 to 65% from their 2005 level by 2030,
- Increase the share of non-fossil fuels in primary energy to approximately 20% by 2030, and
- Increase the forest stock volume by around 4.5 billion cubic meters from 2005 levels by 2030.

China is working towards these goals by implementing the measures in many Chinese provinces and localities. As of June 2016, 23 provinces and cities had committed to peaking CO_2 emissions before 2030.

3.6 United Arab Emirates

The UAE is a union of seven emirates located in the Middle East (the eastern part of the Arabian Peninsula). Comprising a total of 84,000 km^2 of this hot, desert land, Abu Dhabi is the largest emirate and the capital, while Dubai is the second-largest and a hub for tourism, finance and regional trade. Mezher et al. (2010) asserted oil and natural gas as the main industries in the economy, followed by construction, chemicals and plastics, and aluminium industries, etc., as other priorities. The UAE has been experiencing extraordinary economic growth in recent years. With the effect of the government's goal to diversify income channels away from oil and gas industries, this growth directly impacts on other industries, such as tourism, banking and finance, manufacturing, etc. (El-Sayegh, 2007). The construction industry's contribution to GDP is consistent and on a path of gradual growth (UAE Interact, 2016).

The UAE's major natural resources are petroleum and natural gas, representing the world's seventh-largest proven reserves of both oil and natural gas, estimated at 97.8 billion barrels (5.8% of the world's total reserves) and 6.1 trillion m^3 (3.3% of the world's total). The discovery of oil and gas reserves has transformed the desert country into one of the most developed nations in the world with high standards of living. Significant ore reserves of any metals are not available in the UAE, whereas the Northern Emirates have abundant resources of limestone and hard rock, which are utilised in the production of construction aggregate, cement, rock wool, gypsum, etc. The UAE also exports urea, ammonia and sulphur, which are by-products of oil and gas operations. Metal industries such as aluminium and steel are flourishing due to low energy costs and higher demand for products.

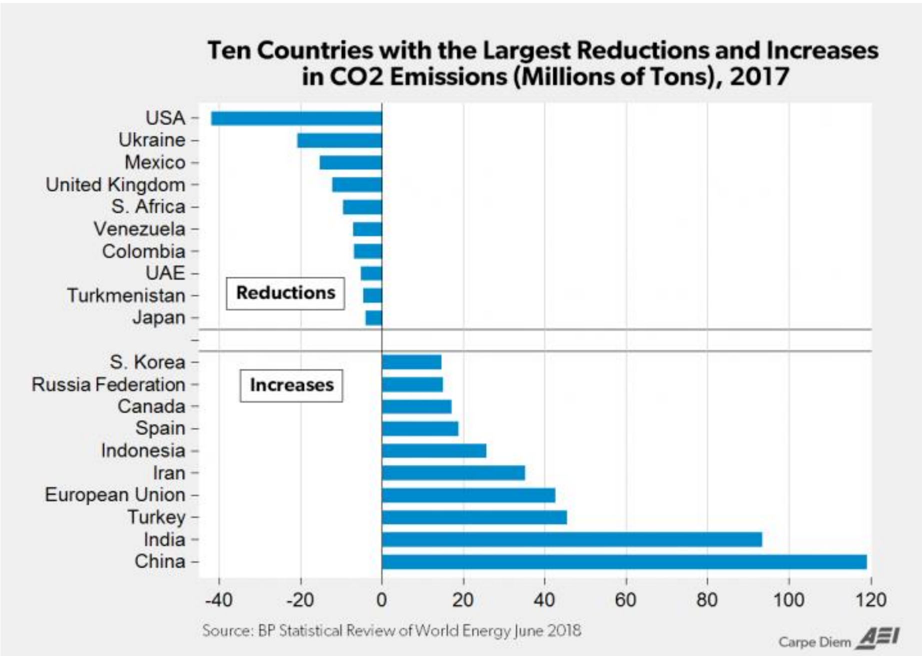


Figure 3.6 UAE in the top ten countries with the largest reduction in CO_2 emissions

The UAE has come a long way in the past few years to meet the challenges of energy and climate change, under the framework of UAE Vision 2021 and the strategic plans of each emirate. Public and private sectors such as oil and gas; water and electricity; industry; buildings, construction and real estate; transport and logistics; waste management; land use and agriculture; financial services; and tourism and hospitality are making efforts towards sustainability. This is visible through the statistical review done by BP in 2017, as shown in Figure 3.6, which lists the United Arab Emirates among the top ten countries with the largest reductions in CO_2 emissions.

Table 3.6 Green Economy Scenarios

(Source: UAE State of Green Economy Report, 2014)

Scenarios/ Investment	GDP in 2030	Jobs in 2030	Export boost in 2030	Domestic oil consumption (average annual % 2013-30)	Domestic gas consumption (average annual % 2013-30)	Electricity demand (average annual % 2013-30)	GHG emissions (cumulative % 2013-30)
Green growth (1.6%of GDP)	+4.0%	+160,000 (+2.2%)	+AED 34 billion	-7%	-13%	-11%	-20%
Green growth plus(1.9%of GDP)	+5.5%	+165,000 (2.3%)	+AED 47 billion	-10%	-17%	-15%	-25%
Carbon pricing (1.0%of GDP)	+4.1%	+139,000 (+1.9%)	+AED 24 billion	-10%	-20%	-14%	-18%
Cost reflective pricing (1.0%of GDP)	+4.1%	+161,000 (+2.2%)	+AED 24 billion	-9%	-7%	-13%	-21%

As per the UAE’s macro-economic model, developed along with a business-as-usual (BAU) scenario were the four future ‘Green Economy’ scenarios. The model assumed average annual investment in green measures of 1.0-1.9% of GDP until 2030 (UAE State of Green Economy Report, 2014). The study shows the potential benefits of a green economy with four Green Economy scenarios projected, as shown in Table 3.6

3.6.1 Impacts of current practices on emissions in the UAE

With the boom in construction and real estate from 2002, massive buildings and infrastructure developments began to be built, pulling huge numbers of investors, organisations and personnel to the UAE.

Consequently, the demand for energy and electricity, water, food, and other living requirements are increasing. The demand increased for combustion of gas and oil (for energy) and desalination of water (which also depends on energy) (Mezher et al., 2010). The hot and humid climate necessitates mechanical ventilation and higher indoor environmental quality systems, which results in higher CO_2 emissions due to a higher consumption of energy than other countries (Lahn and Preston, 2013; Radhi, 2010). However, 99% of the electricity requirements of the UAE are fulfilled by natural gas and the rest by oil (Mezher et al., 2010). These circumstances caused huge CO_2 emissions and much more negative effects on the environment. Figure 3.7 shows the overview of GHG emissions ranging from sources to sectors, key sub-sectors and end-users.

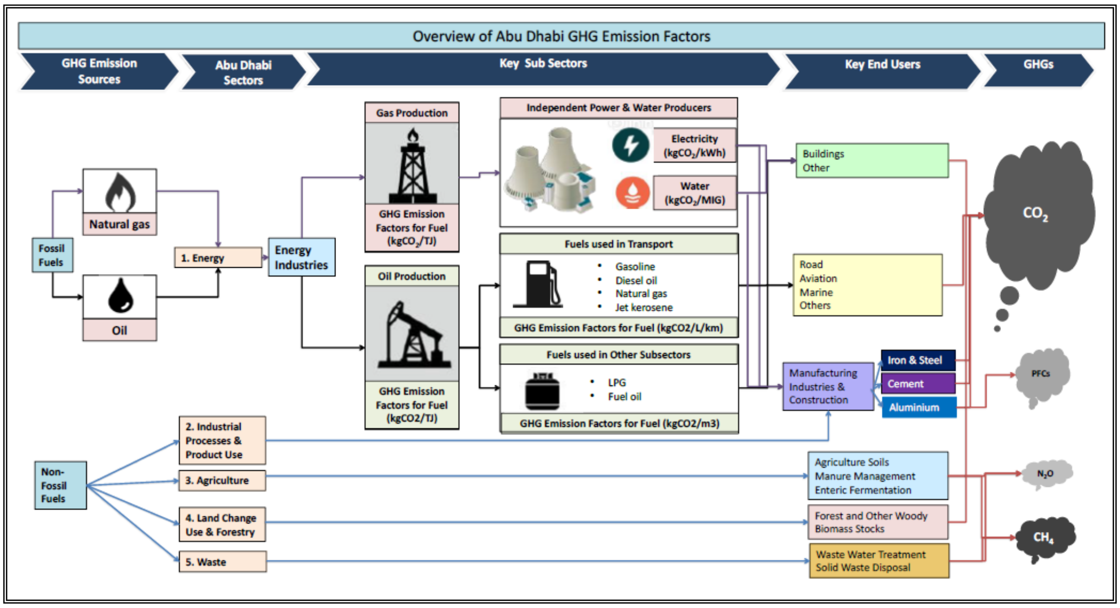


Figure 3.7 Overview of Abu Dhabi GHG emissions

(Source : Abu Dhabi Technical Report, 2015)

The ecological footprint as a sustainability indicator shows impact on natural systems from each country and illustrates how much a nation protects or pollutes the Earth.

Higher footprints reflect higher natural resources consumption. The UAE had recorded the highest footprint in 2003 and continued in top levels (3rd place) (Living Planet Report, 2006 and 2014). With improvements, UAE is no longer in the list of top ten highest footprint countries. The UAE began experiencing more frequent storms, droughts, floods and fog, spelling serious problems for public health and safety and the economy. Temperatures could increase by between 2°C and 3°C during the summer months, while humidity could rise by as much as 10% throughout the entire Arabian Gulf by 2060-2079 (WWF, 2016). The UAE's key infrastructure, including oil and gas stations, power and desalination plants, is located near the sea. The rise in Arabian Gulf levels leads to increased coastal erosion and impacts on businesses and homes in all seven emirates.

Researchers agree that the global warming in the past half-century is caused by emissions of greenhouse gases from anthropogenic activities. Gases such as carbon dioxide (CO_2) are not only harmful to humans but also a major contributor to global climate change. For the United Arab Emirates, key impacts of carbon emissions are associated with climate change, e.g., sea-level rise, coastal flooding, increased salinity and temperature of the ocean and coastal aquifers, impacts on the marine environment, heatwave/heat-stress and built-environment impacts, more extreme weather events [floods, droughts, etc.], and the increased risk of dust storms [Abu Dhabi Quality and Conformity Council (ADQCC), 2015]).

As per the Embodied Carbon Industry Task Force Recommendations (2014), the embodied carbon impacts of construction projects are large. Depending on the type of construction and use of a building, between 30 and 70% of its lifetime carbon emissions have already been accounted for by embodied carbon (EC) in its construction phase, which makes up the largest proportion of the carbon emissions of a building during its lifetime. For some sectors such as industrial warehousing, it accounts for more than 70% of lifetime emissions. Approximately 10% of UK emissions (i.e., 57MtCO_2e per year) are associated with the manufacture and transport of construction materials and the construction process. If no improvements, this sector alone will be responsible for additional emissions of more than 3100MtCO_2e (i.e., by 2050, the equivalent of more than 5.5 years of total UK emissions). In the UAE, Abu Dhabi accounted for 99,101

$GgCO_2e$ for 2010, a number which is increasing continuously due to economic growth in the region (ADQCC, 2015).

UAE climatic conditions, construction practices and low awareness levels in the UAE are contributing negatively to the increase in energy consumption and its associated CO_2 emissions. 4% of the CO_2 production in the UAE is due to the direct emissions of buildings, 43% by electricity generation and 45% by manufacturing and construction. It equates to 5.50 million metric tonnes due to direct emissions of buildings, 35.5 million metric tonnes due to electricity use by buildings and 62.0 million metric tonnes due to manufacturing and building construction (Radhi, 2010). To optimize the carbon emissions, it is necessary to estimate, monitor and control Carbon emission during construction and operation phase of buildings. UAE is taking good measures and initiatives to reduce the inefficient used of energy by educating people and providing good energy management (Estidama, 2019; Al Safat 2019; Barjeel 2019).

3.7 Carbon management

Liu (2012) describes carbon management as an effort to reduce the carbon impacts of business activities to address climate change. All GHG emissions are not carbon emissions, but these are included as carbon dioxide equivalents (CO_2e) based on the impacts they will have on climate change. Challis (2008) states that Carbon management is a value creation by assessing the carbon-related strategic, operational and project risks. All sectors established measures of carbon management focusing on GHG emissions reductions, low-carbon technologies and production of renewable energy. One way to drive GHG emissions reductions is through a market-based financial incentive for private-sector entities to reduce carbon emissions. Due to the lack of incentives for private-sector investment, clean technology projects are at risk of being decommissioned, such as emission-reduction projects at landfills and agricultural and wastewater treatment sites (Benjamin and Chantale, 2018). No policies are in place in any country to provide formal incentives for calculating embodied CO_2e, except the Netherlands as part of building regulations which require the calculation but not the reduction. However, during the last decade, the need to reduce carbon emissions has become one of the most pressing environmental concerns and will remain an international priority in decades to come keeping in view the future regulations and rating advantages (De Wolf et al., 2017a; Roosa and Jhaveri, 2009).

Furthermore, during the last decade, organisation and business models have adopted carbon management, but improvements are needed to achieve sustainable targets (Liu, 2012). Liu (2012) conducted research on fossil fuel-intensive sectors in China and found that the companies were aware of and willing to implement carbon management but that implementation was low. Therefore, gaps do exist between awareness and implementation of carbon management. To address these gaps, the U.S. EPA developed a framework to reduce carbon emissions and emphasise that organisations should first quantify carbon emissions and then set objectives to reduce them (EPA, 2007). Under this framework, organisations shall reduce emissions by adapting carbon sequestration and by offsetting the residual amount of emissions. Currently, organisations are minimising energy consumption, maximising their use of alternative energy sources and offsetting carbon (Department of Energy and Climate Change [DECC], 2011b). Carbon management has six components: verifying data sources of GHG emissions, setting and updating performance targets, identifying cost-effective emissions reduction strategies, internal communication management on performance, adapting to new business opportunities and market-based solutions (Del Pino et al., 2009). Abdul-Azeez and Ho (2015) stated that it is necessary to determine the existing levels of emissions to apply suitable sustainable strategies for a project.

Figure 3.8 shows the current technique of deriving the embodied carbon footprint of a building, which requires rigorous data collection and processing procedures summarised into four steps (Yeo et al., 2016). However, implementation of these current techniques in the UAE is not evident from the existing literature review.

Using a similar approach, Lee (2012) developed a comprehensive theoretical framework for carbon management activities, which includes carbon emissions reduction commitment, product development, process and supply improvement, new market and business development, organisational involvement and external relationship development. Czerniawska (2007) has a contradictory view on climate change mitigation, asserting that reducing only carbon emissions is not enough when there is a fragile future related to supplies of natural resources. Also, the acidification of oceans and the consequences of that process could be even greater than those of climate change over a period of time. The failure to implement carbon management is due to lack of intent from senior leadership. Contractual clauses, clear responsibility and accountability for delivering efficient carbon management projects are needed to improve implementation levels (Wehrmeyer et al., 2009). Therefore, changes are required which can be implemented from the outset of a project life cycle.

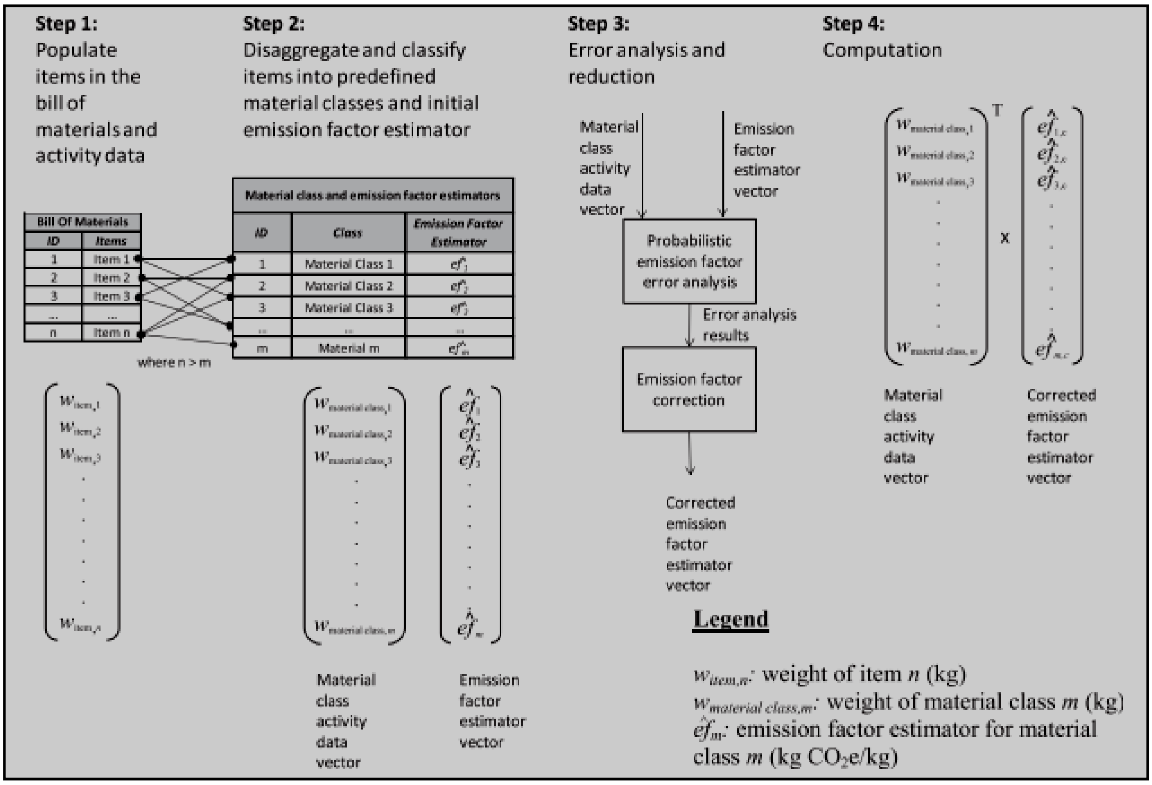


Figure 3.8 Method for embodied carbon calculation

(Source Yeo et al., 2016)

Changes as simple as adapting alternative products can reduce the impacts of carbon emissions considerably. Use of concrete with reduced embodied carbon emissions, replacing conventional concrete with supplementary cementitious materials (SCMs), will reduce the carbon emissions impacts of buildings to a greater extent (Roh et al., 2018).

3.8 A review of the procurement of contracts

Passing on the responsibility to another discipline, in particular towards the sustainability consultants, is identified as one of the reasons for low implementation of embodied carbon emissions management (Moncaster and Ariyaratne, 2014). Methods of quantifying the cost of embodied carbon elements would aid the decision-making process. An important decision in a project is the procurement of contract decision. The subsequent section reviews the procurement process and contractor selection.

The two important stages of the procurement process are pre-qualification and tender evaluation. Each of these stages has its criteria and decision-making models in dealing with the assessment of a contractor's capabilities before the award of contract by the client. Construction is slow to adopt changes, resulting in following the old concepts of procurement and limiting the innovation to use of information technology. To this date, the majority of companies use the traditional pre-qualification process and bidding processes, as shown in Figure 3.9 and Table 3.7.

Table 3.7 Current practices – tender evaluation result
(Source: Watt, Kayis and Willey, 2010)

Criteria	Tenderer A	Tenderer B	Tenderer C
Experience of the organisation	Four to ten years	Less than two years	Greater than ten years
Expertise in project management	Outstanding	Outstanding	Satisfactory
Price of tender	3% below tender	5% above tender	10% below tender
Technical expertise	Above standard	Standard	Very high standard
Performance	Excellent	Standard	High-quality
Reputation	Not known	Neutral	Neutral
Capacity or workload	Numerous projects, sufficient capacity	A small number of projects, excess capacity	Numerous projects, sufficient capacity

The procurement of contractors, also known as the tendering process, comprises three phases (Singh, Nayak and Sheshadri, 2013) The first is the pre-tendering stage, which includes needs, assessment, planning and budgeting, classification of requirements and selection of procedures. The second phase is the tendering stage, which includes an invitation to tender, submitting bids, evaluation and award of tender. The third phase is the post-tender stage, which includes contract management, orders and payments.

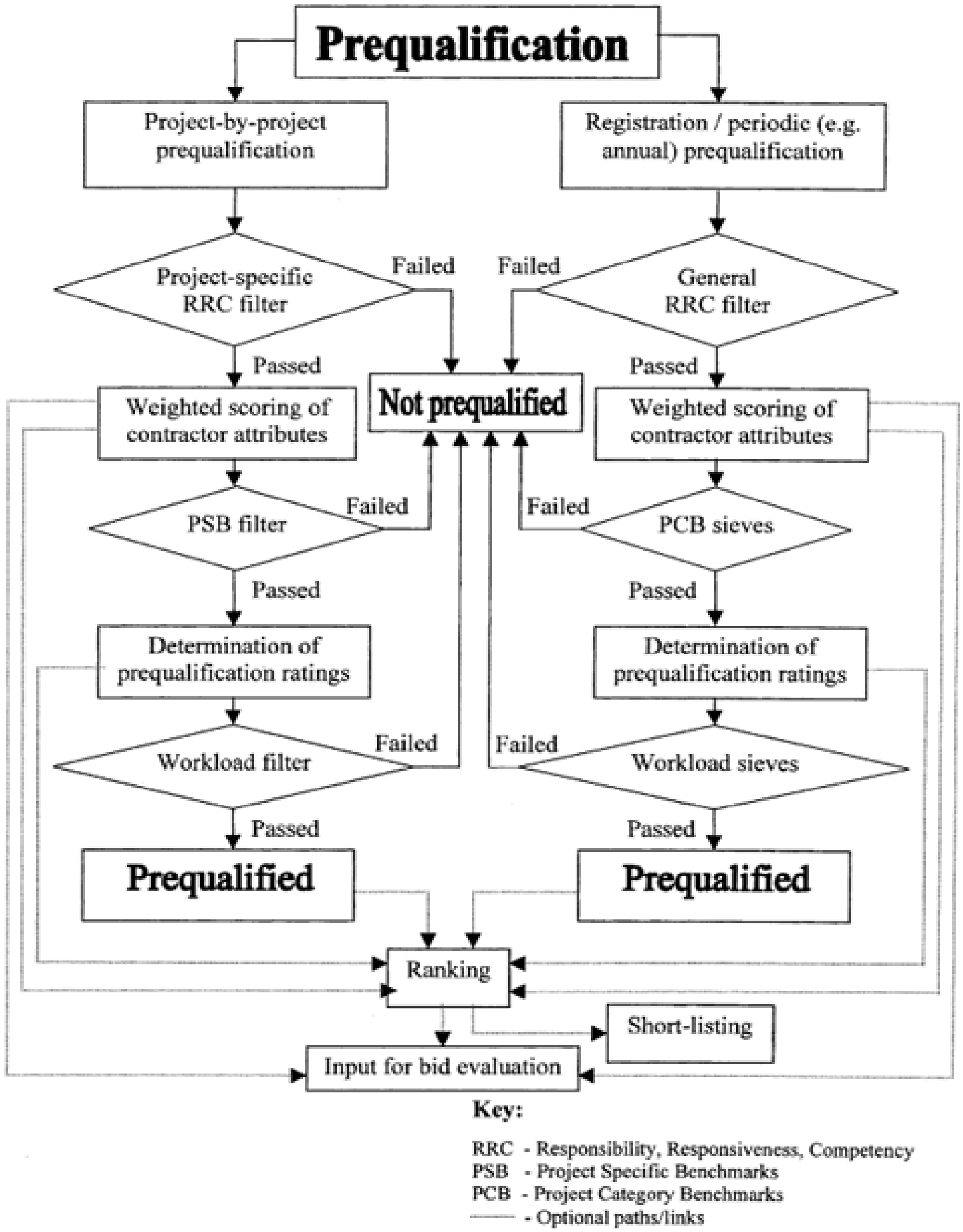


Figure 3.9 Current practices – Prequalification

Traditionally, contractors are selected on a lowest-bid basis (Langdon and Rawlinson, 2006), which was confirmed by a survey conducted by the engineering company AECOM in 2014 across the Middle East region. AECOM’s findings also include that competitiveness and an owner's best possible price by negotiation are prevalent in the market. According to Christoph Schaaffkamp (2014), a 'best practice' acceptable to all is yet to be developed for using competitive tendering as an instrument to provide maximum benefit.

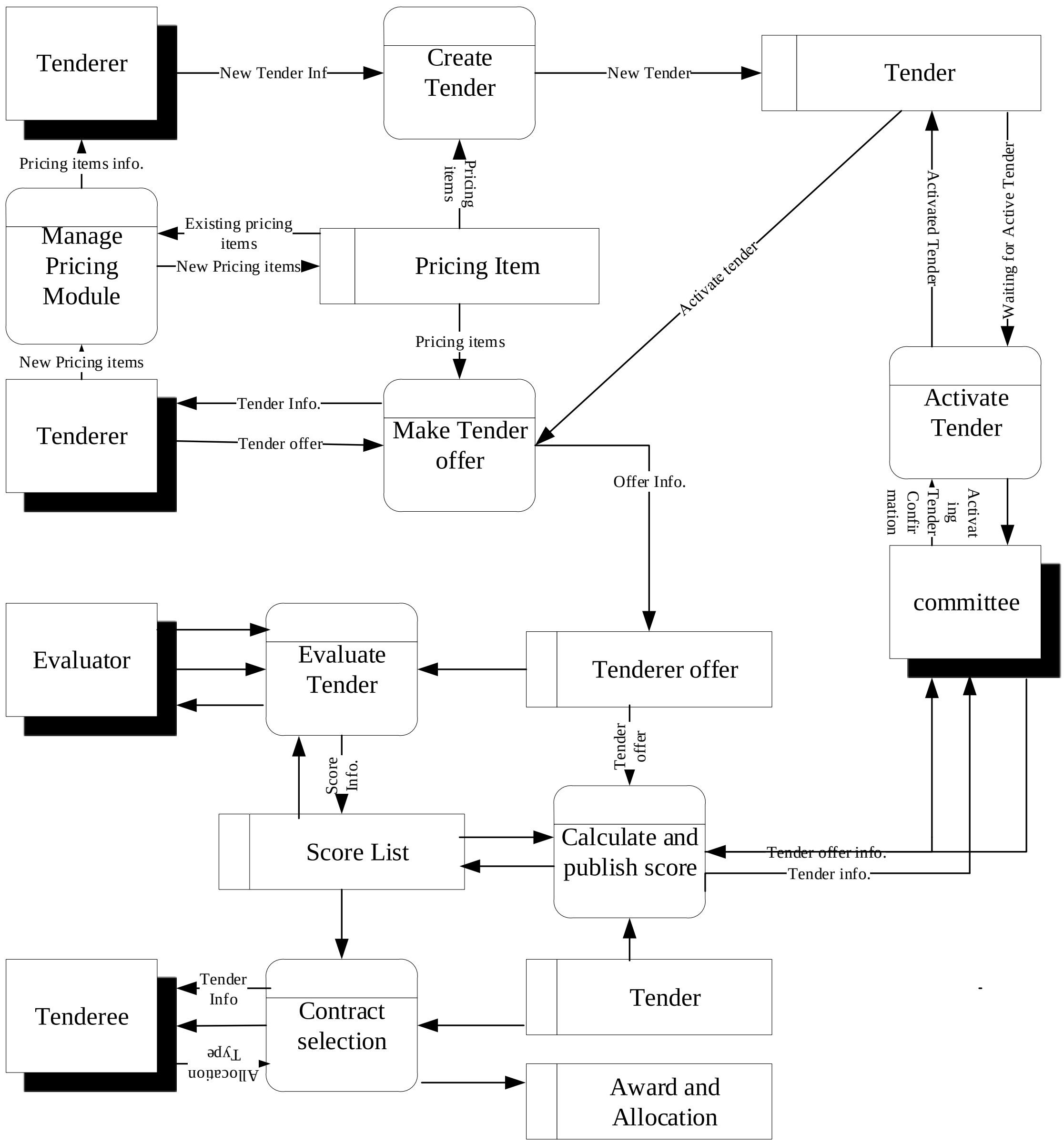


Figure 3.10 Current tendering practices data flow diagram

(Source: Fong and Yan, 2009)

Procurement is an important part of activities, usually characterised by bulk volumes with complex variables, bureaucratic workflows and the need to function in a regulated environment in which many bidders participate (Fong and Yan, 2009). The above tendering flow diagram in Figure 3.10 shows the steps involved in tendering activities; however, the process flow differs from company to company.

The award phase, in which the contractor is selected, is the most significant decision for any organisation responsible for delivering contracts (Watt et al., 2010). The majority of contracts are awarded to the lowest bidder, with a few exceptions in which the owner may award the contract to the bidder who is not the lowest on price scale. However, the evaluation of CO_2 emissions-related capabilities are not specified nor a criterion in the selection of a contractor in the existing literature in the UAE.

3.9 Carbon emissions management and the tools

Awareness levels on sustainable rating systems are greater, whereas the awareness levels on CO_2 emissions are lower. Numerous tools have been developed to estimate the carbon footprint of a building, such as the Faithful-Gould calculator, Build Carbon Neutral, Carbon Calculator, GaBi, etc. (Harmouche, 2012). These calculators are either developed by private companies or non-governmental organisations which typically divide the building profile in stages to generate a quantified amount of CO_2 emitted. Implementation levels in the UAE on carbon emissions estimation and monitoring are low due to the complexity and lack of transparency of carbon calculators, the lack of embodied energy datasheets from manufacturers and a dearth of stringent regulations (Memerzadeh and Fard, 2012). The only visible area where carbon emissions management is implemented on Masdar City project in the UAE, which used a simple tool (Excel) to develop a bill of quantity toolkit using the Bath ICE embodied carbon database. This has enabled sustainability teams to design and assess carbon reductions against a baseline scenario consistent with the PAS 2050 carbon standard (Hammond and Jones, 2011).

Due to the factors stated by Memerzadeh and Fard (2012) and Harmouche (2012), cost estimation software and BIM are not being implemented by small and medium-sized contractors for various reasons, such as lack of awareness, complexity of use, cost of software, hidden data, etc. Instead, the companies and their management are more comfortable using the traditional cost estimation practices of Excel spreadsheet calculations and progress planning/reporting using Primavera. The construction industry has greater implementation of Primavera due to clients' binding requirements in the scope of work, where it is clearly stated that Primavera shall be used as a planning and scheduling tool.

3.10 Sustainability Rating Systems

Egan (1998) stated the importance of performance measurement and benchmarking for the construction industry in the report 'Rethinking Construction'. Challenges of performance measurement frameworks and key performance indicators (KPI) in the industry include the lack of indicators to measure sustainability achievements (Presley and Meade, 2010). Sustainability rating systems such as LEED, BREEAM, GREEN STAR, QSAS and Estidama tried to fill this gap and helped in setting the benchmarking but fell short due to the intangible and unquantifiable nature of analysing sustainable performance. All the sustainable rating systems focus on energy, water, materials, indoor environmental quality (IEQ), site selection and innovation — almost the same issues but in different weightings (Alnaser et al., 2008; Nguyen and Altan, 2011). The shortcoming of these rating systems is the lack of one unit to measure to report CO_2 emissions. The most precise technique is to determine the GHG emission factors from these processes (e.g., kg CO_2/kWh and kg CO_2/gallon), which can be used by the end-users of these resources (i.e., industry, buildings, etc.) to estimate the GHG emissions associated with their operations (ADQCC Technical Report, 2015). Existing environmental methods such as LEED, Estidama and Al Safat, do not require embodied carbon to be carried out as a prerequisite. BREEAM places more emphasis on operational carbon, and embodied carbon is not always addressed in these assessments (Ariyaratne and Moncaster, 2014). In addition to these rating systems, industry should estimate, monitor and report GHG emissions using the available techniques, such as earned value analysis (Kim et al., 2014).

3.11 Cost and Time Management – Earned Value Analysis

Building construction projects are susceptible to cost and time overruns due to a variety of factors. Earned value management (EVM) is a project performance evaluation technique in which the earned value analysis provides early signals on project performance to highlight the need for eventual corrective action (Bhosekar and Vyas, 2012). Abdi et al. (2018) utilised the advantages of cost and time management using earned value management to monitor and control carbon emissions.

In EVA, the earned value (EV), planned value (PV) and actual cost (AC) are measured and monitored. The schedule performance index (SPI) and cost performance index (CPI) is used to monitor the performance of a project by identifying the schedule and cost variances.

$$\mathrm{SPI} = \frac{EV}{PV} \qquad \mathrm{CPI} = \frac{EV}{AC} \tag{1}$$

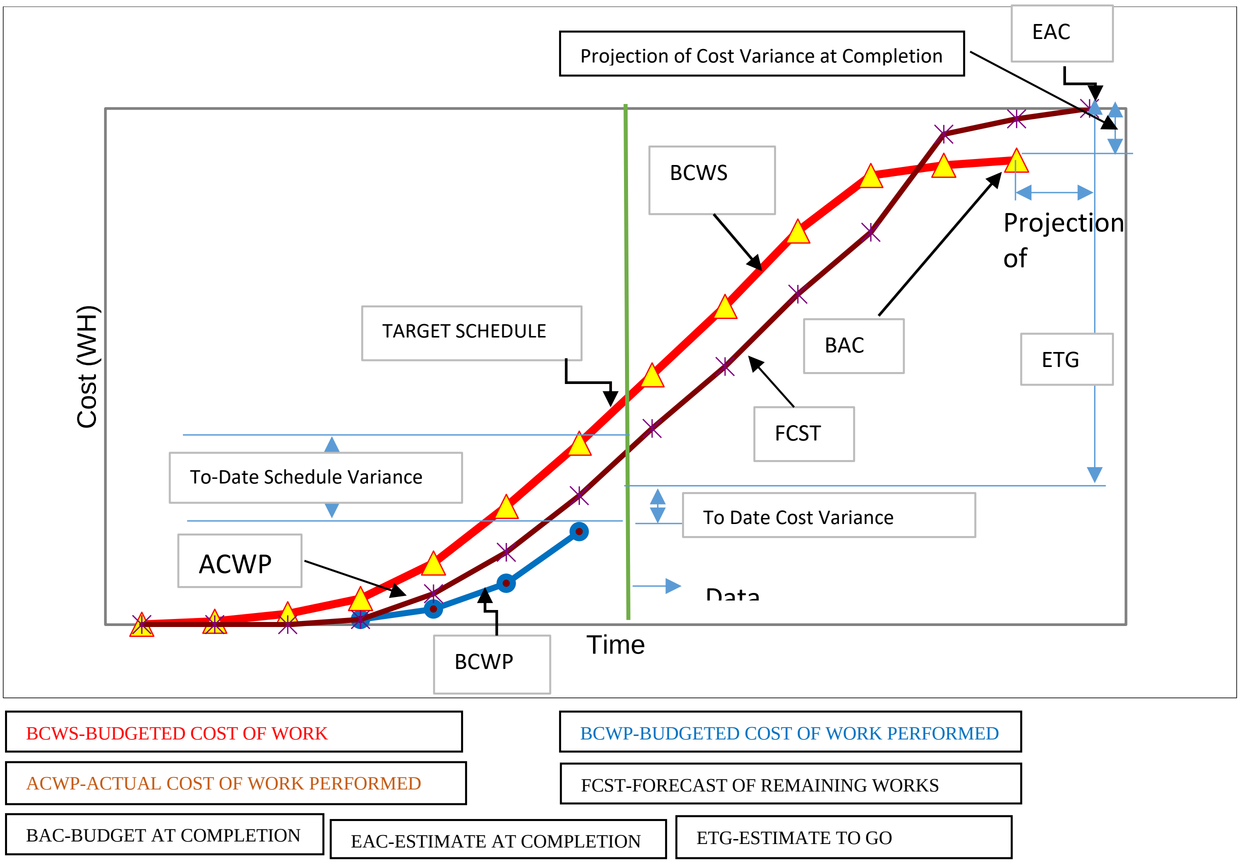


Figure 3.11 Performance measurement

(Source: Wilkens, 1999)

Generating performance measurement curves and earned value analysis, as shown in

Figure 3.11 involves laborious calculations which are made easier with the use of Primavera software (Oracle, 2013). Primavera earned value management software provides extensive earned-value capabilities with which organisations can manage project costs to measure earned value, analyse budgets and estimate and monitor costs and resources. Primavera earned value management software also helps organisations to generate the statistically accurate estimates (time, cost, resources) needed to understand and communicate project performance during the project life cycle stages to address and deal with issues.

3.12 Alternative Approach to Carbon Emissions Management

Current practices and research on the integration of project management and sustainability are mostly interpretive and less prescriptive. Silvius, Schipper and Nedeski (2013) agree that researchers attempt to interpret the concepts of sustainability in a project management context and do not prescribe how the sustainability aspects should be practically integrated into project management. Using a similar approach, Gareis, Huemann and Martinuzzi (2010) state that sustainable development has conventionally received less attention at the project management level compared with the programme/portfolio management level.

A performance-based methodology is required to achieve the implementation of sustainable management rather than the current technology-based approaches at the project management level. It is proven that methods based on performance will produce true appreciation by rewarding effective management and will encourage continual improvement and innovation in management and raise awareness initiatives (Jiang and Tovey, 2009).

Reluctance to change by clients, consultants and contractors in the construction industry is delaying sustainable transformation, as stakeholders do not implement sustainability practices due to their attitude of seldom moving outside of contract specifications (Lam and Yu, 2011). Government greening procurement practices, non-price sustainability contractor incentives and rewards are positive mechanisms to promote innovation in construction practices (Kenley et al., 2012; Infrastructure Australia, 2012). Even though construction industry practitioners do not commonly use the term 'green procurement', there are green practices being successfully adopted in the industry, such as the inclusion of green criteria in tenders and contracts (Bohari et al., 2017).

Earlier, Latham (1994) and Egan (2002) initiatives made important improvements in the construction industry, and stakeholders such as governments, clients, contractors and product manufacturers also made real improvements as significant customers of the industry. However, those changes generally were incremental and not comprehensive given the current environmental scenario in which the vision and ambition of the Kyoto Protocol ratifications for 2020 and 2050 will not be achieved without radical, transformational change. The following are the alternative approaches identified from existing literature, to enhance the environmental efficiency of buildings during the tendering and construction stage.

3.12.1 A common unit of measurement – CO_2e

The carbon emissions generated during the construction of buildings is gaining importance all over the world. The United Nations Environment Programme (UNEP) proposed the use of a Common Carbon Metric which quantifies the weight of the carbon dioxide equivalent ($kgCO_2e$) emitted per square metre per annum ($kgCO_2e/m^2$/year), to measure and quantify GHG emissions. The common CO_2e unit allows for the gathering and comparison of consistent data to report the sustainable performance of buildings. Having a common unit of measure will also be helpful in the formation of policies aimed at the reduction of GHG emissions from buildings (UNEP-SBCI, 2013). Also, ADQCC (2015) recommends the use of one unit, i.e. CO_2.

3.12.2 Assessment of sustainability using carbon emissions management

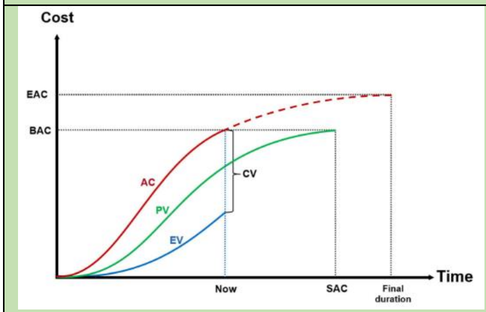
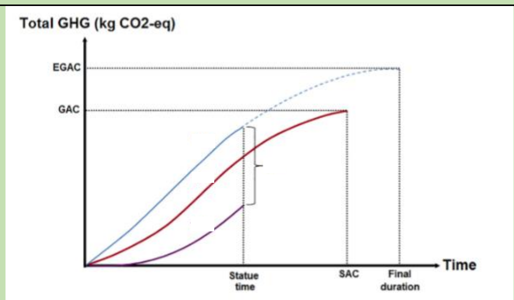
As part of the Kyoto Protocol, the Clean Development Mechanism (CDM) is a financing initiative for developing countries to adopt GHG-reduction, low-carbon sustainable development projects. The majority of CDM projects focus on renewable energy projects or the efficiency of industrial processes. Jiang and Tovey (2009) argue that even after the availability of systems, buildings-related GHG emissions have been overlooked.

For instance, the CDM agreed as part of the Montreal Conference of the Parties (COP) (2005), is limited in implementation. Limitations of CDM projects are due to a variety of factors, including registering as a legal CDM project activity and submitting relevant project design documentation (PDD) specifying the essential aspects, such as technical, organisational and approved baseline methodology and the monitoring and assessing criteria (UNFCCC, 2006). CDM projects fall into two categories: relatively large and small-scale (SS). For SS projects, the documentation requirements are less onerous, and eligibility is based on having an energy demand of less than 60 GWh per annum (Jiang and Tovey, 2009). Rather than limiting the projects for which carbon emissions are being calculated and monitored, it should be done on all projects regardless of size using an integrated project management approach through simple-in-use tools.

Therefore, to achieve a more sustainable environment, it is desirable to practice sustainability through effective measurement of CO_2 emissions (Abdul-Azeez and Ho, 2015). Industry should assess and monitor the CO_2 emissions of buildings to report the contribution of industry to global emissions and also to report country-wide emissions. The building construction industry emissions are broadly classified as embodied carbon emissions and operational carbon emissions. However, embodied energy during construction is being neglected by the industry for several reasons. The primary reasons provided by researchers are the 80:20 ratio, wherein the CO_2 emissions of building are 80% during the operational phase. Other reasons include the backing and support of product manufacturers who are not willing to take responsibility for divulging the details of embodied energy due to the additional efforts required, aversion to corporate social responsibility (CSR) or desires for cost savings.

Table 3.8 Integration of sustainability with earned value

(adapted from Abdi et al., 2018)

Current Practice	Integrating the sustainability indices
	
Planned Value (PV) The sum of budgets for all authorised work. Also known as performance measurement baseline. Planned value = (Planned % Complete) X Budget at completion (BAC)	Sustainability Planned Value (SPV) The sum of the carbon budget for all authorised work. Also known as sustainability performance measurement baseline. Sustainability Planned Value = (Planned % Complete) X Budgeted CO2 emissions at completion (BCEAC)
Earned Value (EV) The authorised work physically accomplished. EV=PV*% of completed work	Sustainability Earned Value (SEV) The authorised emissions accomplished. SEV=SPV*% of work completed
Actual Cost (AC) The total cost to achieve the actual work performed to date.	Actual Carbon Emissions (ACE) The total carbon emissions to achieve the actual work performed to date.
Schedule Variance (SV) Determines whether the project is ahead of or behind schedule. SV = EV-PV	Sustainability Schedule Variance (SSV) Determines whether the project is ahead of or behind schedule. SSV=SEV-SPV
Schedule Performance Index (SPI) Indicates how efficiently the time has been used when compared with the baseline. SPI=EV/PV Ahead (> 1) or behind (< 1) schedule	Sustainability Schedule Performance Index (SSPI) Indicates how efficiently the time has been used when compared with the baseline. SSPI=SEV/SPV Ahead (> 1) or behind (< 1) schedule
Cost Variance (CV) This is the difference between earned value and actual cost. It gives you a measurement of how much a project is under or over budget. CV = EV – AC	Carbon Emissions Variance (CEV) This is the difference between earned value and actual carbon emissions. It gives you a measurement of how much a project is under or over budget for carbon emissions. CEV = SEV – ACE
The Cost Performance Index (CPI) is a measure of the cost efficiency of budgeted work. It measures the value of the work completed	The Carbon Emissions Performance Index (CEPI) is a measure of the carbon efficiency of budgeted work. It measures the value of the work completed

compared with the actual cost spent on the project. CPI = EV / AC Over (< 1) or under (> 1) budget	compared with the actual carbon emissions spent on the project. CEPI = SEV / ACE Over (< 1) or under (> 1) budget

Therefore, attempting to calculate, monitor and control the carbon emissions using earned value management will contribute to fulfilling the current construction industry demands (Varma et al., 2016). Integration efforts with time and cost using the EVM technique was also carried out for quality parameters in projects (Ghazvini et al., 2017)

3.12.3 Integrate carbon emissions management with project management

The work carried out extensively is in the energy efficiency area, where competitors sell their products, highlighting their energy efficiency performance. Therefore, an alternative approach is the need of the hour for the construction industry. This alternative approach should be an integrated approach which will increase the acceptability and implementation levels. Carbon emissions management should be integrated into the project management to encourage successful implementation. Improvement opportunities for integrating sustainability in building construction project management is shown in Table 3.9. Literature supports that one of the effective approaches is to manage carbon emissions the way cost and time are managed, i.e. through earned value analysis. Abdi, Taghipour and Khamooshi (2018) presented a monitoring and control model based on the logic used in earned value management (EVM) methodology. Table 3.8 shows a method for integrating carbon emissions management with overall project management. Abuzeinab et al. (2017) investigated the benefits of the Green Business Model (GBM) in the construction sector by adopting five essential elements: green value proposition; target group; key activities; key resources (KR); and financial logic.

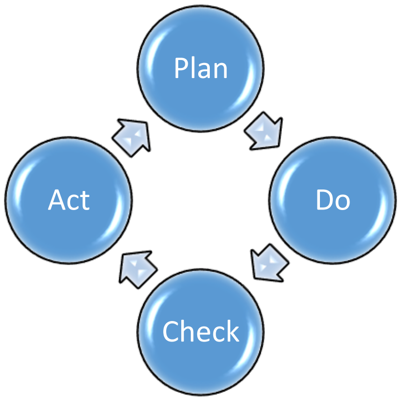


Figure 3.12 PDCA cycle

(Source: Taking the First Step with the PDCA)

Project management literature and energy management systems promote a Plan-Do-Check-Act (PDCA) cycle to manage projects, as shown in Figure 3.12 (Gastl, 2009). Carbon emissions management can follow the same PDCA cycle and integrate into the overall project management stream.

Embodied carbon emissions management involves making much more radical use of it at the design, tender, material procurement and construction stages, giving real-time readings to plan, monitor and track the embodied CO_2 emissions. Comparisons of existing practices with the areas of improvement for integrating carbon emissions management (CEM) with project management practices are conducted throughout the literature. Table 3.9 shows the RIBA plan of work, the practices, the concerns and the areas of improvement needed to integrate CEM.

The focus of research is in the technical design and construction phase, including tendering activities. The opportunity for improvement identified in the Table 3.9 has paved the way for primary data collection, model and framework development for effective carbon emissions management for the building construction industry, particularly in the United Arab Emirates.

Table 3.9 Improvement opportunities for integrating sustainability in building construction project management

(Sources: RIBA, 2013; Xi and Xua, 2015)

Phases of a Project	Typical Course of Action	Sustainability Concerns	Opportunity for Improvement
Strategic definition	Identify client's business case and strategic brief and other core project requirements. Client mobilises different professionals, such as a strategic planner, real estate broker, an architect/designer, master planner, and facility manager.	Preliminary scope definitions do not consider the environmental impact as part of the conventional building process.	The environmental issue should be included in the project initiation phase. Sustainability consultants/professionals shall be part of initiation teams.
Preparation and brief	Develop project objectives, including quality objectives, project outcomes, sustainability aspirations, project budget and other parameters or constraints and develop an initial project brief. Undertake feasibility studies and review of site Information Client needs are evaluated based on available sites, anticipated costs etc.	Life cycle cost impacts of the building and life cycle carbon emissions are not addressed. Instead, the focus is predominantly on time, cost (initial cost) and quality. Sustainability aspirations are limited to use of which rating tool and what level of certification.	Life cycle cost and life cycle carbon emissions shall be included in this phase to help the developer make long-term decisions with minimum environmental impacts.
Concept design	Prepare concept design (Pre-FEED), including outline proposals for structural design, building services systems, outline specifications and preliminary cost information, along with relevant project strategies following the design programme. Agree alterations to brief and issue Final Project Brief. Developer and relevant authorities are inclined to focus on the basic technical design with little concern about environmental issues, such as the energy performance of the project, carbon emissions from the project. The architect selected by the client selects the consultants. The contractor can be selected in the bidding process.	The architects propose designs based on the program needs and budget other than environmental issues. Conventional design process lacks the participation of the contractor in the design phase, which causes the insufficient implementation of carbon emissions management strategies.	Sustainability and in particular, the carbon emissions estimation shall be included in the design process to address environmental issues. Sustainability professionals shall be part of integrated design this phase to provide inputs.
Developed Design	Tender and award Front End Engineering Design (FEED). Prepare developed design including coordinated and updated proposals for structural design, building services systems, outline specifications, Cost Information and Project Strategies following Design Programme.	Review and update Sustainability, Maintenance and Operational and Handover Strategies and Risk Assessments. Conventional design process lacks the participation of the contractor in the design phase, which causes the insufficient implementation of carbon emissions management strategies.	Sustainability and in particular the carbon emissions alternate solutions shall be evaluated and included in the FEED to address environmental issues. Sustainability professionals shall be part of integrated design this phase to provide inputs.

Phases of a Project	Typical Course of Action	Sustainability Concerns	Opportunity for Improvement
		Tools for the schematic modelling of energy, day-lighting, and LCA were rarely used.	Use of sustainability tools shall be encouraged on every project to assess the impacts and benefits
Tendering (Engineering, Procurement and Construction – EPC)	Construction can be performed by a design-bid-build model. Other Prevalent route for procurement can be traditional procurement route and the low-bid award process.	The construction industry mostly prefers traditional Procurement route in the UAE Scope Interpretation issues crop up due to time limitation given to bidders and also due to non-involvement of contractors at early stages of the project. EPC Bidders is likely to minimise the commercial offer because of the low-bid award criteria. Upon award, the contractor cannot function as a team member effectively and will always try to cut corners to avoid financial losses.	Alternative processes, such as a design/build model should be adopted as one of the best solutions to implement sustainable management effectively. The general contractor should not be selected based on a low-bid process. Instead, the carbon emissions bids shall be part of the evaluation criteria. COCO2 carbon Cost bids shall be used for tendering instead of low-price cost bids.
Technical Design (Also known as Engineering phase in a design and build procurement route)	Prepare Technical Design per Design Responsibility Matrix and Project Strategies to include all architectural, structural and building services information, specialist subcontractor design and specifications, following Design Programme Consultants follow the architect's design.	Little integration is observed because of budget limitations. The design team do not consider alternative solutions because of unidentified environmental goals. Tools for the schematic modelling of energy, day-lighting, and LCA were rarely used. Review and update Sustainability, Maintenance and Operational and Handover Strategies and Risk Assessments. But sustainable aspects are limited to descriptive ways without any tangible unit to measure and compare at later stages of the project. Energy modelling is performed on a few projects at this point if ESTIDAMA or LEED require any. The architect/client is sinking into a mindset "to do –if required" that is difficult to change.	The design process to encourage integration of environmental goals and a systematic approach. Not only the use of energy-saving tools and other simulation tools to achieve the best cost-effectiveness but also the embodied carbon tools should be encouraged. All stakeholders should be involved while making decisions. An integrated design process can encourage information sharing among the parties and make timely changes. Regulations shall be mandated to calculate operational and Embodied carbon emissions with a life cycle approach on every project.
Construction (Including Procurement of materials)	Off-site manufacturing and onsite Construction following Construction Programme and resolution of Design Queries from site as they arise.	With the traditional procurement route, the separation of design and construction results in the insufficient implementation of sustainable strategy.	Design and Build procurement shall be encouraged to provide contractors

Phases of a Project	Typical Course of Action	Sustainability Concerns	Opportunity for Improvement
	Processes are monitored by the Project Management team (PMT) weekly and monthly.	Lack of awareness of other sustainable measurement units such as greenhouse gas emissions or CO2eq emissions Lack of availability of carbon emissions management guidelines, carbon emission factors, User-friendly tools are impacting the implementation of effective, sustainable management in projects.	Awareness levels shall be improved for all stakeholders to have an effective carbon emissions management on projects by providing training. Life cycle carbon emissions estimation, benchmarking, monitoring, control and closeout shall be enforced on all projects. The details and relevant clauses shall be available in contracts.
Handover and closeout	Handover of building and conclusion of Building Contract. Commissioning, Occupancy and Operation and Maintenance Addressed on the final inspection, including testing and balancing operational testing at a minimum.	The importance of the commissioning process is not valued. Therefore, the operation data related to only technical aspects are included in Handover documentation. Carbon Emissions data and the details are not maintained or handed over for operations team or maintenance team to carry it further.	The commissioning process is important to sustainable building. Commissioning reflects the real operational status of the building and should be regulated. Complete carbon emissions data related to each element shall be handed over in handover documents for the ease of future maintenance and refurbishment works.
In use	Undertake in Use services under Schedule of Services.	The construction team usually neglects building operation and facility management issues.	Carry out activities in Handover Strategy including Post-occupancy Evaluation, review of Project Performance, Project Outcomes and Research and development aspects. All maintenance and refurbishments shall be carried out after evaluating the total carbon emissions and their impacts.

3.12.4 Carbon emissions –award criteria for projects

The Asia Pacific Economic Corporation (APEC), Low-Carbon Model Town Development in Malaysia, had implemented a policy to pre-qualify and select bidders based on environmental competence in addition to performance criteria of time, cost and quality (APEC, 2016). Figure 3.13 shows the bidder selection criteria which will ensure an eligible sustainable contractor to execute the work to meet carbon emission management requirements.

The Bidder will need to supply evidence of ability and experience to undertake the specified objective/duties in this Request for Proposal, and explain their approach to the Services including:

1. Method:
   - An outline of approaches to the tasks and the methodologies to be applied
2. Work plan:
   - Overall feasibility study execution plan
3. Analytical an research skills:
   - Evidence of a breadth and depth of knowledge and experience of low-carbon design including analysis on CO_2 Emissions reduction impacts for the selected low-carbon measures
   - Evidence pf the project management capacity to deliver high quality products on time and within budget
   - Personal connection which is useful for implementing the Services, for example, with local and central government as well as local stakeholders in Indonesia
4. Experiences:
   - Demonstrated experience and expertise in
     a) Undertaking feasibility studies for low-carbon town designs;
     b) Preparing low-carbon town development master plans;
     c) Preparing low-carbon development projects which are concrete and feasible enough to be implemented
5. Organization:
   - An implementation structure and responsibilities
   - The names and brief biographies of the main personnel responsibilities for this project
   - Financial statements.

Figure 3.13 Qualification for bidders on sustainability projects

(Source: APEC-LCMT Phase 5, 2016)

Decisions taken in the early stages of a project have a strong impact on that project's sustainable performance and environmental footprint. Procurement/tendering is considered one of the significant early steps capable of integrating sustainable practices throughout the project life cycle (Bratt et al., 2013; Ruparathna and Hewage, 2015). Implementation of sustainable procurement creates a demand for carbon-efficient materials, products and services in the market (Bohari et al., 2017). There is no standardisation across the industry for sustainable procurement, not even in terminology. For example, 'green procurement' and 'sustainable procurement' are used interchangeably (Hughes and Laryea, 2013; McMurray et al., 2014). There is a need for more research to understand the best green procurement practices (Appolloni et al., 2014) and a universal way of assessing sustainable and tangible parameters.

Companies are adapting alternate procurement strategies, but this is limited to strategic projects and not mainstream projects such as building construction. Green public procurement (GPP, 2017) is working along with many partners on one of the projects for which adopted the following procurement approach, resulting in a savings of 94% when all electricity is procured from green sources (Anon, 2015).

Table 3.10 Alternate procurement strategy

<table>
<tr><th colspan="2">Electricity from renewable sources</th></tr>
<tr><td>Technical Specifications
• 50% of electricity from renewable sources- mandatory requirement.
Verification: Statement of the bidder that they shall supply a minimum of 50% of total required electricity from renewable sources</td><td>Award Criteria/ most economically advantageous tender(MEAT):
• 95% for the price.
• 5% for a higher amount of electricity from renewable sources(with mandatory requirement of 50% from renewable sources)</td></tr>
<tr><td colspan="2">Eligibility of bidders
• The bidder/tenderer must prove that they have the appropriate permit from the national energy
Verification: The bidder/tenderer shall supply this permit in line with the Croatian Act on the Regulation of Energy Activities, the Energy Act and other acts regulating particular energy activities.</td></tr>
</table>

Although the sustainable procurement objectives, strategies and mechanisms are available (as shown in Table 3.10) in government strategic planning, researchers argue that studies of the actual delivery and practices involved in green procurement are limited (Bohari et al., 2017). Specific guidelines on and awareness of sustainable procurement are unclear and fragmented, which will directly impact on the implementation of sustainable practices, particularly carbon emissions management. As tender evaluation is one of the tools used for examining environmental criteria based on a project's environmental requirements (Varnas et al., 2009), an alternative approach to include carbon emissions is required for tendering and awarding of building projects.

3.12.5 Carbon emission monitoring frameworks

Based on the partial LCA framework conducted in the construction phase, Fu et al., (2014) developed an information system, as shown in Figure 3.14, to calculate the carbon emissions of designers' construction plans for sustainable optimisation and also as a tool for owners to check and compare the carbon emission of different construction plans. This system involves three major processes: calculation, comparison and feedback. The calculation process assesses the carbon emission of the building construction processes based on an LCA framework, which later leads to comparison to analyse the carbon emissions of alternate plans for embodied material, transportation types and equipment. The tool also provides a report after comparing the carbon emissions of the different scenarios. Carbon emissions factors of materials and transport used are based on an inventory of carbon and energy data (ICE, 2008), and the database of carbon emissions factors of construction equipment is from 'The Fourth Assessment Report of the Intergovernmental Panel on Climate Change' (IPCC, 2007). However, it provides open access for users to edit or revise the data for special performance or add new factors into the database for using new technology or materials introduced to the market.

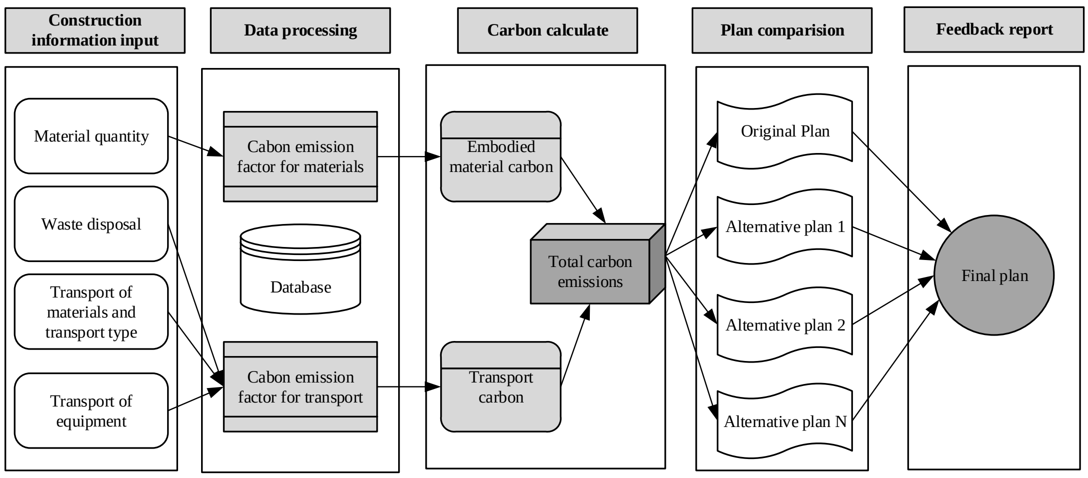


Figure 3.14 System operation process flow chart – carbon emissions for building construction (Source: Fu et al., 2014)

Yu et al. proposed the Construction Project Sustainability Assessing System (CPSAS) to provide project management teams with a suggested list of assessment indicators for monitoring project sustainability during each stage of a project lifecycle (Yu et al., 2018). Based on these assessments, the project performance is rated as bronze, silver or gold, which, again, is prescriptive, as the factors and weight assigned to it may vary from user to user.

Figure 3.15 shows the framework, which requires the Project Sustainability Index (PSI) to be assessed by the project management team. If the PSI is not satisfied, improvement actions should be planned and implemented according to the SI assessment obtained from CPSAS.

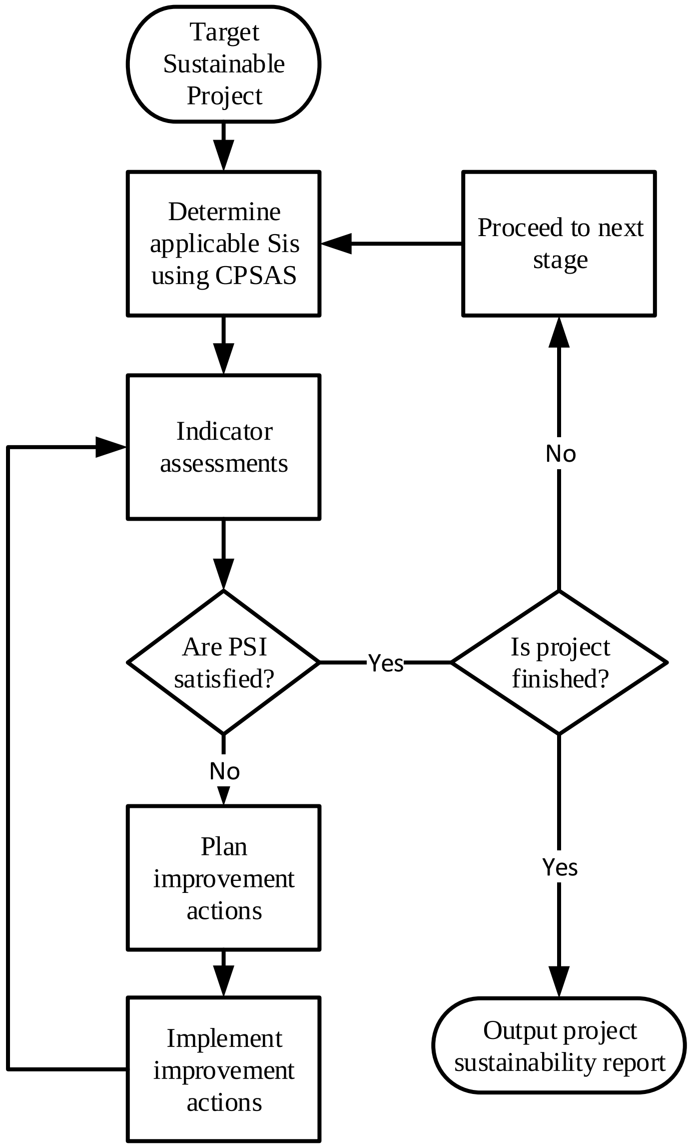


Figure 3.15 Framework for monitoring project sustainability
(Adapted from Yu et al., 2018)

A similar sustainable framework in Figure 3.17 for the management of rural road networks was developed by Alondra (2012). The framework considered the development of three system modules: a condition performance module, a network maintenance module and a long-term prioritisation module. Another framework, shown in Figure 3.16, for an integrated cost, time and carbon footprint was developed by Kim et al. (2014), but the system is complex and does not specify any tools for implementation.

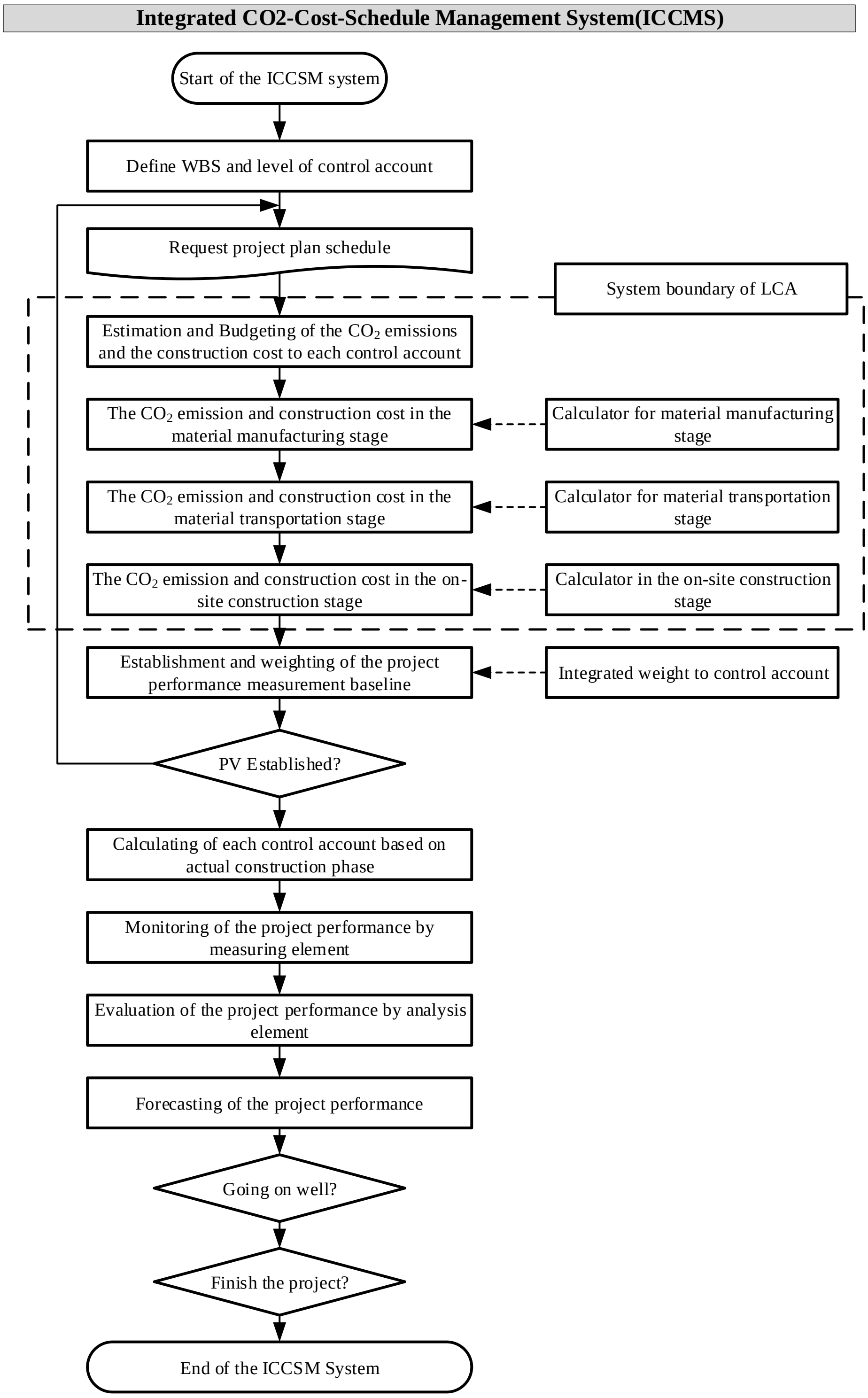


Figure 3.16 Integrated cost, time and carbon footprint framework (Kim et al., 2014)

All these frameworks fell short of quantifying the sustainable performance in tangible units; rather, they continued with the approach of compliance-based criteria. Thus, there is a need for a framework focussing on the use of a tangible unit, standard in nature across all industries, to specify, estimate, monitor, control and report sustainable performance in terms of CO_2 emissions using simple-in-use tools (Abdul-Azeez and Ho, 2015). However, the concept of managing carbon emissions using EVM has wide acceptance in the literature reviewed. Chhatwani (2015) used a similar technique and explained the similarities in frameworks for monitoring time-cost during the construction phase with the carbon emissions monitoring approach, as shown in Figure 3.18. The need for simple-in-use tools is still valid, and the next section shows the carbon emissions management application using simple tools.

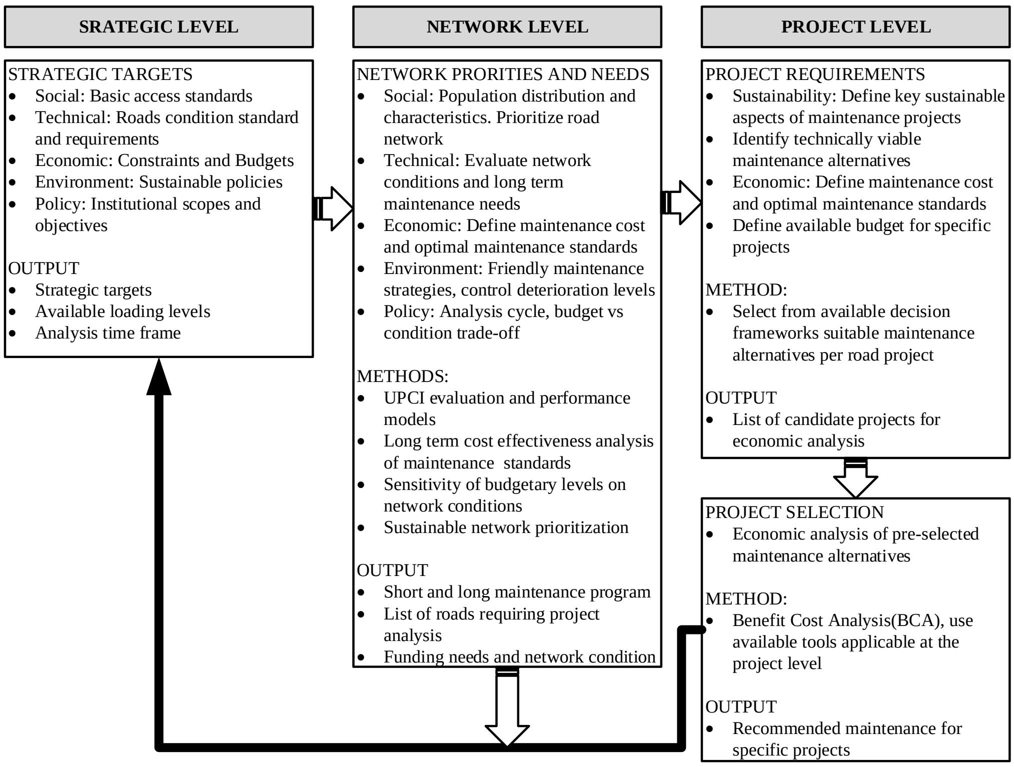


Figure 3.17 Sustainable framework for the management of rural road networks (Alondra and Gin, 2012)

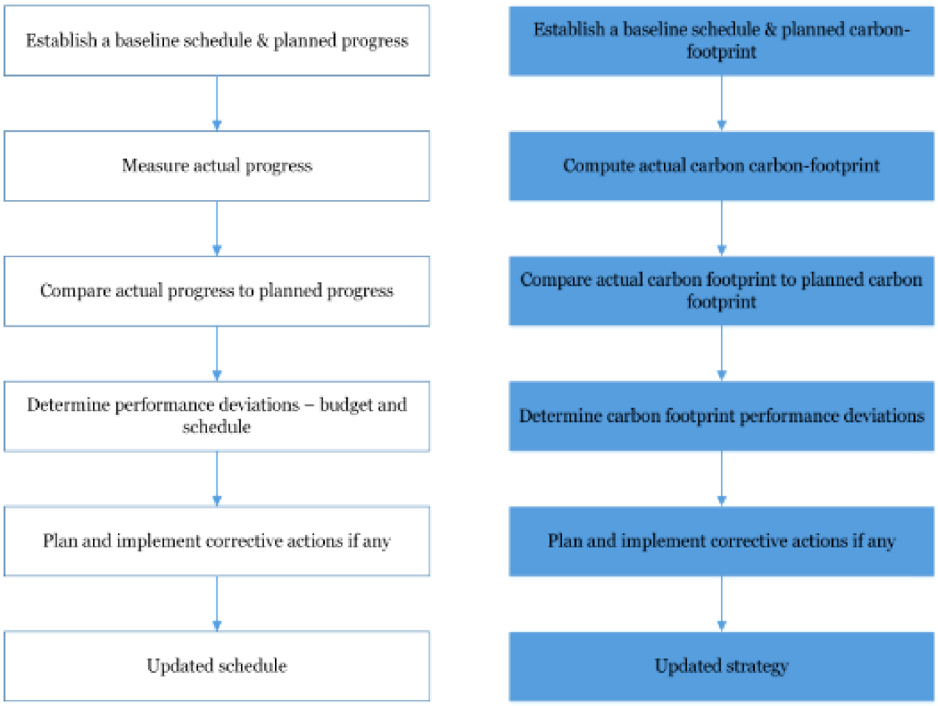


Figure 3.18 Similarities in time-cost construction progress and carbon emissions monitoring framework

(Source: Chhatwani 2015)

3.12.6 Use of Simple-In-Use tools (SIUT)

Masdar City in the UAE used a simple tool (Excel) to develop a bill of quantity toolkit using the Bath ICE embodied carbon database. Having the toolkit in Excel enabled quick, efficient calculations of the carbon impacts of building projects, covering a full LCA from cradle-to-grave, including onsite activities, operational energy and maintenance. It also enabled sustainability teams to design and assess carbon reductions against a baseline scenario consistent with the PAS 2050 carbon standard (Hammond and Jones, 2011). Tools used for controlling and monitoring carbon emissions should be the same tools used to monitor cost and time aspects of projects to increase acceptability, efficiency and repeatability.

Kim et al. (2014) developed an integrated CO_2, cost and schedule management (ICCSM) system for building construction projects using the earned value management theory. The ICCSM system helps project managers to monitor and forecast CO_2 emissions and consists of five steps:

(i) Definition of the project scope and organisation;

(ii) Project planning and scheduling;

(iii) Estimation and budgeting of the CO_2 emissions and construction costs;

(iv) Establishment and weighting of the project performance measurement baseline; and

(v) Monitoring and forecasting of the project performance.

Excel spreadsheets were used for PERT, CPM and EVM calculation. Furthermore, this research did not show an integrated CO_2 and schedule management but only an integrated cost and schedule management. Varma et al. (2016) conducted project tracking of the cost, time and carbon footprint of a construction process applying EVM using the construction computer software (CCS) Candy. Candy is project control software dealing with estimation, planning, cash flow and earned value.

A review of the literature shows that simple-in-use tools are preferred by industry to estimate, monitor and control carbon emissions.

3.13 Summary

The review of the literature findings has revealed the importance of carbon emissions management in addition to the need for change in the tendering and award to contractors based on environmental performance. On the other hand, the review finding has emphasised the issues associated with the neglect of embodied carbon emissions and the need for integration with cost and schedule management for ease of implementation and acceptability. The literature review also emphasised the possibility of achieving a more sustainable environment through practising sustainability by effectively measuring and monitoring the CO_2 emissions of buildings for the whole lifecycle.

UAE climatic conditions, construction practices and awareness in the UAE are contributing negatively to the increase in energy consumption and its associated CO_2 emissions. 4% of the CO_2 production in the UAE caused by the direct emissions of buildings, 43% by electricity generation and 45% by manufacturing and construction. Which equates to 5.50 million metric tonnes due to direct emissions of buildings, 35.5 million metric tonnes due to electricity use by buildings and 62.0 million metric tonnes due to manufacturing and building construction. It is necessary to estimate, monitor and control Carbon emission during construction and operation phase of buildings to optimise the carbon emissions. UAE is taking good measures and initiatives to reduce the inefficient use of energy by educating people and providing good energy management.

Chapter Four: Research Methodology

4.1 Introduction

The literature review was carried out in chapters 2 and 3 to discover the knowledge gaps, current thinking, awareness, and implementation levels to further the study. This chapter presents the methods and choices considered for research methods to achieve the set aim and objectives of this research. Justifications for the chosen research and research design details are addressed. This chapter discusses the philosophical assumptions, characteristics of the most likely research approaches, strategies, methods, limitations, and how these are addressed in the chosen research design. The conclusion of the chapter details the credibility of research in terms of validity, reliability and generalisation.

4.2 Ethical Considerations

Researchers are expected to research in an ethical manner (Denscombe, 2010). Heriot-Watt University (HWU) research guidelines mandate the ethical considerations and outline the necessary actions to undertake as part of any study to avoid any potential harm to the participants, whether involved directly or indirectly, so as not to violate accepted research practice or university standards in conducting the research. Approval has been obtained from the University Research Ethics Committee to conduct the study.

Information was provided to research participants giving details about the objective of the research, the research teams and privacy procedures. Respondents were assured that the information of participants will only be used for the PhD study and will not be shared with other parties. Participation was voluntary, and participants can withdraw from the study at any time without prejudice or adverse consequences. Data protection was handled in compliance with the Data Protection Act of the UAE – Article 378 for all the data collected and processed in this study. The names of the research project and participants were not disclosed, including in publications and reports. Information, if published, was in aggregated form to protect anonymity. Measures were taken to ensure that respondents were not harmed during participation in the case study by adapting the Health safety and environmental (HSE) plan.

4.3 Research Design

Research design is a rational and coherent way of ensuring logical links between data collected and conclusions made regarding research questions (Rowley, 2002). In the initial stages of any research, it is imperative to choose and justify the research methodology adopted. If attention not paid to the research design, the researcher may face complications during the process (Robson, 2011). The research question governs the research strategy and methods. There are several ways of designing and conducting the same research study; however, the present researcher chose the research onion method (Figure 4.1) as a simple way of presenting the research process (Robson, 2002; Saunders et al. 2012).

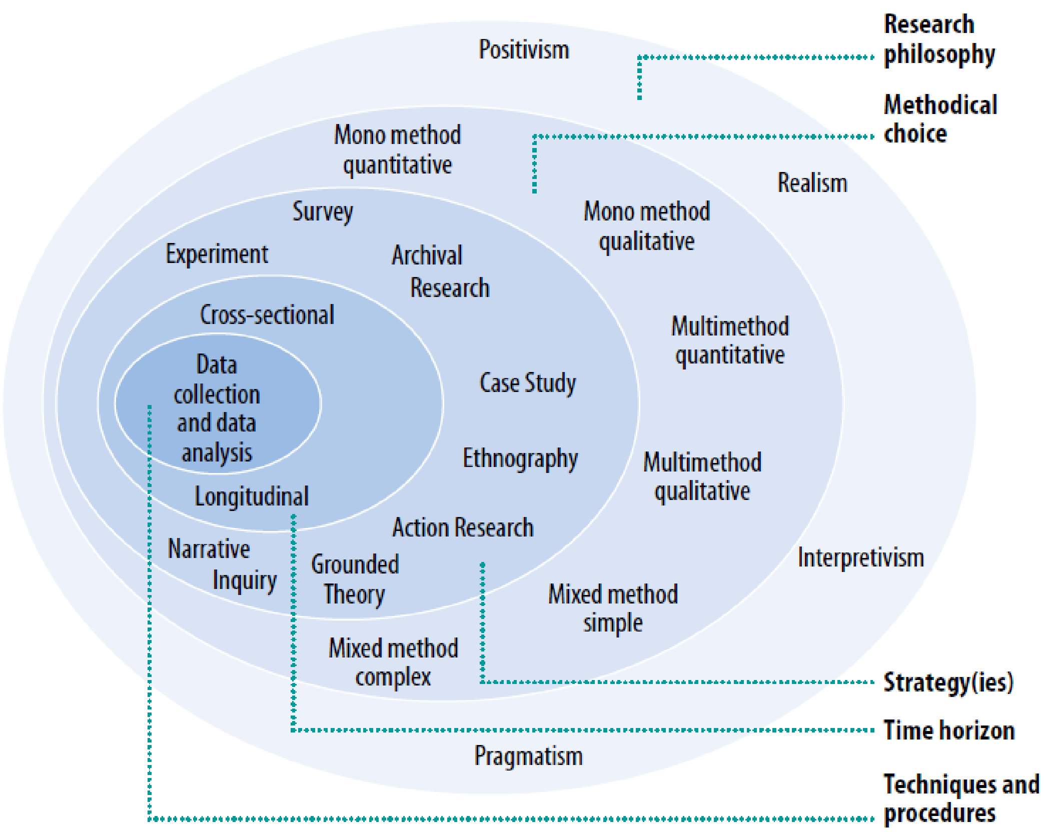


Figure 4.1 Onion research process

(Source: Saunders et al., 2012)

4.4 Research Philosophy

Positivism, interpretivism and realism are three broader philosophical views of research, which are different and mutually exclusive, addressing how knowledge is acquired and accepted (Saunders et al., 2003). Through these lenses of philosophical assumptions, insights about the world can be garnered. Thus, a link exists between the theoretical position adopted by a researcher, the research methodology and the data collection methods (Crotty, 1998). If positivism, it indicates the philosophical position of a natural researcher who desires observable social reality. The results of this type of research are generalisations similar to those concluded by physical and natural scientists (Remenyi et al., 1998). The researcher is an objective analyst who makes isolated interpretations after the data collection. Positivism assumes that accurate and value-free knowledge generation is possible by studying human beings, their actions and institutions objectively, similar to the natural world (Fisher, 2003). Furthermore, Bull et al. (2013) stated that the knowledge available to science could only be gained from direct experience or observation. Thus, by implication, anything which cannot be tested 'scientifically' cannot be defined as acceptable knowledge.

Interpretivism is an epistemological position which is the reverse of positivism and argues that natural and social realities are different and require different research methods. Saunders et al. (2003) stated that the role of the interpretivist is to understand subjective reality and understand a participant's motives, actions and intentions (Saunders et al., 2003). This philosophy differentiates between the objects of the natural sciences and people, and, therefore, it necessitates the subjective meaning of social actions (Bryman, 2004). This is an anti-positivist philosophical position which takes into account only the culturally derived historical interpretations of the social world (Crotty, 1998). Remenyi et al. (1998) argue that there is a necessity to discover the details of social phenomena to understand the reality or the reasons behind reality for any research. This is also called constructionism because it shows that the world is socially constructed and subjective (Gray, 2004). Thus, knowledge is constructed as a result of personal experience in a social context in which people interact with the natural environment and make their interpretations of the actions they see around them: 'A clear distinction exists between the beliefs about the world and the way the world is' (Ritchie and Lewis, 2003, p.16).

Realism is a philosophical position based on the belief that an external reality exists independent of beliefs and the understanding of individuals (Ritchie and Lewis, 2003).

Saunders et al. (2012) argue that the essence of realism is based on what the senses show us as reality and that objects have an existence independent of the human mind. Realism is a branch of epistemology which assumes a scientific approach for developing knowledge and claims that there is a reality independent of the human mind. There are two types of realism: direct realism and critical realism. Direct realism holds that what you see is what you get and that our experiences reflect the world accurately. Critical realism, which is also known as pragmatism, states that what we experience are sensations and the images of the things in the real world (Saunders et al., 2012).

Table 4.1 Comparison of research structure of three philosophies
(Adapted from Yin [2014], Creswell [2013], and Bryman [2016]).

Positivism	Critical Realism/Pragmatism	Interpretive
Method: • Intro – set aims, objectives • Review the literature (very critical), find gaps, develop a model (hypothesis) • Research methodology • Collect data (distribute questionnaire) • Analyse data using statistical tools • Write up, conclude and recommend • Test	Method: • Intro – aims, objectives • Review the literature, find gaps, develop a model (hypothesis) • Research methodology • Collect data (triangulation methods, questionnaire followed by observations, case study) • Analyse data/develop a model • Validate with objective method (e.g., focus group) • Write up, conclude and recommend	Method: • Intro – aims and objectives, research questions • Research methodology • Review the literature, explore whether similar work done not to re-invent the wheel, • Develop a model, collect data (case study or interviews) • Analyse data/model developed • Validate the data/model by applying other case study/organisation. • Write up, conclude and recommend

This research was concerned with the implementation of carbon emissions management and adopted a ‘critical realism’ philosophy based on the attributes, as shown in Table 4.1 above. As researchers, we will only be able to explore what is happening in the social world around us if we understand the social structures which have given rise to the phenomena which we are trying to study. The critical realist’s position is that our knowledge of reality is a result of social conditioning (Saunders et al., 2012). Critical realism is valid when ‘how and why’ questions are posed and does not need to conform to a pre-determined theoretical framework. This philosophy is more relevant to new fields of study in which there is a lack of knowledge, and it helps in knowledge production (Saunders et al., 2012).

Table 4.2 Comparison of research philosophy

(Adapted from Yin [2014], Creswell [2013] and Bryman [2016])

Positivism	Critical realism/Pragmatism	Interpretive
Single reality i.e. price rise / demand reduced	Its combination of both i.e creates the reality by questioning observing & setting Hypothesis	There is no single reality, i.e. it changes from place to place, depends on context
Research Hypothesis is set here and tested through statistical tools.	Hypothesis as well as research questions are set here	Research Questions are set here to be observed through case study, Interviews (open ended), Delphi methods, participatory workshops, focus groups etc
Sample size shall be big	Sample size varies and contains both aspects	Sample is smaller
Quantitative	mixed	Qualitative/Descriptive
Deals mostly with questions like Do you think? Is there ...	Deals with reality	Deals mostly with What? Why? Type of questions
Conceptual model is developed to find relationship between two variables/hypothesis.	Deductive & inductive ways are used	Model developed will be tested by implementation
Generally Validation is not required as its validated by statistical tools	Validation as well as generalization is done.	Validation shall be carried out by other mediums. eg: if case study conducted to test the model then validation shall be carried out by another case study or interviews etc
Can be easily published	Can be published as the data are validated	Cannot be easily published, but v imp for industry and organization where the study will be carried out

Critical realism experts argue that only knowing the reality is not enough; subjective responses to it are necessary. Such objective realities produce ‘real boundaries to’ and constraints on behaviour and link with subjective issues such as resources, leadership, policies, knowledge base and priority to solve problems. This philosophy holds the view that the researcher can use his/her experience, experience of the practitioners (contractors, consultants, clients and owners) and pre-existing knowledge to develop an understanding of the phenomenon which is being investigated (McEvoy and Richards, 2006). Jeppesen (2005) adopted critical realism to research environmental management practices in small and medium-sized manufacturing enterprises (SMMEs) in South Africa, which also supports the philosophical position of this thesis and study.

Based on that, this philosophy could help explore how the social settings (in the UAE construction industry) are guiding the implementation of carbon emissions management as a result of objective realities of the impacts of carbon emissions and climate change. Observations with the help of data collection tools and techniques are interpreted and conveyed for investigation. This research involves realist aspects, such as embodied carbon, energy consumption, time and duration of activities, deliveries, surveys, interviews and focus group meetings. This research aims to evaluate the environmental efficiency of construction management techniques for buildings in the UAE. Environmental efficiency is evaluated in terms of embodied carbon emissions using an 'CEM' framework, covering the tendering and construction phases.

4.5 Research Approaches

Research is done to answer the questions posed by theoretical considerations. An alternative approach is to examine theory which emerges from data collection and analysis (Bryman, 2016). Research design can be divided into two research approaches: deductive and inductive. The deductive approach is used to design a research strategy for testing a theory or hypothesis (Saunders et al., 2003). Bryan (2016) explains that in the deductive approach, existing literature is reviewed to deduce a hypothesis or hypotheses first, to form and drive the data collection and analysis. The deductive approach works from a more general to a particular case, and this owes more to positivism philosophy (Saunders et al., 2003). The inductive approach involves data collection and then develops a theory from data analysis (Saunders et al., 2003). Induction refers to patterns and themes with real observations, whereas deduction refers to intentions and possible hypotheses theoretically resulting in systematic data analysis

(Ritchie and Lewis, 2003). The inductive approach works from specific observations to broader generalisations and leads to theory development. A combination of both approaches in the same study can be used if it is advantageous to do so (Saunders et al., 2012). ‘Data collected can be used as a set of concepts, models or even theories (inductive approach) which can be tested through experimentation (deductive)’ (Gray, 2004, p.11). Table 4.3 shows a comparison of the deductive and inductive approaches.

Table 4.3 Comparison of deductive and inductive approaches

Inductive	Deductive
• This approach involves data collection and then develops a theory from data analysis.	• It tests a theory or hypothesis. Existing literature is reviewed to deduce hypothesis first, to form and drive the data collection and analysis.
• This approach works from specific observations to broader generalisations and leads to theory development.	• This approach works from a more general to a particular case.
• Induction refers to patterns and themes with real observations.	• Deduction refers to intentions and possible hypothesis or hypotheses theoretically resulting in systematic data analysis.
• It includes Action research, ethnography and archival research.	• Experiments and surveys.

There is one more approach used by realists: the ‘abductive’ approach, which is a combination of the deductive and inductive approaches (Robson, 2011). It is an innovative social sciences approach, which is a nonlinear, path-dependent process of combining efforts with the ultimate objective of matching theory and reality (Dubois and Gadde, 2002, p. 556). There exists a link between an empirical world and a model world through systematic combination. The research problems and the analytical framework are consecutively reoriented when they are challenged with the empirical world in this approach. It is a process in which a theoretical framework, empirical fieldwork and case study analysis evolve at the same time, and it is useful for developing theories. The important role of abduction is that it describes and understands the world from participants’ perspectives and infers a social scientific account of the social world as seen from these perspectives (Bryman, 2016). This approach is used for the present research.

4.6 Research Phases

The current research has three iterative phases detailed in the conceptual framework. Exploratory research was carried out in the first phase of the project by using surveys to develop a provisional thematic framework. This provisional thematic framework can be called a 'conceptual framework'. 'A conceptual framework explains, either graphically or in narrative form, the main things to be studied – the key factors, constructs or variables and the presumed relationships among them' (Robson, 2011, p. 67). Robson (2011) argues that developing this type of framework helps the researcher to select and decide important features to be focussed on explicitly, informing the type of data to be collected and analysed.

The first phase of the research consists of Literature review and an exploratory survey with 60 professionals from 10 construction companies involved in building construction, including tendering managers, estimation managers, costing engineers, planning engineers, project managers, construction managers, design consultants and other key individuals.

The second phase of the research also observes the implementation of sustainable practices through survey-2, development of a CEM model, testing of the model through case studies and development of an Integrated CEM framework thorough.

The third phase of the research was the validation of CEM framework using the focus group, where the survey results, case study findings, an Integrated CEM framework was presented for user-implementer insights and feedback. Components of an Integrated CEM framework, consists of CEM estimation model, CEM monitoring and control model and the $COCO_2$ tendering model. The focus group was organised as per the procedure which requires the researcher to recruit and convene a small group of specialists in the area of research, amongst whom a moderated discussion takes place regarding aspects of the research, with an intent to extract the views of each individual in the group and to validate the research (Yin, 2014).

4.7 Research Strategy

This section discusses the third layer of the onion. The selection of strategy depends on the research question (Robson, 2011). This research is exploratory as it aims to explore the implementation and integration of carbon emissions in the project management of building construction. An exploratory study seeks to investigate what is currently happening, and questions are asked about a particular phenomenon. This is useful when insufficient knowledge is available about a particular topic in a particular location (Gray, 2004). Key themes are sought and combined with the literature to cross-reference the research findings. There are different strategies available for both deductive and inductive approaches, and they should not be treated as mutually exclusive (Saunders et al., 2003). There are three types of research strategy: a fixed, flexible or multi-strategy design strategy. A fixed design demands a predefined design before the data collection begins. Data for such a design are in the form of numbers, and this is known as a quantitative strategy, as with surveys and experiments (Robson, 2011). A flexible design evolves during the data collection process. Data for such a design are not numerical, and this is known as a qualitative strategy (Robson, 2011). Case studies, ethnographic studies, grounded theory and action research, are flexible design strategies and include more than one data collection process (Robson, 2011). Multi-strategy design is a combination of both fixed and flexible designs.

This research adopted the multi-strategy design. Surveys, a focus group and an in-depth case study strategy is the most appropriate methods based on the nature of the research questions. The researcher did not consider the other strategies for several reasons; first; a larger sample size was needed, if surveys only, which could be hectic and challenging to manage qualitatively due to resource constraints and difficulties in dealing with huge data. Second, the research aims to determine the effective implementation of carbon emissions management practices in building construction in the UAE, which is difficult to provide in-depth insights with any other strategy, apart from a case study. The findings of Saunders et al. (2012) support this argument that research strategy is guided by the research question(s), the extent of existing knowledge, the time and resources available and the assumptions made. The survey paves the way for model development and addresses the need for effective and integrated carbon emissions management quantitatively. The survey balances depth and width during the research and complements and validates the findings. The survey, case study and focus group shall be acknowledged as research strategies which are not mutually exclusive but can be used together (Saunders et al., 2012).

4.7.1 Case study

> *A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be evident (Yin, 2014).*

Robson (2002), defines a case study as ‘a research strategy which involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence’. Yin (2014) states that case study research is the conventional way of conducting implementation evaluations as it captures the complexity of a case and also captures changes in the case over time. Yin (2014) argues that phenomenon and context are not always sharply distinguishable in real-world situations. It is an all-encompassing method which can embrace different epistemological orientations. A case study tends to be much more focused on strategy and can explore a wide range of themes and subjects among a large number of people, organisations and contexts (Gray, 2004). This strategy is applied in challenging endeavours to contribute to the knowledge of individuals, organisations and groups and to understand socio-political phenomena (Yin, 2009). A case study is not just a form of qualitative research but goes beyond it by mixing both qualitative and quantitative evidence along with the necessity for defining a case. However, there exists a supporting argument that if a case study strategy is relevant for a study, there is a need to combine the case study with the real-world practice (Gill and Johnson, 1997). This could provide better insights into the process under investigation. A case study is not only suitable for investigating ‘how and why’ questions but also for developing and testing a theory and further refining it (Voss et al., 2002).

There can be a single case or multiple cases. A case study is well-suited to new topics for which existing theory is inadequate in the literature (Eisenhardt, 1989), and this is the case with the current research topic of effective carbon emissions management in building construction. Two case studies are used for one building in Habshan and two buildings in Bu Hasa to address broader and more complicated research questions. Therefore, a case study strategy was adopted. Critical realism offers a philosophical justification for a smaller number of case studies and provides a structured way of arguing for the generalisability of the findings (Easton, 2010b). This is the research approach based on 'systematic combining' grounded in 'abductive' logic (Dubois and Gadde, 1999).

The identification of 'which case to study' is an integral part of any research (Dubois and Gadde, 2014). Bu Hasa and Habshan buildings were chosen as in-depth case studies to investigate how the construction industry in the UAE can implement effective carbon emissions management at the set project boundaries. The detailed justification for Bu Hasa and Habshan case studies is presented in chapter 7.

There may be exceptional circumstances in which a single case is so unique or important that the researcher has no desire to generalise the findings to other cases (Yin, 2009). For an in-depth case study to provide insights into the phenomenon, it should be representative of a broad range of cases, which the Bu Hasa and Habshan projects are. Based on this fact, the typical case study approach is adopted. The typical case exemplifies typical values and provides some general understanding of a phenomenon (Gerring, 2007). Two case studies can be selected as it may provide an opportunity to observe change and analyse the phenomenon (Saunders et al., 2012). This research has adopted a two-case strategy because it is argued that even a single case is sufficient to represent a critical, extreme or unique case. It is argued that learning from a particular case (conditioned by the environmental context) should be considered a strength rather than a weakness. 'The interaction between a phenomenon and its context is best understood through in-depth case studies' (Dubois and Gadde, 2002). However, 'studying a single case in detail does not guarantee that rich theoretical insights, of course, using multiple cases would not guarantee insights either' (Dyer and Wilkins, 1991, p. 618).

A case study strategy has some limitations. Opponents argue that a case study provides an 'unscientific' feel to the research (Saunders et al., 2003). In contrast, Flyvbjerg (2006, p. 219) states that 'one cannot generalise from a single case; therefore, the single-case study cannot contribute to scientific development'. Yin (2014) states that with 'two-case' case studies, the chances of conducting a good case study will be better than when using single-case design due to the analytic benefits. Scepticism about a single-case study may turn into criticism if strong arguments and justifications are not available. Two-case case study arguments supplement the first case study and can fill gaps left by the first case study or respond better to some obvious shortcoming. Yin (2014) explains that case studies were traditionally seen as a less desirable form of inquiry than either experiments or survey strategies, perhaps because of the concern over lack of rigour in case study research. Carelessness in following the procedures, equivocal evidence and biased views can influence the research findings and conclusion, whereas, in other methods, lack of objectivity and lack of rigour are less likely, possibly due to methodological and statistical procedures followed in research (Rowley, 2002; Yin, 2014). The main argument against it has been that case studies provide little basis for scientific generalisation of the findings (Yin, 2014). Yin (2014) concludes that a case study is remarkably difficult to conduct, although it is considered a 'soft' approach. The researcher made informed decisions to address the case study concerns with 'two-case' case study at different times and locations and used a triangulated approach to data collection.

A case study is capable of creating complex descriptions and rich understandings of social contexts, offering valuable research insights for public policymakers (Macpherson et al., 2000). Another limitation in conducting a case study is time: the time the researcher requires to conduct the case investigation and the time that the researcher has available to devote to it. The researcher overcame this limitation by becoming involved with the case study of the Habshan project at the onset of research, after Survey 1 analysis and model development. With lessons learned from the Habshan project, Survey 2 analysis and further development of the CEM model, improvements in implementing the carbon emissions management were made for the case study of the Bu Hasa project. The communication with project teams was integral both for carrying out the case study and in accessing and employing the right people for data collection (Coley, 2008).

4.7.2 Survey

Case study shortcomings regarding not being able to generalise the findings beyond a single case can be addressed by adopting a rational approach of integrating qualitative and quantitative data in a multi-method study (Macpherson et al., 2000). Therefore, a survey strategy and focus group can be adopted, which can provide a representation of research findings through quantitative and qualitative investigation. Survey is widely used in social sciences and management research. The main reason for surveying in empirical research is to have wide and inclusive exposure to obtain information (Denscombe, 2010).

The first phase consists of a quantitative survey-1 and a qualitative case study-1 and the second phase consists of a quantitative survey-2 and case study-2. The last phase of the research adopts a qualitative study of focus group for validation of the Integrated CEM framework. Kopinak's (1999) study verified the findings of qualitative data collected through interviews and ethnographic observations made through a quantitative survey while adopting the mixed-methods study on refugees' wellbeing. This triangulated approach is advantageous from a positivist and a critical realist perspective, and it is based on the assumption that there is a tangible social reality. The goal of confirmation makes less sense from the perspective of an interpretivist philosophy. This research design supports the argument of conducting a quantitative survey before the qualitative study.

The survey strategy brings the quantitative aspect into this study. This survey investigates the current practices of sustainable management and carbon emissions management in the UAE construction industry. The survey also helped in identifying the drivers and barriers to implementation of effective carbon emissions management according to global ratifications agreed on climate change. Surveys include self-administered postal surveys, telephone surveys and internet surveys (Robson, 2011). Postal surveys are self-administered questionnaires and were the best type of survey until the advent of IT technology (Denscombe, 2010). In present times, they are expensive and time-consuming with relatively low anticipated response rates. Telephone surveys are not effective for this research, either because of the resulting sample size and associated costs. It would not have been possible to achieve a high response rate through a telephone survey as it is extremely difficult to target individuals with the required professional profiles. Based on the available resources and research needs, an online internet survey was chosen. Internet surveys are an inexpensive and quick alternative to other types of surveys (Denscombe, 2010). As the internet is becoming part of nearly everyone's daily life, this seems to be the most suitable option for collecting data. All of the construction professionals working in the UAE construction industry have easy access to the internet to complete the survey.

The main advantages include collection of empirical data, collection of both quantitative and qualitative data, wider geographical coverage and efficiency and low cost associated with collecting a large set of data (Denscombe, 2010). On the other hand, surveys do not offer the opportunity to study responses in detail and also are not effective for sensitive and complicated issues. There are risks of a low response rate and a tendency to focus more on the data than theory (Denscombe, 2010).

For this research, the limitations were not prominent as the objective was to assess the lack of implementation of carbon emissions management and to understand the wider perspectives of construction companies. The strategy adopted was to conduct two surveys to maximise the benefits of the survey, which seem to align with the research objectives directly. First survey was carried out at the onset of the research to explore the current practices, status of sustainable management, tools in use etc. and the second survey was conducted to evaluate current practices, perceptions of respondents on the proposed model, framework, prospects of CEM and approach for effective CEM in the UAE construction industry. Gray (2004) points out that surveys also offer an opportunity for simple data analysis and are suited to the potential respondents.

4.7.3 *Sample size*

Sample size determination for a study area is a complex process which involves several qualitative and quantitative considerations, including the nature of the research, the number of variables, nature of the analysis, incidence rates, completion rates and resource constraints (Creswell, 2013). Based on the objective and the area of study and considering that a large number of variables were to be analysed, a reasonably large sample was required. To determine a survey-2 sample size, the following formula from Czaja and Blair (1996) and Creative Research Systems (2003) was applied.

$$SS = \frac{z^2 \times p(1-p)}{c^2} \quad \text{-------------------------eq} \quad 4.1$$

Where: SS = sample size,

z = standardised variable,

p = percentage picking a choice, expressed as a decimal, and

c = confidence interval, expressed as a decimal.

As has been suggested by other researchers, a confidence level of 95% was assumed (Munn and Drever, 1990). Based on the need to find a balance between the level of precision, resources available and usefulness of the findings, a confidence interval of ±10% was also assumed for this research (Czaja and Blair, 1996). Under the 95% confidence interval for a population of approximately 6750 companies in the UAE and a margin of error of approximately 5%, a representative sample size was calculated to be approximately 364 companies. Actual gathered responses were obtained from representatives of 371 companies.

4.8 Research Methods

Research methods are the techniques for collecting data through a specific instrument, such as questionnaires, interviews and participant observations (Bryman, 2014). Critical realist researchers argue that the selection of data collection methods should be governed by the nature of the research being conducted (McEvoy and Richards, 2006). Noor (2008) strengthens the argument employed in this research by stating that a combination of multiple techniques in case studies supports and strengthens the results of research. Yin (2016) acknowledges that any single source will not have a complete advantage over all the others; instead, various sources complement each other, and a good case study uses as many sources as possible. Robson (2002) argues that one research approach makes it easier to learn and to keep the study focussed. The methods used in case study research may differ and can include questionnaires, interviews through focus group, observations and analysis (Saunders et al., 2003).

4.8.1 Types of research methods

There are two distinct clusters of research methods and orientation to conduct research: quantitative and qualitative methods. The quantitative research method emphasises quantification in the collection of data and analysis (Bryman, 2016). Quantitative research methods allow large amounts of data to be collected and analysed in a logical and replicable way, with statistical advantages (McQueen and Knussen, 2002). This method examines the relationship between variables with a range of statistical techniques and incorporates controls to ensure validity (Saunders et al., 2012). Bryman (2016) argues that quantitative methods embody a view of social reality as an external objective reality.

The qualitative research method emphasises words, the generation of theories and aspects of how individuals interpret their social world, rather than quantification (Bryman, 2016). Ritchie and Lewis (2003) agree that this method provides an in-depth investigation of the social world by learning about people’s experiences, perspectives, circumstances and history. Qualitative data provides an in-depth understanding of a research problem, whereas quantitative data provides a general overview and understanding of the problem being studied (Creswell and Clark, 2011). Qualitative and quantitative methods often provide different perspectives, and each method has its limitations.

4.8.2 Mixed methods research

Mixed methods research has considerable potential for optimising the strong points of the two approaches and negating the weaker ones (Bryman, 2004; Denscombe, 2010; Ritchie and Lewis, 2003; Saunders et al., 2009). Mixed methods are employed to reveal different aspects of the same reality and examine reality from different viewpoints in the study (McEvoy and Richards, 2006). The mixed-methods approach is best suited for understanding complex research issues, due to the lack of ability of one single approach to capture reality from all aspects.) A significant aspect of systematic combining is to use different data sources and methods to complement each other (Dubois and Gadde 1999). Saunders et al. (2012) identifies the reasons for selecting mixed method design as initiation, facilitation, complementarity, interpretation, generalisability, diversity, problem-solving, focus, triangulation and confidence.

Research relies on philosophical assumptions of what constitutes ‘valid’ research and also states which research methods are appropriate for knowledge development in a given area of study (Creswell, 2013; Yin, 2014). The quantitative approach includes theory verification using figures and statistics, whereas the qualitative approach deals with descriptive reports of individuals’ perceptions, attitudes, beliefs, views and interpretations (Robson, 2002). A combination of both qualitative and quantitative research methods provides an improved quality of research findings (Yin, 2014);

The mixed-methods approach was adopted based on the research objectives and the advantages of a mixed method. The triangulated approach could help provide a rich understanding of the implementation of the carbon emissions management process in-depth and width by employing different tools and techniques to collect data. The combination of qualitative and quantitative methods enables the research findings to be complementary. The qualitative research aims to deal with qualitative factors around the implementation of an Integrated CEM framework in the UAE in general and building projects in particular. The quantitative aspect investigates reasons for the lack of implementation of CEM more widely from a larger sample of UAE professionals. Overall, data collected through different methods, and theoretical insights are produced in the form of a CEM Model and Integrated CEM framework. The qualitative study also explored the current practices and mitigation measures for effective implementation of carbon emissions management, from research participant observations. It also helps to understand main drivers, barriers and the key features to be embedded, to improve CEM implementation in the UAE construction industry. The qualitative study through the focus group of UAE professionals tests the Integrated CEM framework comprising of CEM models.

Research design, according to Yin (2014), is a basic step-by-step plan which depicts the data collection and analysis phases of the research. It establishes a framework for the type of information to be collected, its sources, collection procedure and justification (Creswell, 2013). The mixed-method approach, also known as pragmatism, arises from actions, situations and consequences rather than antecedent conditions (i.e., what works and solutions to problems). It not only focusses on methods but also enables researchers to place emphasis on the research problem and use all approaches available to understand the problem. Mixed-method then use pluralistic approaches to derive knowledge about the problem (Creswell, 2013). It also falls under the category of descriptive research, which does not fit into the definition of qualitative or quantitative research methodologies but instead utilises elements of both (Knupfer and McLellan, 1996). This is what, conducted through the model validation step of the study, in which elements of qualitative and quantitative research are employed. Descriptive research is often concerned with the type of research question, which is, in this case, how efficient is the current project management system in controlling the carbon emissions and the sustainability impact of the building construction industry in the UAE? The main purpose of research is to evaluate, analyse and validate findings.

There are three types of mixed design approaches; sequential mixed methods design, embedded mixed-method design and convergent parallel mixed method design. Sequential mixed method is further divided into two categories based on the sequence of the method adopted, such as explanatory sequential mixed method or exploratory sequential mixed method.

For this research, the exploratory sequential mixed methods approach was selected. It involves a two-phase study in which the researcher collects quantitative data in the first phase, analyses the results, and then uses the results to build on in the second, qualitative phase. The overall intent of this design is to have the qualitative data help explain in more detail the initial quantitative results. A typical procedure might involve collecting survey data in the first phase, analysing the data, developing a CEM Model and then following up with a survey-2, case study-2 to test the developed model and the way forward. Upon testing of Model, these models are used to develop an Integrated CEM Framework.

4.8.3 Questionnaire

A questionnaire is a data collection method for a survey to collect information directly from the research participants through a written list of questions (Denscombe, 2010). The data can be collected in a short period in a relatively cost-effective way. As part of the survey strategy in this study, data were collected through the questionnaire within the UAE building construction sector. The decision about sample size is not easy and depends on several considerations, and it has no specific answer (Bryman, 2004). A web-based tool, SurveyMonkey, was used to develop an online survey. This is a user-friendly tool and helps in customising the survey questions, distributing the questionnaire and collecting the responses (SurveyMonkey, 2018).

Surveys were conducted in the first phase of the research to explore current practices and to find out reasons for lack of implementation of carbon emissions management to refine the focus of the research at the earlier stage. This survey was conducted with 60 respondents from 10 companies working on UAE building construction projects. These surveys helped to explore the research domain and gather scoping information about the case. The context of the first-phase survey was existing practices, awareness and difficulties in implementing sustainable practices.

The second survey was conducted after the conceptual model development, testing and implementation of it on the first case study. The organisations are not named due to ethical reasons, and the survey was conducted using SurveyMonkey. A list of questions was drawn up relating to carbon emissions management, sustainable practices, tools in use, reasons for lack of implementation, proposed changes and preferences. The second-phase surveys administered to the construction industry respondents in the UAE included the questions related to; the case study-1 findings, mathematical model development, intended framework questions, prospects and the areas of improvement to enhance CEM implementation. As interviews are time-consuming, resource-intensive, difficult to analyse in terms of qualitative data and may suffer from poor levels of reliability, this research used the survey strategy (Denscombe, 2010).

Other reasons for including the surveys were that total reliance on case studies with a researcher involved might be biased, due to the researcher's perspectives and limited generalisability and reliability (Huberman and Miles, 2002; Yin, 2009). All shortcomings of the different research strategies were addressed by carrying out surveys, a two-case case study and focus group analysis. This can aid in comparing and verifying results through a mixed approach.

After the design of the questionnaire, a pilot study was conducted by sending the online survey to five sustainability managers in five different companies from the first-phase sample. A pilot study is a small-scale version of a real study, used to see the posed questions and to check the study's objectivity (Robson, 2011). The pilot team reviewed the questionnaire, and it was further revised to address their comments and feedback so that the survey study met the research purpose. A convenience sampling method was adopted, and respondents were contacted individually via emails taken from the UAE contact directory, the contact directory of companies where the researcher worked and from personal contacts of building contractors, consultants and clients. A web link was sent to respondents to complete the survey.

4.8.4 Focus group

Focus group is a form of an interview with group of experts. Focus group is a purposeful conversation between people in which one person has the role of a researcher to ask purposeful questions, carefully record and explore these further (Gray, 2004; Saunders et al., 2012). Questions are targeted to focus on the research objectives for causal inferences and explanations (Yin, 2009). Interviews are categorised in various typologies, such as structured, semi-structured, unstructured, standardised, non-standardised, focussed and non-directive (Saunders et al., 2012). The approach of focus group workshops is similar to group interviews (Ahmed, 2013).

According to Krueger & Casey (2000), a workshop technique is a useful and effective data collection method as it provided a conducive platform for evaluating various concepts. Since the amount and range of data can be collected from several people at the same time, the focus group workshop is known to be a highly efficient qualitative data collection technique (Robson, 2004). Focus group workshops are effective in obtaining information, insight, experience, and knowledge of a large group of industry practitioners in the shortest period. By adopting a workshop as an approach for understanding and facilitating BIM adoption in the AEC industry, Gu & London (2010) used focus group to share and clarify views on various BIM adoption issues such as benefits, hurdles, requirements, and expectations. Marshall-Ponting & Aouad (2005) used the focus group workshop to obtain discipline-specific knowledge and to establish the similarities and conflicts in the design requirements of nD modelling approach. These focus group workshops can determine the level of communication differences, conflicts, and potential problems. Use of focus is not new to construction management research. Howard & Bjork (2008) used to get the expert views on standardisation and industry deployment for BIM, while Sacks and Barak, (2010), used focus group workshops to evaluate the visual interfaces for BIM-based construction management systems.

As for this research, the focus group workshop is the most appropriate and effective way of validating the Integrated CEM Framework including the survey results, case study findings, CEM estimation model, CEM monitoring and control model and the $COCO_2$ tendering model. The focus group offers an opportunity to capture insights and reactions from industry professionals, users and implementers. The focus group can be a small group of specialists in the area of research, in which a moderate discussion happens about aspects of the research with an intent to extract the views of each individual in the group and to validate the results (Yin, 2014). This research had 18 participants for the focus group to receive validation from all stakeholders such as contractors, design consultants, PMC consultants, client and manufacturers.

The participants were presented with the four key areas of research and were provided freedom to express their feedback across topics during the focus group discussion; however, the feedback was requested such that it covered the following four key areas for CEM, as shown in the focus group agenda in Table 9.1. The four key areas were:

1. The carbon emissions management (CEM) model and framework as a complete approach in managing sustainable projects.

2. The stakeholder's comfort level, ease and the efficiency of the proposed CEM model in increasing implementation levels of sustainable performance in the UAE (contractors, consultants, PMC and client).

3. The CE-EM and CE-MCM models using the SIUTs concept for improving carbon emissions management implementation and sustainability (economic, social and environmental dimensions of sustainability).

4. $COCO_2$ tendering to award contracts based on cost and carbon emissions.

The focus group validation process helped in getting suggestions for improvements to the developed model and framework. Their feedback was mainly concerned with the issue of ensuring that a regulatory framework is established for mandating carbon emissions monitoring and adoption of $COCO_2$ tendering, which is well-founded and transparent. Also, the focus group helped by introducing the payment flow chart as part of the Integrated CEM framework. The focus group participants raised the importance of sustainability reporting on each project monthly and weekly in addition to annual reports showing the sustainability indicators in terms of CO_2 emissions, which will encourage companies to quantify the impacts on global warming. Based on the focus group recommendations, CEM framework was changed to include the reporting and linking of Payments to the CO_2 emissions progress performance as shown in Figure 8.7 of chapter 8.

4.8.5 Observations

Saunders et al. (2012) state that if your research questions are concerned with what and how people behave, an obvious approach to obtaining data is to watch them. The data collected as part of this research two-case case study was through observation, which involves observing, recording, description, analysis and interpretation of people‛s behaviour (Robson, 2002; Saunders et al., 2012). Denscombe (2010) argues that the observation research method does not only rely on what people say, do or think, but offers direct and first-hand evidence of events.

Saunders et al. (2003) divided observation into two categories, participant observation and structured observation (often called systematic observation). Participant observation is qualitative and derives from the work of social anthropology. Structured observation is quantitative and is more concerned with the frequency of actions. Observation is used as a main method in case studies and to supplement other methods (Saunders et al., 2003). The current research used participant observations in the case study. Participant observation offers a platform to gain rich insights and holistic explanations, including the relationships between different factors involved in the study (Denscombe, 2010). This technique is beneficial if the researcher is working in the same organisation, and it provides easy access to data (Saunders et al., 2012). As part of a case study, procurement, detailed design development of a project, material selection and delivery, transportation and construction were observed. Observation approaches are of two types: overt and covert. In 'overt observation', those being observed are aware of being observed, while in 'covert observation', those being observed are not aware of the process (Gray, 2004). The overt observation approach was adopted for the case study in which the researcher participated in data collection. This approach was adopted to gain a better understanding of the current practices and to see the improvements after the model was implemented for carbon emissions management. The covert approach was used in spite of it raises ethical issues of not informing participants (Gray, 2004), but Gross and McIlveen (1998) argue that observational research is the most effective as those who are being observed are not aware of it.

Observations gave an understanding of 'what is going on' in terms of carbon emissions management at the project level, measures being taken, and how these measures are being documented. Site registers and forms were useful in recording the observations of the use of material, manpower, machinery, water, electricity and transportation as well as waste generation. Denscombe (2010) identifies access, commitment, reliability, generalisation of data and deception as the main disadvantages of the participant observation method. Access and commitment were not issues, as the researcher is a project manager of the projects being studied. Furthermore, the data were triangulated with other methods, such as surveys, a focus group and another case study to address the disadvantages of observation issues (Gray, 2004).

Observation research has two types of bias: participant bias and observer bias (Saunders et al., 2012). If participants are aware of the observation, there is a chance that they might change their behaviour to present a positive outlook and avoid acts which can affect the outcome. Full-term participation in the projects being observed can decrease the impact of participant bias. But the risk of observer bias is stronger due to the relationships built between observer and participants. Observers can adopt four roles: complete participant, complete observer, observer as participant and participant as observer (Gill and Johnson, 1997). This research adopted the 'observer as participant' role in data collection and decision-making, in which the participants of the case study and focus group were informed of the purpose of participation and the objective of the research.

4.9 Data Analysis

The research objectives shaped data analysis techniques. The research collected qualitative and quantitative data. The software packages SPSS 24, Primavera P6 and Excel, were used for analysing the qualitative and quantitative data, respectively. Excel spreadsheets enable researchers to collect, organise and analyse the data of case studies based on observations recorded on-site as the work progresses. In this study, SPSS 24 was used for statistical analysis of the quantitative data collected through surveys. Carbon emissions data was uploaded in Primavera P6 for planning, scheduling, monitoring and reporting the case study sustainable performance based on CO_2e emissions.

4.9.1 Credibility of the research

Qualitative and subjective methods carry doubts about the credibility of research findings. Validity, reliability and replication are three criteria to evaluate the quality of any social research (Bryman, 2016). On the other hand, Saunders et al. (2012) state that two criteria, reliability and validity assess the quality of research. Ascertaining the element of credibility is important for case study because of the reliance on data generated from limited or specific samples (Gray, 2004).

4.9.2 *Reliability, replication, validity and generalisability*

Reliability refers to the ability to repeat the results of the study with the set research questions (Bryman, 2016). Yin (2003) explains reliability in the context of case study, asserting that if another researcher follows the same research techniques as carried out by a previous researcher and undertakes the same case study, he or she should arrive at the same results and conclusions. Robson (2011) argues that in the real world, attempts to replicate the research are rare, and it is not feasible to repeat a study with the same people in the same situation. There are four types of threats to reliability: participant error, participant bias, researcher error and bias. Yin (2014) states that the goal of reliability is to minimise errors and biases, achieved by documenting the procedures followed in earlier cases. This research followed the recommendations of Yin (2014) by documenting case study research procedures to avoid doubts about the reliability of the research. The researcher also followed the recommendations for reducing participant bias, error, researcher bias and error in this research.

According to Saunders (2012), reliability alone is not sufficient to ensure good quality of research; other characteristics are also required, such as construct validity, internal validity and external validity. Validity is concerned with the integrity of the results generated from a piece of research (Bryman, 2016). Validity means that the data and methods used are correct, whether or not the data reflects the reality and truth and covers all crucial matters of study (Denscombe, 2010). This research enhanced the accuracy of the data collection process by adopting a mixed-methods approach (survey, two-case case study, focus group) and triangulation to the overall research design. Triangulation of data reduces the threat of researcher and respondent bias to increases the validity of the findings (Robson, 2002). Triangulation is an effort to offset the biases associated with a single method. A mixed-method is useful in supporting robust conclusions (McEvoy and Richards, 2006).

Construct validity is challenging in a case study research if the researcher fails to develop a sufficiently operating set of measures and due to subjective judgements made with preconceived notions (Yin, 2014). This research addressed the construct validity issues by using multiple sources of evidence, establishing a chain of evidence and having the case study draft report reviewed by the informants during the focus group sessions.

Internal validity deals with experimental and quasi-experimental research and explanatory case studies (Bryman, 2016; Yin, 2014). For instance, a researcher incorrectly concludes that there is a causal relationship between x and y without realising that third-factor z is affecting the outcome. This type of validity is difficult to identify while doing case study research (Yin, 2014). On the other hand, in a questionnaire survey, internal validity is established when the set of questions can be shown as statistically associated with the outcome (Saunders et al., 2012).

External validity deals with the issue of knowing whether the research findings are generalisable beyond the immediate case study regardless of the research methods used (Yin, 2014). Saunders et al. (2012) explain that external validity is concerned with the question of whether the case study research findings can be generalised to other relevant settings or groups. Bryman (2014) states that it is important to be aware of the major issues in case study research, such as external validity and generalisation. The findings of one study may not necessarily help in understanding other cases. A case study cannot be used to generalise up to a wider population in the same way that it is possible, for example, through a randomly chosen population in survey research (Yin, 2014). Therefore, Yin (2014) suggests that it is useful to identify other cases to which the results are generalisable. Conversely, Dyer and Wilkins (1991) advocate ‘deep case studies’ rather than ‘surface case studies’. The main argument for this is that there is a greater need for better stories than for better constructs.

This study has adopted a two-case case study strategy (Habshan and Bu Hasa projects), and this is supported by Yin, (2014) who states that a two-case case study is better than using a single-case design because of the analytic benefits. Two cases have the advantage of direct replication. Saunders et al. (2012), argue that the selection of two cases should be carefully chosen, on the basis that similar results are predicted to be produced, from each one. In this research, the two-case case study provided depth and breadth. As far as breadth is concerned, this study involves a quantitative survey, a qualitative study of two building projects and qualitative validation through a focus group. Depth in the case study was achieved, through calculating the elemental contributions to total carbon emissions. This mixed approach helped in a generalisation of the findings, which is relevant to the entire building construction industry in the UAE and beyond. Case study research also provides ‘generalisations to theory’, meaning theoretical explanations of the data observed, which may be applicable in similar cases in which similar conditions prevail (Yin, 2014).

4.10 Data Collection Techniques

Providing a clear theoretical framework for a study is the basis upon which the desired study is developed (Yin, 2009). An explanatory review enables the researcher to understand the theme better, assess the feasibility, suggest research questions, to determine the most suitable data collection and analytical techniques for the study.

Primary and descriptive research methods are used, in which data is collected through questionnaires, interviews and observations. An estimated population number was determined to enable the calculation of an optimum sample size for the questionnaire. The sampling method chosen for this research was the stratified convenient sampling method for survey 1, as it provides a varied cell which enables the population divided into groups and ease of access: client, PMC, consultant, contractor, vendor and sub-contractor (Hofmann and Stetzer, 1998). Sarkar et al. (2015) indicate that the stratified convenient sampling method is one of the best statistical approaches to sampling. It will identify the implementation levels in management because of its associated advantages, such as large, different clusters of the desired population and diversity in its elements.

Random sampling adopted for survey-2, and participants were randomly selected. Under the 95% confidence interval for a population of approximately 6750 companies in the UAE and a margin of error of approximately 5%, a representative sample size was calculated to be approximately 364 companies. Actual gathered responses were from representatives of 371 companies.

Data is verified by applying the statistical test to categories of data to understand the differences between the two sets. The correlation method is selected due to its accuracy in capturing all data categories in detail and providing a mechanism for project significance and independence for each category being studied.

4.11 Research Time Horizon

This section discusses the overall research methods used for the study and the justification of the reasons for using them. The fundamental requirements associated with the research objectives are addressed through the following method using a combination of horizontal and longitudinal time horizon approach:

- Stage 1: Conceptual research framework development stage
- Stage 2: Methodological development stage
- Stage 3: Empirical study stage

The need to adopt this methodology is due to a lack of academic references related to UAE on carbon emissions management and due to unavailability of the CEM model for the construction phase. This methodological route is selected to help in identifying the gaps in literature, to confirm the gaps in industry practice thorough a preliminary survey. Surveys and case study testing provides industry views which is often more current and insightful information. These initial observations collected thorough survey-1 helped to form ideas on issues relating to the lack of implementation of embodied carbon emissions management before the development of a model. After developing the CEM model, a thorough survey was carried out to investigate current practices, rating tools in use, software in use, preferences of industry and willingness to participate in CEM projects. Case studies were used to test the model, and the validation of the CEM model and integrated framework is carried out using the focus group.

4.11.1 Stage 1 - Conceptual research framework development stage

Literature review

An exploration and review of relevant literature through synthesis and analysis of recently published data, using a range of information collection tools, such as books, peer-reviewed journals articles and dissemination notes from libraries and internet-based sources.

This task helped to confirm initial observations and develop preliminary ideas on issues specific to the research theme relating to lack of implementation of embodied carbon emissions management during the construction phase and their role in sustainable construction. Next, it focusses on the history of sustainability, the impacts of rising carbon emissions, initiatives in various sectors, the role of the construction industry, global warming and the implementation of sustainable measures. Literature review also emphasises carbon emissions during the operation phase and investigates the need for embodied energy calculations in a project's life cycle. Furthermore, it investigates the tools and standards available for managing carbon emissions and reviews the database and inventory sources. To evaluate sustainable construction management practices, a comparison of cost management and carbon emissions management are discussed. Also, the current and alternate procurement practices which should have been a driver in promoting the need for carbon emissions management are analysed.

Literature review also provided insights into the knowledge deficits of various carbon assessment tools currently available for managing CO_2 emissions, which helped the study to identify appropriate strategies needed for the development of the proposed model using simple-in-use tools.

Survey-1

Conducted a preliminary study through surveys to further examine views, practices and current thinking from practitioners in relevant building professional groups, such as clients, consultants and contractors, who influence decisions and possess sufficient industry knowledge relating to sustainable construction and management.

The need to include industry views arose due to a lack of academic references and an acknowledgement that the industry often provides more current and insightful information. The respondents included mainly building professionals from targeted regions, such as Dubai, Sharjah, Abu Dhabi, Ras Al Khaimah, Ajman, Fujairah and

Umm Al Quwain emirates. Criteria were long-standing experience and versatility in the sustainability assessment tools. The constraints informed the choice of an online semi-structured questionnaire at this stage, of distance, time, budget and sample size. The inclusion of both closed-ended and open-ended questions provided an opportunity to validate prior assumptions in the background section and elicit more information from respondents willing to express and elaborate on their views. This method allowed, for a large number of other potential decision-making factors and relevant information, not found in the literature base to be further explored.

A questionnaire survey to investigate the awareness of CO_2 emissions among industry professionals and to explore the current practices in the UAE construction industry was prepared and was launched via email in mid-April 2013. The first survey attracted more than 60 eligible respondents from 10 construction companies. The questionnaire's introduction clearly stated the questionnaire's purpose, target group and approximate time required to complete it. Likert scale ranking questions are also included, to allow respondents to share their thoughts and comments. As an incentive to increase response rates (Malhotra et al., 2002), the respondents were assured that they would receive the summary report of the final survey.

A stratified convenience sampling method was used for survey 1. Ten construction companies were approached to find out whether any CO_2 emissions were being estimated and tracked in their organisations.

4.11.2 Stage 2 - Methodological development stage

This stage covers the research methodology, survey-2, CEM model development and integrated CEM framework development.

Survey 2

The second survey was launched in May 2016. It was closed after two months to ensure balanced participation. The second survey was structured to include questions related to all objectives of the research. The literature review explored the area from which sets of research questions were developed. Having identified the key variables which would be included, the next step was to design a questionnaire. The respondents, who were mainly building and construction professionals in the housing construction industry, were the source of information, chosen based on their expertise in the area of study.

Random samples from within each group were selected. Under the 95% confidence interval for a population of approximately 6750 companies in the UAE and a margin of error of approximately 5%, a representative sample size was calculated to be approximately 364 companies. Actual gathered responses were obtained from representatives of 371 companies.

The second stage of the questionnaire design involved determining the question content, type and distribution process. UAE construction is diversified, with specialists from countries including the U.S., the UK, Australia, South Africa, India, Pakistan and other south Asian countries. The major advantage of the respondents was the experience of working in their countries and also in the UAE. Optimum consideration was given to the design of the questionnaire and the types of questions to minimise any potential bias or errors in responses arising from cultural, language, ethnic and other differences among respondents.

- Structured and pre-determined questionnaire is prepared targeted towards developers, clients, consultants, contractors and suppliers, to identify the factors affecting the lack of implementation of CO_2 emissions in the industry and to understand their needs.
- Survey questionnaire was prepared using the following hypothesis :
    - Integration of carbon emissions management with time and cost management should be done to improve the implementation levels.
    - Simple-in-use tools (SIUTs) will increase implementation and will reduce factors such as complexity and additional cost incurred.
    - Use of SIUTs will enable contractors, consultants and clients to reliably and effectively estimate, benchmark and monitor the embodied CO_2 emissions of a project.

- Organisations can develop their own databases for corresponding resources and activities to gain a competitive advantage.
- Bidding and project award criteria should include carbon emissions (i.e., bids should include technical evaluation, commercial evaluation and carbon emissions evaluation as part of the award process).

Literature review and survey-2 responses helped in developing a Carbon emissions management model (CEM) comprising of tendering, estimating, monitoring and controlling the carbon emissions during Phase 4 & 5 of RIBA Plan of work.

An Integrated Carbon Emissions Management (CEM) framework is developed using the CEM model and the literature review findings, to enhance the environmental efficiency of building construction.

4.11.3 Stage 3 - Empirical study stage

In Stage 3, the CEM Model is tested, Integrated CEM framework is validated, and the conclusion of the research are made. CEM model was applied and tested on two case study projects. Case studies also tested the means of estimating, monitoring and managing carbon emissions during construction using EVA analysis. An Integrated CEM framework is developed using the CEM Model is validated by a focus group workshop comprising of UAE Construction industry practitioners to record the efficiency and ease of use. Feedback is collected to validate the role of the Integrated CEM framework in increasing the implementation levels of carbon emissions management in the UAE. Conclusion is derived from the research findings, with limitations, recommendations and suggestions for further research.

Case study for testing

Use of multiple methods to collect data is an essential aspect of a case study, including in-depth interviewing, obtaining information from secondary records, gathering data through observations, collecting information through focus groups and group interviews, etc. by considering the case as a single entity (Kumar, 2011). The essential characteristics of a satisfactory case study include continuity, completeness of data, validity of data, confidential recording and synthesis, which is scientific. A similar approach is followed in the case study for this research by collecting data through secondary records and observations.

A case study to estimate, implement and monitor CO_2 emissions by using the developed CEM model encompassed fieldwork, carried out at the Habshan and Bu Hasa. Weekly monitoring of emissions was conducted by recording the quantity used, waste produced, travel distances, energy metering, etc. Material selection and review of alternative options and the factors considered in selecting the material, process, etc. were recorded. These values were compared to achieve the overall design intent of reducing CO_2 emissions, using the planned values via S curves. Intangible factors/variables, such as awareness levels, ease of managing the CO_2 emissions, overheads related to it, team enthusiasm, etc., were also continuously monitored.

Focus group for validation of CEM Model and Framework

A focus group was organised for validating the Integrated CEM framework consisting of survey results, case study findings, CEM estimation model, CEM monitoring and control model and $COCO_2$ tendering model. The focus group offers an opportunity to capture insights and reactions from industry professionals, users and implementers. The focus group can be a small group of specialists in the area of research, in which a moderate discussion happens about aspects of the research with an intent to extract the views of each individual in the group and to validate the results (Yin, 2014).

The focus group was held at the client's organisation building in the UAE with a panel of 18 experts from six different categories: cost managers (four participants), project managers (three participants), contracts managers (two participants), construction managers (three participants), planning managers (two participants) and client representation (two participants). The participants were presented with the four key areas as shown in section 9.2 and were provided the freedom to express their feedback across topics during the focus group discussion.

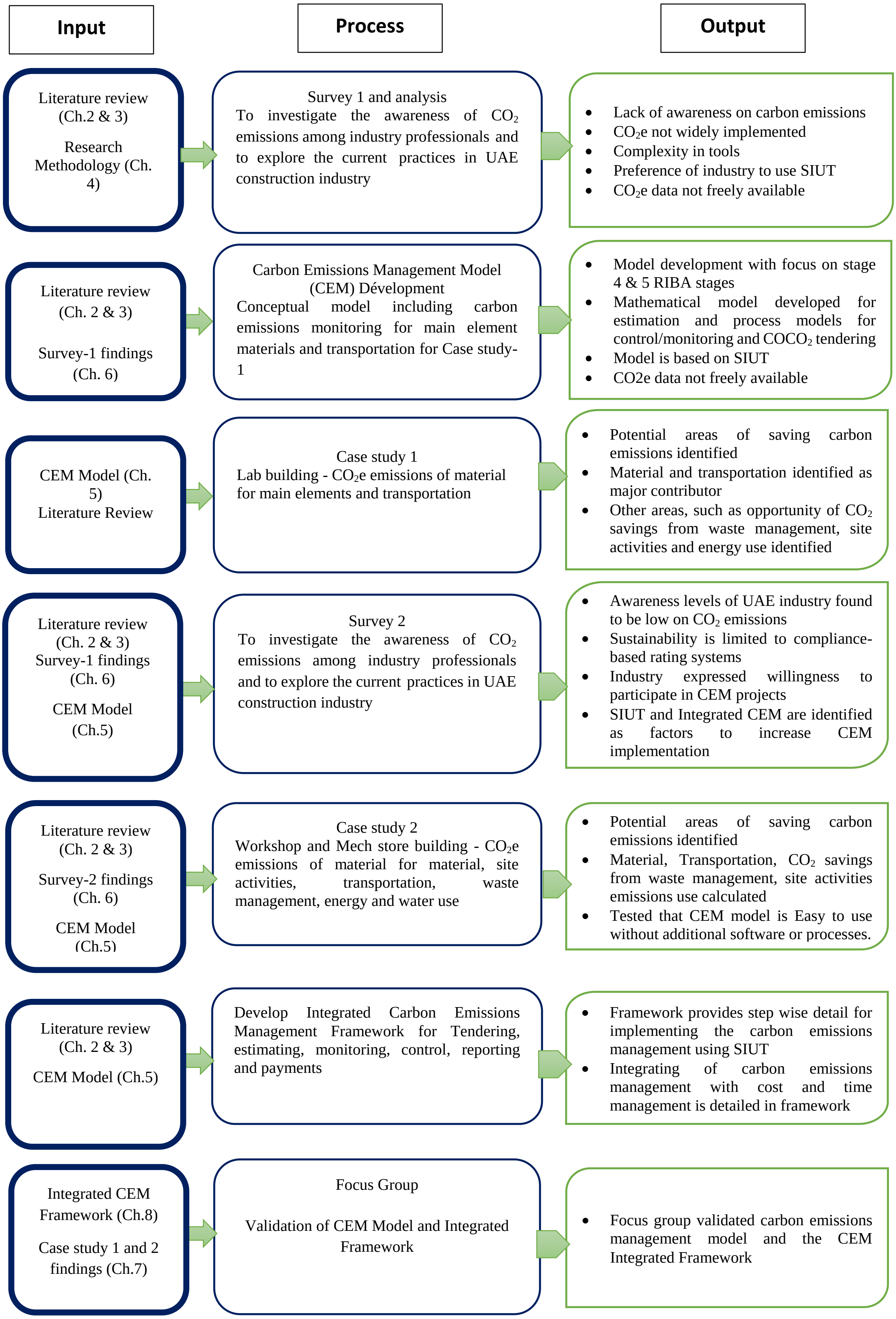


Figure 4.2 Research methodology – Input and Output chart

4.12 Summary

This chapter presented the research design with appropriate methodological justifications. There are various options and alternatives available to conduct research, and there is no universal agreement on a single methodological concept. Evaluation of carbon emissions management in the UAE construction industry requires a real-world research approach, which involves issues of problem-solving and is focussed on actionable factors to change the outcome. This thesis adopts a 'critical realism' research approach, along with the mixed method to explore the implementation levels of carbon emissions management and sustainability aspects in the UAE building construction industry. The research aimed to investigate the implementation levels of carbon emissions management and how projects, organisations and sectors 'behave', which is not easy. Thus draws upon input from fields such as sociology, philosophy, economics, communication and statistics.

The combination of qualitative and quantitative methods enables the research findings to be complementary. The qualitative research aims to deal with qualitative factors around implementation of carbon emissions management in the UAE in general and building projects in particular. The quantitative aspect investigates reasons for the lack of implementation of sustainable issues more widely from a larger sample of UAE professionals. Overall, data was collected through different methods, and theoretical insights were produced in the form of a CEM Model and Integrated CEM framework. The qualitative study explored the current practices and mitigation measures for effective implementation of carbon emissions management from research participant observations to understand its main drivers and barriers and the key features to be embedded in the UAE construction industry to improve implementation. The qualitative study through the focus group of UAE professionals tests the CEM model and framework.

Chapter Five: Conceptual Model Development for Carbon Emissions Management

5.1 Introduction

This chapter presents the process of formulation of the theoretical carbon emissions management model (CEM) to enhance implementation levels of carbon emissions monitoring in the building construction projects. The models for three processes are developed to estimate, tender, monitor and control the sustainable performance of building construction, by leveraging the literature review, surveys and case study input.

The goal of the proposed study is to provide a multi-objective model and an integrated framework for project stakeholders in such a way that contractors, consultants, clients and regulatory authorities can understand the environmental impacts related to carbon emissions in the construction phase of a building project. The study aims to enhance the environmental efficiency of buildings during the tendering and construction phase. It focusses on developing models to evaluate the impacts through tendering, estimation, benchmarking, monitoring and controlling the emissions during the construction phase (i.e., stages 4 and 5 of RIBA plan of work) (WRAP, n.d.).

5.2 Model and framework definition

Objectives of the research include the development of model and framework for carbon emissions management; hence, an understanding of the terms model and framework are essential. A model is the presentation of information related to existing or future situation in a schematic and simplified way (Verbrugge, n.d). A good Model shall be theoretically consistent, fit the real world and have predictive power. The modelling technique determines the way a situation is represented schematically. Examples of these modelling techniques are Input-output model, process model, workflow model, life cycle model etc. A model provides an environment to implement a framework. (Software process measurement, 2016)

A framework is an entity between a 'model' and a 'method'. A framework is a structure detailing the system to realise the defined goals. Frameworks can contain one or more models and sub frameworks. Frameworks give the users much more freedom regarding the partial or entire use of the framework and the use of the models or techniques therein, whereas Methods do not. (Wiese et al., 2018). It is imperative to know the meaning and use of terms ‘practice’, ‘best practice’, ‘Model’, ‘Modelling technique’, ‘Framework’, ‘method’, ‘Methodology’, ‘body of knowledge’, ‘standard’, ‘guidelines’ to avoid confusion.

Table 5.1 Description of model, framework and other terms

Source ((Verbrugge, n.d); (Wiese et al., 2018); (Software process measurement, 2016))

Term	Description
Practice	Practice is the description of how professionals work within their profession to carry out a specific task. Best practice is the description of the best way of working based on the situation in hand. Also, the best practice can help future professionals to adapt the way of working.
Model	A model is the presentation in schematic form, often in a simplified way, of an existing or future state or situation. A model provides an environment to implement a framework. Models represent a real-world system and may consist of multiple hard- or soft linked sub-models to answer clearly defined research questions. Models can be built with an analytical and mathematical approach by the use of a pre-defined set of equations.
Modelling technique	The modelling technique determines how the situation is represented schematically. Popular modelling techniques are process model, workflow model, life cycle model.
Framework	A framework contains, a structure or system for the realisation of a defined goal. A framework is an entity between a 'model' and a 'method'. Framework provides an organised structure of ideas, concepts, and other aspects involved to indicate the coherence and clarity to other people. It includes concepts, sub-frameworks and models. Compared with methods, frameworks give the users more freedom on partial or entire use of the framework or models.
Method	A method is a systematic approach to achieve a specific result or goal and offers a description cohesively and consistently. Methods embedded in frameworks consists of ‘a way of thinking’ and ‘a way of working’ and provides an approach to achieve a specific goal.
Methodology	Methodologies provides a disciplined set of the processes so that the outcome is more predictable and more efficient. It is a systematic, theoretical analysis of the methods

	applied to a field of study. It includes concepts such as paradigm, theoretical model, phases and quantitative or qualitative techniques.
Body of Knowledge	A body of knowledge is the complete set of concepts, terms and activities that make up a professional domain. BOK is more than simply a collection of terms, description of professional functions; or even a collection of information.
Standard	ISO definition: A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.
Guidelines	It's a recommended practice which allows discretion in its interpretation and implementation. Guidelines is the first version of a document that will eventually become a standard.

5.3 Carbon Emissions Management Model Development and Testing

The CEM model was developed to evaluate the environmental performance of building construction, in terms of carbon emissions, with input from the literature review, surveys and case study findings. The overall CEM model consists of mathematical and process models. The three sub Models (CE-EM, CE-MCM, $COCO_2$) are adequately defined for the users, along with a step by step framework and recommendations for the industry to adapt in the form of an Integrated CEM Framework. Accordingly, the Integrated CEM Framework will help to address the specific areas for improvement in enhancing the environmental efficiency of building projects using carbon emissions management:

1. Mathematical model for the estimation of carbon emissions in a building construction project (CE-EM).
2. Process model for monitoring-and-control of carbon emissions (CE-MCM), during the procurement and construction phases of a building project.
3. Process model, for tendering using cost and carbon tender ($COCO_2$) as the governing criteria in awarding building construction projects.

5.3.1 *Mathematical model for the estimation of carbon emissions*

The embodied carbon emissions of the material type k, which includes the raw material extraction and material production, can be calculated as in equation 5.1. (Li et al., 2016; Kumanayake et al., 2017).

$$\text{EC for Material} = \sum_{k=1}^{n} . Q_{\text{k}} . I_k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 5.1$$

The embodied carbon emissions coefficient factor of the type k transport vehicle (i.e., diesel-powered truck, electric locomotive) for travel distance – $KgCO_2$/functional unit of material/per KM for Q_k (i.e., functional quantity of material or manpower being transported) (Langston et al., 2018; Li et al., 2016). Akbarnezhad and Xiao (2017) calculated transportation emissions factors for each material by considering its transport requirements by multiplying the carbon emissions factor by the quantity of material transported. The distance covered in moving material from the factory gate to the construction site and the associated emissions per kilometre from the burning of fossil fuels can be calculated as equation (5.2) (Akbarnezhad and Xiao, 2017).

$$\text{EC for Transport} = \sum_{k=1}^{n} . Q_{\text{k}} . T_k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 5.2$$

EC is the embodied carbon emissions coefficient factor for the energy used in site construction – $KgCO_2$/functional unit of material, which also includes the power consumption of machinery and equipment in the construction process, and it can be calculated as equation (5.3) (Kumanayake and Luo, 2018; Devi and Palaniappan, 2014):

$$\text{EC for site construction} = \sum_{k=1}^{n} . Q_{\text{k}} . E_k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 5.3$$

The overall carbon emissions of a building project are presented in a mathematical model based on a process analysis approach for estimating the embodied carbon emissions, as shown in equation (5.4) (Roh et al., 2018):

$$EC_k = \sum_{k=1}^{n} . Q_k . Ik + \sum_{k=1}^{n} . Q_k . T_k + \sum_{k=1}^{n} . Q_k . E_k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad 5.4$$

where:

EC_k - Embodied CO_2 of material type k, unit $KgCO_2$

Q_k – Total functional quantity of material

I_k – Embodied CO_2 factor – $KgCO_2$/functional unit of material

T_k – CO_2 factor for travel distance – $KgCO_2$/functional unit of material/per KM

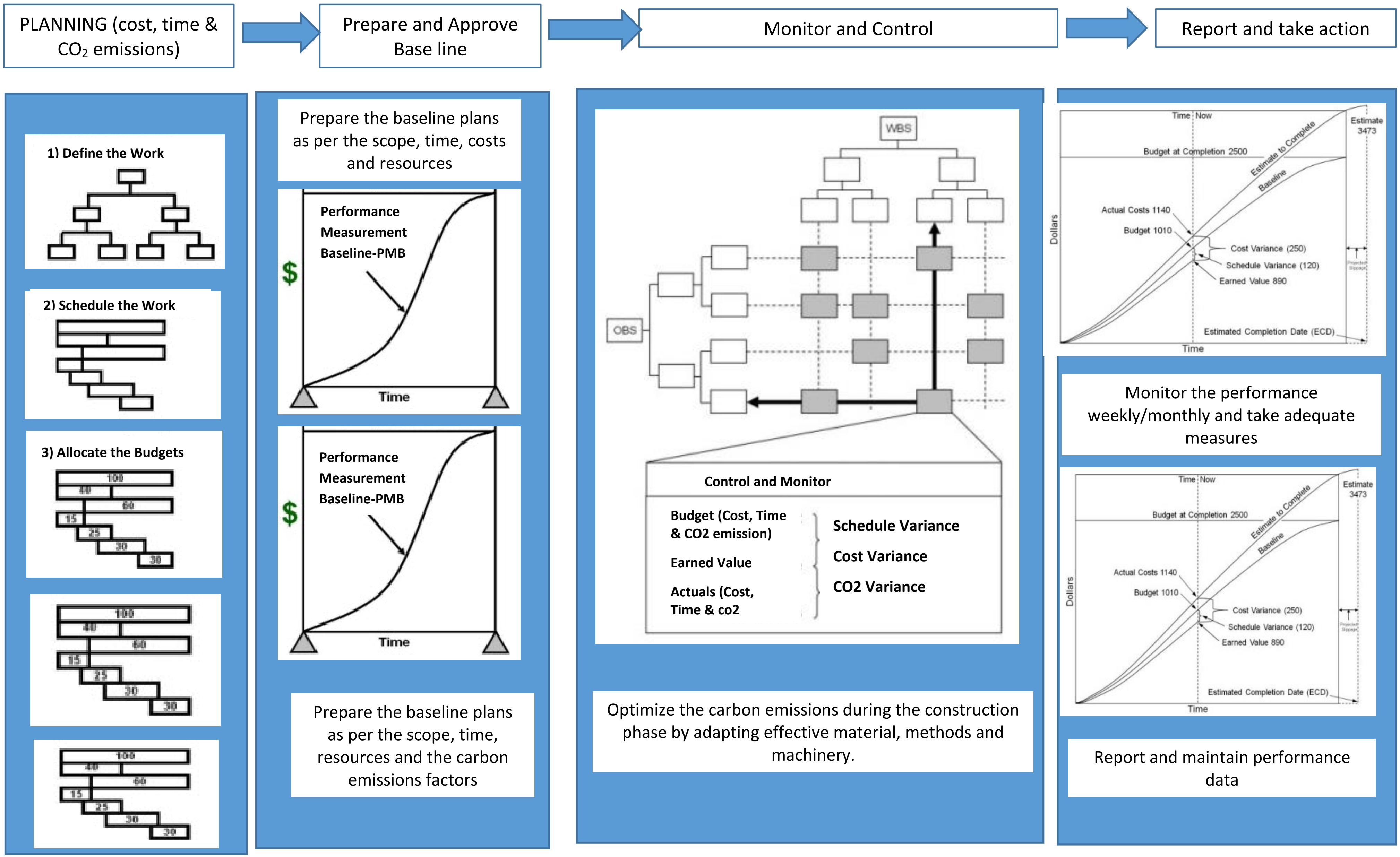
E_k – CO_2 factor for energy used at site construction – $KgCO_2$/functional unit of material.

5.3.2 Process model for monitoring and control of carbon emissions

Reducing embodied carbon is a viable and worthwhile carbon-reduction strategy, and significant savings can be achieved without added capital cost and with minimal extra effort (WRAP, n.d.). WRAP also emphasised on the material and construction phase carbon emissions. Wang et al. (2015), Syngros et al. (2017) and Langston et al. (2018) follow a similar method by performing a detailed material analysis first, followed by a mass analysis and then the ECO_2 analysis.

The process-based model for monitoring and controlling carbon emissions for projects in construction covers four stages: planning, preparing a baseline, monitoring and reporting the carbon emissions. The CE-MCM process model of the overall CEM framework is presented in Figure 5.1, showing the four stages. The four stages comprise the sub-processes of the CE-MCM process. The level processes of the four stages are carried out using simple-in-use tools, such as Excel, Primavera and Microsoft Project. A similar study was conducted by Varma (2016) to monitor carbon emissions using earned value management with the time management software CCS Candy (Varma et al., 2016). The process-based model for monitoring and control of carbon emissions is shown in Figure 5.1

Figure 5.1 Integrated CO_2 emissions monitoring and control model (CE-MCM)



In the planning sub-process, the cost-, time- and CO_2 emissions-related data are collected for the preparation of the baseline. The project work will be defined in terms of activities distributed over the respective work breakdown structure (WBS) to ensure that the entire project scope is covered. Later, preparation of the schedule will commence by assigning duration and activity logic relationships. A project activity schedule meeting the contractual duration of the project will be prepared, and the associated budgeted costs and planned resources will be added. Any normalisation required for the resources can be done to avoid unrealistic peaks in resource utilisation. This is a standard practice for cost and time monitoring using Primavera or MS Project. The additional process of including the CO_2 emissions will be added. Similar to resource allocation, a CO_2 emissions resource will be added to each activity by including the CO_2e factor in the unit rate. Also, the budgeted quantities of carbon emission for activities will be added. This will be done by taking the quantities from section 5.2.1. The BCWS for the CO_2 emissions resource will provide the total emissions which shall be released for executing that particular activity.

Upon preparation of the base-line plan for CO_2 emissions, the actual values for the activities performed are updated in Planning toll Primavera. Actual work performed, actual quantities of material consumed, man-hours spent etc. are recorded in site observations sheets and reports. Periodically (daily, weekly, monthly) the performance is monitored using the SPV, SEV, ACE, SSV, SSPI, CEV and CEPI as shown in Table 3.8.

If the project is emitting CO_2 as planned, the value of SSPI would be one. If SSPI is less than one, the project environmental performance is worse than initially planned, and if the SSPI is greater than one, the project is performing better than expected environmentally. Table 3.8 of chapter 3 shows the components of carbon emissions earned value management.

5.3.3 Process model for tendering using cost and carbon (COCO$_2$) tender

Rating systems, a clean development mechanism (CDM) and voluntary ISO standards, as discussed in the literature section 3.12.2, are not enough to reduce the carbon emissions being emitted by the construction industry. It is necessary to devise an alternative approach to encourage contractors to contribute to carbon emissions reduction, particularly embodied carbon emissions. DEFRA proposed awarding contracts based on carbon emissions (i.e., to make carbon footprint one of the bid evaluation criteria) (DEFRA, 2011). To improve fairness, transparency, consistency and reliability, carbon emissions should be systematically estimated, bid and evaluated according to a well-defined carbon emissions tendering framework (Ng, 2014).

In the $COCO_2$ tendering model, a client prepares the tender documents, including specifications, drawings, requirements and guidelines for carbon emissions management, as part of the project. The client also prepares pre-tender estimates for carbon emissions to compare with the bids in the same way pre-tender cost estimates are prepared to compare with the cost bids received at a later stage. After receiving the tender documents, the project's carbon emissions are estimated by the bidders based on the material being proposed, travel distances and construction methods being adopted. Bidders can use the embodied carbon emissions factors from the ICE database, CESMM4, EPDs or the in-house indices. The carbon emissions determined by the bidder based on the tender drawings and specifications will represent the base-case scenario. This is where this model differs from carbon encompassed tendering (CEET), in which the client provides the base-case scenario for subsequent monitoring and reporting (Ruth et al., 2000).

Bidders will compete in submitting low-carbon proposals along with details of alternative construction materials, methods and reductions they can achieve over the values of the established databases such as ICE. The associated additional cost incurred due to alternative materials and methods are included in the commercial bids. Upon the submission of bids, the client will make an informed decision to evaluate carbon reduction goals and budgetary constraints (Ng, 2014). Commercial and carbon bids are evaluated as identified in the tender evaluation criteria and based on the pre-tender estimates for carbon emissions and cost. Tendering moves to the award phase if the received bids are equal to or less than the pre-tender estimates. After negotiations and clarifications on the cost and carbon emissions, the project is awarded to the bidder with the lowest carbon emissions and the lowest cost.

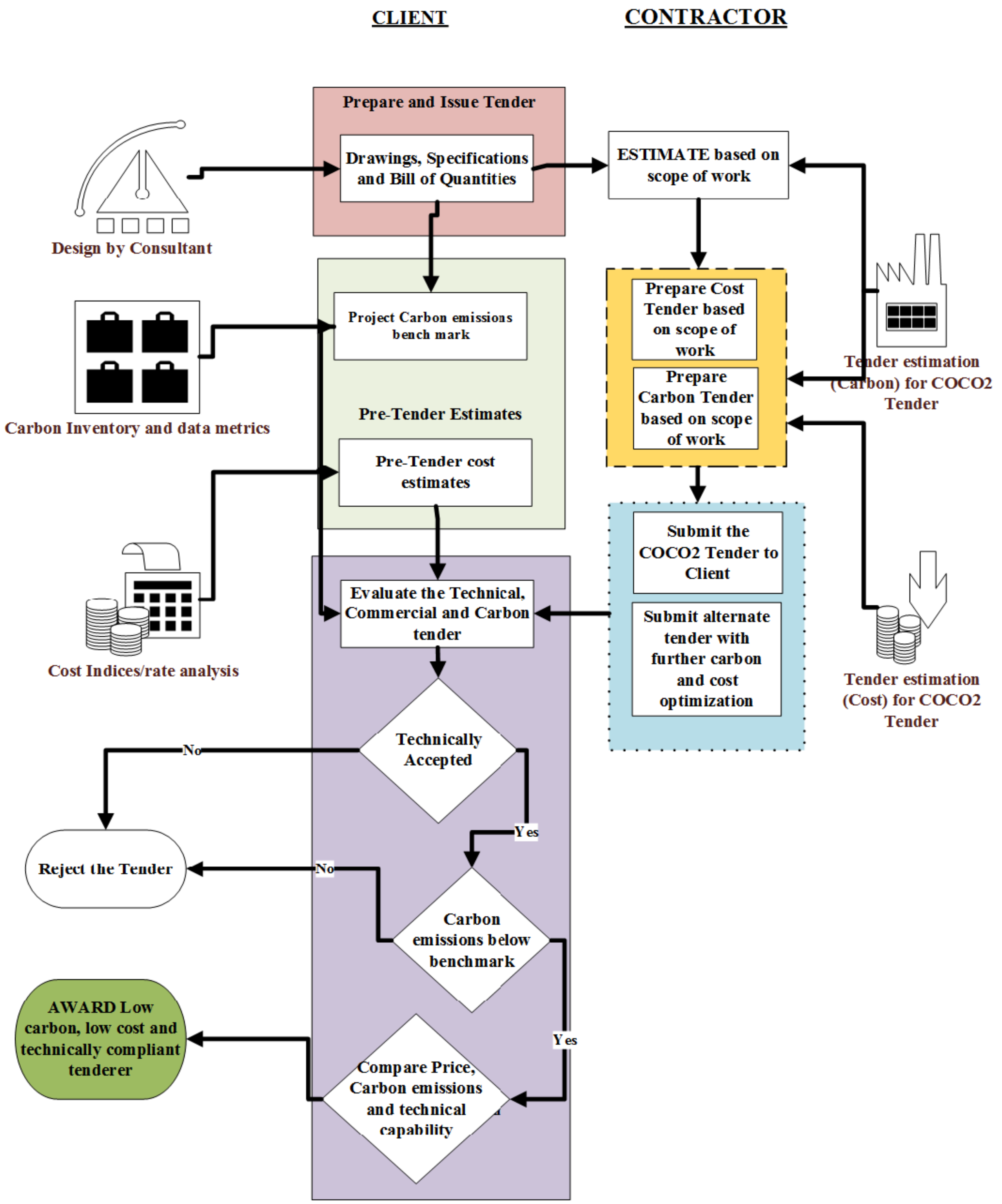


Figure 5.2 Model for tendering building construction projects – $COCO_2$ tendering model

5.4 Focus of CEM Model Generation

Life cycle assessment involves all life cycle stages of the building, which emit embodied as well as operational carbon emissions. In addition to the stages of the Royal Institute of British Architects Plan of Work (RIBA, 2013), LCA includes the CO_2 emissions for demolition. The focus of the research and the carbon emissions management model is on stages 4 and 5 of the following RIBA plan of work:

- Stage 0 - Strategic Definition
- Stage 1 - Preparation and Brief
- Stage 2 - Concept Stage
- Stage 3 - Developed Design
- Stage 4 - Technical Design
- Stage 5 - Construction
- Stage 6 - Handover and Closeout
- Stage 7 - In Use

Stages 4 and 5 are selected as the project stakeholders can estimate the CO_2 emissions on the firm quantities and further measures to reduce the CO_2 emissions can be carried out at these stages by selecting alternative materials, improving performance, reducing waste, etc.

Although sustainability consultants prefer that carbon management should be done at the earliest possible stage, subject to factors such as budget, programme and resource availability, the right time to carry out an environmental impact assessment on a design is a matter for debate (Aryaratne and Moncaster, 2014). Keeping in view the current practices and higher implementation levels during design, the boundaries are set around the detailed design and construction phases only.

5.5 Scope of the CEM Model

The goal of the proposed methodology is to provide a multi-objective model and framework for project stakeholders in such a way that contractors, consultants, clients and regulatory authorities can understand the environmental impacts related to embodied carbon emissions and manage them from the design to the construction phase (i.e., stages 4 and 5 of the RIBA plan of work). As this study aims to enhance the environmental efficiency of buildings during construction and tendering stage, it focuses on evaluating the impacts through estimation, benchmarking, monitoring and controlling the emissions during stage 5 of the RIBA plan of work. It further covers stage 4 of RIBA Plan of work, to evaluate the inclusion of carbon emissions as tender evaluation criteria to award projects. Akbarnezhad and Xiao (2017) made considerable efforts to develop strategies and models for reducing the embodied carbon of buildings and stated that the available literature is highly scattered across different relevant disciplines and that a lack of a comprehensive reference for decision-makers is apparent. The literature review identified that complexity and other challenges involved with the existing LCA tools are limiting the implementation (RIBA, 2018; Varma et al., 2016). Hence SIUTs, such as Excel and Primavera, are being used to develop a model and to propose an integrated framework for carbon emissions management.

Evaluating the bidders based on proposed carbon emission bids is similar to cost bids submissions currently in practice. So, the model focusses on the tendering phase and presents the cost-carbon tendering ($COCO_2$).

The functional units of this study comprise all the material and activities involved during the detailed design, tendering and construction phases of the building. The ICE database provides life-cycle impact assessment values or equivalent carbon emissions associated with all materials with a boundary covered from cradle to gate for materials (Hammond and Jones, 2011). The functional unit is defined as the measures applied in evaluation of the system or product performance, while the boundary limits are adopted. As shown in Figure 5.3, boundary limits are; the construction phase, use of the ICE database, calculation of embodied carbon emissions of materials used, direct carbon source and indirect carbon source.

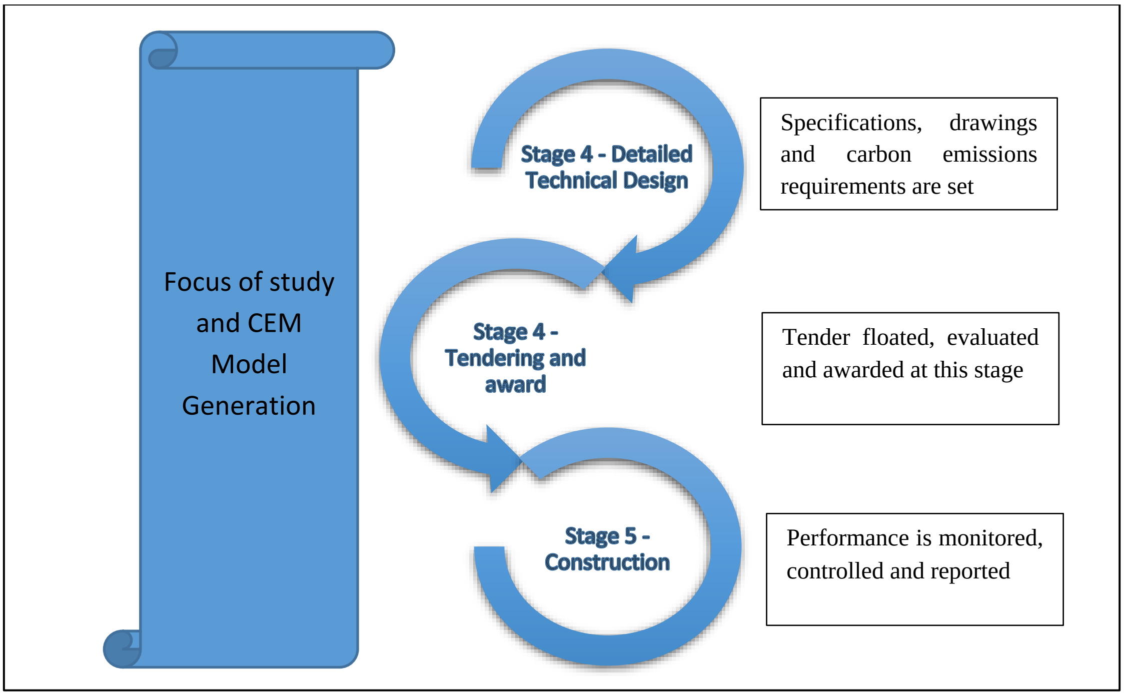


Figure 5.3 Focus of study and the building life cycle
(Adapted from RIBA, 2013)

5.6 Calculation Principle for Model Development

Embodied carbon emissions data for materials differs based on the energy used, methods adopted, and the distances travelled during production. To overcome this, carbon emissions management should start with credible industry average for material carbon footprint data and well-defined boundary conditions (K et al., 2017). The total amounts of embodied carbon emissions during the construction phase are calculated using the consumed amount of materials and the equivalent carbon emissions factor for the ICE data for one unit of material (Hammond and Jones, 2011). Embodied carbon emissions related to transport of materials from the factory gate to the site gate caused by consuming fuel are calculated based on fuel consumption parameters of the vehicle used, its working hours, distances travelled and the national emissions factors for the type of fuel used.

5.6.1 Calculation principle for direct carbon source

Embodied carbon emissions caused by consuming fuel in the construction process are calculated based on the fuel consumption parameters of the equipment, its working hours, distances travelled and the national emissions factors for the type of fuel used. Office staff travel, machinery use, transport, generators, etc. fall under this scope.

5.6.2 Calculation principle for indirect carbon source

Embodied carbon emissions caused by consuming electricity in the construction phase are calculated based on the consumption parameters of the equipment, its working hours and the national emissions factors for one unit of electricity used.

5.7 Stepwise - Estimation, Monitoring and Control Principle

The existing models from the literature review from section 3.12.4 are adapted to formulate a conceptual model for the estimation, monitoring and control of carbon emissions. The use of SIUTs were arrived at, based on the Survey 1 findings, in which the respondents expressed their preferences in using the simple tools for carbon emissions monitoring similar to cost and time management.

The Integrated CEM framework use SIUTs such as Excel spreadsheets and Primavera and do not add additional tools or processes. The case study is limited to the use of these tools; however, the framework will allow users to use any tools to integrate carbon emissions management with time and cost management.

Step 1:

Productivity factors, such as manpower, fuel consumption by tools and machinery, quantity of material being used, etc., were determined based on the daily reports submitted for achieving each activity. For example, the quantity of plaster used was recorded with the quantity of labour, tools, etc. for various buildings and an average were taken as constants in an Excel spreadsheet. The quantity of each raw material required for the activity is calculated by the Excel spreadsheet when the elemental quantity (sqm/cum.lm) of the building is entered in the prescribed cells in the worksheet (i.e. the quantities from the Bill of Quantity (BOQ) should be uploaded manually by the user in the worksheet; the outcome will be the split details of raw material and their quantities).

Quantities are multiplied by the unit cost of the material in the spreadsheet to obtain the total cost of the project. The elemental cost obtained from these spreadsheets is used for loading the cost details of each activity in Primavera to generate the cost curves and later to track and monitor the cost.

Step 2:

Upon validation of the cost estimation worksheet, the same Excel spreadsheet will be used for estimating the carbon emissions. The total embodied carbon emissions of the materials are calculated by multiplying the quantity of materials and the equivalent carbon emissions factor for ICE data for one unit of material (Hammond and Jones, 2011). This fulfils the calculation principle for materials from cradle to factory gate.

Step 3:

Embodied carbon emissions are calculated in spreadsheets for activities related to the transport of materials from the factory gate to site gate caused by consuming fuel. These are based on the fuel consumption parameters of the vehicle used, its working hours; distances travelled and the national emissions factors for the type of fuel used (RIBA, 2018). Also, direct and indirect embodied carbon emissions are calculated using fuel consumption and electricity parameters.

Step 4:

A Primavera Schedule is prepared for the case study project with respective work breakdown structure, inter-relationships, resource loading and cost loading. Primavera cost and time estimating and monitoring is possible at this stage to generate cost curves and resource curves (Varma et al., 2016). When actual progress is made, the variances using earned value analysis is helpful to review the cost and schedule performance indicators. The EVM concept is used in this CE-MCM model to monitor and control the embodied carbon emissions performance of a project. The traditional EVM technique is one of the most straightforward and widely used methods for monitoring and controlling a project’s cost and schedule (Abdi et al., 2018).

Quantities of elemental resources obtained from the spreadsheet are uploaded into Primavera under the resource category for each activity. The equivalent carbon emissions factor from the ICE data for one unit of material and direct and indirect source emissions are uploaded under the cost category in Primavera for each activity. Variances using a similar concept of EVA will be calculated to show the difference between planned and actual CO_2 emissions to monitor the performance indicators.

Step 5:

All the carbon emissions from materials, direct source and indirect source are integrated to provide the total carbon emissions of a project. This model is based on LCC principles adapted by Kim (2013), as shown in Figure 5.4; however, for this research other major contributors from design construction and operation phase is also considered.

Validation of the model with different combinations of materials or tasks will be carried out through the focus group, in which the industry specialists will be provided with the developed model and their feedback will be analysed to validate the model. Finally, this model, along with the integrated framework, will help in reliable carbon emissions estimation, which can reflect a possible change in emissions levels caused by planning decisions at the project level. It will also allow a comparison of the potential environmental impacts caused by different planning alternatives and will contribute to the highlighting of mitigation opportunities of emissions during the construction phase.

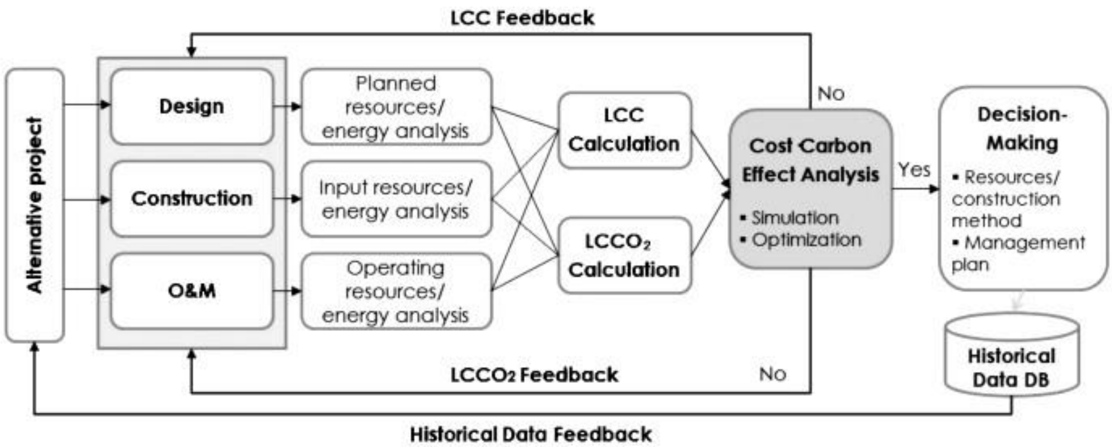


Figure 5.4 Overview of the LCC-based $LCCO_2$ analysis model.
(Source Kim et al., 2013)

5.8 Validation of Model

A mixed-method must establish the validity of the scores from the quantitative measures and discuss the validity of the qualitative findings (Creswell, 2013). Hence, validation of the model will be carried out through a focus group by arranging a workshop with industry practitioners. Focus groups are discussion groups in which several people are invited to come together to discuss a certain issue. The discussion is led by a moderator or facilitator who introduces the topic, asks specific questions, controls digressions and stops breakaway conversations (Dawson, 2007). The developed Integrated CEM Framework, which comprises of carbon emissions estimation model, the carbon emissions monitoring and control model using SIUTs and the $COCO_2$ tendering model will be presented to the focus group. The models will be used and on which focus group feedback regarding its efficiency and advantages are collected. The details of the model validation is discussed and presented in Chapter 9.

5.9 Summary

This chapter presented the formulation process of the carbon emissions management model. The formulation of the CEM consisted of three models: the estimation model, the monitoring and control model and the tendering model. The first model is a mathematical model to estimate carbon emissions by using SIUTs. The second model identified the process and measures to be used to monitor and control carbon emissions during the construction phase using SIUTs and the earned value method. The third model is the process model, which is adapted to make the tendering and award criteria more sustainable by integrating the cost and carbon evaluation approach.

In the following chapters, the models are grouped within the integrated framework of carbon emissions management to show the preparation, reporting and payment mechanisms, along with proposed dimensions and perspectives, for the UAE building construction market. A focus group workshop explored the efficacy and ease of use, based on the opinions of construction project management professionals in the UAE market, to validate the proposed CEM model and framework.

Chapter Six: Survey Results Discussion and Analysis

6.1 Introduction

The previous chapter described the research methods and model development. This chapter presents the process of data collection (i.e., the survey and the results of data analysis). The results have been analysed in correlation with the literature review in previous chapters. The aim of this chapter is to report on the results of the data analysis and draw conclusions from the results which have been used to develop the carbon emissions management model and integrated CEM framework.

This chapter includes the analysis from the questionnaire survey done in the UAE. The basic structure of the chapter transforms those quantitative and qualitative data into actionable information. This chapter explores the current practices of the UAE construction industry, particularly the building construction industry, and practitioners' perceptions, preferences and needs. The current situation of sustainable management practices, assessment tools, tendering practices and factors for lack of implementation of carbon emissions management are discussed and analysed.

6.2 Survey-1 Response Analysis

A questionnaire survey to investigate the awareness of CO_2 emissions among industry professionals and to explore the current practices in the UAE construction industry was prepared and was launched via email in mid-April 2013. A stratified convenience sampling method was used for survey 1.

The questionnaire's introduction clearly stated the questionnaire's purpose, target group and approximate time required to complete it. Likert scale ranking questions are also included, to allow respondents to share their thoughts and comments. As an incentive to increase response rates (Malhotra et al., 2002), the respondents were assured that they would receive the summary report of the final survey.

The collected responses from practitioners (60 No's) of 10 construction companies from the UAE building construction industry were analysed. The data was transferred from Survey Monkey to Microsoft Excel for cleaning, sorting and amending of missing values, anomalies and other errors. The cleaned data of questions were transferred in the SPSS for analysis and to generate findings. The respondent population belongs to the construction companies (10 No's) involving contractors (2), Architectural and design consultants (2), project management consultants (2), suppliers (2) and clients (2) as shown in Figure 6.1. Number of respondents selected based on stratified convenient sampling method.

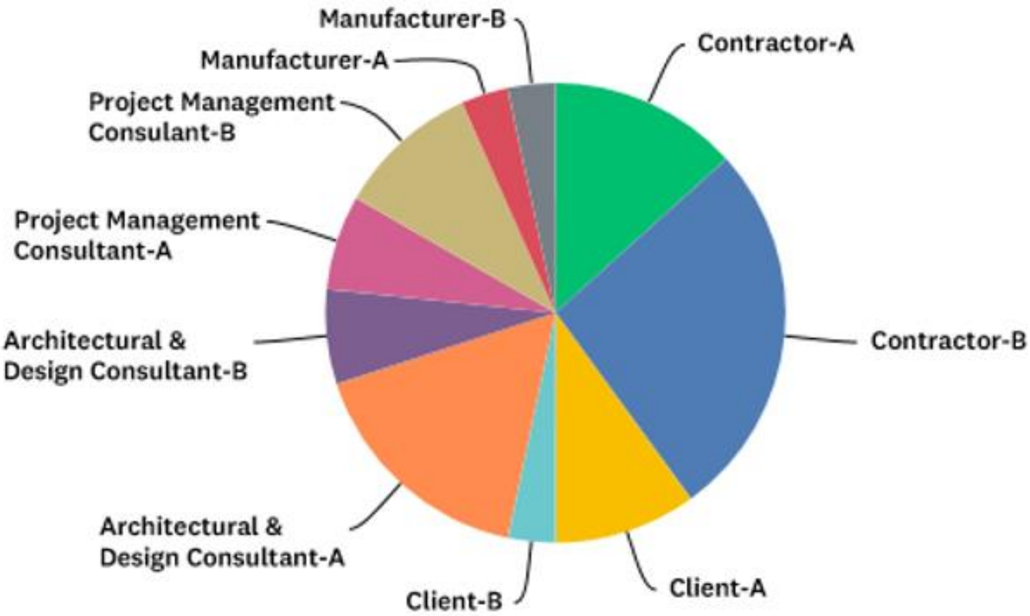


Figure 6.1 Survey-1 Respondents Organizations

The UAE is working towards becoming a mature country in terms of sustainable projects. Figure 6.2 shows that 86% of respondents stated that they had worked on green building projects, which shows that the convenient sampling adapted is adequate to understand the current issues of sustainable construction in the UAE.

The responses in Figure 6.3 show that 80% of the UAE building construction professionals worked on the LEED rating system. Some 30% of respondents stated that Estidama is the rating tool on one of the projects they worked.

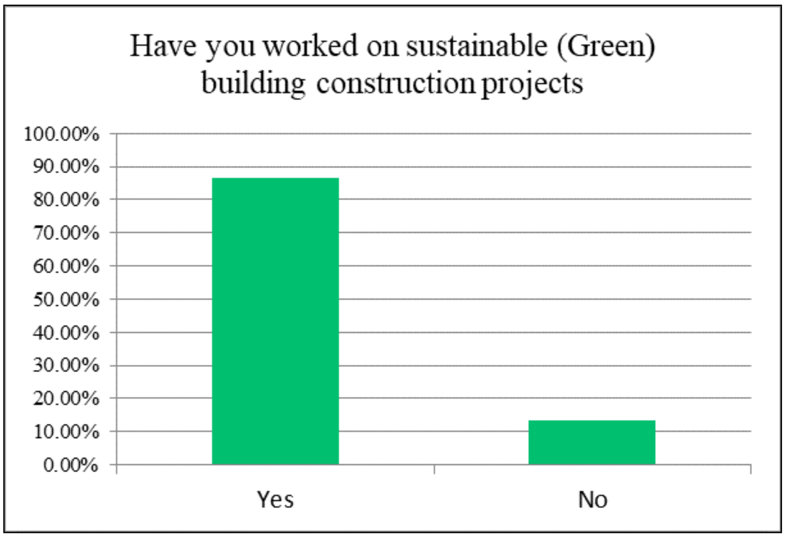


Figure 6.2 Respondents (S1) worked on green building projects

This response rate is low due to the involvement of professionals in survey, working on projects across all emirates in the UAE. The Executive Council Order of May 2010 states *"all-new applicable buildings must meet the 1 Pearl requirements starting in September 2010, while all government-funded buildings must achieve a minimum of 2 Pearls"*. Whereas in Dubai, Al Safat rating tool is still under development. The other emirates of UAE use LEED rating tool, hence the higher response of 80% with LEED as the rating tool widely used.

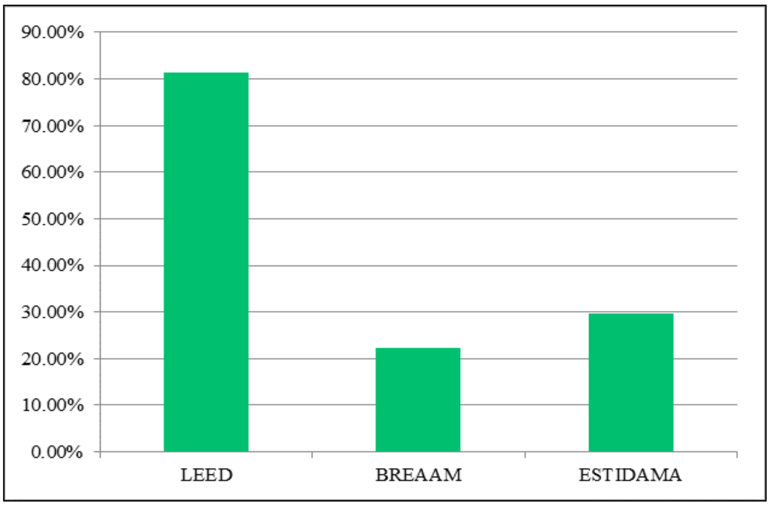


Figure 6.3 Rating tools used in the UAE in 2013

Awareness levels of embodied carbon emissions terminology, factors and know-how of carbon estimates is low. 73% from Figure 6.4 replied 'not aware' for the basic terms of

CEM, because neither LEED nor Estidama mandate CEM as 'pre-requisites'. Even though the rating systems implementation is high, the awareness levels are low on GHG, CO_2 emissions and embodied carbon emissions in the building sector. Lack of awareness of CO_2 emissions, as shown in Figure 6.5, creates a need for more emphasis on effective carbon emissions management, through knowledge sharing and by increasing awareness. The United Nations Environment Programme also proposed the use carbon dioxide equivalent ($kgCO_2e$) emitted per square metre per annum ($kgCO_2e/m^2$/year) to measure and quantify greenhouse gas emissions accurately ((UNEP-SBCI, 2013). Also, CO_2e is the most prevalent GHG present in the atmosphere and is the distinct measure for calculating global emissions (Sreedhar et al., 2016). So the proposed Model and framework shall use CO_2e as a unit of measure.

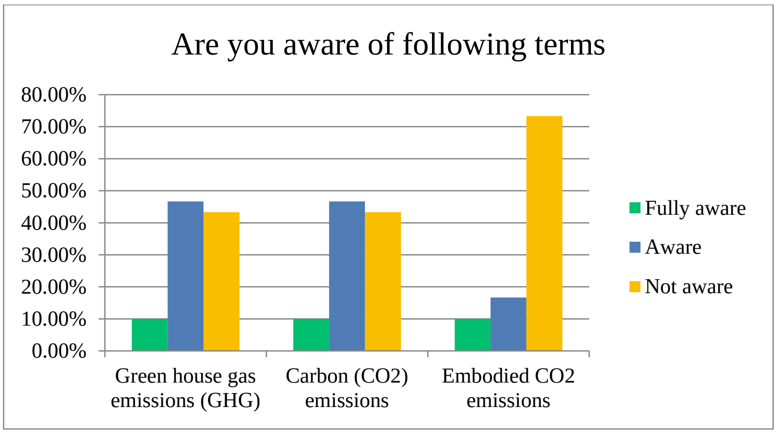


Figure 6.4 Respondent awareness of Carbon emissions terminology

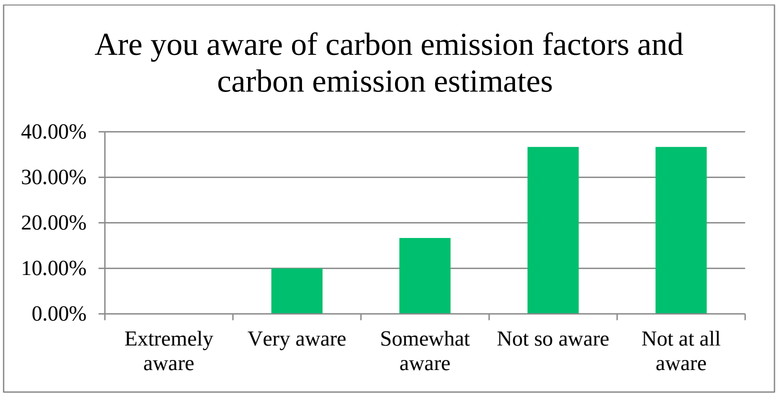


Figure 6.5 Awareness of carbon emissions factors and estimating practices

The responses in Figure 6.6, 100% of respondents stated that CO_2 emissions were not estimated and tracked on their projects. Lack of awareness and experience is one of the major challenges, mainly in developing countries where the technology and the knowledge has not been disseminated or shared. Limited awareness of climate change and its impacts, in developing countries, has overlooked the significance of estimating Embodied Carbon emissions and implementing reduction strategies (Ng et al., 2013). Media campaigns show that sustainability is a priority of all professionals; however, in actual practice, the reality does not appear to be the same (Ariyaratne and Moncaster, 2014). The other reasons being the lack of Open source assessment tools and software for calculating Embodied Carbon emissions (De Wolf, 2017). Based on these findings, to improve implementation levels, an integrated CEM with time and cost shall be encouraged.

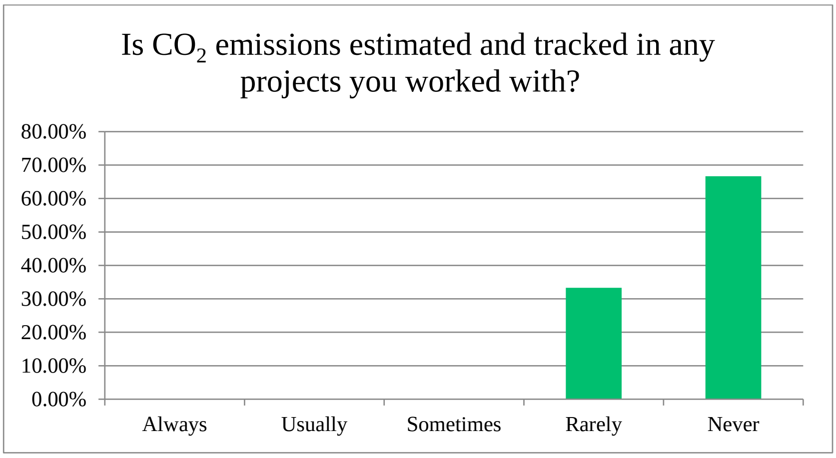


Figure 6.6 Current practice on Carbon emissions management in UAE

All respondents stated that they use excel for estimation during the tendering phase. 30% industry specialist from 10 companies state that other specialist estimation software are also in use, as shown in Figure 6.7. As per Table 6.1, the use of a combination of excel and primavera is the priority of the respondents (Rank 1). In spite of the specialist tools available, Kravari (2017), states that Excel remains a preferred tool for carbon footprint calculation due to ease of use and familiarity. Based on the findings, the proposed model and framework of carbon emission management shall consider simple in use tools such as Excel and primavera.

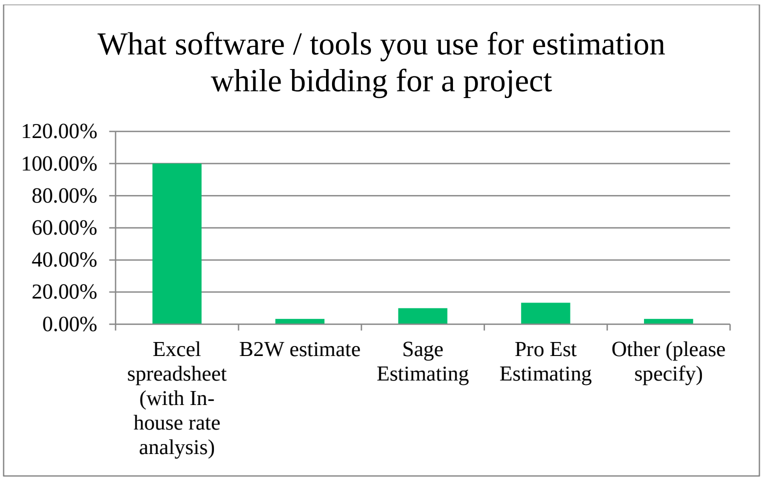


Figure 6.7 Software used for cost estimation

Table 6.1 Software tools used for planning and controlling a project

	Never	Rarely	Sometimes	Often	Always	Weighted Average	Rank
A combination of Excel and the planning software (primavera, MS project)	0.00%	0.00%	13.33%	26.67%	60.00%	4.47	1
Only Primavera	3.57%	42.86%	21.43%	25.00%	7.14%	2.89	2
Only MS Project	17.24%	58.62%	24.14%	0.00%	0.00%	2.07	3
In house developed company software	55.17%	31.03%	10.34%	0.00%	3.45%	1.66	4

As shown in Figure 6.8, in-house cost indices were the basis for cost estimates as per the survey responses received. The use of in house cost indices contradicts to the practices pursued elsewhere. The UK construction industry uses BCIS as one basis to estimate and bid for projects (RICS, 2018). The UAE construction industry predominantly relies on in-house cost indices. This factor shall be taken into consideration while developing a model and framework for carbon emissions management for the UAE construction industry.

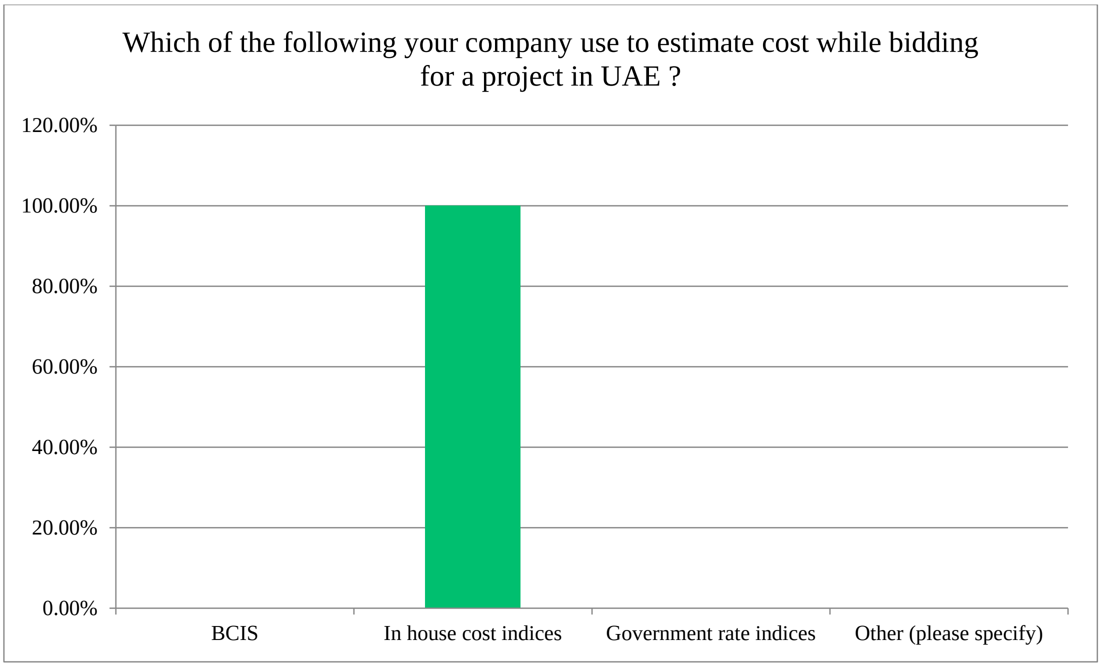


Figure 6.8 Cost indices for tendering

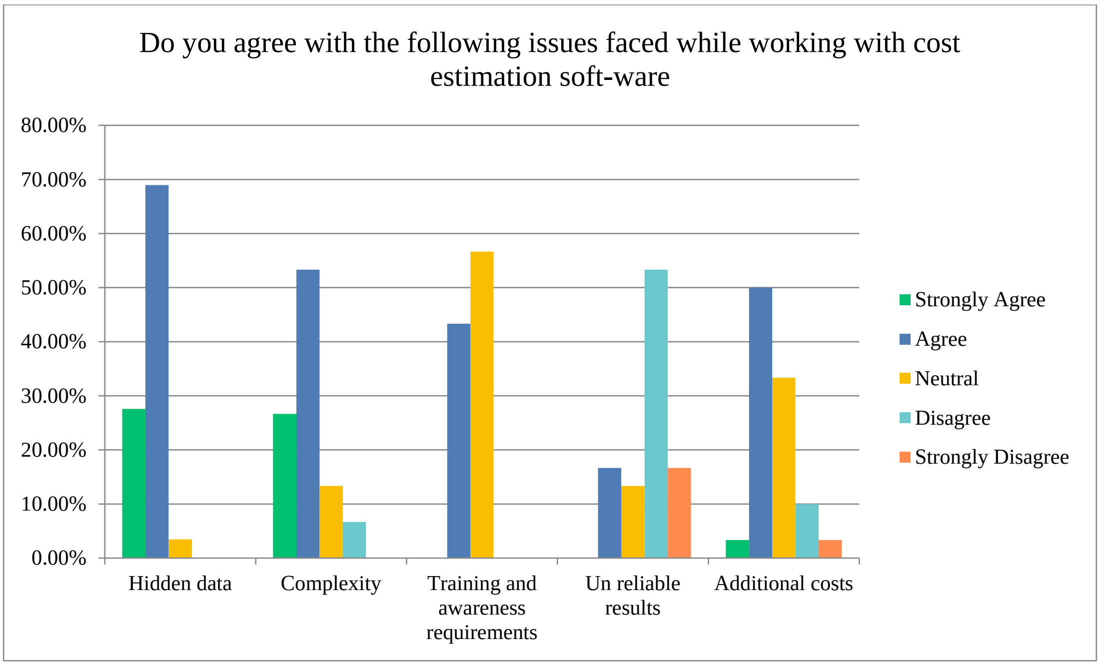


Figure 6.9 Issues with available cost estimation Software

In Figure 6.10, IES VE and SimaPro are the tools used by the UAE respondents, but the majority of the respondents either are unaware of CO_2 emissions or do not use any software to manage CO_2 emissions. The implementation or usage levels are low, respondents (up to 60%) replied that none of the tools are used to assess carbon emissions, which shows low levels of implementation of CEM in the UAE. Moreover, the responses in the UAE are contrary to a survey conducted by Cooper and Fava (2006), which found that GaBi and SimaPro were the most popular LCA tools, accounting for 58% and 31% of the market, respectively. The reasons could be due to the complexity, hidden data and additional cost associated with the software as shown in Figure 6.9. The model required for effective CEM is simple in use tools, which users can see and understand the data behind the calculations. Also, it will encourage companies to optimise the factors by taking efficient measures.

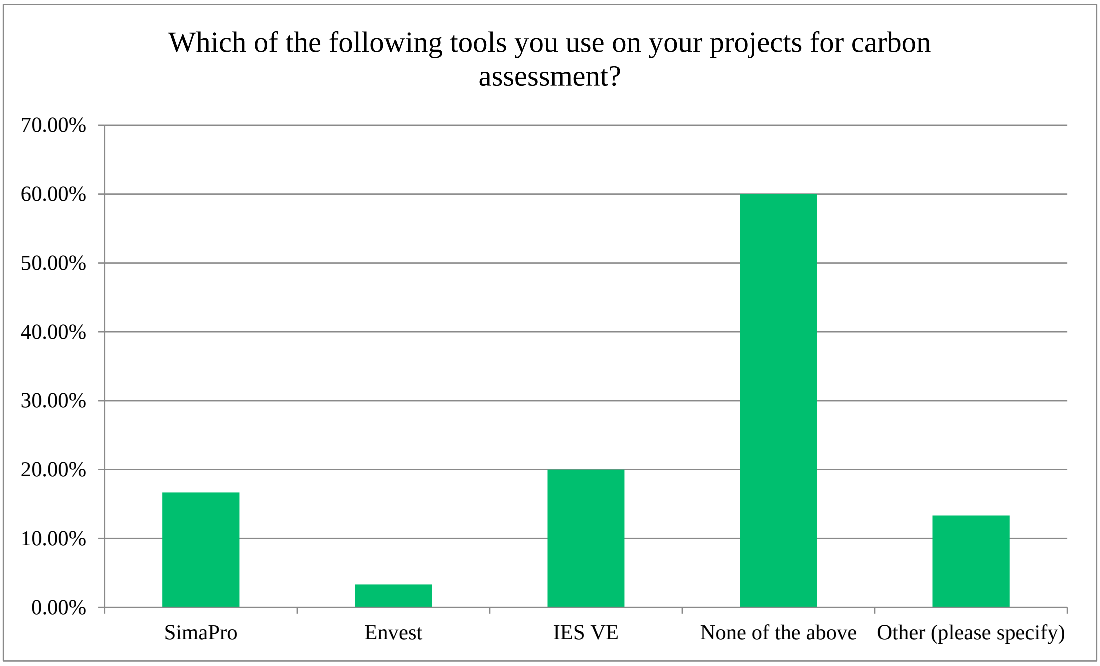


Figure 6.10 Software used for CO_2 assessment in projects (Survey-1)

As shown in Table 6.2, EVA and is the most prevalent methods for monitoring project performance in the UAE due to their advantages over others. Some 64% (weighted avg of 4.47) of respondents strongly agree that EVA technique is used widely in UAE, whereas purely CPM techniques using only Primavera or MS Project were chosen as second rank (weighted avg of 2.59). The findings are in line with the literature review which states, Earned value management (EVM) is a project performance evaluation technique in which the earned value analysis provides early signals on project performance to highlight the need for eventual corrective action (Bhosekar and Vyas, 2012).

The findings in Table 6.2 provides an opportunity to integrate carbon emissions management with time and cost using the EVM technique, similar to a study carried out by Ghazvini et al. (2017) for integrating quality parameters in projects (Ghazvini et al., 2017).

Table 6.2 Measurement of Project performance (time and cost)

Tools	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Weighted Average	Rank
EVA Technique via Excel S curves to monitor weekly/monthly performance	3.33%	0.00%	6.67%	26.67%	63.33%	4.47	1
Use of only Primavera/MS Project	24.14%	17.24%	37.93%	17.24%	3.45%	2.59	2
Last Planer Methods	55.17%	10.34%	34.48%	0.00%	0.00%	1.79	3

Fatigue has been a rising concern with industry specialists due to numerous software, fragmented tools and passwords used on the projects and in personal life. Figure 6.11 shows, 53% state fatigue as affirmative and 30% stated that the level of fatigue depends on the complexity of the tool. The reasons for this response is due to the preference of ease of use, familiarity of the tools, reduced complexity, which results in lower fatigue (Kravari, 2017). Due to these factors, fatigue will indirectly impact on the implementation levels of sustainable management and, in particular, carbon emissions management. Fatigue is one of the factor considered while developing the model for carbon emissions management in the UAE.

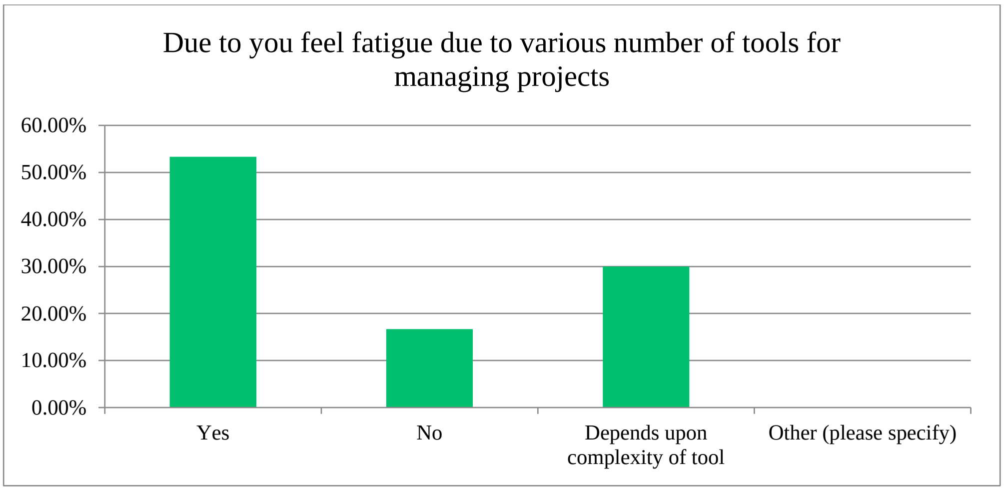


Figure 6.11 Fatigue issues with various software (Survey-1)

Stefan and Paul (2008) state that improving a company's sustainability performance has a positive impact on the economic and financial performance indicators of any company. One way to achieve sustainable goals is through the effective Supply chain of the building construction sector. Companies can adopt sustainable practices in tendering and award of projects to improve a company's competitive advantage. The respondents received on the ultimate criteria set was for the award of work shows that it is a purely commercial basis. According to Figure 6.12, 96% of the respondents stated that the ultimate criteria for award were purely commercial, which shows the preference in the industry to accept the lowest bid. Only 4% of projects use technical aspects as the ultimate project award criteria. The integrated CEM framework shall consider these findings to include CO_2 as a criteria for the award.

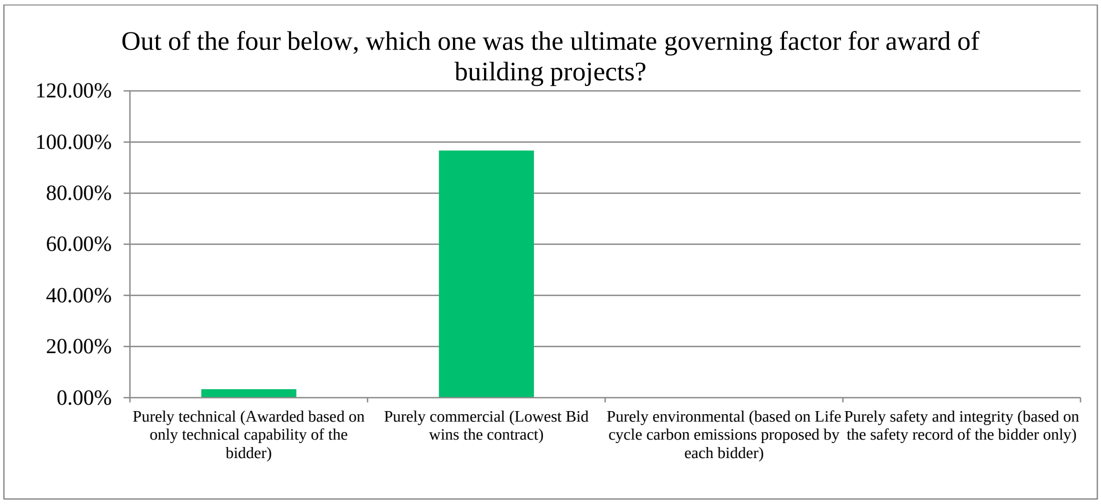


Figure 6.12 Ultimate Bid award criteria (Survey-1)

Summary of Survey -1

Ten construction companies were approached to find out whether any CO_2 emissions were being estimated and tracked in their organisations. The reply was exclusively negative, and there was a lack of awareness of CO_2 emissions. Green building rating tools have provided a means for the construction industry in the UAE to build green; however, they do not offer guidelines for reducing CO_2 emissions.

Furthermore, these companies were asked how cost estimations are being carried out for bidding on projects. Nine out of 10 companies replied that they use Excel spreadsheets for cost estimation. These companies do not follow the standard pricing but have their cost indices, and rate analyses developed over time and updated as required. Time estimation and monitoring are predominantly done using Primavera and Microsoft Project. Seven out of 10 companies used Primavera for time schedules and progress monitoring for projects. Upon reviewing the practices of these companies, we noticed that resource and cost loading are being done in Primavera. Cost per week/month is being extracted and used in Excel to prepare the tables and curves for progress reporting and cost control.

Cost estimation software and BIM are not being implemented for various reasons, such as lack of awareness, complexity of use, cost of software, hidden data related to carbon emission factors or cost indices, etc. Rather, the companies and their management are more comfortable using the traditional cost estimation practices of Excel spreadsheet calculations.

6.3 Survey-2 Respondent Analysis

A survey (see Appendix A) was carried out with the help of an online questionnaire in the UAE building construction sector to investigate the current state of sustainable management practices and to evaluate the implementation levels of carbon emissions management, its barriers and prospects. The underlying conceptual framework for the survey was based on the model for carbon emissions management which was developed in the first phase of the research. The survey questions were designed based on the above themes and sub-themes to be tested in this study. Strauss and Corbin (1998) followed a similar approach in conducting a qualitative study and then integrating it with a quantitative study. The quantitative questions included closed-ended, multiple-choice, ranking, rating and Likert scale questions. The qualitative questions in the survey focussed on UAE construction industry practitioners' opinions and perceptions. The survey also included a section on demographic information. Iterations were done on finalising the questionnaire to ensure it was specific and focussed and also to avoid insignificant issues before the commencement of analysis (Vanek, 2013). A pilot study was conducted by sending the survey to five respondents from five companies in the industry: a project manager, a sustainability manager, an estimation manager, a contracts manager and a project controls engineer.

The survey was designed using the Survey monkey tool and disseminated with the help of mailing lists from the Federation of UAE chambers, the UAE Society of Engineers, the RICS UAE chapter, the PMI UAE chapter, a list of approved Pearl Qualified Professionals (PQP) for Estidama and the list of LEED Accredited Professionals (LEED-AP) in the UAE. Personal contacts gathered over 20 years working in the UAE were also utilised. The potential respondents were contacted via emails, direct interactions during the seminars conducted by the RICS, Urban Planning Council (UPC) and the Society of Engineers, and in total more than 675 industry specialists were approached via email with a request to forward the survey to similar specialists who might be interested in completing the survey. Periodic reminders were sent to achieve the required responses as per the sample size.

A total of 383 responses were received from UAE building construction industry practitioners from across all the emirates. There were 12 incomplete questionnaires, which were discarded, in which respondents had only provided partial responses. In total, 371 responses were considered for analysis. The demographic information is presented in the following sections. Overall, the response rate was considered satisfactory. The data was transferred from Survey Monkey to Microsoft Excel for cleaning, sorting and amending of missing values, anomalies and other errors. The cleaned data of several questions were then transferred into the SPSS for analysis and to generate findings. The subsequent sections present the results of descriptive statistics based on the variables used to measure sustainable practices in the UAE. Correlations between key variables and differences were calculated and analysed.

6.3.1 Types of respondents' organisations

It can be inferred from Figure 6.13 that the respondent population belongs to the construction teams involving contractors, consultants, project management consultants, suppliers and clients, representing approximately 88% per cent of the respondents. Manufacturers and real estate represent the second-largest respondents' category, with 12% of responses. Since the focus of the survey is on building construction projects and effective carbon emissions management in a project, responses from suppliers, manufacturers and real estate professionals were beneficial. Construction professionals require a manufacturing awareness to understand and evaluate the environmental performance indicators of construction materials used in buildings (Tam et al., 2006). The 'other' section percentage was smaller due to the convenience sampling method used and is assumed to be negligible for data analysis. This stratification will help reflect the current practices, preference and needs of the construction industry to be analysed accurately and to develop an Integrated CEM framework to enhance environmental efficiency of buildings in the UAE.

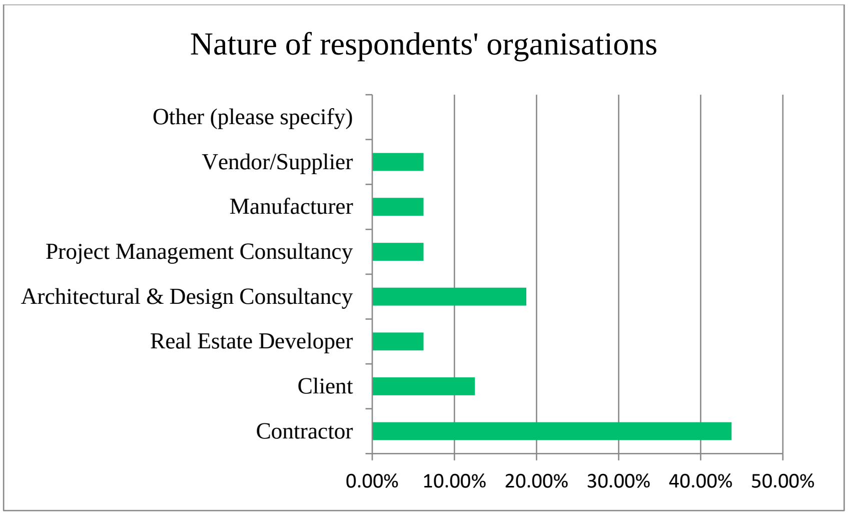


Figure 6.13 Respondents' organisations

6.3.2 Respondents' education levels

Figure 6.14 shows that 90% of the respondents hold a bachelor's degree and a master's degree while 6% of the respondents hold an undergraduate (bachelor's degree) and 4% have a PhD. Most of the respondents in the latter two groups are positioned in managerial and directorial positions. Lower education levels represent one of the key social barriers in the implementation of sustainable practices in the construction industry (Shi et al., 2013). Education is essential to understanding the criticality of climate change, sustainable construction approaches and low carbon emissions materials. The UAE building construction sector is well-placed in terms of the education levels of its professionals, either due to good talent hunt practices or the challenging projects, which tend to attract more highly educated professionals. With the necessary educational qualifications and knowledge, the question remains why the implementation of carbon emissions management is low in the UAE. Subsequent questions and analysis will highlight the reasons and identify a relationship between the findings.

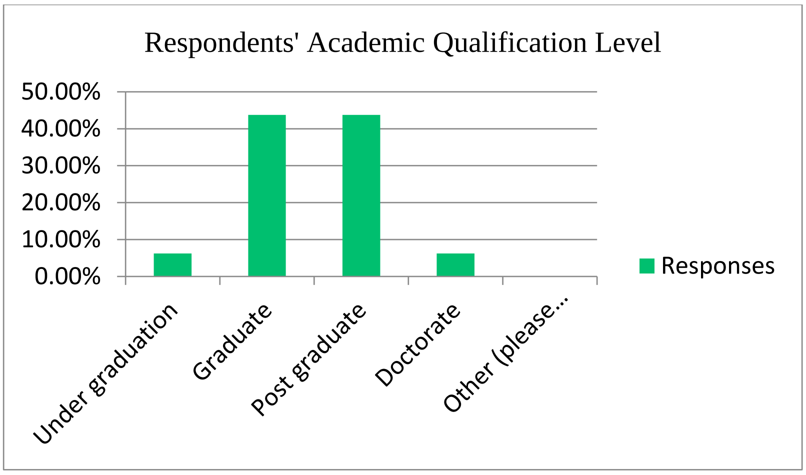


Figure 6.14 – Respondents' Qualification Levels

6.3.3 Roles of respondents

Figure 6.15 shows that the surveyed population is diverse in terms of the positions they hold in their respective organisations. Management and senior engineers from various departments represent the largest qualification levels of respondents, with 74% of responses. Since the focus of the questionnaire is to seek details on current practices, perceptions and future needs, management/senior engineers will help in the outcome of the research. These numbers reflect the realistic organisational structures of companies in the UAE construction industry, in which most employees are at the project construction sites than in the other support disciplines, such as design, procurement and quality.

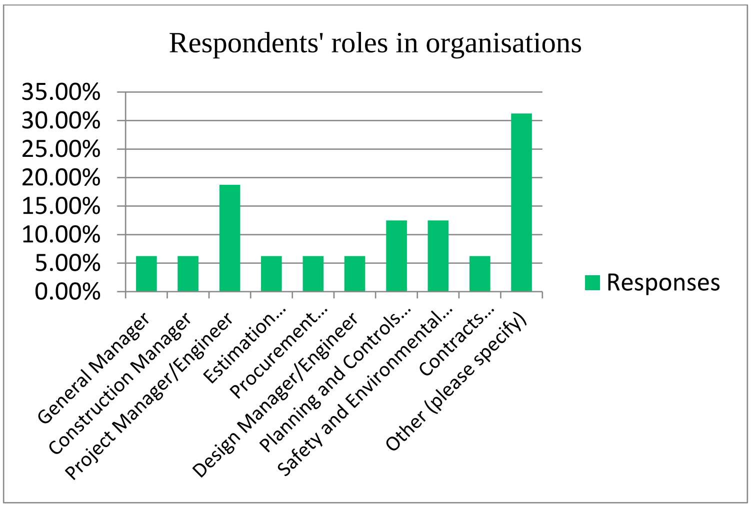


Figure 6.15 Respondents' roles in organisations

6.3.4 Respondents' experience levels

Respondent's experience levels, as shown in Figure 6.16, reflect that 56% of the respondents are practitioners with more than 20 years of experience and 25% of the respondents are practitioners with 10 to 20 years of experience. Approximately 6% of the respondents have 5 to 10 years of experience, and only 7% of the respondents have less than five years of experience. Experience levels are not evenly distributed among respondents. Instead, the experienced respondents constitute 81% of the sample size, which shows the involvement of decision-makers in the survey, while 'doers' are in the minority at 19%. The figure shows that these experienced professionals are working at different cost brackets. It is noteworthy that 35% of respondents are involved in projects costing more than 100 Million US Dollars. Balaban's (2012) argument supports the survey responses, that lack of experience in the construction industry can lead to negative influences on the sustainability and planning phases. Therefore, to ensure effective implementation of the carbon emissions management of projects, highly experienced professionals dealing with varied cost scales help address the construction methods, material selection, adequacy of design and use of equipment keeping in view the life cycle phases. Moreover, the research questions and responses in sections 6.4 and 6.5 will be of higher integrity as they have been received from experienced and decision-making experts.

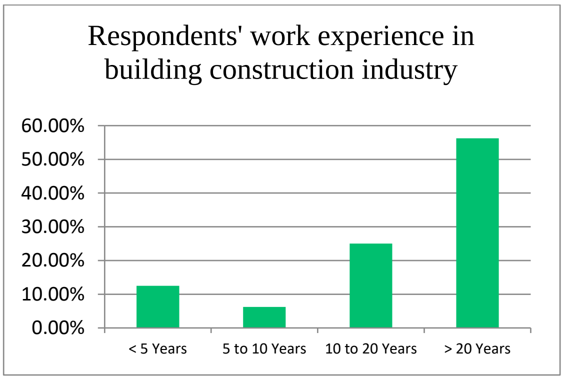


Figure 6.16 Respondents' work experience

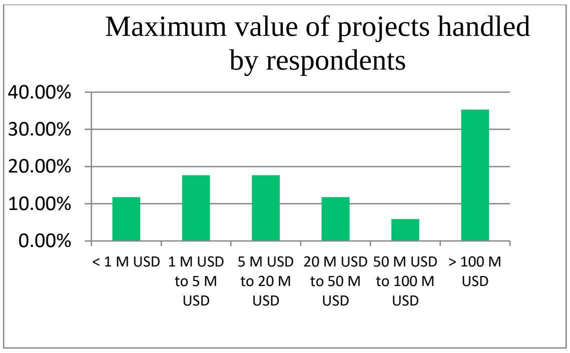


Figure 6.17 Maximum value of projects handled

The UAE has grown into a mature country in terms of execution of sustainable projects. Figure 6.18 shows that 88% of respondents stated that they had worked on green building projects, which shows the benefits of mandating the requirements. Estidama, a sustainability rating system in Abu Dhabi, and Al Safat, a sustainability rating system in Dubai, are mandated by regulations. Upon seeing the responses in Figure 6.18, policies, regulations, incentives and commitment by leadership may not be sufficient. Instead, a mandatory system is required to enhance sustainability performance (Orchieng, 2014). Barjeel- Ras Al Khaimah Green building regulations also will become mandatory in the year 2020.

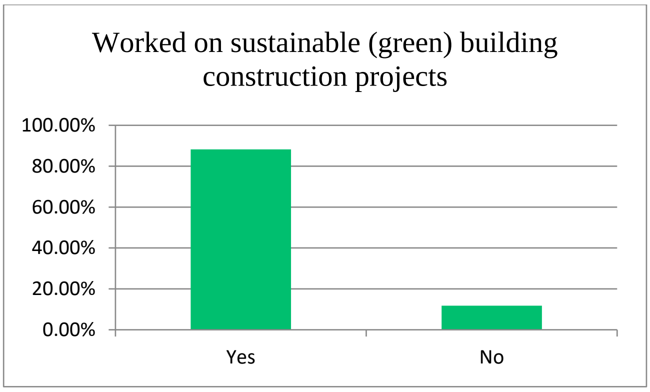


Figure 6.18 Respondents worked on green building projects

6.3.5 Professional certifications of respondents

Figure 6.19 shows the certifications levels of industry professionals working in building construction projects in the UAE. Certifications keep the professionals updated with continual development and recent developments in their respective fields. As construction and emissions management fall under the project management discipline, 32% of respondents were PMP certified, whereas 13% of respondents in other specialised disciplines such as cost, procurements and contracts were certified. It is also interesting to see a large percentage of professionals who did not opt for certification (25%). These values can explain the reasons for low implementation levels of carbon emissions management in the UAE.

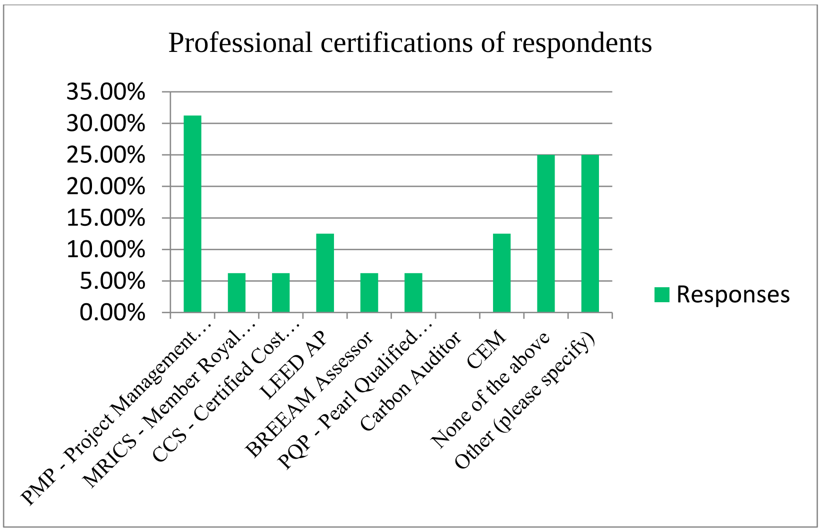


Figure 6.19 Professional certifications of respondents

6.4 Procurement Routes and Influencing Factor for Award

Improving a company's sustainability performance has positive impacts on the economic and financial performance indicators of any company (Stefan and Paul, 2008). Sustainable practices currently will not subject companies to substantial additional cost, but they provide opportunities and make the companies competitive in the market. Supply chains of the building construction sector can make their procurements by adopting sustainable practices to improve a company's competitive advantage. Procurement includes the tendering and award of the main contractor for a client, whereas for contractors it involves the tendering and award of sub-contractors and the purchase of materials and services. The respondents were asked what their procurement route was for one of the major projects they had executed and what the ultimate criteria set was for the award of work. According to Figure 6.20, 75% of the respondents stated that the ultimate criteria for award were purely commercial, which shows the preference in the industry to accept the lowest bid. Only 6% of projects were awarded with environmental aspects as the ultimate criteria, which is cause for concern. These findings are in line with the literature, which shows only Masdar City implementing carbon emissions management with criteria specified in tenders (Hammond and Jones, 2011). As per Figure 6.21, 53% of respondents stated that a traditional procurement route was used for their large project, whereas 24% stated the selected route was design and build. Traditional procurement is widely used in the UAE due to its advantages. The region is progressing well in terms of spreading awareness and also by the mandating of environmental performance in all projects through Estidama and Al Safat. To find the relationship between the type of procurement route and the ultimate award criteria, statistical analysis was done to reveal that the two sets of response are different. The chi-square statistic is 49.2778. The p-value is < 0.00001, which means that the result is significant at $p < 0.05$. The proposed model proposes an alternate approach by adding CO_2 as an award criterion in addition to cost.

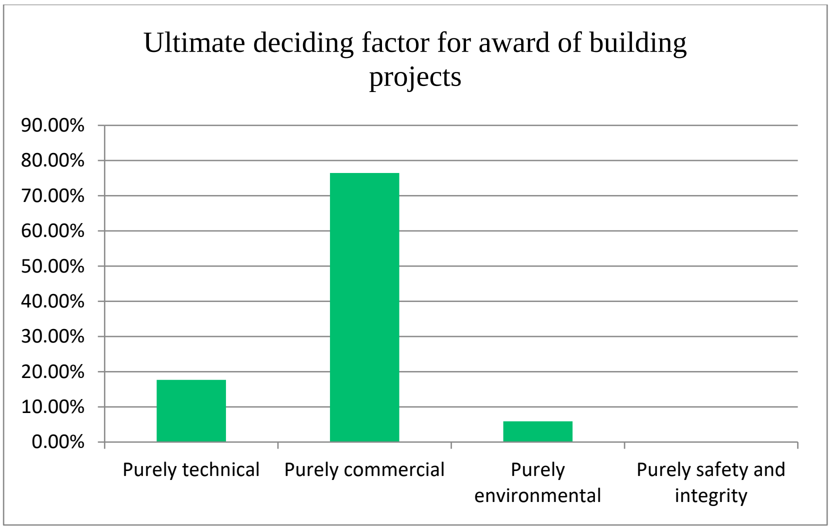


Figure 6.20 Project award criteria

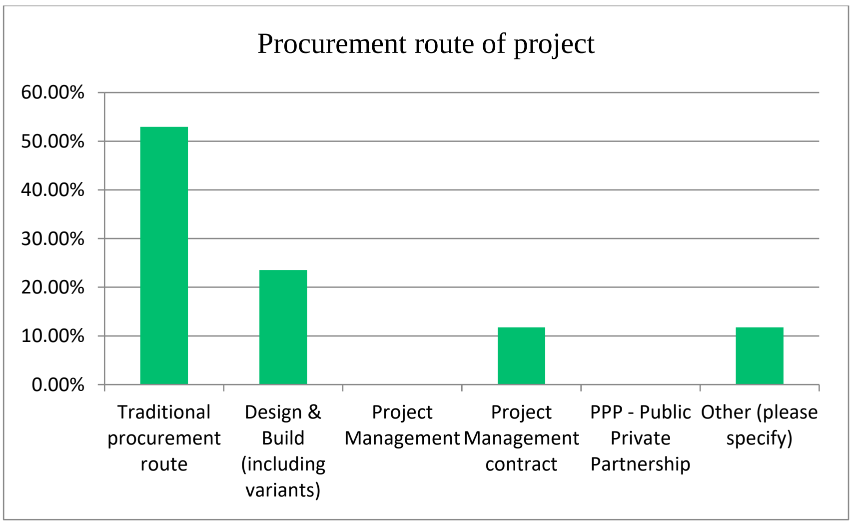


Figure 6.21 Procurement route of respondents' projects

Sourani and Sohail (2011) state that low levels of awareness and understanding about sustainability issues exist among all the stakeholders' organisations, such as contractors, end-users, vendors and funding organisations. As per Figure 6.20, a 6% response in selecting environmental aspects as the ultimate criteria is low, and it might be attributable to the lack of training in sustainability issues by several institutions and professional bodies, a lack of clear structure and guidance, the nature of relevant codes of practice and the terms of implementation, which are advisory rather than mandatory (Ochieng et al., 2014). However, when the same respondents were asked about the feedback on project award criteria with yes or no options, the percentage of responses for projects awarded on an environmental basis, as per Figure 6.22, is 30%. The difference in results might be due to the words used to phrase the questions; since, in the previous question, respondents were asked about the ultimate criteria, whereas in the question below, they were asked about projects awarded on an environmental basis. The Integrated CEM framework proposes to include tangible unit i.e. CO_2e as an environmental basis, instead of compliance-based rating tools.

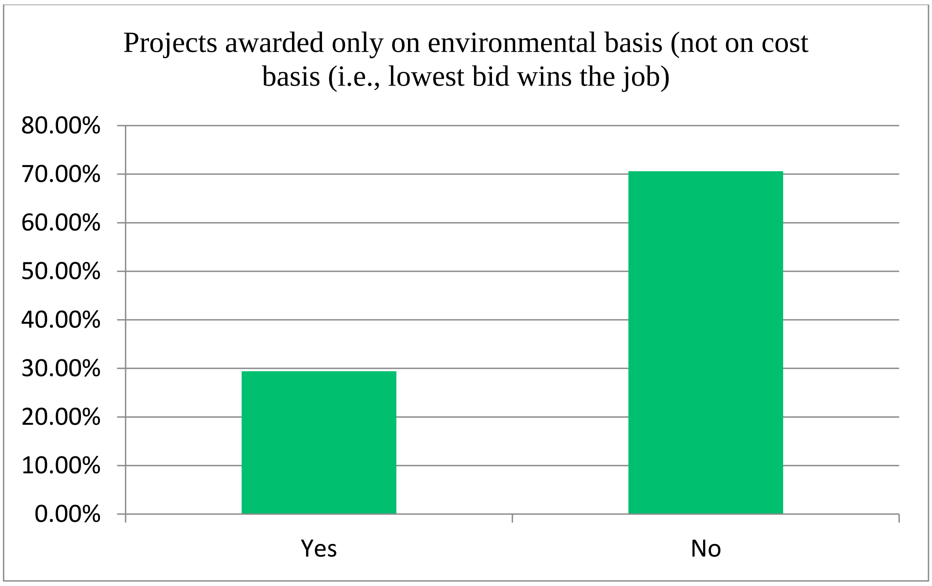


Figure 6.22 Projects awarded only on an environmental basis

6.5 Impacts of Carbon Emissions on Global Warming

Respondents' replies to the question of to what degree they agree or disagree that the impacts of carbon emissions lead to global warming were unclear: 88% of respondents were working on green buildings, as seen in Figure 6.18, while less than 84% of the same respondents as shown in Figure 6.23 stated that carbon emissions have adverse effects on global warming. This 4% difference of respondents might be attributable to the conspiracy theories such as ‘greenwashing’ fake news, stories claiming that climate change is a hoax and the recent events which have taken place since Donald Trump took over as U.S. president, and downplaying the dangers of Climate change. The impacts of global warming can be seen from the concentration of carbon dioxide (CO_2) in the atmosphere, which is increasing from pre-industrial levels of approximately 280 ppm to 401 ppm in 2016. In 2018, the concentration reached more than 412 ppm. The continuous and increasing production of carbon emissions is, therefore, a matter of global concern (Yue et al., 2015). Accordingly, many countries have set ambitious long-term carbon emissions reduction targets; for example, the U.S. has committed to lower carbon emissions by 17% and 83% below 2005 levels by 2020 and 2050, respectively. The proposed CEM framework will help the industry in managing the CO_2 emissions and also will help in reporting and quantifying the impacts of climate change.

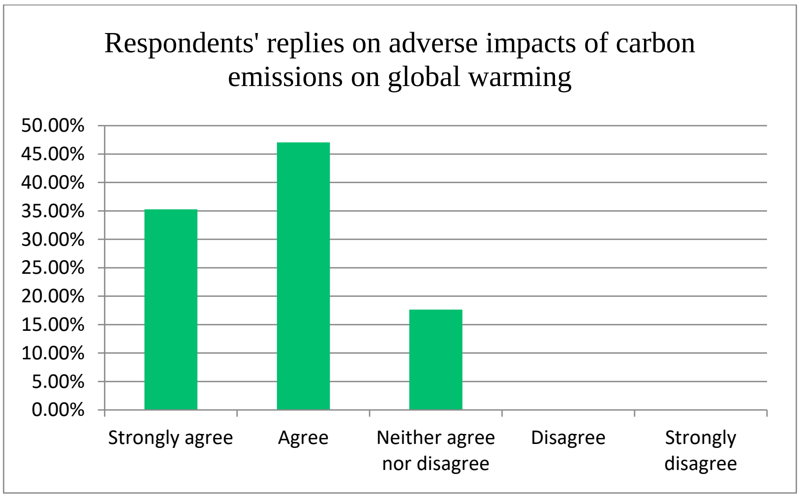


Figure 6.23 Respondents’ replies on adverse impacts of carbon emissions on global emissions

6.6 Factors Limiting Sustainable Construction Management Practice in UAE

Respondents were asked to pick one factor, which they think is dominant in limiting carbon emissions management in the UAE. The responses in Figure 6.24 show that 54% cited lack of awareness and experience as the reason for lack of implementation, followed by fast-track construction (18%) and lenient regulations (12%). Media campaigns show that sustainability is a priority of all professionals; however, in actual practice, the reality does not appear to be the same (Ariyaratne and Moncaster, 2014).

The construction industry relies on knowledge and experience acquired over time with tried and tested methods.

Hwang and Ng (2013) argue that there are other challenges for green construction project management besides lack of awareness but agree on lenient regulations and contractual clauses as part of the problem. Lack of awareness was addressed in a different paradigm in that study, such as a need to increase meetings and coordination among consultants and specialist engineers. A fast-track construction period implies that there is an immediate need or requirement to implement and complete a project. The urgency of a project could heavily influence project performance, and the activities performed to meet the timeline and expectations of all project stakeholders, particularly the project client (internal or external to the organisation). In the UAE, most of the projects have the shortest duration as an attribute of a project, and this becomes a critical success factor, and hence the other parameters become secondary.

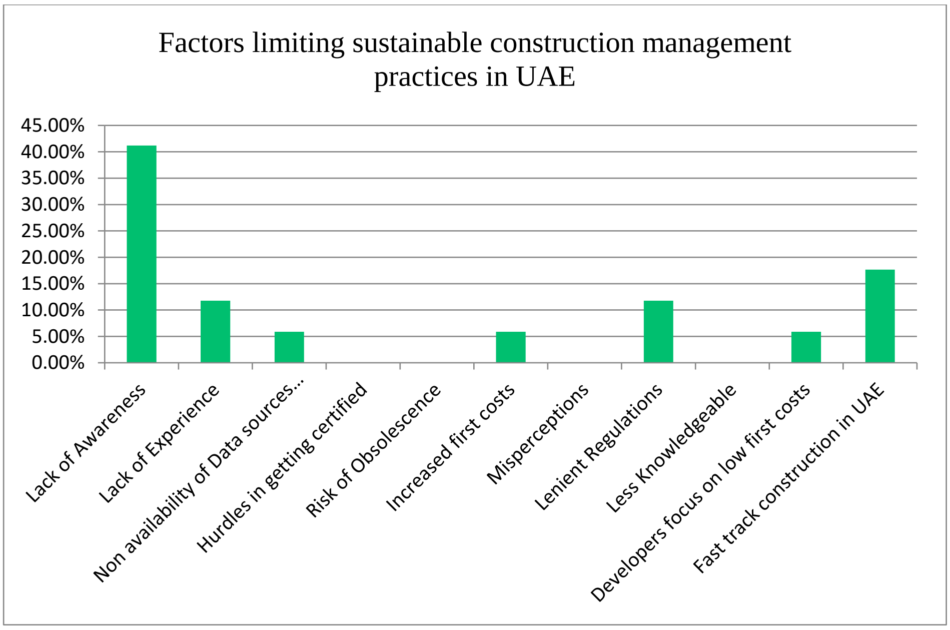


Figure 6.24 Factors limiting sustainable construction management in UAE

Nawarathna et al. (2018) identified 11 challenges in the Sri Lankan construction industry which are limiting the implementation of embodied carbon estimation: which can be summarised in the areas of lack of awareness, lack of stringent regulations, complexity in tools, inconsistencies in methods, non-availability of databases for carbon emissions factors and lack of intent by industry. Survey responses and findings from UAE construction professionals identified similar challenges, such as non-availability of data sources, lack of experience and regulations. Lack of awareness has a lower mean among the other factors contributing to lower sustainable management implementation in the UAE. The data metrics are the most fundamental attributes to the carbon emissions management of projects and consist of a sequence of phases: estimating, benchmarking, controlling and closeout. The fact that it has the lowest mean indicates that project professionals do not perceive it to be of high importance compared with the other factors. It could be that the lack of data is deemed not as important when compared with the other attributes because of lack of awareness. Therefore, it could be that the one attribute of lack of awareness can be controlled and improved through implementation of CEM on projects in the UAE.

6.7 Current Practices of Sustainable Construction Management

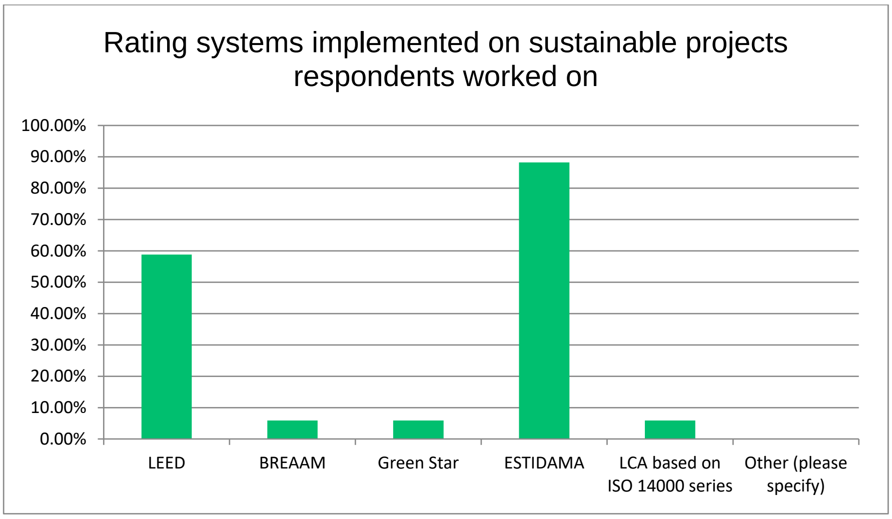


Figure 6.25 Rating systems implemented on projects respondents worked on

The responses in Figure 6.25 show that the UAE building construction industry uses Estidama as a rating system on all projects in the Emirate of Abu Dhabi. Some 88% of respondents stated that Estidama was used in one of the projects they worked on. This higher response rate is due to the mandatory requirements in Abu Dhabi and due to professionals working on projects across all emirates in the UAE. LEED stands second at 58%, which is contrary to the findings for 2008, in which the researcher (2008) found that prior to mandatory regulations on Estidama, LEED implementation was 80% and Estidama implementation was 10% (Estidama, 2019). Al Safat, green building rating system of Dubai and the regulation are in place from 2016 (Dubai Muncipaility, 2019). Ras Al Khaimah also launched a green building rating system 'Barjeel' in 2019 (RAK Municiplaity, 2019). UAE is making a positive impact on sustainable development by focussing on four pillars — economic, social, cultural and environmental — in keeping with the Bedouin ideals and historic ecological and cultural principles (Alobaidi et al., 2016; Al Safat, 2019).

Low awareness levels of embodied carbon emissions of 25% from Figure 6.26 are because neither LEED nor Estidama had mandated levels as 'pre-requisites' associated with them. Even though the rating systems implementation is high, the awareness levels are low on CO_2 emissions in the building sector, which is reflected in the responses received in Figure 6.27. As can be seen, 69% of respondents state that they had not used any of the carbon assessment tools. Therefore, to achieve a more sustainable environment, it is desirable to practice sustainability through effective measurement of CO_2 emissions (Abdul-Azeez and Ho, 2015). The proposed Integrated CEM framework will use CO_2 emissions as a unit to manage the environmental efficiency of the project.

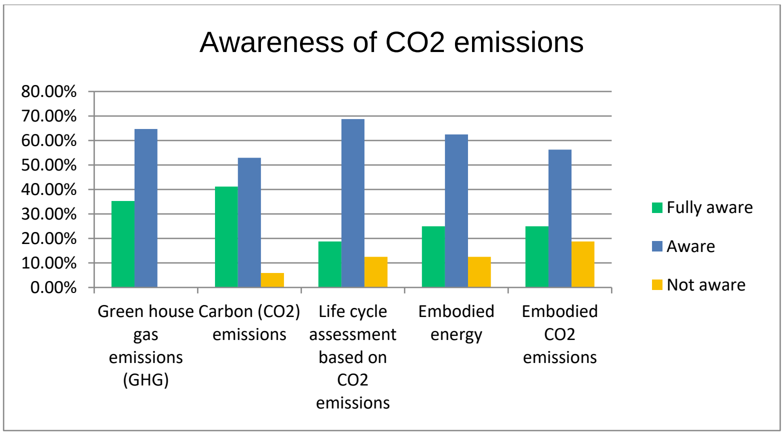


Figure 6.26 Awareness of CO_2 emissions concept

Spearman's rank correlation is a non-parametric test used to measure the degree of association between two variables (i.e., coefficients of 0.50 and above represent a strong association or relationship). As per Table 6.3 and Figure 6.26, in which the awareness levels of respondents are displayed statistically, their awareness levels were found to be significantly correlated. As the Sig (2-tailed) value is less than .05, it is concluded that there is a statistically significant correlation among the variables. That means that awareness of terms related to sustainability is higher in one variable (CO_2 emissions) and does significantly relate to high values in the second variable (GHG emissions).

Table 6.3 Spearman's correlation on awareness of sustainability terms

Correlations

			Green house gas emissions (GHG)	Carbon (CO2) emissions	Life cycle assessment based on CO2 emissions	Embodied energy	Embodied CO2 emissions
Spearman's rho	Green house gas emissions (GHG)	Correlation Coefficient	1.000	.817**	.679**	.551**	.542**
		Sig. (2-tailed)	.	.000	.000	.000	.000
		N	371	371	371	371	371
	Carbon (CO2) emissions	Correlation Coefficient	.817**	1.000	.727**	.704**	.802**
		Sig. (2-tailed)	.000	.	.000	.000	.000
		N	371	371	371	371	371
	Life cycle assessment based on CO2 emissions	Correlation Coefficient	.679**	.727**	1.000	.496**	.652**
		Sig. (2-tailed)	.000	.000	.	.000	.000
		N	371	371	371	371	371
	Embodied energy	Correlation Coefficient	.551**	.704**	.496**	1.000	.923**
		Sig. (2-tailed)	.000	.000	.000	.	.000
		N	371	371	371	371	371
	Embodied CO2 emissions	Correlation Coefficient	.542**	.802**	.652**	.923**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.
		N	371	371	371	371	371

**. Correlation is significant at the 0.01 level (2-tailed).

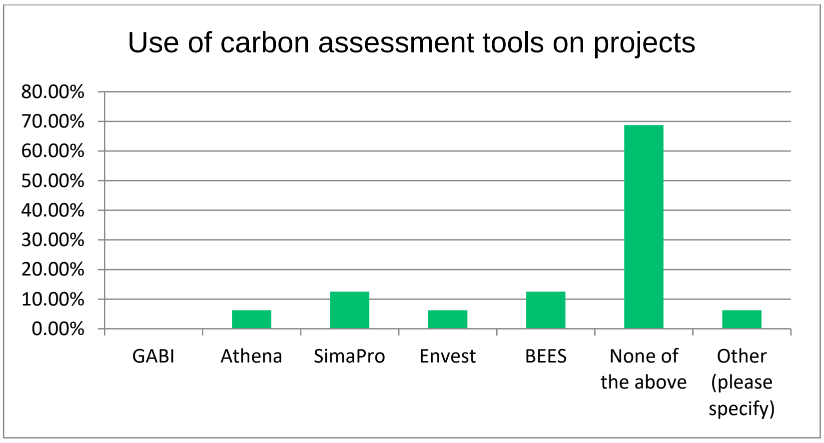


Figure 6.27 Use of carbon assessment tools on building projects

In Figure 6.27, SimaPro and BEES are the tools used by the UAE respondents, but the implementation or usage levels are low. Most of the respondents (up to 78%) replied that none of the tools are used to assess carbon emissions, which shows low levels of implementation of CEM in the UAE. Moreover, the responses in the UAE are contrary to a survey conducted by Cooper and Fava (2006), which found that GaBi and SimaPro were the most popular LCA tools, accounting for 58% and 31% of the market, respectively. Based on these findings, the CEM Model takes into account the current practices and preferences of the industry and proposed simple in use tools like excel and primavera.

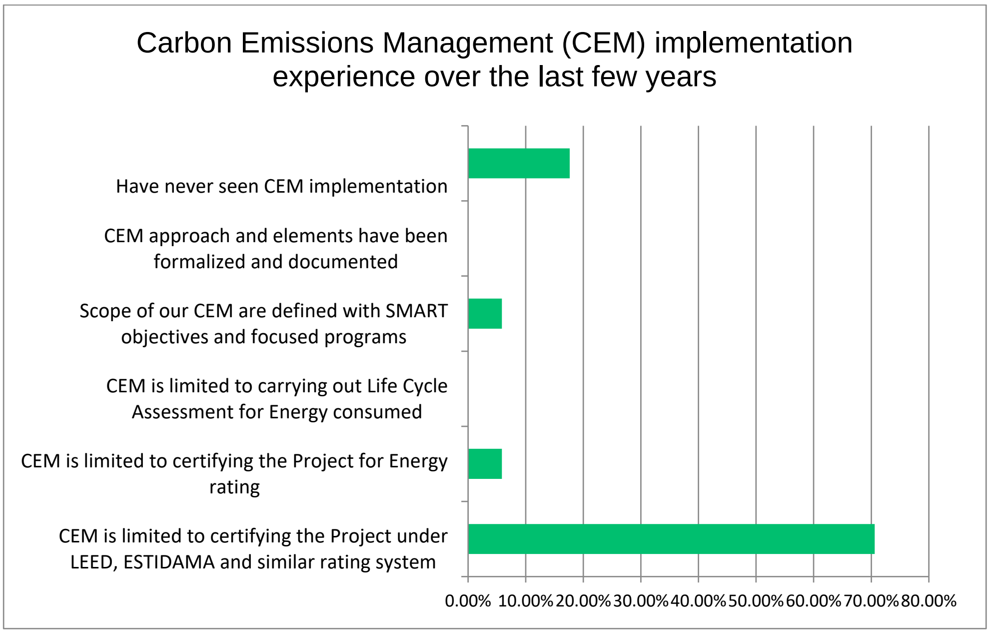


Figure 6.28 Carbon émissions management (CEM) implémentation

Figure 6.28 shows that CEM implementation is limited to the use of rating systems (70% of respondents agree to it), whereas the survey findings show that 18% did not implement any CEM in their projects at all. Compliance-based rating systems, which do not mandate carbon emissions calculations and monitoring as a pre-requisite, are weakening the implementation rates of carbon emissions management in the UAE. Annexe 1 countries partly meet their GHG emissions commitments by investing in GHG reduction projects through the Clean Development Mechanism (CDM) of the Kyoto Protocol (Jiang and Tovey, 2009). Implementation of effective carbon emissions management as a way to promote low-carbon strategies can be promoted in developing countries such as the UAE. Further to these findings, the researcher recommends integrating CEM with time and cost management to increase implementation levels.

6.8 Current Practices of Cost, Time and Contract Management in the UAE

As shown in Figure 6.29, in-house cost indices were the basis for cost estimates as per the survey responses received. This is in contradiction to the practices pursued elsewhere. The UK construction industry uses BCIS as one basis to estimate and bid for projects. The UAE construction industry predominantly relies on in-house cost indices. The responses for the tools used in Figure 6.30 accord with the results in Figure 6.29, which shows that the most widely used tool is Excel spreadsheets. Only 20% of the respondents use the software tools for cost estimation, which is in line with the literature review findings on the preferences of the building construction industry in the UAE.

In the area of schedule management, industry is utilising software such as Primavera (score of 4.69) and MS Project (score of 3.38) extensively on their projects during bids as well as during project implementation. Excel spreadsheets still appear, with a score of 3.4, mostly due to the UAE industry practices of combining Primavera and Excel to produce the planning package. Based on these findings, the CEM framework used excel and primavera as the simple in use tools to manage carbon emissions during the tendering and construction stage. The framework does not restrict the use to excel and primavera but is versatile to accommodate other relevant in-use software.

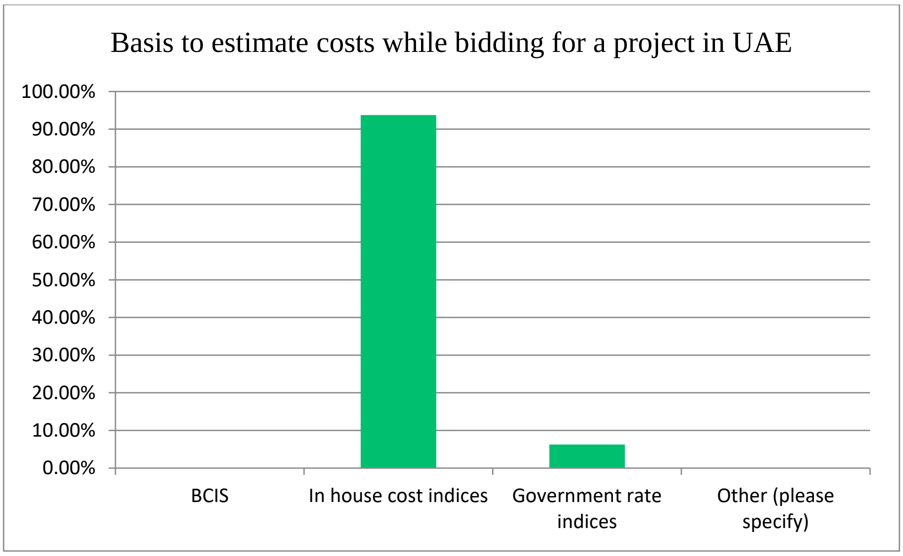


Figure 6.29 Basis for estimating costs while bidding

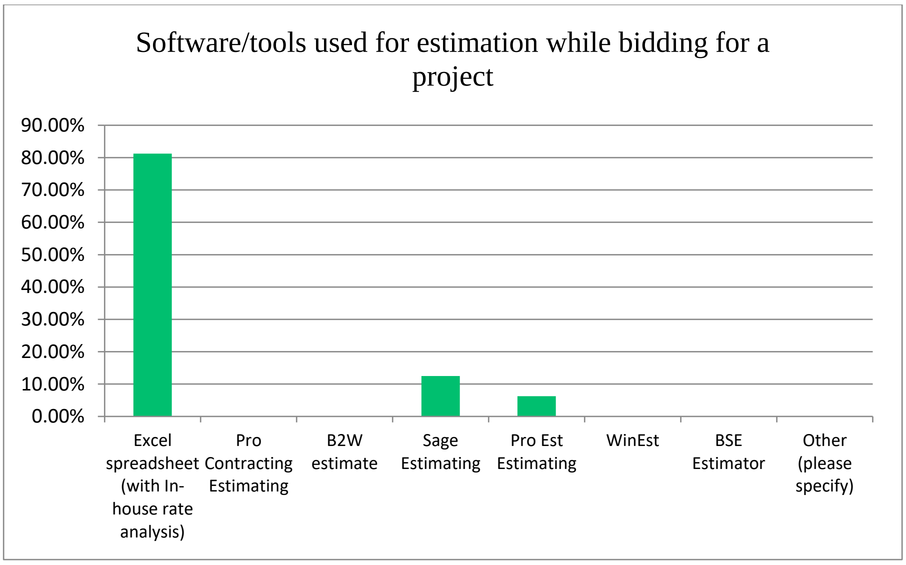


Figure 6.30 Software/tools used for estimation while bidding for a project

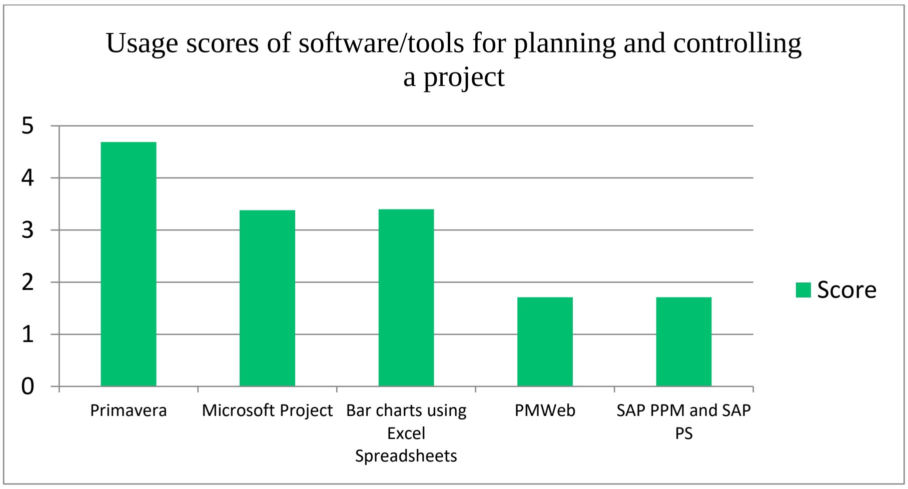


Figure 6.31 Usage scores of software for planning and controlling a project

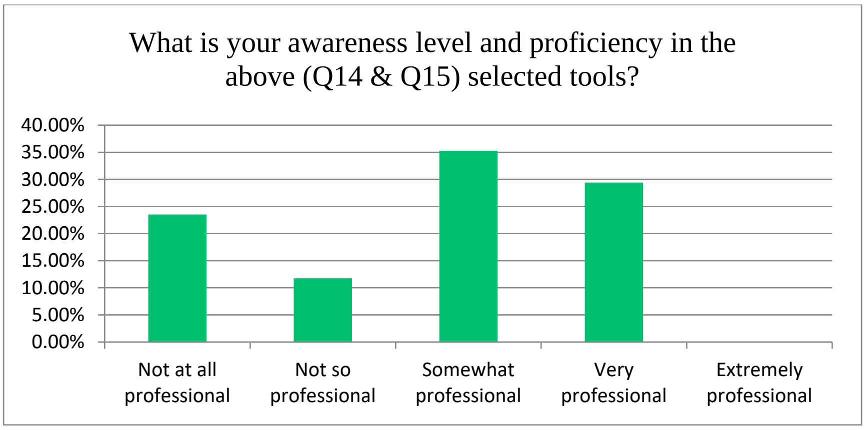


Figure 6.32 Awareness levels of planning and controlling tools

EVA and CPM techniques are the most prevalent methods for monitoring project performance in the UAE due to their advantages over others. Some 52% of respondents chose cash flow and EVA technique via the S-curve, whereas pure CPM techniques using only Primavera or MS Project were chosen by 36% of respondents. A question related to accounting software was included to see if any of the respondents manage and control project performance using only the budgeted cost vs expenditure. None of the respondents chose this option, which shows a maturity of professionals regarding schedule management and control. Based on these findings, EVA technique is used to calculate the carbon emissions performance in the proposed integrated CEM framework.

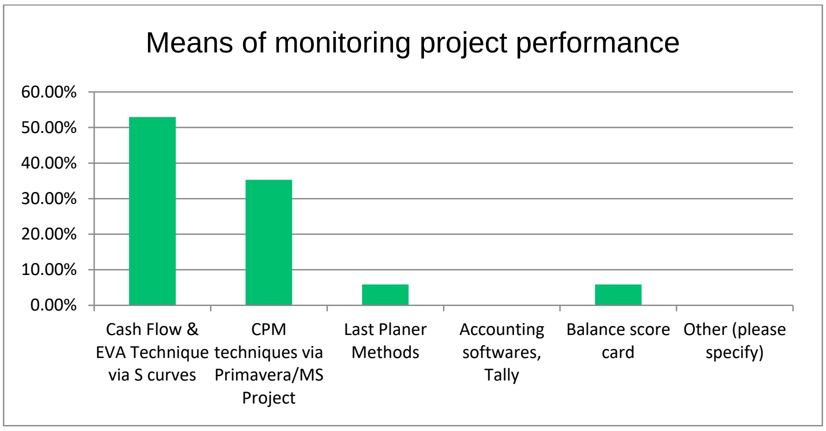


Figure 6.33 Means of monitoring project performance

6.9 Issues with Cost Estimation and Carbon Emissions Estimation Tools

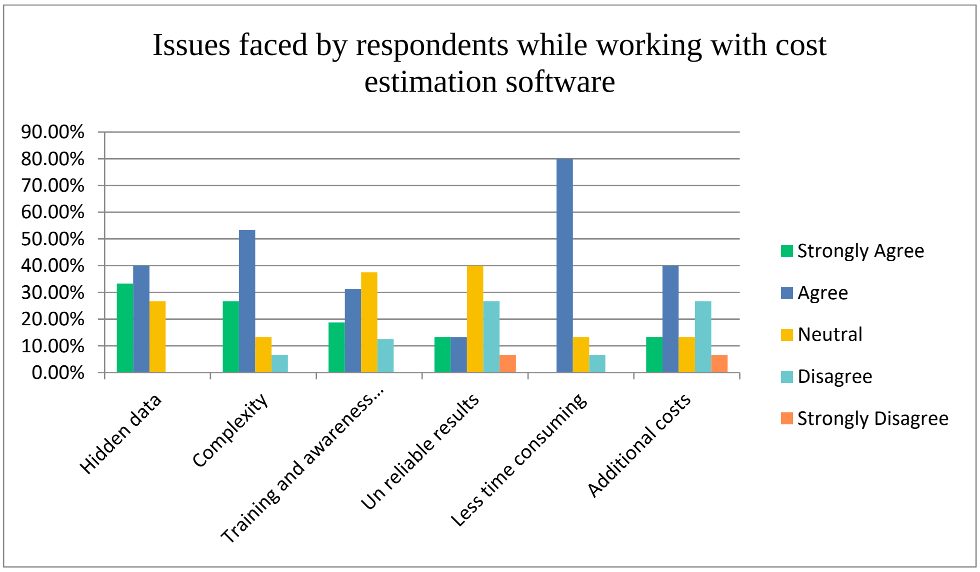


Figure 6.34 Problems associated with estimation (cost and CO_2) software

Cost estimation and carbon emissions estimation tools were found to present issues of hidden data more than complexity, unreliable results and additional costs. Respondents' replies are similar to the barriers/challenges connected with the software identified by Dixit et al., Moncaster, etc., who stated complexity in use and hidden data as barriers. Based on these findings, simple in use tools are recommended in developing the Integrated CEM framework. In-use tools such as Excel and primavera address these factors considerably.

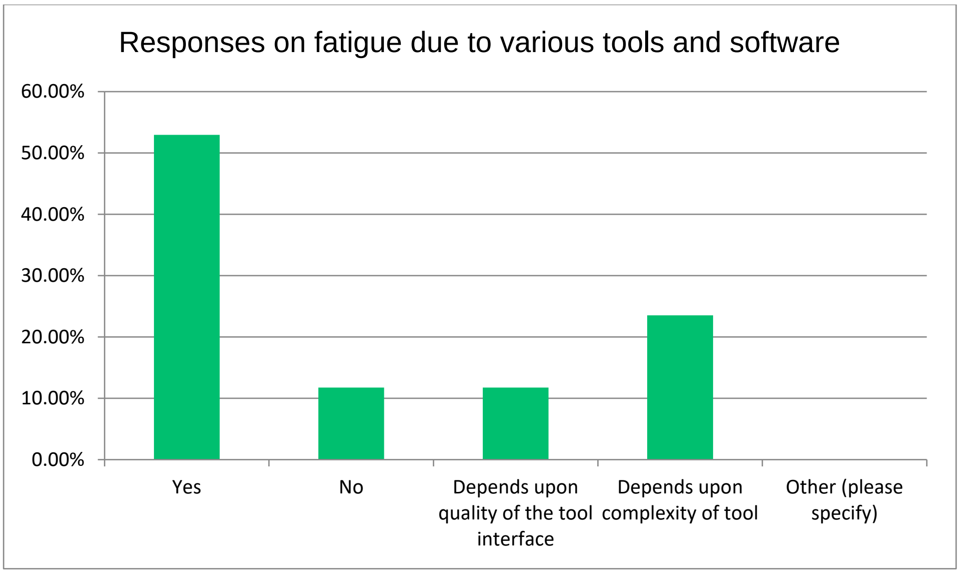


Figure 6.35 Fatigue due to various software and tools used on a project

Fatigue has been a rising concern with industry specialists due to numerous software, fragmented tools and passwords used on the projects and in personal life. Fatigue is seen in the responses received in Figure 6.35, which shows 53% affirmative and 24% stating that the level of fatigue depends on the complexity of the tool. Due to these factors, fatigue will indirectly impact on the implementation levels of sustainable management and, in particular, carbon emissions management. The proposed CEM framework shall use simple in use tools to avoid fatigue issues.

6.10 Measures for improving carbon emissions management in building projects

Literature review identified various reasons for low implementation levels of Carbon emissions management such as monitoring and controlling of embodied carbon emissions (Nawaratna et al., 2018). The reasons include lack of mandatory regulations, unavailability of carbon emissions factor database, lack of awareness, complexity of tools and other reasons as identified in section 2.3 and Table 2.1. These reasons are converted into a question to identify the reasons in the UAE. Measures for improving carbon emissions management as identified from the survey responses are as follows:

- Use of simple-in-use-tools
- Make it mandatory to estimate and monitor carbon emissions in building construction projects
- Spread awareness of CEM
- Integrate CEM with current practices of project management; in particular, base the award criteria on cost and CO_2 emissions.
- Make available the data related to carbon emissions, such as emissions factors, success case studies, etc.

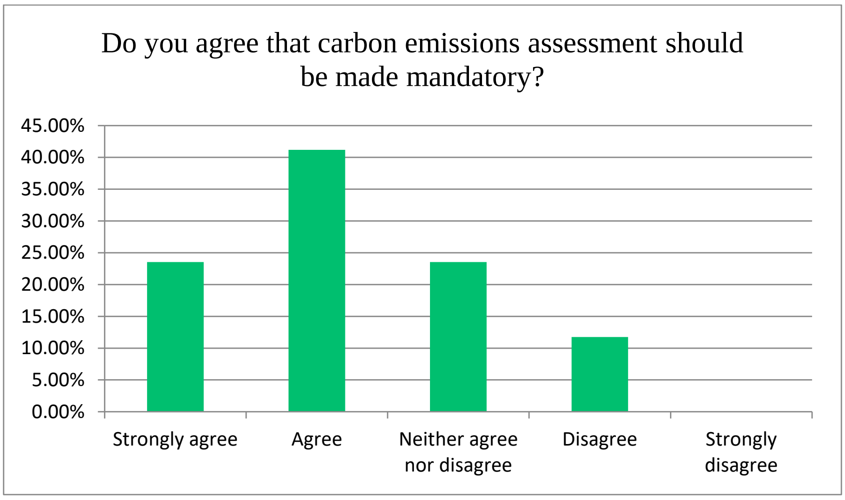


Figure 6.36 Respondents' views on making carbon emissions management mandatory

Making the requirements mandatory is another way of improving implementation levels (Moncaster and Song (2012); Moncaster and Symons (2013)). The UAE construction industry has seen improvements since the Estidama rating system was made mandatory. As shown in Figure 6.36, 65% of respondents agree that carbon assessment should be mandatory on all projects. Based on these findings, the researcher recommends mandating the Carbon emissions management on building projects in addition to the compliance based rating systems. This will help the industry to quantify, manage and report the CO_2 emissions at project level, industry level and country level,

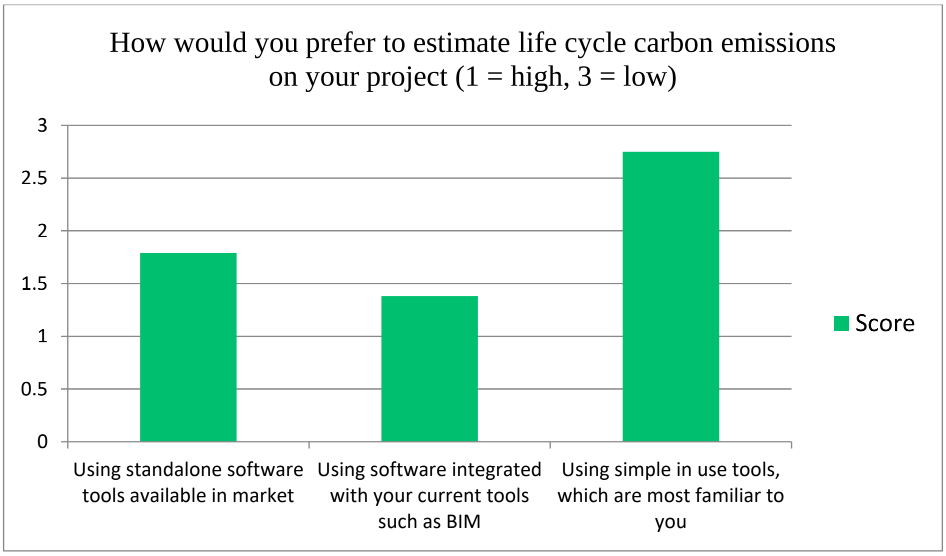


Figure 6.37 Preference of tools to estimate life cycle carbon emissions

Various assessments tools and indicators are available to the building construction industry, but the challenges of clarity, when they should be used and by whom are limiting the implementation of carbon emissions management among practitioners (Sourani and Sohail, 2011). Respondents' answers, as shown in Figure 6.37, are in line with the previous research findings by agreeing with a score of 2.75 that there is a need to develop simple but wide-ranging tools and techniques to deal with sustainability needs of assessment. The response of the survey regarding simple-in-use tools reflects the literature findings as shown in Table 2.1, which also reflects that the majority of carbon footprint calculators use Excel as a back-end tool due to ease of use (Kravari, 2017). Marchman and Clarke (2011) agree that addressing these problems requires significant and sustained focus on awareness, education and training. Nevertheless, specialists also prefer to have an integrated approach through BIM, with a score of 1.4. When these results were compared with the literature review findings of one of the similar studies, it was found that the use of BIM software to calculate embodied carbon, replied to by both the survey respondents and the interviewees, was 81% (Ariyaratne and Moncaster, 2014). BIM software has the capabilities to host embodied carbon data attached to the 3D models; however, in practice, its use is limited and has not been explored to its full potential by the industry, even in the design process, while in the construction phase it is neglected (Motawa and Carter, 2013). Based on these findings, the proposed Integrated CEM framework use simple in use tools.

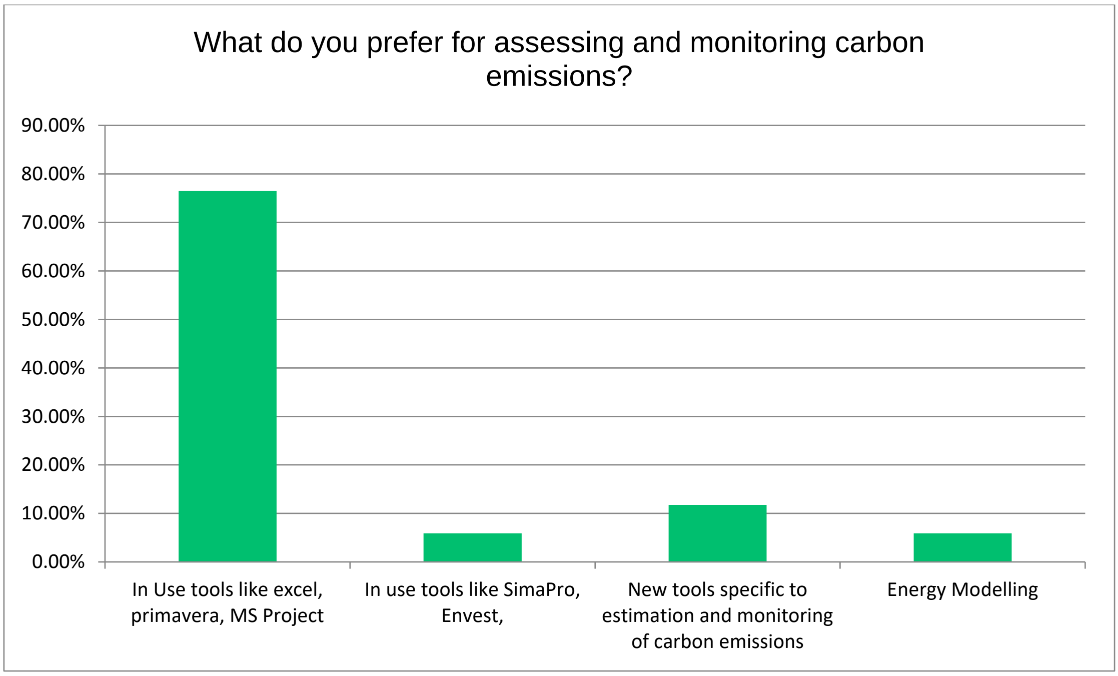


Figure 6.38 - Preference of tools to assess and monitor carbon emissions

The preference of respondents for estimating, monitoring and controlling carbon emissions using simple-in-use tools such as Excel, Primavera and MS Project is 76%, as per Figure 6.38. The reasons for this preference can be ease of use, familiarity of the tools, reduced complexity, lower resultant fatigue or a reluctance to change (Kravari, 2017). A review of water calculators and waste calculators in the Estidama rating system and its ease of implementation found that its ease of implementation is due to the simplicity of the tools, on similar lines as Excel spreadsheets (Estidama, 2018).

It can be seen from Figure 6.38 that the percentage of preference for SIUTs, such as Excel, Primavera and MS Project, are higher than the percentages for preference of SimaPro, Envest and energy modelling solutions. Both energy modelling solutions and the dedicated carbon calculators have low scores in sustainability practices compared with SIUTs. To ascertain the statistical significance of this, analysis of variance (ANOVA) was used, and the results are shown in

It can be seen from the above ANOVA table that there is a significant variance in the sustainability tools preferred by UAE construction professionals among different company types. The F value is 3.49 (>1) and the Sig. value is 0.002 (<0.01); hence, we can conclude with 99% confidence that our prediction of 'SIUT having higher preference as a sustainability tool' is statistically significant.

Table 6.4

It can be seen from the above ANOVA table that there is a significant variance in the sustainability tools preferred by UAE construction professionals among different company types. The F value is 3.49 (>1) and the Sig. value is 0.002 (<0.01); hence, we can conclude with 99% confidence that our prediction of 'SIUT having higher preference as a sustainability tool' is statistically significant.

Table 6.4 ANOVA Table – Preference of CEM tools and type of company

ANOVA

What do you prefer for assessing and monitoring carbon emissions

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	27.142	6	4.524	3.491	.002
Within Groups	471.650	364	1.296		
Total	498.792	370			

Null hypothesis – There is no significant variance in the sustainability tools preferred by UAE construction professionals among different company types.

It is because SIUTs are easy to use, practitioners have more familiarity with them, and there is greater fatigue associated with using numerous tools in project management. As per Figure 6.35, fatigue is seen as a primary reason for a user's acceptance of specialised software for each discipline. It could be argued that there are other factors for improving carbon emissions management which are not currently implemented in the UAE building construction industry. The next paragraph analyses the factors to be considered for effective carbon emissions management in projects.

In this question, the participants were asked to rank the levels of importance of those measures to improve CEM from 1 to 5 (1=most important, 5 = least important or not important).

- Mandate carbon emissions management for all projects in the UAE.
- Integrate carbon emissions management in project management systems.
- Upon technically qualifying the bidders, carbon and cost bids should be criteria for award.
- Spread awareness and knowledge in using simple-in-use software to improve implementation.
- Make carbon emissions factors freely available to industry for estimation and monitoring.

The Relative Importance Index (RII) is used in this study to assess the relative importance of the indicators. In this question, RII is used to rank the factors for improving the implementation levels of carbon emissions in the UAE:

$$RII = \frac{\Sigma a_i x_i}{A*N}$$

where a_i = constant expressing of the weight of the i^{th} response,
x_i = level of the response given as a percentage of the total response for each factor
A = highest weight
N = total number of respondents

The RII value ranges from 0 to 1; a higher RII indicates that one factor is more significant than another. The RII for the collective group was calculated by averaging the RIIs of all individual factors within the same category. The RII results are shown in Table 6.5.

As can be seen in Table 6.5, professionals are conscious of the most important factor for improving the implementation levels of carbon emissions management in construction projects. The primary factors which can improve CEM are identified as the integration of CEM with the project management from all fields of professionals, followed by mandating carbon emissions tracking and making CO_2 emissions an award criterion. These findings are considered in developing the Integrated CEM framework.

Table 6.5 – Factors for improving the implementation levels of sustainable management

Factors	RII					Mean of RII	Rank
	Contractor	client	Real estate Dev	Design consultant & PMC	Manufacturer & Vendor		

Integrate carbon emissions management in project management systems	0.86	0.83	0.87	0.84	0.80	0.84	1
Mandate carbon emissions tracking for all projects	0.68	0.71	0.66	0.72	0.74	0.70	2
Upon technically qualifying the bidders, carbon and cost bids shall be criteria for award	0.59	0.64	0.70	0.61	0.66	0.64	3
Spread awareness and knowledge in using simple-in-use software to improve implementation	0.54	0.57	0.65	0.62	0.52	0.58	4
Make carbon emissions factors freely available to industry for estimation and monitoring	0.81	0.25	0.40	0.69	0.61	0.56	5

Carbon emissions management has not attracted enough attention from all the stakeholders in the building industry, which include developers, consultants, construction managers, etc. The different professionals may have different concerns regarding the above factors, but when considering the factors for improving sustainable practices, they have similar ideas and did not negate any of the factors posed to them in the question. The least mean RII for the ‘Making carbon emissions factors freely available’ is 0.56, which shows the varied response and importance of all the factors as critical.

The top three drivers of carbon emissions management, as per the responses of the survey, are energy prices and financial savings, complying with regulations and reputation. The responses were unexpected as the researcher was implying that due to higher awareness levels, climate change could be one of the major three drivers of implementing carbon emissions management.

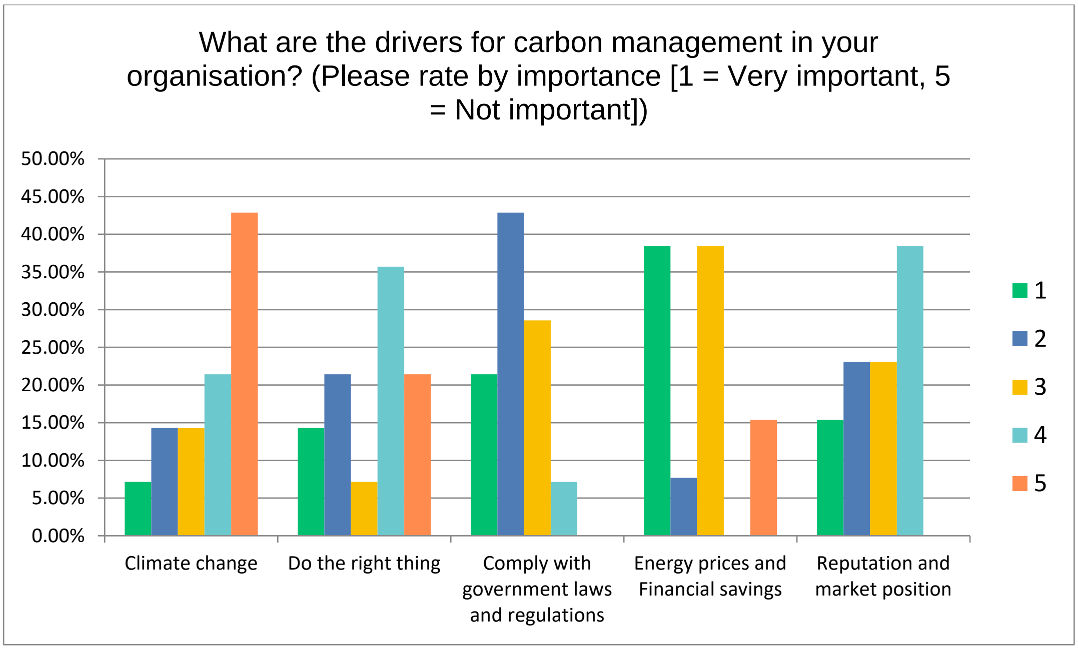


Figure 6.39 Drivers for effective implementation of carbon emissions management

6.11 Alternate Procurement of Works – COCO$_2$ Tendering

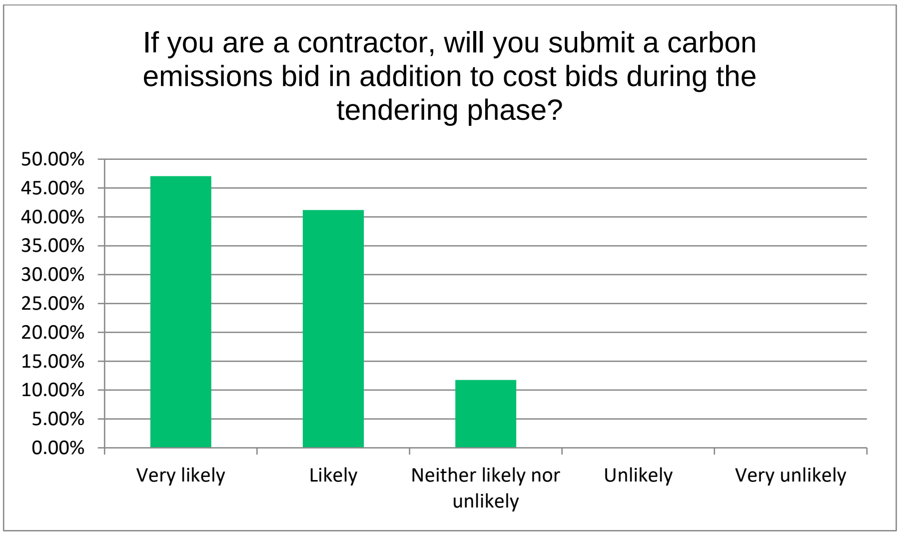


Figure 6.40 Responses on carbon emissions bids

Competitive tendering is a conventional method of procuring building construction projects. Clear procedures and evaluation criteria should be followed by clients and contractors to guarantee transparency and equal opportunities to participant bidders (de Boer et al., 2001; Falagario et al., 2012) and to avoid unfair bias or corruption (Auriol, 2006; Celentani and Ganuza, 2002). The simplest, most transparent and effective means currently being used is the traditional method of awarding the contract to the lowest bidder (Waara and Brochner, 2006; Wang et al., 2006).

Nevertheless, as shown in Figure 6.40, based on the industry professionals survey, the prospects of $COCO_2$ tendering seems to be high, with 47% of respondents replying 'very likely' and 42% replying 'likely'. It is promising to see 'unlikely' at 0%, which is in accord with the response received in Figure 6.42. These findings are promising to see the willingness of the industry for a change to adopt CEM framework.

6.12 Willingness of Industry to Adopt Additional Tender Evaluation Criteria

In the survey, 95% of respondents expressed a willingness to bid for the projects in the capacity of a contractor, for which the tender evaluation criteria include carbon emissions along with the financial, technical and commercial criteria. This response shows that the industry is ready for change and ready to adopt innovative criteria to be competitive in the market.

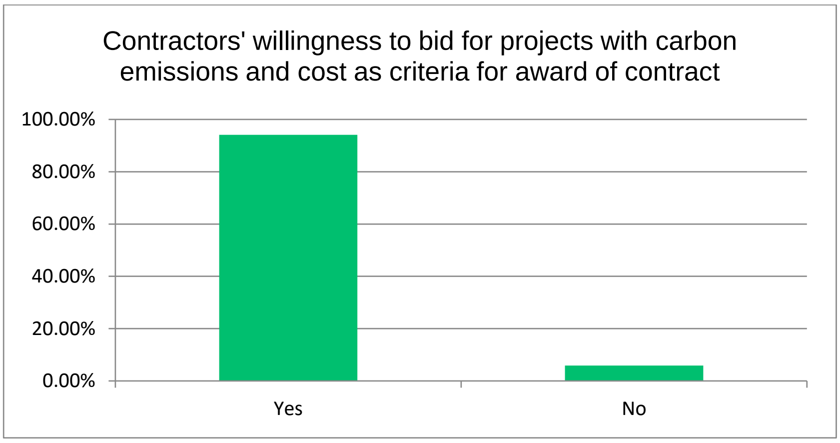


Figure 6.41 Willingness to bid for projects with COCO2 approach

This question in Figure 6.41, 'If you are a contractor…', was asked to ascertain the responses from different specialists working for clients, consultants and contractors to measure the willingness of all stakeholders involved in the project. The responses received are promising and provide a rationale for adopting this approach of $COCO_2$ bids. Similar research conducted in Malaysia indicated that, in any procurement setting, whether conventional, design and build or partnering, the environmental criteria of the desired products and services stated in the technical specification act as guidelines for the evaluation team, design team and other stakeholders (Bohari et al., 2017). Responses to the survey question reflect, 'If specified, we do it'.

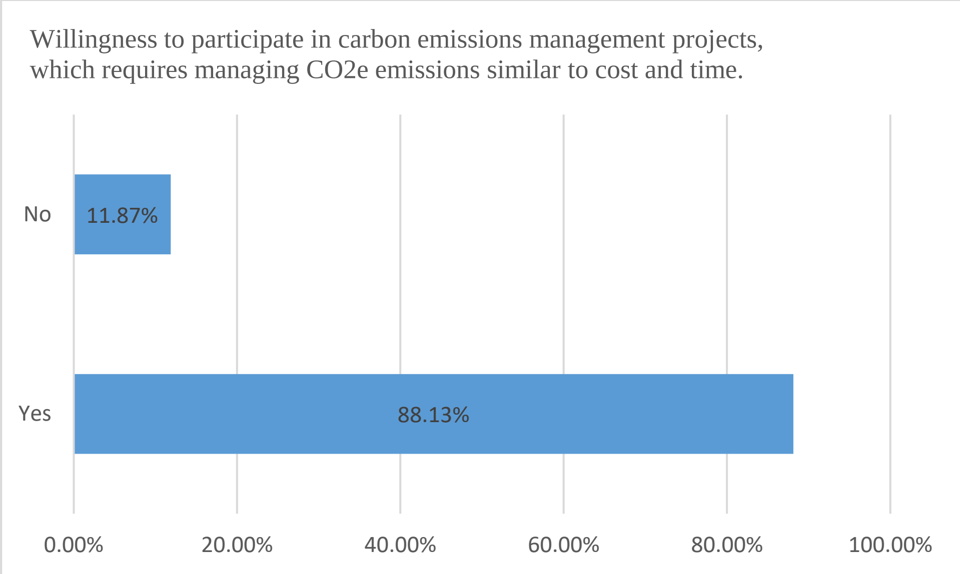


Figure 6.42 Willingness to participate in carbon emissions management projects

A further question was included to cover the performance monitoring and control of the project based on carbon emissions. Respondents replied to it, as can be seen in Figure 6.42, with 88% in the affirmative, which shows again the overall acceptance of managing projects using carbon emissions management integrated with other project management disciplines. The survey responses received were contrary to the findings of Bohari et al. (2017), which state that the major challenge is to shift the status quo of current practices.

6.13 Summary

In this chapter, 371 questionnaires were analysed. It includes the respondents' backgrounds, which shows that the survey obtains opinions and attitudes from diverse professionals in the construction industry in the UAE. A well-distributed sample of different groups such as clients, contractors, design consultants, PMC consultants, manufacturer and vendors, as well as age, professional certifications levels and experience, assist in avoiding bias.

Next, the current procurement routes and award criteria for sustainable projects in UAE were analysed. Though the current situation is discussed based on the literature in the previous chapter, to obtain primary data from the industry is valuable to establish a carbon emissions management model and $COCO_2$ tendering framework. Based on the discussion in sections 6.7, 6.8 and 6.11, the UAE construction industry requires a transformation in terms of improving carbon emissions management implementation. Professionals ranked the need to integrate CEM with project management as number one and the need to mandate carbon emissions tracking and setting carbon emissions as part of the award criteria.

Based on the discussion in the questionnaire survey, developing a carbon emissions management model and $COCO_2$ tendering framework which is suitable for the building construction industry is recognised to be important to improve the implementation levels of sustainability by professionals. The reasons for lack of implementation of sustainable management were also analysed based on responses received regarding issues with current carbon emissions tools, current sustainable tools and the factors limiting the construction management practices. According to the survey results, 94% of the professionals stated that prescriptive sustainable tools such as Estidama, LEED and BREEAM were used on their projects as sustainable performance criteria, whereas only 5% of professionals stated that ISO standards (for LCA) were used to ensure the sustainable performance of the project. Lack of awareness was also found to be one of the main factors limiting sustainable management implementation in the UAE.

Furthermore, the need to increase awareness about the importance of embodied carbon emissions during construction amongst construction professionals as well as construction companies was also seen as vital. It was highlighted by the participants that raising awareness is more important than acquiring external consultancy, which could imply that raising awareness would be a more sustainable option which will help shift the focus towards sustainability in the long term whereas obtaining external consultancy might only help to develop systems which might not achieve the long-term goals of the organisation. Hence, raising awareness about sustainability should be seen as a priority for policy, which can be achieved through a series of programmes such as educational and training initiatives, workshops, conferences, in-house advertising and training.

After the identification of factors and current practices, the measures for improving the implementation levels of sustainable construction through carbon emissions management were analysed based on survey responses. RII was adopted to rank the relative importance of a series of factors which can improve implementation levels. The most important factors were chosen for a model and framework development, including applicability and practicability considerations.

The willingness of the industry to adopt the alternative award criteria and carbon emissions management is promising, with a 88% acceptance rate. Acceptance rates were found to be higher when the question was asked in comparison to cost and time, and also due to the familiarity with cost and time estimation and control management in projects.

The participants believe that without a strict regulatory framework, sustainability adoption in terms of carbon emissions management will be very difficult. This was highlighted by the survey findings as 'strict regulations and policies' for mandating carbon assessment and control in building construction projects received the highest mean score against other measures in ensuring that all project impacts are quantified in CO_2e units and thereby achieve real sustainability.

In summary, the questionnaire survey helps to verify the importance and feasibility of this research. The need for a model using the simple-in-use tools, an integrated carbon emissions model, a cost carbon ($COCO_2$) tendering framework and an assessment unit in terms of CO_2e for the building construction industry have been generated.

Chapter Seven: Case Study Results Discussion and Analysis

7.1 Introduction

After the model establishment in chapter 5, two case studies with three buildings have been chosen for model verification in this chapter: a laboratory building in the Habshan region, a workshop and office building and mechanical store in the Bu Hasa region. The two case studies are analysed based on the CEM model for estimation, monitoring and control of carbon expenditure during the construction phase. In this chapter, the sustainable performance of the three case studies in the construction stage of the building life cycle, as well as the overall performance for operational energy and water, will be analysed. The carbon cost tendering ($COCO_2$), and the integrated framework for efficient carbon emissions monitoring were later validated via focus group.

7.2 Description of Case Study Buildings and Analysis

One of the major barriers in any stage of a project's life cycle assessment is the availability of data. Data are difficult to obtain, and lack of or incomplete data in the analysis can deter the researcher from pursuing such study. Moreover, the data quality has an impact on the analysis and findings. Researchers working on multiple case studies used the concept of the pedigree matrix for data quality assessment (Table 7.2) (Huijbregts et al., 2001; Weidema, 1998; Weidema and Wesnæs, 1996). The importance of this matrix is that it indicates reliability and completeness and shows different correlations of the data and their intended use.

Calculation of carbon emissions and, in particular, embodied carbon is typically the most data-intensive of all environmental assessments, mainly because of expectations for comprehensive assessments. For this reason, simple carbon assessment /LCA tools are developed and used by teams of experts. Most of the burden of data collection is on the team which develops and uses the tool. The primary data in the inventory stage are directly obtained from the Front-End Engineering and Design (FEED) documents prepared by the consultant/architect through the specifications of each project and bill of quantities. Other building data are quantified based on floor plans and sections. Other data sources were interviews with the contractor on the site and direct observations during construction of the buildings. The buildings are owned, designed, constructed and operated by different companies, and they were constructed in 2012 and 2017. The following building systems were included in the study: foundations, structural frame, external walls, floors, roofs, internal walls/partitions, finishes, HVAC, electrical, plumbing, sewage and asphalt works. Each floor plan of the presented cases represents a typical office building in the Western Region of Abu Dhabi. Choosing a typical plan for office, workshop and laboratory building helps in generalising the research findings to a larger sample of the same type. Descriptions of cases, similarities and differences are presented in Table 7.1.

7.2.1 Case study 1: lab building

The lab building is a newly built laboratory building in the Habshan region. Its construction ended in 2015. The building has 3716 m^2 of gross floor area. The building has a ground floor only. The structural frame is RCC concrete, and the exterior walls are hollow blocks with cement plastering. The interior walls are also hollow blocks but of 10cm thickness with plastering to receive paint or wallpaper. The foundations are cast-in-place concrete. The annual energy and water consumption are not calculated.

7.2.2 **Case study 2: workshop and mechanical store building**

The new workshop project comprises a workshop/office building and mechanical store located in the western region of the UAE. Construction of these buildings, including the external works, ended in 2017. The building has 4,532 m^2 of gross floor area. The building consists of two floors for office areas built with cast-in-situ reinforced cement concrete. The other workshop area has a ground floor only, double-height with a structural frame using hot-rolled structural steel columns, beams, rafters and purlins for roof sandwich panel support. The floor is light reinforced concrete. The exterior walls are RCC due to blast-proof requirements for the building. Interior walls are hollow block with plaster to receive paint or wallpaper. Foundations are cast-in-situ concrete. The annual electricity consumption is calculated 846,431 KWh/year as base case. The estimated water consumption of the building is 687,298.65 litres/year.

Table 7.1 – Comparison of case study building characteristics

Description	**Laboratory building-Habshan (Case study 1)**	**Workshop building-Buhasa (Case study 2)**		**Mechanical store building – Buhasa (Case study 2)**
		Workshop area	**Office and substation area**	
Floor Area	1320 m^2	4,532 m^2		678 m^2
Number of floors	Ground only	Ground only	Two floors	Ground only
Floor height	4 Mts	10 Mts	10 Mts	10 Mts
Floor-to-floor height	3 Mts	9.5 Mts	4 Mts	9.5 Mts
Foundation	Cast-in-situ RCC	Cast-in-situ RCC	Cast-in-situ RCC	Cast-in-situ RCC
Structure – columns	Cast-in-situ RCC	Hot-rolled steel sections	Cast-in-situ RCC	Hot-rolled steel sections
Structure – beam	Cast-in-situ RCC	Hot-rolled steel sections	Cast-in-situ RCC	Hot-rolled steel sections
Structure – roof	Cast-in-situ RCC	Hot-rolled steel sections	Cast-in-situ RCC	Cast-in-situ RCC
Structure – floor	Cast-in-situ RCC	Cast-in-situ RCC	Cast-in-situ RCC	Cast-in-situ RCC
Exterior skin	Cement plaster/paint	Cement corrugated cladding/plaster/ paint	Cement plaster/paint	Cement corrugated cladding/plaster/paint
Glazing	Double-glazed windows with aluminium frames	Double-glazed windows with steel frames	Double-glazed windows with steel frames	Double-glazed windows with steel frames
Insulation – exterior walls		200 mm-thick concrete walls up to 8 mts and 2 mts sandwich insulated sheets	350 mm-thick cavity wall with 50mm insulation	200 mm-thick concrete walls up to 8 mts and 2 mts sandwich insulated sheets
Insulation – roof	100 mm-thick insulation along with the waterproofing system (cement screed+bitumen primer coat+waterproof membrane+protection board+insulation+geo-tex+loosely laid tiles)	Sandwich panel with 110mm thick insulation	100 mm-thick insulation along with the waterproofing system (cement screed+bitumen primer coat+waterproof membrane+protection board+insulation+geo-tex+loosely laid tiles)	Sandwich panel with 110mm thick insulation
HVAC cooling	Centralised chilled water system	Centralised chilled water system	Centralised chilled water system	Centralised chilled water system
HVAC equipment	AHUs, FCUs with heating coil	AHUs, FCUs with heating coil	AHUs, FCUs with heating coil	AHUs, FCUs with heating coil
Electrical fixtures	CFL	LED	LED	LED
Plumbing and sanitary fixtures	Normal flow fixtures	Efficient low-flow fixtures	Efficient low-flow fixtures	-

Electricity consumption (kWh/yr)	NA	689,854.07	156,576.41
Water consumption (Litres/yr)	NA	687,298.65	NA

7.3 Selection Criteria for the Case Study Projects

A suitable building and built components for this case study were selected after reviewing many buildings to fulfil the requirements for analysis. The reasons for choosing these specific building were similar to those used by Alwan and Jones (2014), which are as follows:

- Environmental commitments
- Design-stage material balance
- Ability to replicate methodology
- Inventory of materials
- Use of simple-in-use tools

Environmental commitments: The intent of the clients for the building is to construct an exemplary deliverable in terms of its sustainable approach. The expectation is that the FEED consultant designs and achieves the sustainable performing facility with minimum impact on the environment.

Design-stage material balance: The engineering, procurement and construction (EPC) contractor are committed to a low-carbon project by scope and obligation to construct the building with minimal impact on climate change. The nature of the project provides an opportunity to influence the selection of materials at the detailed design and construct phase.

Ability to replicate the methodology: The building being selected will be efficient, with low embodied carbon emissions over its lifetime, and will be adapted to different building types for carbon footprint analysis.

Inventories of materials: The building uses conventional construction methods and materials, thus making it easier for a basic inventory of materials needed for the analysis of their embodied carbon emissions.

Use of simple-in-use tools: The project uses simple-in-use tools such as Excel and Primavera for estimation and monitoring of the cost and time parameters of the project.

The other reasons for choosing these case study buildings are based on data quality assessment. Assessment of the quality of data is very important as higher quality lends more credibility to the results, increases the robustness of the findings and gives more confidence in drawing correct conclusions and making informed decisions using the results. Lindfors et al. (1995) and Weidema and Wesnæs (1996) developed a comprehensive matrix to assess data quality considering the following six indicators ranked on a scale of 1 to 5, in which 1 represents the top-quality data, and 5 represents the lowest quality data:

Acquisition and independence of data supplier represent the reliability of the data, which assesses the data sources, acquisition and verification methods. Data which is directly measured and verified is considered more reliable as it is verified in different ways (e.g., on-site checking, by recalculation, through mass balances, or cross-checks with other sources). Completeness is a representativeness indicator which assesses the statistical properties of the data and how representative they are of the processes being assessed. The complete set of data includes data from an adequate number of sites over an adequate period. Temporal correlation, also known as data age, assesses the correlation between the year of data collection and the year of assessment. This indicator considers that aspects such as technology change over time. Data collected within three years of the study year are considered top-quality data. Geographical correlation assesses the relationship between the geographical area where the data are collected and the area of the study. The best data for this indicator are those collected from the same geographic area under study. The technological correlation indicator assesses enterprise, process or materials-specific aspects of the data.

Table 7.2 Pedigree matrix used for data quality assessment (based on Lindfors et al. [1995] and Weidema and Wesnæs [1996])

Indicator Score					
Item	1	2	3	4	5
Acquisition method	Measured data	Calculated data based on measurements	Calculated data partly based on assumptions	Qualified estimate by specialist consultants	Nonqualified estimate
Independence of data supplier (reliability)	Verified data from public or other independent source	Verified information from enterprise with interest in study	Independent source but based on non-verified information from industry	Non-verified information from industry	Non-verified information from the enterprise interested in the study
Representativeness of sample (completeness)	Representative data from a sufficient sample of sites over an adequate period	Representative data from a smaller number of sites but for an adequate period	Representative data from an adequate number of sites but for a shorter period	Data from an adequate number of sites but shorter periods	Representativeness unknown or incomplete data from smaller number of sites and/or from shorter periods
Temporal correlation (data ages)	Less than three years between data collection and study	Less than five years of difference	Less than ten years of difference	Less than 20 years of difference	Age unknown or more than 20 years of difference
Geographical correlation	Data from the area under study	Average data from the area under study	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from an unknown area or area with very different production conditions
Technological correlations	Data from enterprises, process and materials understudy	Data from process and materials under study but from different enterprises	Data from processes and materials under study but from different enterprises	Data on related processes or materials but with the same technology	Data on related processes or materials but with different technology

The data used in this study were targeted at the level of good or better, which corresponds to number 2 in the data quality assessment framework (Table 7.2). In practice, this means that data have at least the following qualities: 1) calculated based on measurements; 2) verified information from an enterprise which might have an interest in the study; 3) representative from a smaller number of sites but for adequate periods; 4) less than 5 years old; 5) average data from a larger area in which the area under study is included and from processes and materials under study though perhaps from different enterprises.

7.4 Case Study 1 – Construction of Lab Building in Habshan

The proposed building project (case study 1) is the Habshan lab building, which is located in the Western Region of Abu Dhabi (Figure 7.1 Elevation of the lab building).

Figure 7.1 Elevation of the lab building

7.4.1 Methodology followed for carbon emissions management — case study 1

Methodology adopted for the case study 1 project was based on the model developed in section 5.2, the literature review and the Survey 1 findings. In case study 1, carbon emissions of the construction phase are limited to embodied carbon emissions of activity, materials and transportation; only these were estimated and monitored due to Contractual limitation on the project. Carbon emissions due to construction equipment, site lighting, emissions savings due to waste management and recycling, and carbon emissions of the operation phase for energy and water are not included, as the contractor was claiming additional cost variation to estimate and monitor. The two models developed in section 5.3 were used to address the specific areas of the case study-1 project for improvement in carbon emissions management as follows:

- Mathematical model for estimation of carbon emissions in a building construction project; and
- Process model for monitoring and control of carbon emissions during the procurement and construction phases of a building project.

7.4.2 Estimation of embodied carbon emissions

The two models developed in section 5.3 were used to address the specific areas of the case study project for improvement in carbon emissions management as follows:

1. Mathematical model for estimation of carbon emissions in a building construction project; and
2. Process model for monitoring and control of carbon emissions during the procurement and construction phases of a building project

A three-step (bottom-up) analysis was implemented, in which a detailed material analysis is performed first, followed by a mass analysis and then by an ECO_2 analysis (Syngros et al., 2017). Due to the unavailability of carbon emissions data inventories for the UAE, relevant values of carbon emissions factors (I_k) were taken from existing literature and globally recognised databases (e.g., the ICE database [University of Bath, UK]) (Hammond and Jones, 2011). It should also be noted that carbon emissions management using earned value management deals with a comparison of the base case and actual spending, so the accuracy of carbon emission factors has less impact on this study. Embodied carbon emissions from the Bath ICE database are expressed as quantity per functional unit. Quantities from BOQ are multiplied with emissions factors after the quantities are brought to the same functional unit as that of the ICE database. Mathematical models based on the process analysis approach from section 5.3.1 are used to estimate the embodied CO_2 emissions of construction materials and transport activities:

$$EC_k = \sum_{k=1}^{n} . Q\text{k}. Ik \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7.1)$$

where:

EC_k - Embodied CO_2 of material type k, unit $KgCO_2$
Q_k – Total functional quantity of material
I_k – Embodied CO_2 factor – $KgCO_2$/functional unit of material

A further quantification of CO_2 emissions for transport from the factory gate to the site gate and the CO_2 emissions for site machinery and tools used during construction is calculated based on similar simple calculations using Excel:

$$\text{EC for Transport} = \sum_{k=1}^{n} .Qk.Tk \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 7.2$$

Building construction activities are estimated in terms of resources expended or utilised, such as material, man-power and tools. The embodied energy of each building resource is obtained from the ICE database and the literature review, and relevant embodied CO_2 emissions for transport are added to it to calculate the overall CO_2 emissions. Table 7.3 shows the Excel spreadsheet used to calculate material embodied CO_2 emissions.

Table 7.3 Resource-based embodied carbon emissions

S.NO			FOOTING	S.BLOCK	N.COL	TB	E.FILL	PCC FLR	COL	RCC SLAB	R.C.C.PPT	TOTAL	UNIT PRICE	TOT PRICE	Carbon E emissions/Unit	Total CO emissions
	QUANTITIES HERE	→	100	100	10	20	200	20	10	80	20					
	MATERIAL															
		1CUM					0.03									
	SHOWEL WORK	Total Qty					6					6.00	200	1200		
		1CUM					0.01	0.02								
	COMPACTOR	Total Qty					2	0.4				2.40	11	26.4		
		1CUM					1									
	FILLING SAND	Total Qty					200					200.00	12	2400		
		1CUM														
	O.P.CEMENT	Total Qty										0.00	16	0	0.95	0
		1CUM		0.15												
	S.R.C.CEMENT	Total Qty		15								15.00	16	240	0.95	712.5
		1CUM														
	WHITE CEMENT	Total Qty										0.00	40	0	0.95	0
		1CUM		0.03												
	BLACK SAND	Total Qty		3								3.00	50	150		34.272
		1CUM														
	WHITE SAND	Total Qty										0.00	80	0		0
		1CUM														
	AGGREGATES	Total Qty										0.00	65	0	0	0
		1CUM	0.05		0.05	0.05			0.05	0.05	0.05					
	WOOD	Total Qty	5		0.5	1			0.5	4	1	12.00	1100	13200		
		1CUM	0.4		2.5	0.04			0.4	3	0.75					
	NAILS	Total Qty	40		25	0.8			4	240	15	324.80	10	3248		
		1CUM							0.3	0.01	0.2					
	COTTON STRING	Total Qty							3	0.8	4	7.80	12	93.6		
		1CUM						0.1								
	S.R.C.300 MIX	Total Qty						2				2.00	320	640	0.12	576

Later estimates are uploaded as base cases in the Primavera planning tool, with which the cost estimates, resource estimates and embodied CO_2 emissions base case estimates are used to compare and monitor during construction.

7.4.3 Integration of carbon emissions management with cost and time management using Primavera

The model presented in section 5.3.2 and as shown in Figure 7.2 is used to integrate the carbon emissions management using a simple-in-use tool (Primavera). A similar method was used by Varma et al. (2016), but by using another project control tool (CCS Candy). This demonstrates the preference of the industry in using SIUTs, which was validated by the findings of the survey in Figure 6.38 - Preference of tools to assess and monitor carbon emissions.

Define the work based on a review of the scope of work, drawings, bill of quantities and specifications and prepare a work break structure (WBS) for the project. Assign the activities under the respective WBS, set the duration of each activity and arrange the predecessor and successor to activities according to the method of execution. Project schedules are prepared based on the quantities and the available resources, so each activity is loaded with cost and resources, respectively. Upon loading all durations, resources and costs for each activity, the programme is run to schedule the activities. Upon agreement and approval of the engineer or any other party as per the contract, the base-line plan is frozen (i.e., the budgeted cost and budgeted quantities of the project are used as a baseline in Primavera to compare, monitor and produce reports on any time frame such as daily, weekly, monthly and yearly).

Carbon emissions management in a project is integrated with cost and time management using Primavera. The resource directory is created from Enterprise, wherein the resource name, hours per day and unit cost are included. In order to use a similar approach, the embodied CO_2 emissions of each resource (i.e., RCC, blockwork) are entered into Enterprise (e.g., ‘Embodied Carbon Emissions for RCC’) as a resource, and the unit cost of the resource column is used for ‘carbon emissions factor’ (i.e., the CO_2e for RCC).

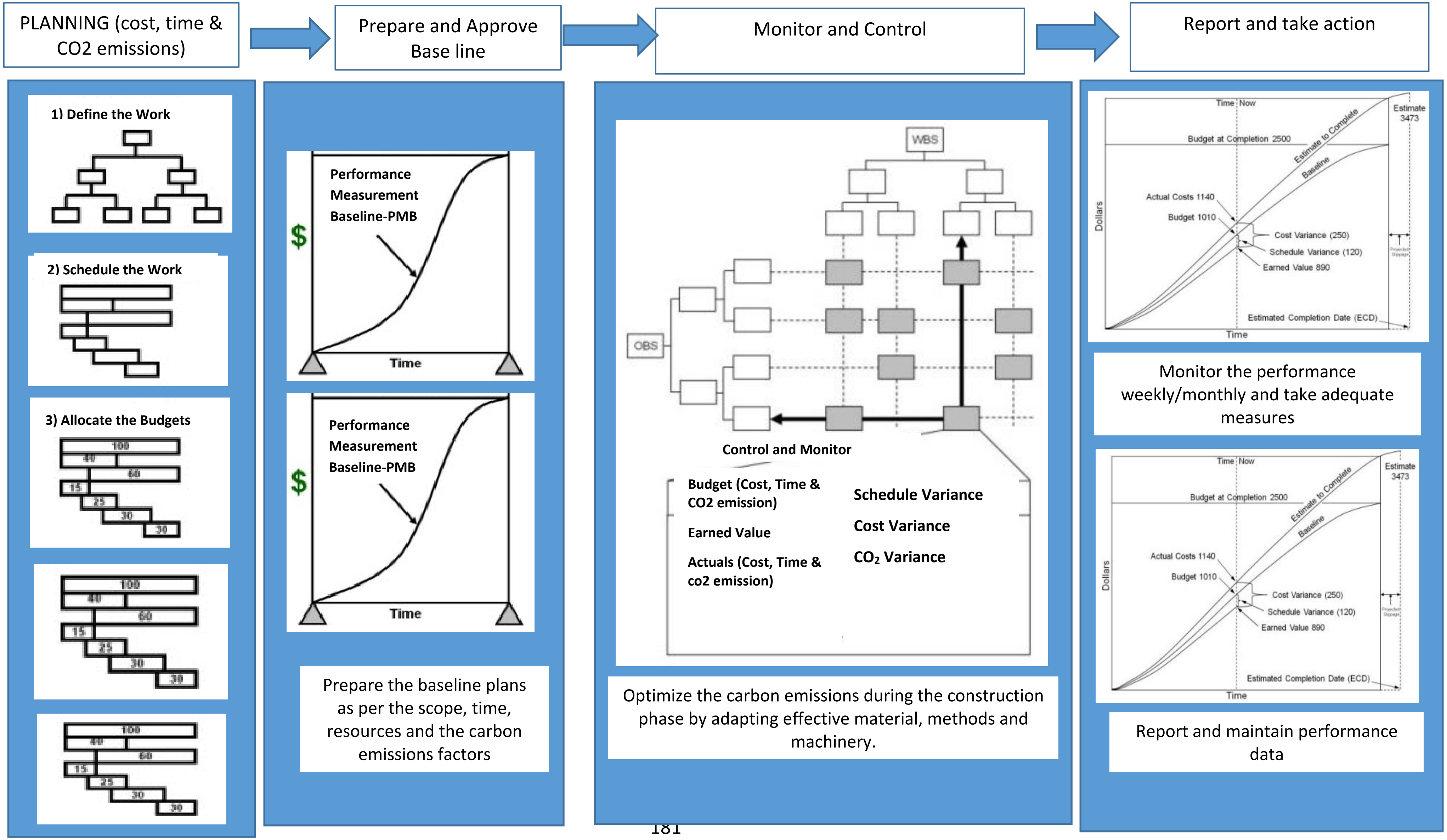


Figure 7.2 Integrated CO_2 emissions monitoring and control model (CE-MCM)

Once the resource is created, it is assigned to each activity using the assign window, which constitutes the resources drop list, resources budgeted quantity, resources actual quantity, remaining quantity, etc. The same approach was used to create and assign the embodied carbon emissions resources to produce the S curves of prime building activities in the next section.

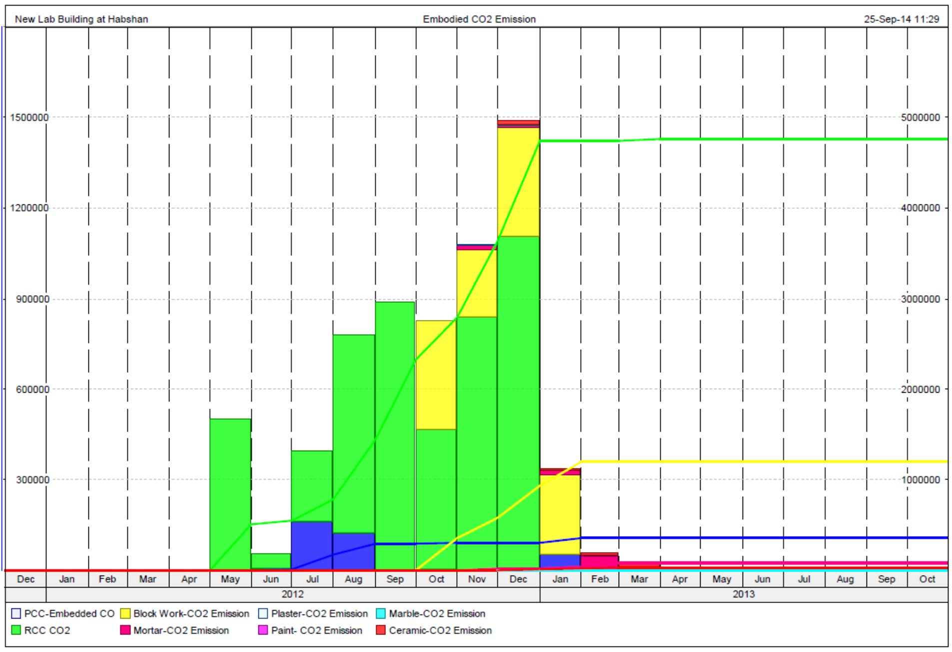


Figure 7.3 S Curve of CO_2 emissions for major elements

Case study analysis was carried out for embodied CO_2 emissions of only key elements, such as PCC, RCC, blockwork, plaster and ceramic. Figure 7.5 and Figure 7.5 show the S Curve generated through Primavera using the ICE emission factors. The planned S Curve is set as the base plan, and actual embodied CO_2 emissions are monitored with the base plan as a benchmark. Individual element CO_2 emissions variances, as shown in Figure 7.6, will be used to report the performance at an elemental level, whereas the overall project carbon emission variances are tracked and monitored in the same way as SPI and CPI using the P6.

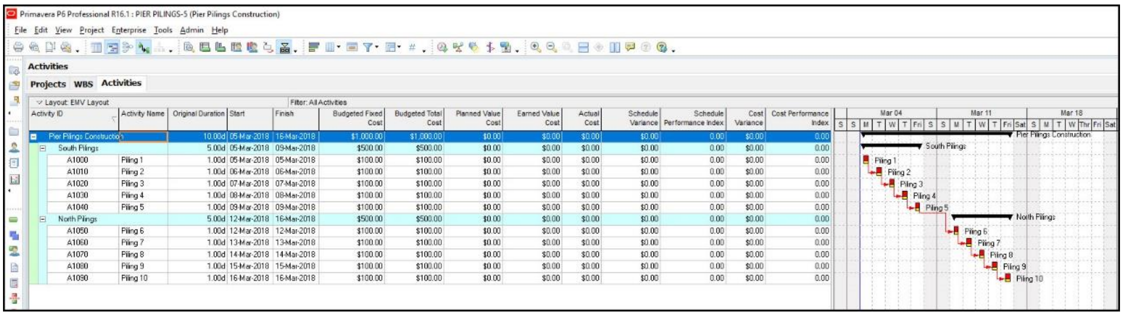


Figure 7.4 SPI and CPI calculations using Primavera

Contractors performing as per the SPI and CPI thresholds and minimising embodied CO_2 emissions through alternate selections of materials, waste minimisation, alternative designs, efficient work methods and reducing travel distances are considered good performers in terms of sustainability and vice versa. As per Figure 7.5, the CEPI and SSPI are obtained from primavera during and after completion of the project.

Table 7.4 CEPI and SSPI bi-yearly values

Timescale	Carbon Emissions Performance Index (CEPI)	Sustainability Schedule Performance Index (SSPI)	Remarks
	Over budget (< 1) or Under budget (> 1)	Ahead of schedule (> 1) or behind schedule (< 1)	
6 Months	0.918	1.01	CEPI was over budget during the initial period due to lack of awareness of the execution team.
12 Months	1.05	1.10	Project was behind schedule; however, carbon emissions were improved mainly due to savings on RCC.
18 Months	1.20	1.00	Net savings of 20% is evident through CEPI.

Table 7.4 shows the values of the CEPI and SSPI at an interval of 6 months until completion. Initial over-budget spending is normal on sustainable projects, as identified by Clayson et al. (2018) in a study carried out in the U.S. of environmental remediation projects. The study stated that CPI usually stabilises when projects are approximately 40 percent complete. Case study-1 project too demonstrated the similar performance which shows that CEPI stabilized after 12 month which is 50% progress complete.

7.4.4 Graphical output of S Curve from Primavera

Estimation and monitoring of embodied carbon emissions is made easy by the use of simple-in-use tools as well as the embodied carbon emissions factors available for the industry through the ICE database. The approach and fundamentals are the same as those for progress monitoring for project stakeholders to improve implementation levels. Figure 7.5 shows the budgeted (estimated) CO_2 emissions of primary elements, such as ceramic, reinforced cement concrete, mortar, blockwork 200mm thick and plain cement concrete, which is set as the baseline for monitoring the emissions during the construction phase.

The SIUT approach requires estimated quantities of the building, then by using an embodied carbon footprint inventory associated with different materials and the transportation distance to the job site, the expected carbon footprint is calculated for each construction schedule activity at the bidding stage similar to cost/time estimates.

Upon award, the information from the contractor submittals, request for inspection forms and daily reports is used to measure the released carbon footprint for the same activity. Data is recorded at the site for material, quantities and fuel type used by the main contractor and subcontractors during the construction phase on a monthly basis. The conversion factors were used from the DEFRA Guide (DEFRA, 2012). Similar to the approach used by Davies et al. (2014), the embodied carbon of materials required in the execution of each elemental activity was assessed via the ICE material database.

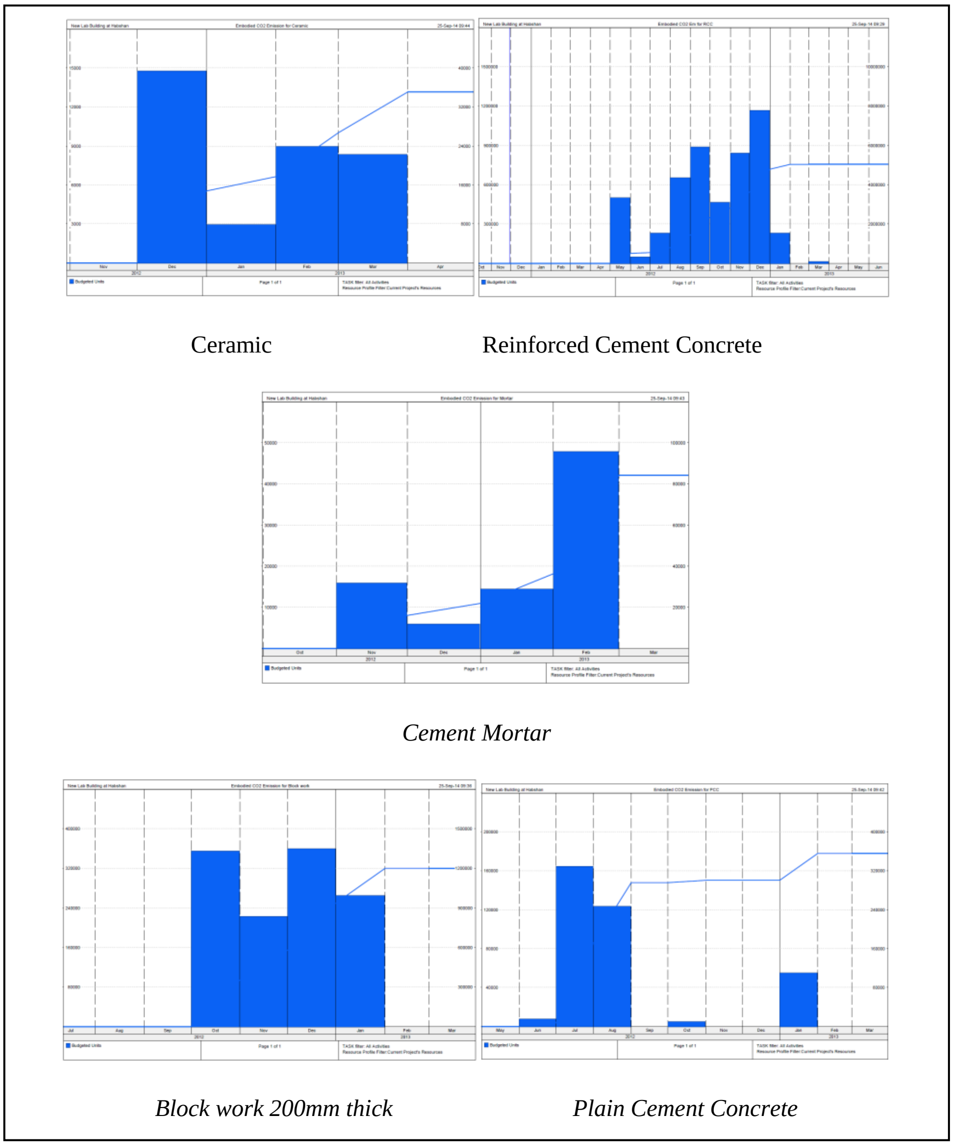
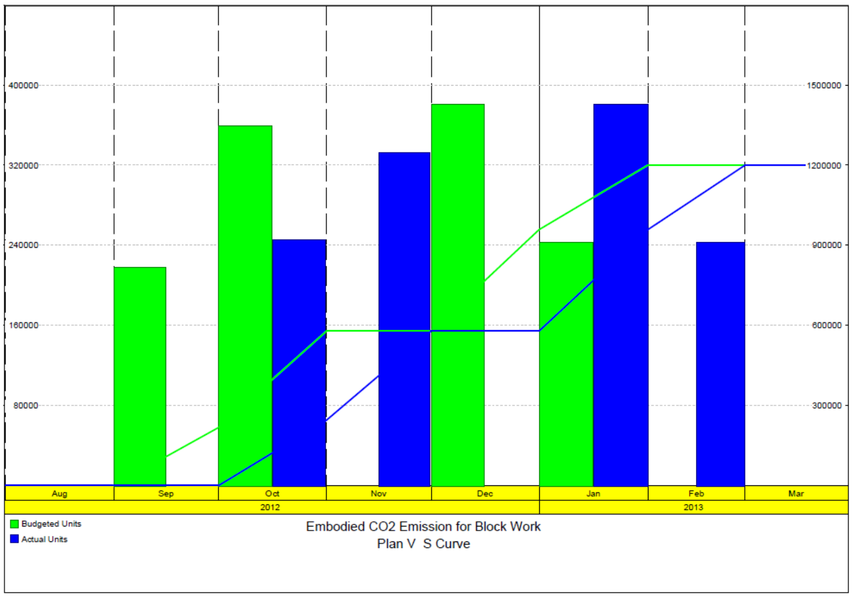


Figure 7.5 Budgeted (estimated) CO_2 emissions of primary elements

The estimated and actual carbon emissions associated with each activity are compared for monitoring, similar to earned value analysis using SIUT.



Tracking of Budgeted vs Actual Embodied CO_2 emissions- Block Work

Figure 7.6 Curves for planned and actual embodied CO_2 emissions

The study found that the UAE can achieve a higher implementation rate of carbon emissions management by simplifying the estimating and monitoring tools based on the survey responses received from the industry specialist in Table 6.5 – Factors for improving the implementation levels of sustainable management. Simplifications can be achieved through increasing awareness, stringent regulations and access to the data metrics of carbon emissions factors. The study found that the cost and time management implementation is higher due to use of less complicated SIUTs such as Excel spreadsheets and Primavera.

7.4.5 Results and discussion for case study 1

The percentage contribution and the savings achieved from the building elemental materials on total carbon emissions for the case study 1 Lab building is presented in Table 7.5. The estimated embodied carbon per unit area of the Lab building (1320 M^2) based on the main elements was found to be 1,195 kg CO_2/m^2 after the award stage. Upon implementation of the CE-EM model and the CE-MCM model, the embodied carbon emissions for the Lab building (eight-building element and transportation) was reduced to 958.41 kg CO_2/m^2. RCC was found to be a major contributor to carbon emissions followed by the transportation emissions. The results of many previous studies on reinforced concrete structures agree with the significant contribution of concrete and steel to carbon emissions in the material production stage (Asif et al., 2007; Biswas, 2014; Dimoudi and Tompa, 2008; Hong et al., 2015; Kofoworola and Gheewala, 2008).

Site location far in desert added up to the additional emissions for transportation, but when compared to emissions in United kingdom which was 32% in 2008, the values are comparatively low in case study 1 i.e. 25% only (SFCC, 2010).

Table 7.5 Summary of actual carbon emissions of case study-1

S.No	Material	Units	Cum	Density kg/m^3	ECC $kgCO_2e/kg$	Planned carbon emissions in kg/CO_2e	Actual carbon emissions in Kg/CO_2e	Remark
1	Blinding concrete	M^3	131.67	2,350	0.123	38,059.21	30,827.96	ECC=0.123 prior to optimization
2	RCC concrete	M^3	3,122.51	2,350	0.132	968,601.60	755,509.25	ECC=0.132 prior to optimization
3	Waterproofing membrane	M^2	1,256.74	4.3	4.20	22,696.80	18,157.44	mass per unit area 4mm thick = 4.3 kg/m^2
4	Hollow blockwork 400x200x200mm	M^3	1,167.93	1437	0.063	105,733.76	94,103.05	
5	Plaster	M^3	54.64	1600	0.213	18,622.79	16,015.60	12mm thick plaster
6	Paint	M^2	1,133.07		2.54	2,878.00	2,762.88	Coverage for 2 coats 3.33 sqm/kg
7	Ceramic floor and wall tiles	M^3	1,762.79	20.97	0.74	27,354.60	24,619.14	ICE and GreenSpec 0.74$kgCO_2e/kg$, @ 20.97 kg/m^2 as per product data sheet
8	HVAC ductwork	M^2	370.00		19.94	7,377.80	6,566.24	19.94 kg CO_2eq/M^2
9	Transportation	LS	1.00			386,731.00	316,543.00	Refer appendix B for detailed Carbon emissions
	Total CO_2 emissions					1,578,056	1,265,105	$KgCO_2e$

7.4.6 Carbon emissions reduction measures adopted in case study 1

Case study-1 project achieved the optimisation in embodied carbon emissions of material and transportation as compared to the base case calculation carried out at the onset of the project, as shown in Table 7.5. Only key elements of the project were estimated, monitored and controlled using the CEM model. The reduction measures in achieving 20% lower embodied CO_2 emissions in case study-1 project are:

- Teams involved in design and construction were informed about the sustainable objective of the project. The team was made aware of carbon emissions monitoring and the means of achieving emissions reductions from time to time during design meetings and construction progress meetings.
- Re-engineering was carried out after award to review the design and make the structure lean. This resulted in the reduction of concrete and steel cross-sections.
- Alternative materials were used instead of those proposed to reduce CO_2 emissions, such as concrete, steel, aluminium, glass, doors, ceramic, water-proofing, masonry, cement, insulation, backfill material, paint, chemicals, adhesives, etc.
- Concrete-related embodied emissions were reduced by increasing the Ground-granulated blast-furnace slag (GGBS) content in the design mix. The initial specified supplier was also replaced with a supplier who has batching plants in a nearby location closer to the site.
- Turkey steel was replaced with Emirates steel, which has lower embodied carbon emissions and also required smaller travel distances from the factory gate to the site. Steel and aluminium procured had recycled content, which reduced embodied emissions.
- Ceramic tiles made in Italy were replaced by tiles made locally (RAK Ceramics) to reduce the embodied carbon emissions in travel and product.
- Blockwork, interlock and masonry material were procured from nearby sources rather than sourcing them from Dubai, which is 300 km away from the site location. Also, the product manufacturers were informed about the project’s assessment, which resulted in the manufacturer producing the concrete blocks with less embodied energy.
- Cement was procured from a local manufacturer (Al Ain Cement) rather than cement being imported from other countries, which resulted in savings in embodied energy.
- Backfill soil and aggregate were taken from the closest quarries to reduce the emissions related to transportation. Meetings were conducted with the

regional municipality to allot a quarry near the site location by explaining the project's CO_2 reduction objective.

- Waterproofing material manufactured in the UAE was used rather than the products imported from EU-specified material, to reduce the embodied carbon emissions.
- HVAC chillers and construction materials were replaced with local manufactured equipment and materials to reduce emissions.
- Formwork and plywood were re-used 3 times or more times with adequate care, reducing the purchase of new material.
- Reduction in waste was on the priority list, and material ordering-as-required philosophy was implemented.
- Waste segregation and recycling of waste were promoted.
- Awareness sessions and daily recording of consumption led to a controlled use of materials, machinery and transportation.
- Reduction in the use of power, use of water and idle machinery and tools kept running was discouraged with proper awareness sessions.
- Machinery in use was well maintained to reduce emissions.
- A tower crane for construction use was replaced with mobile cranes (use when required) to reduce electricity consumption.
- The office and accommodations of workers and staff were kept closer to the site as much as possible to reduce the transportation distances.
- Carpooling was promoted to reduce emissions related to transportation.

7.4.7 Conclusion of case study 1

This case study demonstrates that the implementation rate will increase by using simple-in-use tools such as Excel and Primavera for carbon emissions management. Also, as the project performance, material used, transportation emissions were being monitored on case study-1 project, the researcher noticed a sense of accountability. The factor of being monitored and recorded also played an important role in reducing carbon emissions. Project team were motivated when the results were being shared on their achievement of carbon emission reduction; this was recognized and rewarded by the contractor management as a positive sign. The approach of using a simple Excel spreadsheet in combination with Primavera Project Planner and the ICE database assisted contractors, consultants and clients to make informed decisions about the carbon emissions of each element in the building. By seeing the results of case study-1, the researchers recommend making a start in implementing carbon emissions management at the organisational level by using SIUTs on elements which are major contributors of CO_2 emissions in a project. Also, the researcher recommends to include more building elements in the study to achieve better results. The CEM model shall be implemented on all projects due to its ease and acceptability. In doing so, an organisation can gradually build up a company-specific database for corresponding resources (such as man-power, equipment and material) and its CO_2 emissions to ensure a competitive advantage.

7.5 Case Study 2 – Construction of Mechanical Store and Workshop Building in Bu Hasa

A summary of the project details are shown in Table 7.6.

Table 7.6 Case study 2 project details

Description	Workshop building – Buhasa (case study 2)		Mechanical store building – Buhasa (case study 2)
	Workshop equipment area	Office, services area and substation area	
Floor area	1050 Sqm	3482 Sqm	678 Sqm
Number of floors	Ground only	Two floors	Ground only
Floor height	10 Mts	10 Mts	10 Mts
Floor-to-floor height	9.5 Mts	4 Mts	9.5 Mts
Foundation	Cast-in-situ RCC	Cast-in-situ RCC	Cast-in-situ RCC
Structure – columns	Hot-rolled steel sections	Cast-in-situ RCC	Hot-rolled steel sections
Structure – beam	Hot-rolled steel sections	Cast-in-situ RCC	Hot-rolled steel sections
Structure – 1st floor slab	NA	Cast-in-situ RCC	NA
Structure – 2nd floor/ roof	Hot-rolled steel sections with insulated sandwich panel	NA	Hot-rolled steel sections with insulated sandwich panel
Structure – floor	Cast-in-situ RCC	Cast-in-situ RCC	Cast-in-situ RCC
Exterior skin	Cement corrugated cladding/ plaster/paint	Cement plaster/paint	Cement corrugated cladding/ plaster/paint

Figure 7.7 3D Model of New Workshop and Mechanical Store Project

7.5.1 Methodology followed for carbon emissions management — case study 2

The methodology adopted for the case study 2 project was based on the model developed in section 5.3, the literature review, Surveys 1 and 2 findings and the lessons learned from case study 1. In case study 1, the carbon emissions of the construction phase were limited to the embodied carbon emissions of activity materials and transportation, and only these were estimated and monitored. In case study 2, the scope was increased with estimation and monitoring of embodied carbon emissions related to activity materials, transportation, energy and fuel use for construction equipment, waste recycling, and operational phase emissions reduction for water and energy. Moreover, 29 building element items for Mechanical store and 38 building element items for Workshop building were included in the study.

The two models developed in section 5.3 were used to address the specific areas for improvement in the carbon emissions management of the case study project, as follows:

- Mathematical model for estimation of carbon emissions in a building construction project; and
- Process model for monitoring and control of carbon emissions during the procurement and construction phases of a building project.

7.5.2 Estimation of embodied carbon emissions

Based on the carbon emissions coefficient method and the LCA approach, the total embodied carbon emissions of a building were calculated (Chau et al., 2015; Kumanayake and Luo, 2018).

The mathematical model based on a process analysis approach is shown below:

$$EC_k = \sum_{k=1}^{n} .Q_k.Ik+\sum_{k=1}^{n} .Q_k.T_k + \sum_{k=1}^{n} .Q_k.E_k \quad \text{------------------- -------------} \quad (7.3)$$

where:

EC_k - Embodied CO_2 of material of a building, unit $KgCO_2$

Q_k – Total functional quantity of material

I_k – Embodied CO_2 factor – $KgCO_2$/functional unit of material

T_k – CO_2 factor for travel distance – $KgCO_2$/functional unit of material/per KM

E_k – CO_2 factor for energy used at site construction – $KgCO_2$/functional unit of material

The embodied carbon emissions for the material includes the extraction of the raw materials, and the material production can be estimated as given in Eq 7.3. (Li et al., 2016). Due to the unavailability of carbon emissions data inventories for the UAE, relevant values of carbon emissions factors (I_k) were taken from the existing literature and globally recognised databases such as the ICE database (Hammond and Jones, 2011). Carbon emissions management using earned value management deals with a comparison of the base case and actual spending, so the accuracy of carbon emission factors has less impact on this study.

The transportation-related carbon emissions involves the material transportation calculated based on the amount of carbon emitted by the types of vehicles used to deliver materials and transport man-power to the construction site. The equation for transportation-related emissions was developed using the methodology suggested in the literature (Devi and Palaniappan, 2014). The carbon emissions coefficients for various types of transportation were calculated using data obtained from the research literature and local and international reports, such as the Common Carbon Metric (United Nations

Environment Programme, 2010), International Energy Agency statistics (IEA, 2015) and DEFRA statistics.

Carbon emissions related to equipment tools and lighting (E_k) used during the construction phase were estimated using fuel/electricity usage rates. The equation was developed using the methodology suggested in the literature by various researchers (Devi and Palaniappan, 2014; Kumanayake and Liu, 2018). The data related to typical construction activities of a reinforced concrete building were obtained from data collection (i.e., from the in-house data repositories of various construction companies and in consultation with construction professionals).

7.5.3 Monitoring and control of carbon emissions

The process-based model for monitoring and controlling carbon emissions for construction projects covers four stages: planning, preparing a baseline, monitoring and reporting the carbon emissions. The CE-MCM process model of the overall CEM framework is presented in Figure 7.8, showing the four stages. The four stages are the sub-processes of the CE-MCM process and are carried out using simple-in-use tools such as Excel, Primavera and Microsoft Project; hence, it is called an SIUT model.

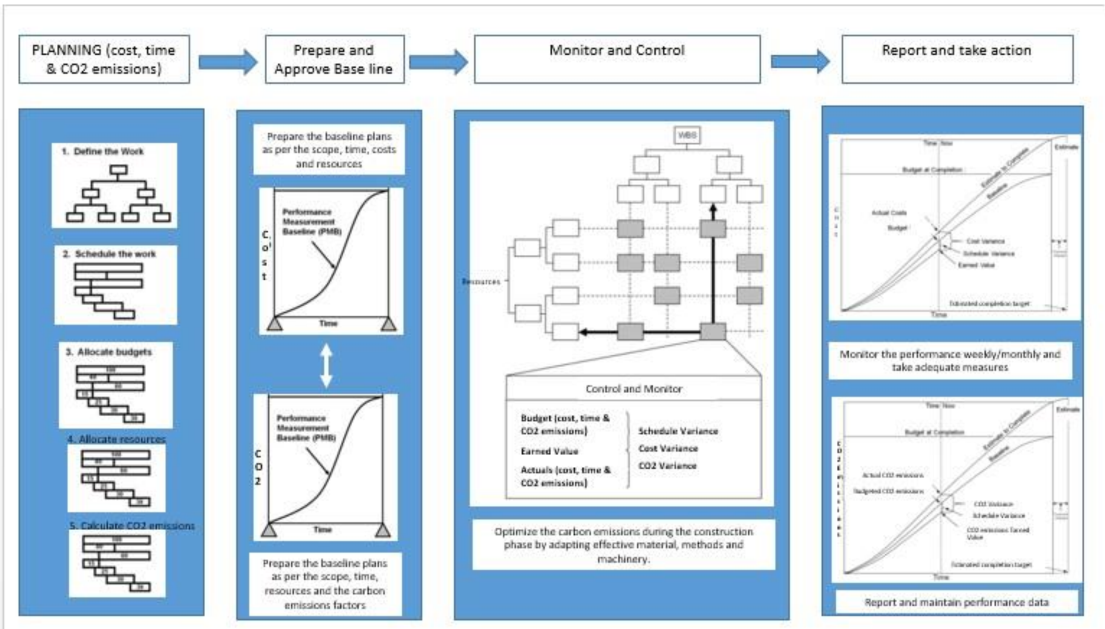


Figure 7.8 Integrated CO_2 emissions monitoring and control model (CE-MCM)

Define the work upon review of the scope of work, drawings, bill of quantities and specifications and prepare a work break structure for the project. Assign the activities under the respective WBS, assign the duration of each activity and arrange predecessors and successors to activities according to the method of execution. Project schedules are prepared based on the quantities and the available resources, so each activity is loaded with costs and resources. Upon loading all durations, resources and costs for each activity, the programme is run to schedule the activities. Upon agreement and approval of the engineer or any other party as per the contract, the base-line plan is frozen (i.e., budgeted costs and budgeted quantities of the project are used as baselines in Primavera to compare, monitor and produce reports on any time frame such as daily, weekly, monthly or yearly).

The resource directory is created from Enterprise, in which the resource name, hours per day and unit cost are included. To use a similar approach, embodied CO_2 emissions of each resource (e.g., RCC, blockwork) is created in Enterprise. For example, 'Embodied Carbon Emissions for RCC' would be a resource, and the unit cost of the resource column is used for 'Carbon emissions factor' (i.e., the CO_2e for RCC). Once the resource is created, it is assigned to each activity by using the assign window, which constitutes the resources drop list, resources budgeted quantity, resources actual quantity, remaining quantity, etc. The same approach was used to create and assign the embodied carbon emissions resources to produce the S curves of all building activities.

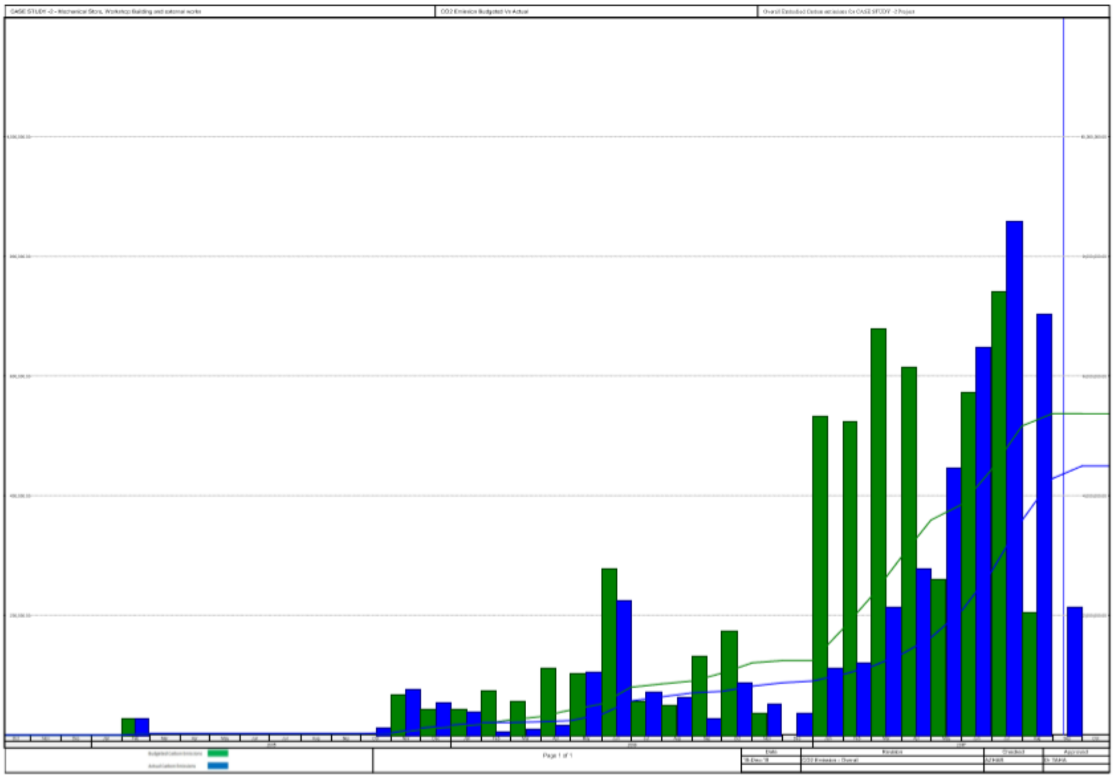


Figure 7.9 S Curve of CO_2 emissions for all planned and actual major elements, case study 2

Case study analysis was carried out for embodied CO_2 emissions of only 39 key elements for the workshop building and 30 for the mechanical store building, as shown in Table 7.8 and Table 7.12. Figure 7.5 shows the S Curve generated through Primavera using the ICE emission factors. The planned S Curve is set as the base plan, and actual embodied CO_2 emissions are monitored using the base plan as a benchmark. Individual element CO_2 emission variances, as shown in Figure 7.9, are used to report the performance at the elemental level. The overall project carbon emission variances are tracked and monitored in the same way as SPI and CPI using the P6, as in Figure 7.10.

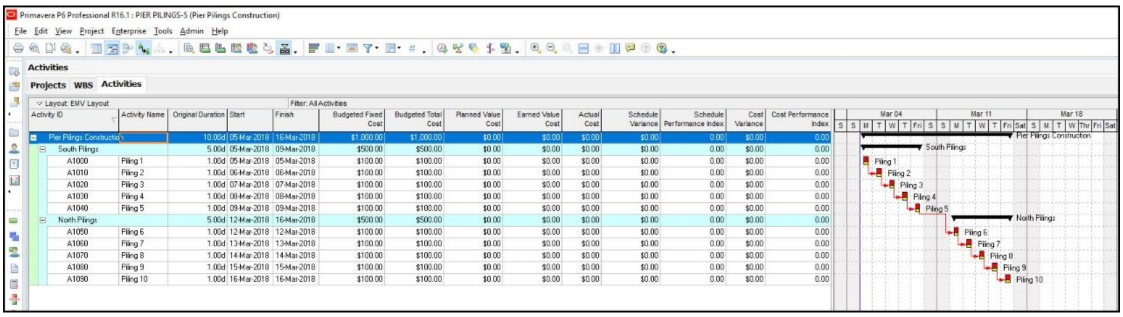


Figure 7.10 SPI and CPI calculations for case study 2 using Primavera

Contractors performing according to the SPI and CPI thresholds and minimising embodied CO_2 emissions through alternative selections of material, waste minimisation, alternative design, efficient work methods and reducing travel distances are considered good performers in terms of sustainability and vice versa.

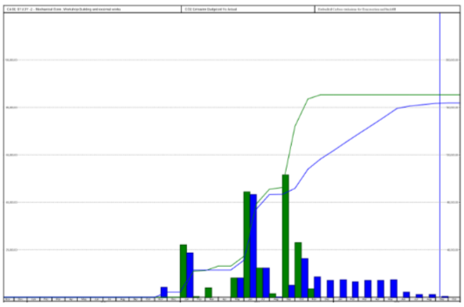
Table 7.7 CEPI and SSPI bi-yearly values for case study 2

Timescale	The Carbon Emissions Performance Index (CEPI)	Sustainability Schedule Performance Index (SSPI)	Remarks
	Over budget (< 1) or Under budget (> 1)	Ahead of schedule (> 1) or behind schedule (< 1)	
6 Months	0.861	1.30	CEPI was over budget during the initial period due to lack of awareness among the execution team.
12 Months	0.96	1.19	Project was behind schedule; however, carbon emissions were improved mainly due to savings on RCC.
18 Months	1.20	1.15	
24 Months	0.83	1.00	Net savings of 17% is evident through CEPI.

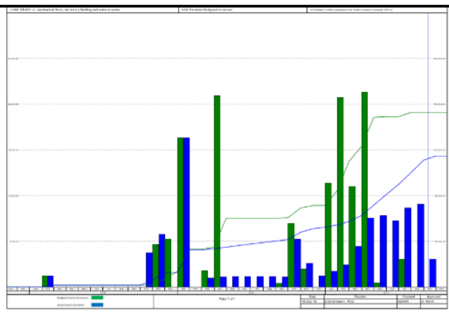
As per Table 7.7, the CEPI is 0.83, which shows 17% savings for the base case, and SSPI varied between 1.3 to 1.00 during the project. The table below shows the values of CEPI and SSPI at intervals of 6 months until completion. At initial months 6 and 12 of the project, over-budget spending is normal on sustainable projects, as identified by Clayson et al. (2018) in a study carried out in the U.S. of environmental remediation projects. The study stated that CPI usually stabilises when projects are approximately 40 per cent complete.

7.5.4 Graphical output of S Curve from Primavera

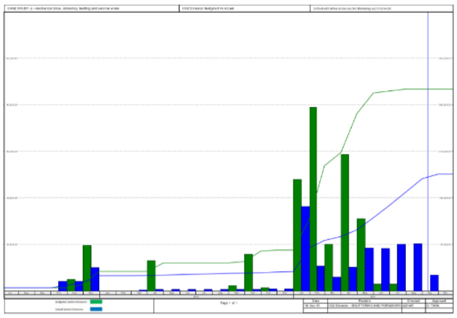
Estimation and monitoring of embodied carbon emissions is made easy by the use of simple-in-use tools and the embodied carbon emissions factors available for the industry through the ICE database. The approach and fundamentals are the same as in progress monitoring for project stakeholders to improve implementation levels. Figure 7.11 shows the budgeted (estimated) CO_2 emissions and actual carbon emissions of primary elements such as excavation, plain cement concrete, reinforced cement concrete, block work 200mm thick, shuttering and waterproofing membrane, which are monitored using Primavera P6 and were reported using the EVM method for the emissions during the construction phase.



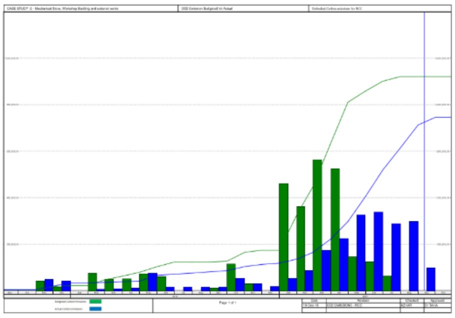
Embodied carbon emissions for excavation



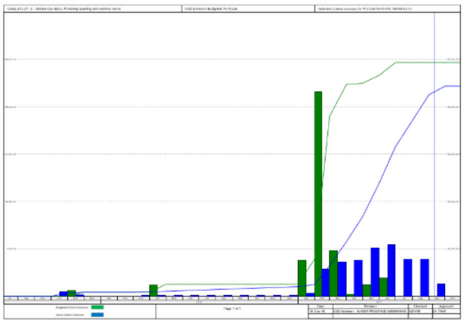
Embodied carbon emissions for PCC



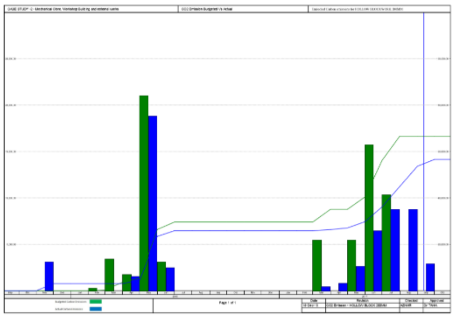
Embodied carbon emissions for shuttering



Embodied carbon emissions for RCC



Embodied carbon emissions for WP membrane



Embodied carbon emissions for blockwork membrane

Figure 7.11 Embodied carbon emission performance at the elemental level, case study 2

Every element of the building is monitored and are included in Appendix-C. The overall carbon emissions savings achieved compared with the budgeted carbon emissions are shown in Figure 7.12.

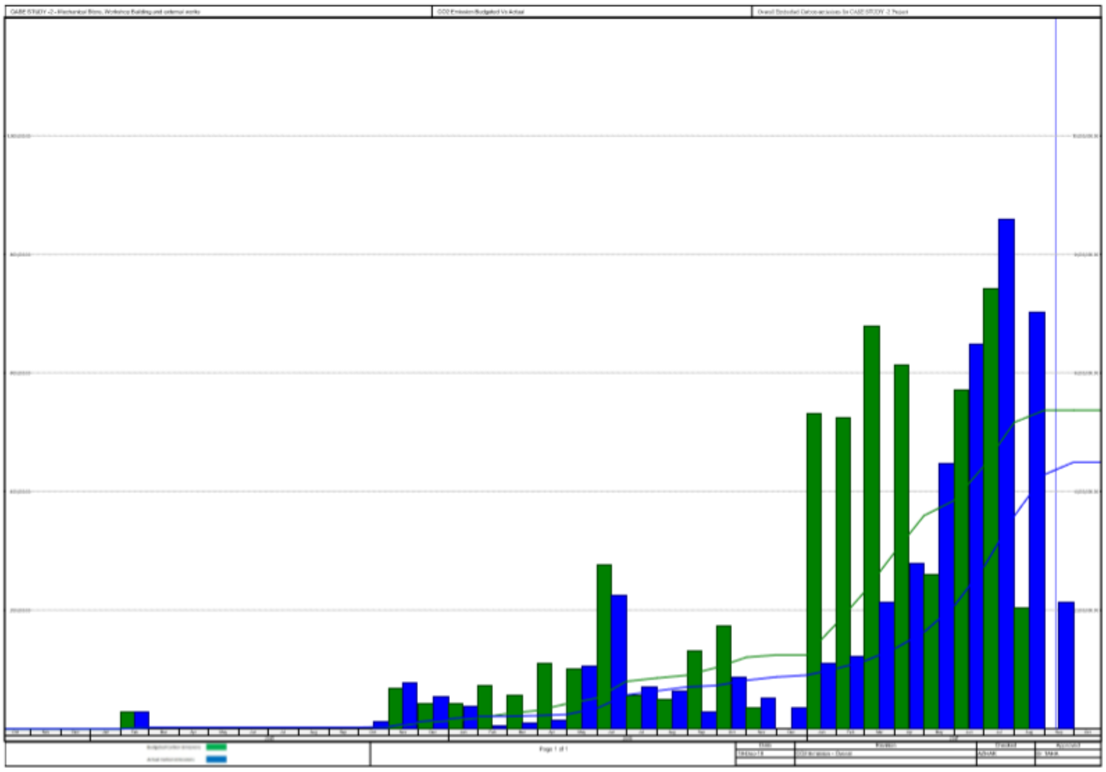


Figure 7.12 Overall carbon emissions performance on the case study 2 project

7.5.5 Results and discussion

7.5.5.1 Embodied carbon emissions of materials

A building comprises numerous materials, including those making the major contributions to the overall emissions. Therefore, to increase the efficiency of managing carbon emissions, the approach of major building materials contributors has been adopted in several previous studies (Roh et al., 2014a; Roh and Tae, 2016; Tae et al., 2011). Using a pilot survey conducted on several construction companies dealing with reinforced concrete buildings in the UAE, the major building materials were identified as RCC concrete, structural steel, blockwork, rubble, cement, sand, steel windows, glass, aluminium, ceramic tiles, false ceiling, waterproofing, insulation boards, paint asphalt, metal pipes, trays, conduits and HVAC equipment.

The percentage contribution and the savings achieved from the building elemental materials on total carbon emissions for the mechanical store building is presented in Table 7.8. The embodied carbon per unit area of the mechanical store building (678 M^2) based on the main elements was found to be 1,376 kg CO_2/m^2 after the $COCO_2$ tendering stage. After implementation of the CE-EM model and the CE-MCM model, the embodied carbon emissions for the mechanical store building (excluding external works) was reduced to 1143 kg CO_2/m^2.

Table 7.8 Overall embodied carbon emissions (plan vs actual) for mechanical store building

S. No	Material	Units	Cum.	Density kg/m³	ECC kgCO² e/kg	Carbon emissions in kg/CO₂e	Actual Carbon emissions in Kg/CO₂e	Remark
1	Excavation and backfilling	M^3	909.33	1800	0.01	8,347.65	8,013.74	
2	Blinding concrete	M^3	113.76	2,350	0.123	32,883.22	24,662.42	ECC=0.123 prior to optimisation
3	RCC concrete	M^3	515.69	2,350	0.132	159,967.66	129,509.82	ECC=0.132 prior to optimisation
4	Shuttering and formwork	M^3	166.85	540	0.325	29,281.64	16,951.14	0.65 kg CO_2/kg. Plywood is used twice for formwork; hence, ECC is 0.325. Also, units are converted to M^3.
5	Polythene sheet-125 micron	M^3	0.11	910	2.54	264.52	253.81	910 kg/m³ x Qty m² x 125x10-6 m
6	Waterproofing membrane	M^2	198.31	4.3	4.20	3,581.48	3,219.75	Mass per unit area 4mm thick = 4.3 kg/m²
7	Waterproofing paint	M^2	1,216.9	4	4.20	20,444.96	18,625.36	
8	Waterproofing protection board (XPS)	M^2	88.90	390	0.32	11,095.13	9,990.06	Mass/area = 4.88 x 80 = 390 kg/m²
9	Cement screed	M^3	62.46	2100	0.221	28,986.29	26,099.26	cement sand 1:3
10	Insulation board 50 mm thick	M^3	47.49	45	4.39	9,382.46	8,558.68	Extruded polystyrene insulation boards
11	Hollow block work 400x200x100mm (Sqm)	M^3	94.99	1750	0.063	10,472.45	9,886.00	8 Mpa comp strength
12	Hollow block work 400x200x200mm (sqm)	M^3	236.97	1437	0.063	21,453.54	19,093.65	
13	Solid block work 400x200x200	M^3	195.00	2000	0.107	41,730.00	37,139.70	

14	Plastering (internal) — cement, lime sand	M^3	167.14	1600	0.213	56,960.66	48,986.17	12mm thick plaster
15	Plastering (external) — cement, sand	M^3	139.77	1900	0.182	48,331.92	42,048.77	15mm thick plaster
16	External epoxy paint	M^2	407.50		3.13	1,275.48	1,173.44	Coverage for 3 coats 2.22 sqm/kg
17	Internal emulsion paint	M^2	406.08		2.54	1,031.45	990.19	Coverage for 2 coats 3.33 sqm/kg
18	Floor paint	M^2	677.37		3.13	2,120.16	2,014.15	ICE and GreenSpec 3.13kgCO_2e/m^2
19	Structural steel	kg	66,329		3.77	250,060.33		
20	Sandwich roof sheeting	M^2	776.29		69.85	54,223.86	249,128.00	69.85 kgCO_2e/m^2 Embodied carbon calculated as per product data sheets and the ICE values
21	Aluminium flashing	M^2	93.80		27.19	2,550.42		27.19 kgCO_2e/m^2 Embodied carbon calculated as per product data sheets and the ICE values
22	Steel doors single leaf	kg	225.84		3.77	851.42		Each door weight is 75.28kgs
23	Roller shutter (3 No's) - 6x5m	kg	3,420		3.77	12,893.40		38 kg/m^2 as per product data sheet and ICE value 3.77 kgCO2e/kg for steel
24	Steel-framed double-glazed windows (1.5mx1.5m)	kg	890.00		3.77	3,355.30	12,261.77	Each window weight is 89kgs
25	Steel-framed double-glazed windows (1.5mx2.4m)	kg	1,248		3.77	4,704.96		Each window weight is104kgs
26	Iron pipes for chilled water supply	LM	708.00		2.87	107,856.44	98,149.36	Factors from World Steel Association. 219mm; '60'SCH: 53.08 kg/lm
27	PVC conduit	LM	670.00		3.23	670.87	642.69	From product data sheet Wt = 0.31 kg/lm
28	HDPE pipes	LM	105.00		2.52	1,420.90	1,307.23	PN 6 wt 5.37 kg/lm
29	HVAC ductwork	M^2	370.00		19.94	7,377.80	6,566.24	19.94 kg CO_2eq/m^2
	Total CO_2 Emissions					**933,576.38**	**775,271.40**	**KgCO_2e**

The main structural material (reinforced concrete and structural steel) had the highest contribution to total material-related carbon for the mechanical store building, which was 24.87 % for PCC, RCC and screed and 34.4% for structural steel. The results of many previous studies on reinforced concrete structures agree with the significant contribution of concrete and steel to carbon emissions in the material production stage (Asif et al., 2007; Biswas, 2014; Dimoudi and Tompa, 2008; Hong et al., 2015; Kofoworola and Gheewala, 2008). Although the quantity of sand, cement and lime might have given a relatively high contribution for plaster to carbon emissions (11.81%), there are other contributors, such as shuttering (3.28%), doors/windows (2.44%) and steel pipes (12%), used for infrastructure and services networks.

The percentage contribution and the savings achieved from the building elemental materials on total carbon emissions for the workshop building are presented in Table 7.9. The embodied carbon per unit area of the workshop building (4532 m^2) based on the main elements was found to be 797.20 kg CO_2/m^2 after the $COCO_2$ tendering stage. After implementation of the CE-EM model and the CE-MCM model, the embodied carbon emissions for the workshop building is reduced to 670.80 kg CO_2/m^2.

Table 7.9 Overall embodied carbon emissions (plan vs actual) for workshop building

S. No	Material	Units	Qty	Density kg/m3	ECC kgCO2e/kg	Carbon emissions in kg/CO2e	Actual carbon emissions in kg/CO2e	Remarks
1	Excavation and backfilling	M^3	7,255.63	1800	0.01	66,606.72	63,942.45	
2	Blinding concrete	M^3	439.29	2,350	0.123	126,975.44	95,237.93	ECC=0.123 prior to optimisation
3	RCC concrete	M^3	4,135.57	2,350	0.132	1,282,853.19	1,038,597.95	ECC=9.132 prior to optimisation
4	Shuttering and formwork	M^3	10,716.61	540	0.33	470,191.26	272,193.72	0.65 kg CO_2/kg. Plywood is used twice for formwork; hence, ECC is 0.325. Also, units converted to M^3. Shuttering and formwork usage is considered 4 times average.
5	Polythene sheet-125 micron	M^3	0.61	910	2.54	1,408.80	1,351.74	910 kg/m³ x Qty m² x 125x10-6 m
6	Waterproofing membrane	M^2	11,454.69	4.3	4.20	206,871.70	185,977.66	Mass per unit area 4mm thick = 4.3 kg/m^2
7	Waterproofing paint	M^2	254.00	4	4.20	4,267.20	3,887.42	

8	Waterproofing protection board (XPS)	M^2	382.34	390	0.32	47,716.03	42,963.51	Mass/area = 4.88 x 80 = 390 kg/m^2
9	Cement screed	M^3	331.57	2100	0.221	153,879.32	138,552.94	Cement sand 1:3
10	Insulation board 50 mm thick	M^3	86.19	45	4.39	17,026.48	15,531.55	Extruded polystyrene insulation boards
11	Insulation board 100 mm thick	M^3	143.43	45	4.39	28,334.60	25,662.64	Extruded polystyrene insulation boards
12	Hollow block work 400x200x100mm (Sqm)	M^3	400.72	1750	0.063	44,179.60	41,705.54	8 Mpa comp strength
13	Hollow block work 400x200x200mm (sqm)	M^3	232.86	1437	0.063	21,080.72	18,761.84	
14	Solid block work 400x200x200	M^3	46.00	2000	0.107	9,844.00	8,761.16	
15	Plastering (internal) — cement lime sand	M^3	1,169.66	1600	0.213	398,618.50	342,811.91	12mm thick plaster
16	Plastering (external) — cement, sand	M^3	933.99	1900	0.182	322,972.53	280,986.10	15mm thick plaster
17	External epoxy paint	M^2	4,587.22		3.13	6,467.57	5,950.16	Coverage for 3 coats 2.22 sqm/kg as per product data sheet. ICE and GreenSpec; 3.13 $kgCO_2e/kg$
18	Internal emulsion paint	M^2	9,587.23		2.54	7,312.78	7,020.27	Coverage for 2 coats 3.33 sqm/kg as per product data sheet. ICE and GreenSpec; 2.54 $kgCO_2e/kg$
19	Floor paint	M^2	1,050.00		3.13	821.63	780.54	Coverage for 4 sqm/kg as per product data sheet. ICE and GreenSpec; 3.13 $kgCO_2e/kg$
20	Porcelain floor tiles	M^2	1,836.00	32	0.74	43,476.48	41,302.66	32 kg/m^2 wt as per product data sheet, ICE and GreenSpec; 0.74 $kgCO_2e/kg$ same as ceramic is taken
21	Ceramic floor tiles	M^3	264.00	20.97	0.74	4,096.70	3,728.00	ICE and GreenSpec 0.74$kgCO_2e/kg$, @ 20.97 kg/m^2 as per product data sheet
22	Ceramic wall tiles	M^3	780.00	20.97	0.74	12,103.88	11,135.57	ICE and GreenSpec 0.74 $kgCO_2e/kg$, @ 20.97 kg/m^2 as per product data sheet
23	Roof tiles 20 mm thick	M^3	26.27	1750	0.12	5,516.70	5,406.37	ICE and GreenSpec 0.12 $kgCO_2e/kg$, @ 2000 kg/m^3
24	False ceiling 60X60mm acoustic ceiling tiles	M^3	21.42	1850	2.7	106,992.90	86,664.25	2.70 $kgCO_2e/kg$ @ 1850 kg/m^3
25	False ceiling 60X60mm aluminium ceiling tiles	M^3	0.63	2700	8.24	14,016.24	11,353.15	8.24 $kgCO_2e/kg$ @ 2700 kg/m3
26	Structural steel	Ton	197,495.0		3.77	744,556.15	677,674.93	3.77 values as per IPCC(2016) and WSI
27	Sandwich roof sheeting	M^2	1,297.20		69.85	90,609.42		69.85 $kgCO_2e/m^2$ Embodied carbon calculated as per product

								data sheets and the ICE values.
28	Aluminium flashing	M^2	527.00		27.19	14,329.13		27.19 $kgCO_2e/m^2$ Embodied carbon calculated as per product data sheets and the ICE values.
29	Iron pipes for chilled water supply	LM	763.00		2.87	116,235.11	109,458.61	Factors from world steel institute (WSI). 219mm; '60'SCH: 53.08 kg/lm
30	PVC conduit	LM	189.00		3.23	189.25	181.30	From product data sheet Wt = 0.31 kg/lm
31	HDPE pipes	LM	800.00		2.52	10,825.92	10,457.84	PN 6 wt 5.37 kg/lm
32	HVAC ductwork	M^2	1,898.00		19.94	37,846.12	36,407.97	19.94 kg CO_2eq/M^2
33	Steel doors single leaf	Kg	5,851.52		3.77	22,060.23	46,692.65	Refer details wt calculations
34	Steel doors double leaf	Kg	3,851.82		3.77	14,521.36		Refer details wt calculations
35	Sliding metal door 6x5m - 2 no's	Kg	5,495.80		3.77	20,719.17		Refer details wt calculations
36	Roller shutter for equipment room (4.2x4.5)	Kg	2,279.96		3.77	8,595.46		
37	Steel frame windows 0.6 x 2.1m; 0.6x5.8 m & 1.2x5.5m on elevation	Kg	3575.8		3.77	13,480.77		Each window weight is 128kgs - Qty 40No's
38	Internal windows	Kg	969.94		3.77	3,656.67		Each window weight is 79kgs - Qty 24 No's
	Total CO_2 Emissions					**2,140,486.07**	**1,788,435.02**	**$KgCO_2e$**

The percentage contribution and the savings achieved from the materials on total carbon emissions for external works for the workshop building is presented in Appendix C. The embodied carbon per unit area of the external works of the workshop was 1,472,348 kg CO_2e after the $COCO_2$ tendering stage. After implementation of the CE-EM model and the CE-MCM model, the embodied carbon emissions for external works reduced to 1,251,462 kg CO_2e.

Door and window frames

The steel doors and window frames of the buildings have a considerable share of the impacts due to the massive embodied energy of steel and the associated emissions during the manufacturing and fabrication processes. Steel doors and window frames are often neglected in embodied carbon emissions studies. For that reason, they were given a special focus on the present research, to quantify the impacts and achieve optimisation benefits during the material procurement phase.

Table 7.10 Embodied carbon emissions for doors and windows for case study 2 (excluding glass)

S. no	Building Location	Doors/windows	Type	Size	Nos.	Location	Weight (kg)	Total Weight (kgs)	Remarks
1	Mechanical store	Steel doors	Single	1000 x 2200	3	External	75.285	225.85	
2	"	Rolling Shutter	Full open	4200 x 4500	3	Store	1140.000	3,420.00	
3	"	Windows	W5	1500 X 1500	10	All around building	89.000	890.00	Each window 89 kgs
4	"	Windows	W6	1500 X 2400	12	All around building	104.000	1,248.00	Each widow 104kgs
Total Weight (Kgs)								5,783.85	
Virgin material sections embodied CO_2eq (Source: ICE Bath)								3.77	kg CO_2eq/kg
Sections - Embodied CO_2eq, actual material values with recycled content								2.12	kg CO_2eq/kg
Planned embodied CO_2eq emissions								**21,805.13**	kg/CO_2eq
Actual embodied CO2eq emissions (after optimisation during EPC phase)								**12,261.77**	kg/CO_2eq
% savings achieved								44%	

Steel doors and windows specified in scope and estimated as a planned were optimized by reducing the overall weight of the steel elements, change of quantity, locally manufactured material instead of Europe made and replacement of virgin content steel with recycled content steel.

Table 7.11 Embodied carbon emissions for doors and windows for case study 2 – Maintenance workshop building (excluding glass)

S.no	Building Location	Doors / Windows	Type	Size	Nos	Location	Weight (kg)	Total Weight (kgs)	Remarks
1	Maintenance workshop	Blast Resistance	Single	1000 x 2200	2	Exit Door	177.859	355.718	
2	"	Blast Resistance	Double	1600 x 2200	2	Exit Door	284.574	569.149	

3	"	Sliding Door	Double	6425 x 5620	2	Workshop Entr	2919.192	5838.383	
4	"	Sliding Door	Double	4000 x 3400	1	Electrical testing room	1099.492	1099.492	
5	"	Steel Doors	Single	1000 x 2200	73	Office area	75.285	5495.800	GF & FF
6	"	Steel Doors	Double	1600 x 2200	15	GF Workshop & Store room	114.299	1714.488	GF
7	"	Steel Doors	Double	1800 x 2400	1	GF Workshop & Store room	126.115	126.115	GF
8	"	Rolling Shutter	Full Open	4200 x 4500	3	Eqiupment Store	759.988	2279.964	
9	"	Windows	W1	600 X 5800	8	Workshop area- Elevation	70.664	565.312	Only Frame
10	"	Windows	W2	600 X 2100	70	Office area- elevation	31.944	2236.080	"
11	"	Windows	W4	1200 X 5500	8	Workshop area - Elevation	64.856	518.848	"
12	"	Windows	W5	1600 X 2100	2	Office area Internal windows	35.816	71.632	"
13	"	Windows	W6	2000 X 1200	29	Office area Internal windows	30.976	898.304	"
14	"	Windows	W8	600 X 2100	8	Office area elevation	31.944	255.552	"
Total Weight (Kgs)								22,024.84	
Virgin material-sections Embodied CO_2eq (source IPCC (2016) and WSI)								3.77	kg CO_2eq/kg
Sections - Embodied CO_2eq ROW values with recycle content								2.12	kg CO_2eq/kg
Planned Embodied CO_2eq emissions								**83,033.64**	kg/CO_2eq
Actual Embodied CO_2eq emissions (after optimization during EPC phase)								**46,692.65**	kg/CO_2eq
% savings achieved								44%	

Earthwork

Reducing GHG emissions from earthworks demands a strong vision from the planner, cooperation with many different actors and sophisticated decisions in multiple planning phases (Säynäjoki, Korba, Kalliala and Nuotio, 2018). Carbon emissions due to excavation and backfilling were high due to plot location which is a low lying area compared to the surrounding topography. The plot was filled up to an average height of

3 meters to match the surrounding road levels. Base case carbon emissions were too high as the municipality approved sand borrow pit assumed was at a distance of 40km from the site location. But as a sustainable measure, the impacts were identified at the early stage of the project and efforts were made to request authorities for approval of sand borrow pit close to the site location. Hence the base case considered the nearest location instead of 40km distant one and further mitigation were done to reduce the carbon emissions.

Structural system

The structural (beams and columns) system of the buildings dominates the impacts due to the massive embodied energy of steel, cement and concrete and the associated water emissions during the manufacturing processes. The building comprises a steel structure for the workshop area, whereas the offices' area was comprised of an RCC structure. Iterations optimised the embodied carbon emissions related to the steel structure during the detailed design and by including the requirement for 50% recycled content in the steel supplied. Reduction in the component sizes was carried out from the initial design based on the revised loads of the structure; however, the savings in emissions are not calculated and the base case values were amended to show the impact of recycled content in the use of hot-rolled sections. As per Table 7.12, the planned quantities of the embodied carbon related to the structural steel material of the workshop building were 849,496 kgCO2e, which were optimised to 677.674 kgCO2e (i.e., 20% savings).

As per Table 7.13, the planned quantities of the embodied carbon related to the steel structure material of the mechanical store building were 306,835 kg CO_2e, which were optimised to 249,128 kg CO_2e (i.e., 19% savings).

Table 7.12 Embodied carbon emissions for structural steel for case study 2 (workshop bldg.)

MAINTENANCE WORKSHOP - STEEL STRUCTURE QUANTITY

Refrenece drawing No :5620-BUH-41-20-45-060-A1 SHEET (1 TO 5)

S.no	Type	Size	Units	Qty	L	H	W	TK	Density kg/m^3	KG per Length	Weight in kg	ECC kgCO2e/kg	Carbon emissions in kg/CO2e	Remark
1	ANCHOR BOLT - 01	8- M56 GRADE 4.6	NOS	32	8.00	-	-	-		33.400	8,550	3.77	32,235	Ø 56 mm
2	ANCHOR BOLT - 02	4 - M36 GRADE 4.6	NOS	4	4.00	-	-	-		11.000	176	3.77	664	Ø 36 mm
3	BASE PLATE - 01	1000 X 950 X 40	NOS	32	1.00	1.000	0.950	0.040	7,850	298.300	9,546	3.77	35,987	
4	BASE PLATE - 02	400 x 400 x 20	NOS	4	1.00	0.600	0.400	0.020	7,850	37.680	151	3.77	568	
5	STUB COLUMN - 01	UB - 610 X 229 X 12	NOS	32	10.00	0.610	0.229	0.125		125.000	40,000	3.77	150,800	
6	STUB COLUMN - 02	UB - 533 X 210 X 45	NOS	4	10.18	0.533	0.210	0.045		45.000	1,832	3.77	6,905	
7	RAFTER	UB - 610 X 229 X 10	NOS	16	17.89	0.610	0.229	0.101		101.000	28,913	3.77	109,004	
8	"C" PURLIN SIDE	CH-305 X 89 X 42	NOS	1	294.60	-	-	-		41.800	12,314	3.77	46,425	
9	FALSE RAFTER	L - 50 X 50 X 6	NOS	1	34.50	0.050	0.050	0.006		4.470	154	3.77	581	
10	BEAM	UB - 356 X 171 X 45	NOS	8	75.20	0.356	0.171	0.045		45.000	27,072	3.77	102,061	
11	BEAM	UB - 356 X 171 X 45	NOS	8	4.23	0.356	0.171	0.045		45.000	1,524	3.77	5,744	
12	EOT CRANE GRIDER	UC - 356 X 368 X 12	NOS	2	75.20	0.356	0.368	0.125		125.000	18,800	3.77	70,876	
13	EOT CRANE GRIDER SUPPORT	UC - 406 X 178 X 74	NOS	32	0.25	0.406	0.178	0.074		74.000	592	3.77	2,232	
14	EOT CRANE SELF WEIGHT	EOT CRANE - 20 TO	NOS	2							10,000	3.77	37,700	
15	BREACHING	UB - 305 x 165 x40	NOS	76	6.16	0.305	0.165	0.040		40.000	18,726	3.77	70,599	
16	ZED PURLIN ON TOP	Z25225	NOS	22	75.20	-	-	-		7.930	13,119	3.77	49,460	
17	SAG ROD INCLUDING BRACING	16 MM DIA	Rmt	1	439.20	-	-	-		1.580	694	3.77	2,616	
18	ROOF SHEETING & FASTERES	0.9 MM X 85MM CORE X 130 MM TK	M^2	1	1297.20	-	-	-		19.400			90,609	CO_2e from data sheet
19	ROOF SHEE FLASHING	0.9 MM X 85MM CORE X 130 MM TK	M^2	1	527.00	-	-	-		19.400			14,329	CO_2e from data sheet
20	RAFTER TO PURLIN SUPPROT	UA - 50 X 50 X 6	NOS	1	660	0.050	0.050	0.006		4.500	2,970	3.77	11,197	
21	WELDED PLATE ON RAFTER	130 X 190 X 12	NOS	1	352.00	0.130	0.190	0.120		2.327	819	3.77	3,088	
22	JOINT BOLTS ALL M20	M20 GRADE 8.8	NOS	1	1296.00	-	-	-		0.280	363	3.77	1,368	
23	JOINT BOLTS AL M16	M16 GRADE 4.4	NOS	1	4048.00	-	-	-		0.123	498	3.77	1,877	
24	JOINT BOLTS AL M24	M24 GRADE 8.8	NOS	1	316.00	-	-	-		0.418	132	3.77	498	
25	JOINT BOLTS AL M30	M30 GRADE 8.8	NOS	1	768.00	-	-	-		0.716	550	3.77	2,073	
	TOTAL WEIGHT IN METRIC TON										197,495		849,496	

Virgin material-sections Embodied CO_2eq (source IPCC (2016) and WSI)	3.77	kg CO_2eq/kg
Hot rolled Sections - Embodied CO_2eq values with recycle content (ICE)	2.03	kg CO_2eq/kg
Planned Embodied CO_2eq emissions	**849,495.83**	kg CO_2eq
Considering 50% of the material supplied with recycled content, the Actual Embodied CO_2eq emissions (after optimization during EPC phase)	**677,674.92**	kg/CO_2eq
% savings achieved	**20%**	

Table 7.13 Embodied carbon emissions for structural steel for case study 2 (Mech store bldg.)

MECHANICAL STORE - STEEL STRUCTURE QUANTITY													
Refrenece drawing No :5620-BUH-41-18-11-113 TO 118													
S.no	Type	Size	Units	Nos	L	H	W	TK	KG per Length	Weight in kg	ECC kgCO2e/kg	Carbon emissions in kg/CO2e	Remark
1	ANCHOR BOLT - 01	8- M42 GRADE 4.6	NOS	18	8.00	-	-	-	11.000	1,584	3.77	5,972	Ø 56 mm
2	ANCHOR BOLT - 02	2 - M30 GRADE 4.6	NOS	4	2.00	-	-	-	11.000	88	3.77	332	Ø 36 mm
3	BASE PLATE - 01	750 x 850 x 24	NOS	18	1.00	0.750	0.850	0.024	120.105	2,162	3.77	8,150	
4	BASE PLATE - 02	400 x 400 x 20	NOS	4	1.00	0.400	0.400	0.020	25.120	100	3.77	379	
5	STUB COLUMN - 01	UB - 533 X 210 X 92	NOS	18	7.27	0.533	0.210	0.092	92.000	12,039	3.77	45,387	
6	STUB COLUMN - 02	UC - 203 X 203 X 46	NOS	4	7.41	0.203	0.203	0.046	46.000	1,364	3.77	5,142	
7	RAFTER	UB - 533 X 210 X 82	NOS	9	13.38	0.533	0.210	0.082	82.000	9,871	3.77	37,216	
8	RAFTER OUT SIDE	UB - 305 x 165 x40	NOS	22	1.50	0.305	0.165	0.040	40.000	1,320	3.77	4,976	
9	FALSE RAFTER	L - 50 X 50 X 6	NOS	1	34.16	0.050	0.050	0.006	4.470	153	3.77	576	
10	BEAM	UB - 305 x 165 x40	NOS	6	44.39	0.305	0.165	0.040	40.000	10,654	3.77	40,164	
11	BEAM	UB - 305 x 165 x40	NOS	1	75.58	0.305	0.165	0.040	40.000	3,023	3.77	11,398	
12	EOT CRANE GRIDER	UC - 305 x 305 x 97	NOS	2	23.16	0.305	0.305	0.097	97.000	4,492	3.77	16,935	
13	EOT CRANE SELF WEIGHT	EOT CRANE - 05 TON	NOS	1						8,000	3.77	30,160	
14	BREACHING	UB - 305 x 165 x40	NOS	24	6.00	0.305	0.305	0.097	40.000	5,760	3.77	21,715	
15	ZED PURLIN ON TOP	Z20220	NOS	14	45.45	-	-	-	5.230	3,328	3.77	12,546	
16	"C" PURLIN SIDE	C-100 x 40 x 20	NOS	1	125.06	0.100	0.040	0.020	2.500	313	3.77	1,179	
17	SAG ROD INCLUDING BRACING	16 MM DIA	Rmt	1	262.92	-	-	-	1.580	415	3.77	1,566	
18	ROOF SHEETING & FASTERES	.9 MM X 85MM CORE X 130 MM TK	M^2	1	776.29	-	-	-	19.400			54,224	CO2e from data sheet
19	ROOF SHEE FLASHING	.9 MM X 85MM CORE X 130 MM TK	M^2	1	93.80	-	-	-	19.400			2,550	CO2e from data sheet
20	RAFTER TO PURLIN SUPPROT	UA - 50 X 50 X 6	NOS	1	224.00	0.050	0.050	0.006	4.500	1,008	3.77	3,800	
21	WELDED PLATE ON RAFTER	130 X 190 X 12	NOS	1	126.00	0.130	0.190	0.012	2.327	293	3.77	1,105	
22	JOINT BOLTS ALL M20	M20 GRADE 8.8	NOS	1	872.00	-	-	-	0.280	244	3.77	920	
23	JOINT BOLTS AL M16	M16 GRADE 4.4	NOS	1	952.00	-	-	-	0.123	117	3.77	441	
TOTAL WEIGHT IN METRIC TON										**66,329**		**306,835**	**kgCO2e**

Virgin material-sections Embodied CO_2eq (source IPCC (2016) and WSI)	3.77	kg CO_2eq/kg
Hot rolled Sections - Embodied CO_2eq values with recycle content (ICE)	2.03	kg CO_2eq/kg
Planned Embodied CO_2eq emissions	**306,834.86**	kg CO_2eq
Considering 50% of the material supplied with recycled content, the Actual Embodied CO_2eq emissions (after optimization during EPC phase)	**249,128.57**	kg/CO_2eq
% savings achieved	**19%**	

Table 7.14 shows that reinforced cement concrete emissions were also reduced by changing the GGBS content and by reducing the waste generated. The other materials savings and optimisation values are available in Appendix C.

Table 7.14 Carbon emissions savings of RCC from case study 2 — workshop bldg.

MAINTENANCE WORKSHOP - RCC Concrete QUANTITY								
S.no	Description	location	Units	Cum	Density kg/m3	ECC kgCO2e/kg	Carbon emissions in kg/CO2e	Remark
1	Blinding concrete for footing	Mechanical Store	m3	19.38	2350	0.132	6,012	
2	Blinding concrete for Tie beam	Mechanical Store	m3	21.66	2350	0.132	6,719	
3	Blinding concrete for grade slab	Mechanical Store	m3	67.72	2350	0.132	21,007	
	Sub Total			108.76				
4	Blinding concrete for foundation and tie beam works (D1-E1 to D7-E7)	Substation building and chiller yard	m3	19.11	2350	0.132	5,928	
5	Blinding concrete for grade slab	Substation building and chiller yard	m3	18	2350	0.132	5,584	
	Sub Total			37.11				
9	Blinding concrete phase-1 foundation (A1-D1 to A10-D10)	Workshop building	m3	94.18	2350	0.132	29,215	
10	Blinding for Tie beam Zone 1 & Zone 2	Workshop building	m3	72.06	2350	0.132	22,353	
11	Blinding for grade slab Zone 1 & Zone 2	Workshop building	m3	23.6	2350	0.132	7,321	
12	Blinding concrete for foundation on grid A11-D11 to A17-D17 Zone 3	Workshop building	m3	47.09	2350	0.132	14,607	
13	Blinding for tie beam Zone 03	Workshop building	m3	36.03	2350	0.132	11,177	
14	Blinding for grade slab Zone 3	Workshop building	m3	88.5	2350	0.132	27,453	
	Sub Total			361.46				
TOTAL QUANTITY			m3	507.33			157,374	
	Concrete used was replaced with 50% GGBS content thereby reducing the Carbon coefficient to 0.1 kgCO2e/kg						127,946	
	Net savings by replacing the sustainable concrete						29,428	Savings

Walls

Walls systems in all buildings dominate the environmental impacts due to the use of insulation materials, which cover large areas of building facades, and the use of metals such as steel and anodised aluminium in windows and curtain walls. Workshop bay external walls were RCC walls, whereas the external walls of office areas were cavity blockwork with insulation. External walls for Mechanical store were cavity walls. All internal walls are hollow blockwork.

Roof systems

Roof systems also have significant impacts due to the manufacturing of roof insulation materials, cement tiles, cement screed, waterproofing paint and the roof membrane (EPDM sheet).

7.5.5.2 *Carbon emissions for material transportation*

In calculating carbon emissions during the material transportation stage, current material transportation practices in the UAE were considered. The average distances for transporting each material were estimated, and the two-way transportation distances were used in the calculations.

The carbon emission factors for the type of transportation were calculated using data obtained from relevant literature (Devi and Palaniappan, 2014; Sim et al., 2016; Tae et al., 2011; DEFRA, 2012). A summary of the actual carbon emissions at the material transportation stage is given in Table 7.15.

Table 7.15 Actual carbon emissions at the material transportation stage for case study 2 project

S.No	**Description**	**Base case CO2 emissions for travel**	**Actual CO2 emissions (kg CO2 eq)**	**Percentage**
1	Backfill Material	43,860.10	2,193.00	0.46%
2	Blinding concrete	5,338.23	4,305.02	0.90%
3	RCC concrete	36,505.68	29,440.07	6.18%
4	Formwork and shuttering	116,278.27	93,772.80	19.69%
5	Structural and rebar steel	14,850.20	11,423.23	2.40%
6	Blockwork	8,533.32	6,564.10	1.38%
7	Plastering- OPC cement	7,135.26	5,754.24	1.21%
8	Painting	1,189.21	959.04	0.20%
9	Waterproofing	2,906.96	2,344.32	0.49%
10	Ceramic	3,845.11	3,100.90	0.65%
11	Man-power transportation of contractor	100,580.71	81,113.47	17.03%
12	Transportation of PMT(Contractor)	170,362.28	137,388.94	28.85%
13	Transportation of PMT(Client)	121,310.60	97,831.13	20.54%
	Total Transportation carbon emissions	632,695.94	476,190.26	100.00%

The main factor which affected the carbon emissions in this stage was the man-power transportation for work as shown in Table 7.15. As the project was situated in desert, the contribution of man-power transport was high; however if the project lies in other location, the values will be much less. Material quantity, as evidenced by ready-mixed concrete, blockwork, painting, ceramic contributed less to the total transportation carbon. As the average material transportation distances were high for this particular construction site due to its location in a remote desert area, transport distance played a significant role in the production of carbon emissions. As can be seen in Table 7.16, the carbon emissions of material transportation for structural steel were found to be 6,773 kg CO_2e.

Table 7.16 Transportation CO_2e emissions for structural steel

S.No	Description of Material	Month	Unit	Quantity in ton	No of trips required	Location of Plant/warehouse	Distance from site (Km)	Mode of transport	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Base plate and anchor bolts	Apr-16	Ton	18.5	2	Dubai/Abudhabi	444	Road	2.664	473.13
2	Columns	Jul-16	Ton	41.8	4	Dubai/Abudhabi	444	Road	2.664	946.25
3	Rafter	Jul-16	Ton	32.8	3	Dubai/Abudhabi	444	Road	2.664	709.69
4	Tiebeams	Dec-16	Ton	47.98	5	Dubai/Abudhabi	444	Road	2.664	1,182.82
5	Bracings	Dec-16	Ton	19.42	2	Dubai/Abudhabi	444	Road	2.664	473.13
6	Purlin, sag rods and other accessories	Nov-16	Ton	26.2	2	Dubai/Abudhabi	444	Road	2.664	473.13
7	Roof sheeting	Nov-16	Ton	1824	8	Sharjah	590	Road	2.664	2,514.82
									Total	**6,772.95**

Transportation impact in the construction phase is considered to produce more accurate results in this study. Interestingly, the literature review shows that transportation contributes 80% and 70% of the global warming potential (GWP) and acidification potential (AP), respectively, to the total life cycle impact during a project's construction phase (Ragheb, 2011). Moreover, as shown in Table 7.24, the impact of transportation as a ratio of the total construction phase impact is high. This supports the argument for using local materials in building construction. Routes selected, vehicle choice and increased operator expertise will influence emissions reduction (Agung Wibowo et al., 2018).

7.5.5.3 Carbon emissions for construction equipment and lighting

One of the contributors to embodied carbon which can be monitored to reduce the embodied carbon of a building is the construction emissions associated with the operation of construction equipment and the use of temporary construction materials (Akbarnezhad and Xiao, 2017). The summary of carbon emissions in the construction stage is given in Table 7.17. The energy consumption rates for construction activities usually are determined from previous project histories based on the anticipated equipment tools envisaged to be used on the project. Earthworks contributed to 62% of the carbon emissions at the construction stage, followed by site lighting and other tool use (28%) and lifting of materials by crane for the larger elements of structural steel (3%). The carbon emissions per unit area for construction equipment and site lighting at the construction stage were found to be 51.3 kg CO_2/m^2.

Table 7.17 Carbon emissions in construction equipment and site lighting

Activity	Energy use rate	Quantity of work	Amount of fuel/electricity	CO_2 emissions factor	Carbon emissions (kg CO_2)	Reference
Earthwork	3.53 L/m^3	17,592.54	62,101.66	2.679 kg CO2/L	166.370.34	Energy use rate reference – (Devi and Palaniappan, 2016; Sim et al., 2016)
Pouring and lifting concrete	0.77 L/m^3	5,523.64	4,253.20	2.679 kg CO2/L	11,394.32	
Concrete compaction	0.21 L/m^3	5,523.64	1,159.96	2.679 kg CO2/L	3,107.53	
Rebar and reinforcing	2 kWh/MT	1,193.10	1,386.20	0.689 kg CO2/kWh	955.09	
Lifting of materials –crane	10 kWh/MT	962.76	9,627.60	0.689 kg CO2/kWh	6,633.41	
Lifting of materials –hoist	3.1 kWh/MT	1440.00	4464.00	0.689 kg CO2/kWh	3,075.70	
Site lighting, including offices	26 kWh/m^2	4,213	109,538.00	0.689 kg CO2/kWh	75,471.68	
Total (for 4532+678 m^2)					267,008.07 51.3 kg/m^2	

7.5.6 Carbon emissions of energy and water for operation phase

The total annual electricity consumption savings due to carbon emissions management is 195,533 kWh. Considering the life span of the building, as 30 years, the total carbon emissions saved during building operation were estimated to be 3942 tonnes CO_2e. The 30-year energy and water, life cycle carbon emissions per unit area at the operation stage, after the carbon emissions management implementation, is 756 kg CO_2/m^2. In calculating the carbon emissions, building maintenance was considered. Table 7.18 and Table 7.21 shows the energy and water savings achieved due to optimisation measures employed by the project team to reduce the carbon emissions and impacts.

7.5.6.1 *Energy efficiency*

Energy simulation is performed using the IES-VE Performance Navigator (PRM), which generates all baseline cases by using ASHRAE 90.1-2010 requirements. Occupant sensors and timer switches were modelled in Radiance IES module and PRM Navigator. Energy efficiency measures were taken based on the carbon emissions management model, as shown in Table 7.20. In addition to these measures, the main measures taken are as follows:

- Selection of air-cooled chillers instead of water-cooled chillers.
- The project cooling system has been modified to a district cooling system.
- Lighting, equipment, cooling and occupancy operational timings and number of days per week were revised to match the actual operation of the building (i.e., 5 days a week for 9 hours full-load operation).

Table 7.18 Carbon emissions savings for case study 2 project due to effective CEM implementation

Building	**Unit**	**Annual Energy Use – Base Case**	**Annual Energy Use – Designed/Constructed**	**% Savings**
Workshop	kWh	689,854.07	561,794.51	18.56%
Mechanical store	kWh	156,576.41	89,102.88	43.09%
Subtotal	kWh	846,430.48	650,897.39	**23.01%**
Savings in Co2e emissions	$kgCO_2/kWh$ (0.672)	568,802 Kg CO_2	437,403 Kg CO_2	131,399 $KgCO_2$ **131.4** Tonnes

Total lifecycle carbon emissions savings due to operating energy efficiency measures = 131.40 x 30 = **3,942 Tonnes**

Table 7.19 Energy savings and associated carbon emissions savings per year for workshop bldg.

Building	**Unit**	**Annual Energy Use – Base Case**	**Annual Energy Use – Constructed**	**% Savings**
Workshop + store (4,530 m^2 +680)	kWh/yr	846,430.48	650,897.39	**23.01%**
Savings in CO_2e emissions ($kgCO_2/kWh$-(0.51))	$kgCO_2/yr$	431,680 Kg CO2/yr	331,958 Kg CO_2/yr	99,722 $KgCO_2/yr$ **99.72** Tonnes/yr
Life cycle carbon emissions saved for the project over 30 years	Tonne CO_2eq			2,991 Tonnes CO_2eq

Table 7.20 Energy efficiency measures: workshop building

Description	Unit	Base Case	Design and Construction Case
Exterior wall construction	Input u-value/% (area weighted)	0.70	0.39
Roof construction – office area – RCC	Input u-value/% (area weighted)	0.20	0.36
Roof construction – workshop area – sandwich panel	Input u-value/% (area-weighted)	0.19	-
Floor/slab construction	Input u-value/% (area weighted)	1.40	1.40
Fenestration U-value/glazing	Input u-value/% (area weighted)	6.82	1.90
Fenestration visual light transmittance	Input u-value/% (area weighted)	0.76	0.35
Fenestration solar heat gain coefficient (SHGC)	Input u-value/% (area weighted)	0.30	0.26
Interior lighting power density	W/m^2	13.07	6.25
HVAC			
System	System 6 package VAV with PFP boxes. COP auto-sized as per ASHRAE 90.1-2010, table 6.8.1.A. Air-cooled screw chiller with FAHU/AHUs and VAV boxes. Full load COP 3.22.		
Electricity			
Internal lighting – energy use	kWh	115,597.26	58,765.98
Internal lighting – demand	kW	60.2	28.67
Space heating – energy use	kWh	1296.58	561.33
Space heating – demand	kW	49.88	31.26
Space cooling – energy use	kWh	333,194.40	267,568.82
Space cooling – demand	kW	211.20	123.93
Pumps – energy use	kWh	0	11,588.51
Pumps – demand	kW	0	4.77

7.5.6.2 Water efficiency

The water efficiency of the building was studied at an early stage during the detailed design, as shown in Figure 7.13. The base case scenario and the design case scenarios show the optimisation achieved and the savings made on the operational carbon emissions of the building.

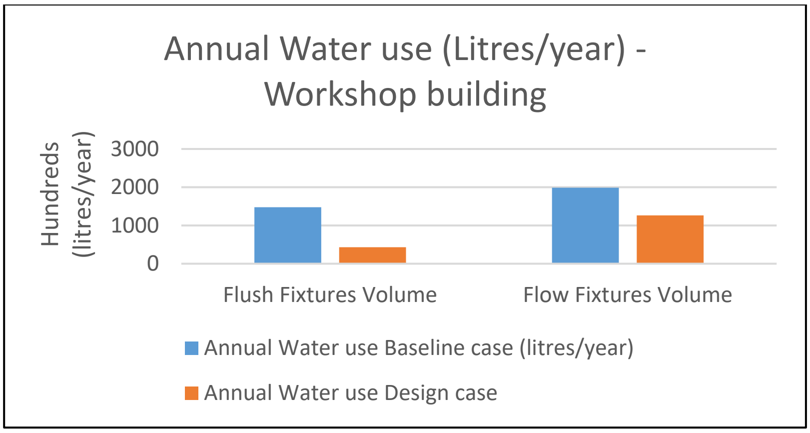


Figure 7.13 Comparison of annual water savings from base case to design case

Table 7.21 and Table 7.22 shows, the carbon emissions savings due to implementation of carbon emissions management of the case study project, when extrapolated to 30 years of life of the building, are 162 tonnes CO_2e. The project achieved a water consumption of 56.99% by adapting low-flow rate water fixtures and low flush urinals and WCs. Instead of an annual consumption of 687,298.65 litres/year, the buildings are designed to consume only 295,613.50 litres/year.

Table 7.21 Annual carbon emissions of operational water use – case study 2 project

Description	Annual volume (litres/year)	Carbon emissions
Base case annual flush volume of flush fixtures (toilet and urinals)	409,311.00	
Actual annual flush volume of flush fixtures (toilets and urinals)	118,807.50	
Base case annual flush volume of flow fixtures (lavatory faucet, kitchen faucet and shower head)	277,987.65	
Actual annual flush volume of toilets and urinals	176,806.00	
Annual savings (litres/year)	391,685.15	
Annual savings (cum./year)	391.69	
Carbon emissions factor for desalination (kg CO_2 eq/cum.)		13.75
Annual carbon emissions (kg CO_2 eq) savings		5,386 **5.4** Tonnes

Table 7.22 Life cycle carbon emissions of operational water use – case study 2 project

Building	**Unit**	**Annual Water Use– Base Case**	**Annual Water Use – Designed/Constructed**	**% Savings**
Volume of flush and flow fixtures (toilets, urinals, faucets and showerheads)	Ltrs/yr	687,298	295,613.00	**56.99**
Savings in CO_2e emissions	5.4 Tonnes CO_2 e/yr			
Life cycle carbon emissions saved for the project over 30	162 Tonnes CO_2e			

7.5.7 Carbon emissions saved with waste management

Recycling is one the strategy for waste minimisation which offers three main benefits: (i) reducing the demand for new resources; (ii) reducing the production and transport emissions and costs; and (iii) saving the space required for landfill (Tam and Tam, 2006). Social impacts of solid waste management systems are reflected in the creation of employment, betterment of health, and improving the quality of social life. Recycling, reusing and salvaging construction waste results in cost optimisation and reduction in net energy savings leading to lower carbon emissions in projects (Kofoworola and Gheewala, 2009).

Carbon emissions reductions are also achieved through implementation of planned waste management through the concept of reduce, reuse and recycle (Agung Wibowo et al., 2018). Waste-related emissions are due to the waste generated during a project, such as bark/wood waste, concrete solid waste, steel waste and unspecified other waste. Although these emissions do not contribute directly to the environmental impact categories in this study, they are considered very important in determining the amount of materials which go to the landfill, mainly during construction. Waste-related emissions show that the construction phase accounts for most of the carbon emissions in the life cycle of a building project.

In building assembly systems, RCC foundations, columns and roofs dominate account for most of the bark/wood waste and concrete waste emissions due to wood formwork and concrete pouring during construction. Other concrete waste during wall construction is also seen. Structure systems also contribute to the steel waste due to the preparation and welding of steel beams sections on-site.

Table 7.23 Carbon emissions from construction and demolition waste

Material Description	Material Type Segregated at Site	Total Waste Generated (Tonnes)	Carbon Emissions Factor ($kgCO_2eq/kg$)	Total CO_2 Emissions ($kgCO_2eq$)	Source for Emissions Factor
Concrete mix	Concrete	125.00	0.16	20,000	IPCC, 2016; IEA, 2016
Broken package wood	Wood	15.00	0.61	9,150	(UN Stats, 2016
Steel pipe, rods	Metals	24.50	3.77	92,365	IPCC, 2016; IEA, 2016
Package plastic materials	Plastic	0.50	3.14	1570	DEFRA
Cardboard/paper packing	Cardboard and paper	0.50	1.50	750	DEFRA
Total construction waste emissions (tonnes)				123,835	$kgCO_2eq$

Nearly 40% of the world's steel production is made from scrap materials now due to recycling benefits; for example, salvaging 1 kg of steel saves 1.1 kg of iron ore, 0.63 kg of coal, 0.055 kg of limestone, 0.642 kWh of electricity, 0.287 litres of Oil, 10.9 thousand BTUs of energy, and 2.3 L of landfill (Cushman, 2017).

Building construction waste, along with waste from the demolition of existing facilities and transportation of the waste material to the recycling plant, were considered in determining carbon emissions related to waste. The total carbon emissions saved from waste recycling was 123,835 kg CO_2. Construction was provided with a recycle segregation area where the workers were encouraged to segregate the waste per type, as shown in Table 7.23. Concrete waste collected at the site was 125 tonnes, which was segregated from other waste and sent to a recycling plant. From the overall embodied carbon emissions for the concrete, the waste recycle quantities will be deducted to arrive at net embodied concrete CO_2 emissions. Another major material used in building construction which contains larger amounts of embodied carbon (i.e., steel) was also recycled.

Other waste generated during the construction phase, such as wood, plastic, cardboard and paper, were also sent to the recycling plant, thereby achieving a savings of 123,835 kgs of carbon emissions. Energy used in the transportation and recycling of the material was not calculated as part of this research.

7.5.8 Carbon emissions reduction measures adopted in case study 2

To reduce life cycle carbon emissions of buildings, several measures were identified by WRAP, such as using fewer materials, using alternative materials with low embodied carbon emissions, design to reduce waste, design to reconstruct and re-use, and use of materials with high levels of durability and low through-life maintenance (WRAP, n.d.).

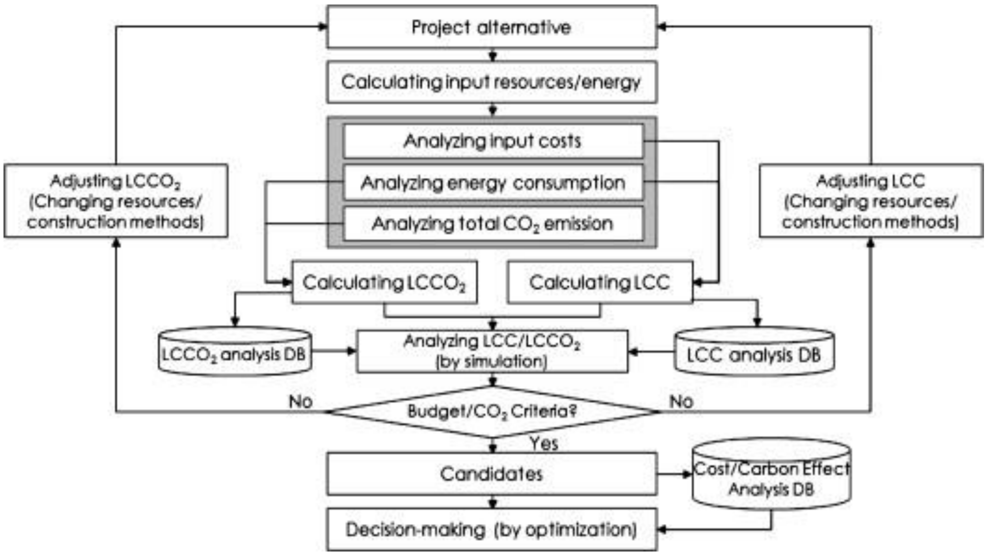


Figure 7.14 LCC-based $LCCO_2$ decision-making process.

(Source: Kim et al, 2013)

Carbon emissions at the material production stage were also significant; at 17.80% of total embodied carbon emissions (Table 7.24). The percentage of embodied carbon to life cycle carbon emissions after implementation of the CEM model is 19.82% for embodied carbon. The remaining 80.18% is for the operational carbon emissions of water and energy. Hence, the simultaneous control of carbon emissions in both the operation and material production stages is critical to achieving low-carbon buildings.

- Appropriate measures for energy-efficient and low-carbon buildings were taken at the early design stages (Wu et al., 2012).
- Optimised designs aimed at reducing carbon emissions were set as a control index and optimisation included carbon emissions assessment, identifying high

emissions sections, provision of possible optimisation schemes and evaluation of outcomes (Zhang and Wang, 2015).

- Set-point room temperatures were advised to be changed from 24°C to 26°C, which resulted in electrical consumption similar to the corresponding reduction of 820 tons of CO_2 per year expected in an office building in Thailand (Kofoworola and Gheewala, 2008).
- Occupancy sensors were installed for switching off office lighting during daily breaks, through which energy use and carbon emissions are reduced at levels similar to the savings of 451 kg/m2 per year achieved in office buildings (Wu et al., 2012).
- Educational signage on the energy savings, water savings, occupant comfort and materials used were displayed across the building corridors to encourage positive attitudes among building occupants towards effective carbon emissions management. Changes in attitudes can be considered a highly effective step towards operational carbon reduction (Delzendeh et al., 2017).
- Sustainable procurement of building materials and the use of green building materials was adopted. This was possible for any building construction in UAE, as these materials and practices are already being promoted by the Estidama rating system in the UAE (PBRS, 2017). The total embodied energy of a building can be reduced by 50% by using energy-efficient building materials (Venkatarama Reddy and Jagadish, 2003).
- In the present study, total demolished waste was recycled, which resulted in additional savings on carbon emissions. These results were compared with similar studies done on an office building in Thailand, which recovered 8.9% of initial embodied energy though recycling (Kofoworola and Gheewala, 2009). In a separate study of an Italian building, the recycling potential was 29% and 18% for life cycle energy and GHG emissions, respectively (Blengini, 2009).

The results were very clear when the operational phase carbon emissions related to energy and water consumption were evaluated. Table 7.24 below shows the savings achieved in carbon emissions related to the operational phase during the construction stage of the building on a design and build project.

7.5.9 Conclusion of case study 2

The adoption of this method by practitioners would help produce systematic data, leading to comparable results and reliable embodied emissions statistics.

Table 7.24 Summary of building life cycle carbon emissions

Phase	**Carbon Emissions as per Industry Average**	**Carbon Emissions as per base values (Kg CO_2e)**	**Carbon Emissions After CEM model Implementation (Kg CO_2e)**	**Remarks**
Material	108.30 KgCO_2e/ m^2/yr as per Kua and Wong study	2,140,486.07	1,788,435.02	Workshop building (4532 m^2)
		933,576.40	775,271.40	Mechanical store (678 m^2)
		1,472,348.11	1,251,461.91	External works
Construction		267,008.07	267,008.07	Energy and fuel use during construction
Transportation		632,695.94	476,190.26	
Waste recycle savings		-	-123,835	
Total embodied emissions		5,446,114.59	4,434,531.66	
Embodied carbon emissions distributed over 30 years for case study 2 (5210 m^2)		34.84	28.37	
Operations (energy and water- life cycle carbon emissions for 30 yrs)		17,064,060.00	13,122,090.00	Energy
		9,450,348	4,064,679	Water
Life cycle carbon emissions for case study 2 buildings after CEM model implementation Kg/CO_2e/m^2	108.3	204.48	138.33	
Total emissions for 30 yrs in kg CO_2 e		31,960,522.59	21,621,300.66	

7.6 Comparison of Results with Previous Studies

A fair comparison to literature review findings is not straight forward due to the differences in geographical location, study boundaries, functional units and other limitations. Khasreen (2013), used a normalisation analysis to make the results of literature studies at the same unit (kg CO_2/m^2/year) as buildings analysis differ according to life span.

The life cycle carbon emissions are impacted on by various factors, such as the assumptions made during estimations, the life cycle methodology used, the location and climate of the project, materials used and energy sources and technologies used. As shown in Table 7.25, there exist different results in life cycle carbon emissions of various building types around the world (246.58–28.10 kg CO_2/m^2 per year). The life cycle carbon emissions of the present study for the mechanical store building and workshop building (137.13 kg CO_2/m^2/year) is comparable to the values obtained in other parts of the world. Carbon emissions values can vary significantly across different regions in the same country. The life cycle carbon emissions for the U.S., Singapore and Turkey are relatively higher, whereas China, Thailand and Australia show lower values (Aye et al.; 2012; Kofoworola and Gheewala, 2008). Due to the vast range of variables involved in building life cycle studies, more detailed comparisons are necessary to arrive at valid conclusions.

Table 7.25 Comparison of GHG carbon emissions of buildings with current case study

S. No	Type of Building	Location	Life Span (Yr)	Gross Floor Area (M^2)	GHG Carbon Emissions ($kgCO_2/M^2$ per year)	Reference
1	Residential	Australia	50	3943	54.97	Aye et al., 2012
2	University	Michigan USA	75	7300	246.58	Scheuer et al., 2003
3	Office	Bangkok, Thailand	50	60,000	20.00	Kofoworola and Gheewala, 2008
4	Residential	Turkey	50	7445	104.40	Atmaca and Atmaca, 2015
5	Commercial	Singapore	30	52,094	108.30	Kua and Wong, 2012)
6	Residential	China	50	4443.3	28.10	Zhang et al., 2016
7	**Current study – Commercial**	**UAE**	**30**	**5210**	**137.13**	**Case study 2 findings of this research**
8	**Current study – Commercial**	**UAE**	**30**	**1320**	**31.95**	**Case study 1 findings of this research**

7.7 Comparison between Case Study 1 and Case Study 2

There exists a major difference in the location of these two projects, and, moreover, the case study 1 project was a laboratory building with a complete RCC structure, while the case study 2 project was a mixed-used RCC and steel structure building.

Case study 1 was carried out with estimation and monitoring of the main elements of the building, including excavation, PCC, RCC, blockwork, plaster, paint, mortar, marble and ceramic, whereas case study 2 included a wider range of materials, including the civil, HVAC and external asphalt works. Waste management savings were not included in case study 1, but in case study 2, it was identified as a potential savings with minimum efforts. In a similar way, the operational phase energy- and water-related carbon savings were not part of case study 1, whereas in case study 2 they were calculated using IESVE software energy modelling for energy and Excel water calculators for water savings. Due to the limited scope of embodied carbon emissions in case study 1, such as taking only eight elements of building, not considering the waste and operational carbon emissions, the values are 31.95 $KgCO_2/m^2$/year. These results concur with findings of previous research stating that the outcome depends on the scope boundary, methodology and the materials used on the project. This concludes to an approach where the carbon emissions per square meter of area is not important, but the percentage of optimisation achieved or the amount of CO_2 emissions optimised from base case to actual case.

7.8 Linkage of Questionnaire Survey and Findings of Case Studies

Mixed methods are employed in the study to reveal different aspects of the same reality and examine that reality from different viewpoints (McEvoy and Richards, 2006). The survey strategy brings the quantitative aspect of this study. The survey investigates the current practices of sustainable management and carbon emissions management in the UAE construction industry. The survey also helped in finding the drivers and barriers to implementation of effective carbon emissions management according to global ratifications agreed on climate change.

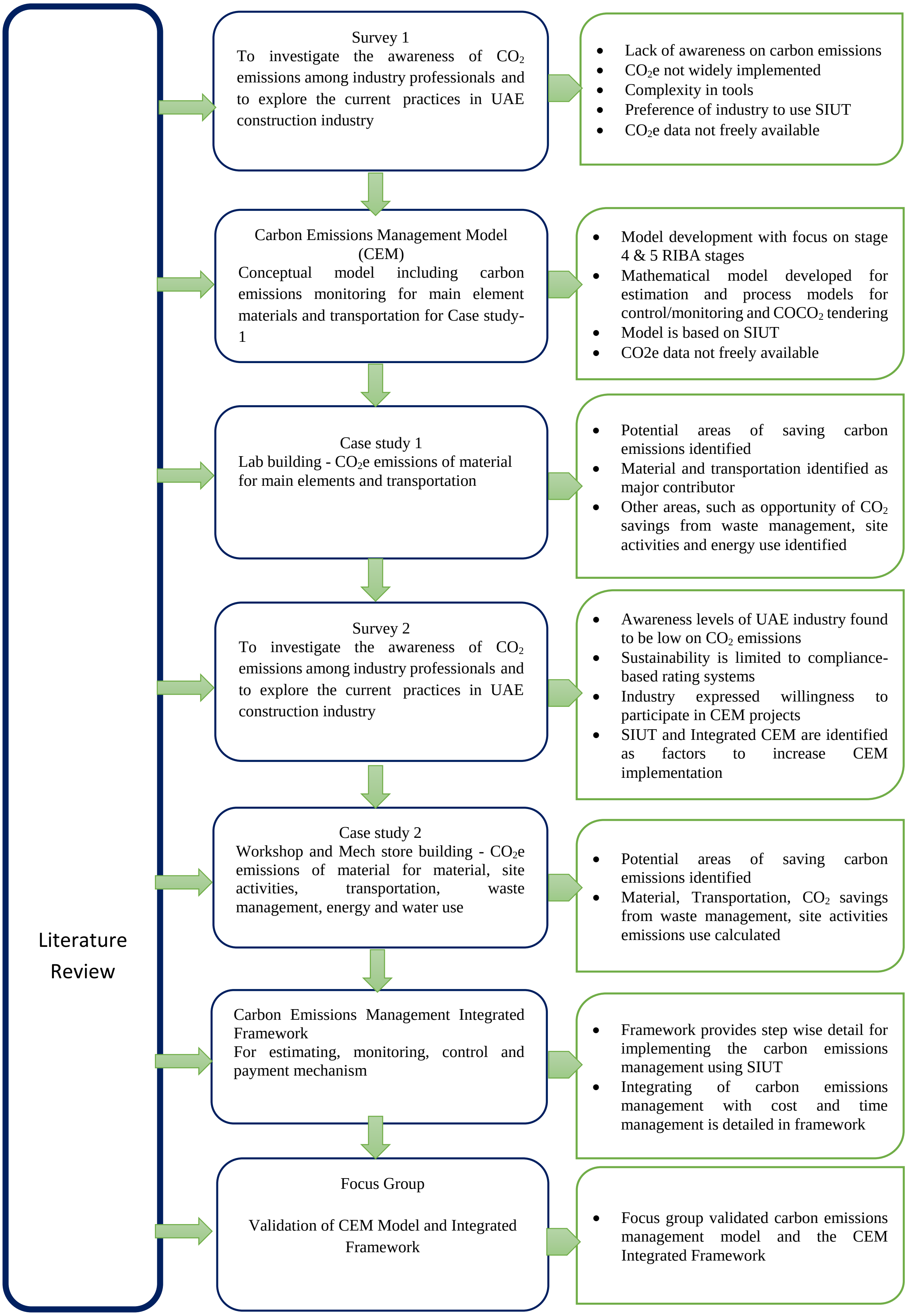


Figure 7.15 - Research framework and linkage of mixed methods adopted

- Case study 1 and case study 2 showed that making the requirements explicitly clear to the contractor and the project team will lead to higher implementation levels and acceptance of applying the carbon emissions management model. Based on the case study experience, making carbon emissions management mandatory, as the Estidama rating system in the UAE did, will result in higher efficiency of the sustainable management of projects. This understanding is in line with the Survey 2 findings, in which 65% of respondents agree to make carbon assessment mandatory on all projects, as shown in Figure 6.36.

- Case studies demonstrated the preferences of the UAE construction industry for estimating, monitoring and controlling of carbon emissions by simple-in-use tools such as Excel, Primavera and IESVE software for energy modelling. These case study findings concur completely with the findings of survey responses received, which show that 76% (as can be seen in Figure 6.38) prefer simple-in-use tools due to ease of use, familiarity of tools, lower complexity of the tools, lower fatigue associated with using the tools or a reluctance to change (Kravari, 2017). In case study 1 and 2, Excel spreadsheets were extensively used by contractors to record the material embodied carbon emissions, site-activities-energy carbon emissions, transport carbon emissions and material usage as part of daily reporting. This again shows the reason why Estidama and LEED used Excel for water calculators (Estidama, 2018; LEED, 2018).

- During the case study, professionals involved were shown ways to obtain carbon emissions factors from the ICE database and other EPDs. During the case studies, both the contracting companies developed their initial in-house carbon emissions factors on similar grounds to those of the in-house rate analysis they practice. Use of earned value management key indicators such as SPI and CPI calculation is being handled using Primavera. The case study project used a similar approach for calculating CEPI and SSPI without any difficulty by the planning engineers team. Integration of CEM with project management is also identified as a primary factor in Survey 1 and Survey 2 findings by industry professionals, as shown in Table 6.5. Stakeholders very well accept performance monitoring and control of the project based on carbon emissions on both case study projects. It is in line with the survey findings, in which 88% respondents agreed to manage sustainable projects using carbon emissions management integrated with other project management disciplines. The case studies and survey responses were contrary to the findings of Bohari et al. (2017), which state that the major challenge is to achieve change in current practices.

- The case study 1 and case study 2 projects were awarded based on the technically compliant, lowest bid offers. Compliance-based evaluations were carried out during tendering for HSE aspects. Carbon emissions and sustainability were not evaluated. These case study findings are in accordance with the survey results shown in Figure 6.20, in which 75% of respondents stated that the ultimate criteria for award was purely commercial. When the case study teams were shown the ease of estimating, monitoring and controlling and the model of $COCO_2$ tendering, contractors were willing to bid for projects which required CEM and were willing to compete for projects awarded with environmental aspects as the ultimate criteria. These findings are contrary to the survey findings on current practices, which show that only 6% of respondents stated that specifications stipulate tracking of carbon emissions in their requirements. Masdar City is the only known client in the Emirate of Abu Dhabi which is implementing carbon emissions management by specifying the criteria in tenders (Hammond and Jones, 2011).

7.9 Summary

The building CEM study presented was based on three buildings in Abu Dhabi, UAE. The entire life cycle of a building — material production, transportation, construction and operation — was considered in a hybrid-based study in which the existing LCA methodology for estimation of building life cycle carbon emissions was modified, resulting in planning, controlling and monitoring of carbon emissions during construction and modification of the procurement framework for the UAE context.

The proposed methodology was applied to two case study projects, a G+1 reinforced concrete laboratory building located in Habshan and a ground-floor-only steel-framed concrete mechanical store plus G+1 office-cum-workshop building in Bu Hasa. With an assumed building life span of 30 years, life cycle carbon emissions per unit gross floor area of Case study 2 building are approximately 137.13 kg CO_2/m^2 per year. The results of this study were compared with previous studies based in different regions of the world, as well as referring to different types of buildings, as shown in Table 7.25. The values for life cycle carbon emissions obtained in the present study are comparable with those of other countries, such as Turkey (104.40 kg CO_2/m^2 per year), Singapore (108.3 kg CO_2/m^2 per year) and USA (246.58 kg CO_2/m^2 per year). Due to a wide range of diverse factors, building life cycle carbon emissions vary greatly between different studies subject to the boundaries selected.

For the new workshop building and mechanical store building, the study explored several options for design and construction phase improvements, such as optimising the envelope attributes, window-to-wall ratios, specifications, shading and thicker thermal insulation for the roof, which can achieve a better u-value for the roof, optimising lighting power density, installation of LED fixtures, occupant sensors, timer switches and change of project cooling systems to a district cooling system. Similar steps were taken for water consumption by installing water-efficient fixtures. This resulted in a 23% energy savings and a 56.99% water consumption savings.

In reducing embodied carbon emissions, two types of materials were identified as significant: materials used in mass quantity such as concrete and materials with high embodied carbon coefficient value such as structural steel. Both types are important in identifying carbon emissions reduction strategies for the material production stage. Reduction, reuse and recycling of materials, use of alternative materials which are available locally and introducing clean manufacturing technologies are expected to enhance the possibility of carbon emissions reduction at the material production stage.

Integrating carbon emissions into traditional project management practices is also proposed. The development of country-specific data inventories is necessary for ensuring the reliability and accuracy of building life cycle carbon emissions studies in the future. To have a better understanding of the life cycle carbon emissions of buildings, future studies should extend to different areas of the country and encompass different types of buildings. This study laid the much-needed groundwork for future building life cycle carbon emissions assessments and presented a methodology which can be used by building planners, designers, owners and certification bodies to assess the carbon emissions of buildings, which is essential to form strategies for carbon mitigation and promote low-carbon buildings.

Chapter Eight: Integrated Framework for Carbon Emissions Management

8.1 Introduction

Apart from addressing the problem from the upper stream of the construction supply chain through greater adoption of sustainable design concepts and energy-efficient building services equipment, contractors may also contribute to carbon reduction, as a sizeable volume of CO_2 is originated from imported materials, material transportation and site activity. Therefore, more stringent monitoring and control of CO_2 emitted at the project level is indispensable (DEFRA, 2008; Smith et al., 2003).

In this chapter, frameworks for project award, planning, monitoring, and controlling carbon emissions are developed by taking into account the entire construction process. Carbon cost tender ($COCO_2$) is proposed as an alternative to enhance the efficiency of the existing practices of sustainable management of building construction. The chapter begins by explaining the concept behind $COCO_2$ tendering. The framework for measuring, planning, monitoring and controlling the carbon emissions of the project at the elemental level is then introduced. Subsequent sections show an integrated carbon emissions management framework, including the tendering phase and the construction phase of the RIBA lifecycle.

8.2 Background and Development of the Framework

The CEM model is developed to evaluate the sustainable performance of building construction in terms of carbon emissions, with inputs from the literature review, surveys and case studies findings (Akbarnezhad and Xiao, 2017; Devi and Palaniappan, 2014; Kumanayake et al., 2017; Langston et al., 2018; Li et al., 2016; Syngros et al., 2017; Wang et al., 2015; Watermeyer, 2012), which state that the construction industry requires the modernisation of the procurement and delivery management systems and the adoption of a systematic, purposeful and strategic approach to the delivery of a construction works.

The Overall CEM model consists of mathematical and process models which are adequately defined for the users, and recommendations were provided for the industry to adopt. Accordingly, the following three sub-models will help to address the specific areas for improvement in the implementation levels of carbon emissions management:

1. Mathematical model for the estimation of carbon emissions in a building construction project (CE-EM).
2. Process model for monitoring and control of carbon emissions (CE-MCM) during the procurement and construction phases of a building project
3. Process model for tendering using cost and carbon tender ($COCO_2$) as the governing criteria for awarding sustainable building construction projects.

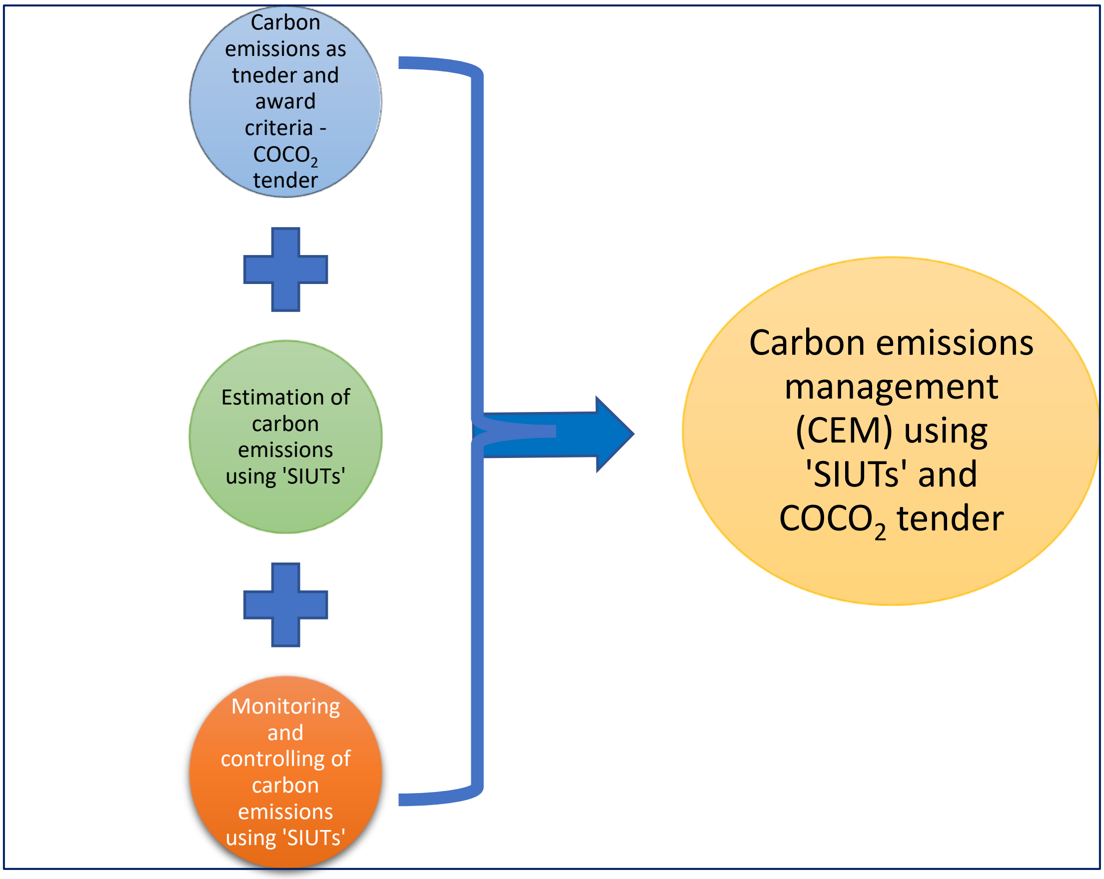


Figure 8.1 Integrated Framework for managing sustainability using Carbon Emissions Management

This research investigates the relationship between adopting carbon emissions management and increased effectiveness of the sustainable management of construction projects, particularly the control and monitoring of the design, construction and tendering aspects of a project. As noted in chapters 2 and 3, there is no existing viable framework which can measure all of the issues emerging from and supporting this relationship. Therefore, this research uses the ideas discovered in the survey, case studies, focus group and literature review, on proposing a holistic conceptual framework for enhancing environmental efficiency by using a standard unit of CO_2e. The way forward is to recommend the use of several existing tools, which individually manage projects successfully to stakeholder satisfaction. Even though the existing frameworks have been proven successful in practice to date, they all share the common shortcoming of not being able to assess the environmental efficiency by a standard unit of measurement. CO_2e is a distinct measure for calculating global emissions (Sreedhar et al., 2016).

This points to the need for the creation of an integrated framework which can assist all the stakeholders, to provide the foundation for managing the sustainable performance of the project. This approach is useful not only because it addresses the issue of carbon emissions monitoring but also because it highlights the importance and role of carbon and cost tender in the achievement of sustainable goals. No other model or framework has previously been developed which specifically covers the tendering, monitoring and control of carbon emissions in building construction while providing a means for validating sustainable performance and determining a single holistic unit of measurement (i.e., CO_2e).

8.3 Carbon Cost Tendering Framework

Even though the need for incorporating the project carbon emissions was recognised as one of the decisive factors in construction bid evaluations, the implementation levels and rational steps taken towards emissions reduction are very low (Ruth et al., 2000).

As the importance of maintaining fairness and transparency in bid evaluation is acknowledged, data related to carbon emissions must be carefully specified in bids and analysed (Ng, 2015). To improve consistency and reliability, a project's carbon emissions should be methodically estimated conforming to an established framework which specifies the major elements of building carbon emissions during the construction processes.

The project carbon emissions as estimated by bidders can then be compared with those of a 'base case' design and construction estimates to decide how much CO_2 emissions are proposed to be saved by the respective bidder. A predefined weightage for evaluation of tenders, including the technical, commercial, quality, HSE and sustainability weightages acceptable to the client, can then be assigned so that bidders' and contractors' commitment to CO_2 emissions reduction can be considered along with their bid submission and, in particular, along with the commercial bid submissions. Tendering frameworks differ from company to company, but the principles remain the same, such as issuance of tenders, evaluation of tenders and award of works. For this research, frameworks of the client organisations and frameworks available from the literature review were used to integrate the carbon emissions management aspects (Fong and Yan, 2009; Schaaffkamp, 2014; Watermeyer, 2012). The framework of $COCO_2$ tendering based on the literature review and survey findings is shown in Figure 8.2.

The framework includes activities from preparation of the scope of work, which corresponds to Stage 4 of the RIBA plan of work. Upon preparation of the scope of work and enquiry documents, including drawings and specifications, the next step is to send expressions of interest to the bidders. Bidders reply with their interest to the client and the bidder list is then evaluated based on pre-qualification criteria, and bidders will be invited to participate in the tender.

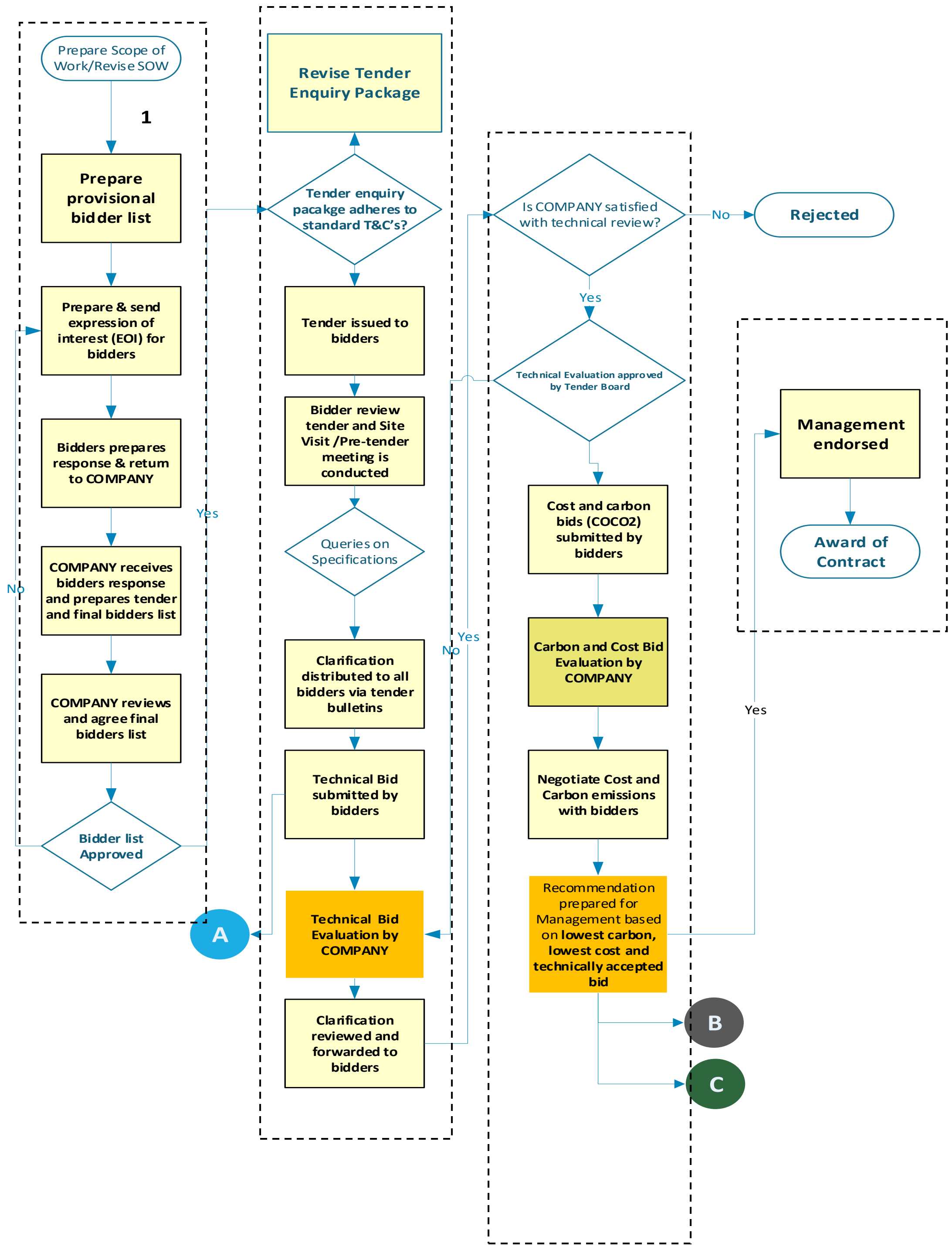


Figure 8.2 $COCO_2$ Integrated framework of tendering

A -Technical Bids Reviewed by Project Team

Category Description	Score Range Max	Score Range Min
HSE	MANDATORY	
HSE Plan	X	
HSE Mgt System	X	
Procedures Specific	X	
HSE requirements	x	
QA/QC	MANDATORY	
System/Certification	X	
Compliance with req./standards	X	
Control procedures	X	
BID QUALITY	18	12
Bid completeness, clarity and quality	6	4
Quality of tech. responses, understanding of scope	5	3
Compliance to tender	3	2
Special requirements specific to particular tender	4	3
ORGANIZATION & PERSONNEL	22	15
Proposed org. chart and histograms	7	4
Engineering support	4	3
Supervision	4	3
Mobilization/demob.plan	3	2
Key personnel (Nb., qualification.)	4	3
RESOURCES	25	18
Use of 3rd Parties	4	3
Subcontractors/Vendors suitability	6	5
Quality/suitability of tangibles	4	2
Quality/suitability of tools etc	6	4
Temporary facilities incl accommodation	5	4
INTERFACES WITH ACENOC GAS PROCESSING	10	7
Impact on operations (incl. cost)	5	3
Integration with existing sys.	5	4
ESECUTION & VALUE	25	18
Robustness to obsolescence	3	2
Impact on environment	3	2
Alignment deliverables vs. expectations/	3	2
Benefit estimation	3	2
Suitability of proposed approach	10	8
Schedule, Control System, milestones…	3	2
Total	**100**	**70**

B -Unpriced Commercial Bids

S.No	Topic	Acceptable /Non Acceptable
1	**Form of Tender (Appendix-2 of ITT)**	
	Compliance with Format	
	Bulletins & Clarifications considered	
2	**Authorised Signatory / Power of Attorney**	
	Scope	
	Notarisation	
	Any validity restrictions	
3	**Official Registration Documents**	
	Valid Trade License from Authorities	(Valid upto)
	Valid Chamber of Commerce & Industry Registration Certificate	(Valid upto)
4	Tender Security (Appendix-3 of ITT)	
	Issuing Bank	
	Value, Validity & Format	
5	**JV Agreement (If applicable)**	
	Compliance with Format	
6	**Exceptions / Qualifications / Clarifications (Appendix-5 of ITT)**	

Figure 8.3 Tendering criteria for technical and unpriced bids

C -Carbon Emission Evaluation

Description	CO2 eq qty
Carbon emissions for Mobilization and site offices	
Carbon emissions for Material procurement	
Carbon emissions for Transportation	
Carbon emissions for Construction activities	
Carbon emissions for Operational phase (Energy and Water)	
Total Emissions for complete project	

Figure 8.4 Tendering criteria for carbon bids

Approved bidders will be issued with tender enquiry packages, and bidders site visits and clarifications will follow this. Further to clarifications being resolved, bidders will be requested to submit their technical bids. These technical bids are evaluated based on criteria set out in Box-A of Figure 8.2, and a report regarding technically qualified bidders will be sent for tender board approval.

Upon being technically qualified, bidders will be asked to submit their cost and carbon bids, which will be evaluated based on the criteria shown in boxes B and C in Figure 8.3 and Figure 8.4. The client will evaluate the tender based on pre-tender carbon emissions estimates available, which are the same as being practised for cost tender. The carbon emissions of the project, along with the carbon BOQ, will become the baseline to be monitored during the construction phase. Bidders win based on the lowest carbon tender and can increase their performance based on the savings achieved during the construction phase.

8.4 Basis of Selected Tendering Process

The concept of $COCO_2$ is similar to that of an alternative tender except that the base case carbon emissions of a project is determined by the design team based on the drawings and specifications issued with tendering for a traditional procurement route (Ng, 2015). For a design and build project, bidders can estimate and submit the base-case project carbon emissions, which are derived by referring to typical information, such as the ICE database, the CESMM4 Carbon and Price Book and carbon estimating tools and solutions (ICE, 2013). The project carbon emissions estimation, monitoring and control guidelines should be issued to the tenderers at the tendering stage as they would serve as baselines for subsequent comparison.

The tenderer role will be to submit a low carbon emissions proposal, the details of alternative construction materials and/or methods, along with the magnitude of carbon emissions reduction, as part of $COCO_2$ tendering. This will motivate the bidders/contractors to establish their own emissions factors data instead of using the norms as identified from established databases. Contractors maintain the cost unit rates related to each element of building as an asset and update it continuously to remain competitive in winning projects. The same should be encouraged for the carbon emissions factors, for which contractors should capture and rely on the actual carbon emissions of alternative construction materials and/or apply established methods to calculate the emissions.

8.5 Planning and Scheduling Framework with CO_2 Emissions Integration

The main objective of planning is to ensure that all activities of the project are completed successfully. During this phase, objectives are established, tasks are identified, and progress is monitored. The project schedule provides the basis for measuring progress and for regular review and updating of the plan (Baldwin and Bardoli, 2014). Sustainability aspects are missing from the available framework of planning and controlling due to the descriptive nature of the sustainable parameters and objectives set. The parameters should have been tangible, with standard units of measurement. This research finding through the literature review and interviews identified the need to set the unit of measurement of CO_2e emissions in kg to plan, monitor and control the sustainability aspects, similar to the method used for cost and time. Planning definitions must also be amended by integrating the CO_2e emissions to improve the implementation levels. The current Chartered Institute of Building (CIOB) definition for planning is 'the determination and communication of an intended course of action incorporating detailed methods showing time, place and the resources required' (CIOB, 2011). Hence the existing framework should be modified to integrate CO_2e emissions, as shown in Figure 8.5.

Upon award of the project, as per the contractual conditions, the contractor submits the level 3 contract schedule in line with the contractual duration, specified WBS and project control milestones. Upon approval of the Level 3 schedule by the client or client representative, contractors submit 'Engineering Design Deliverable Registers' (EDDR), P6 schedules - level 7 and the itemised carbon emissions estimate of the project. These deliverables, which are known as planning and control deliverables, will be reviewed and approved by the client or client representative.

Integrated CEM Framework- Carbon Emission Monitoring & Control

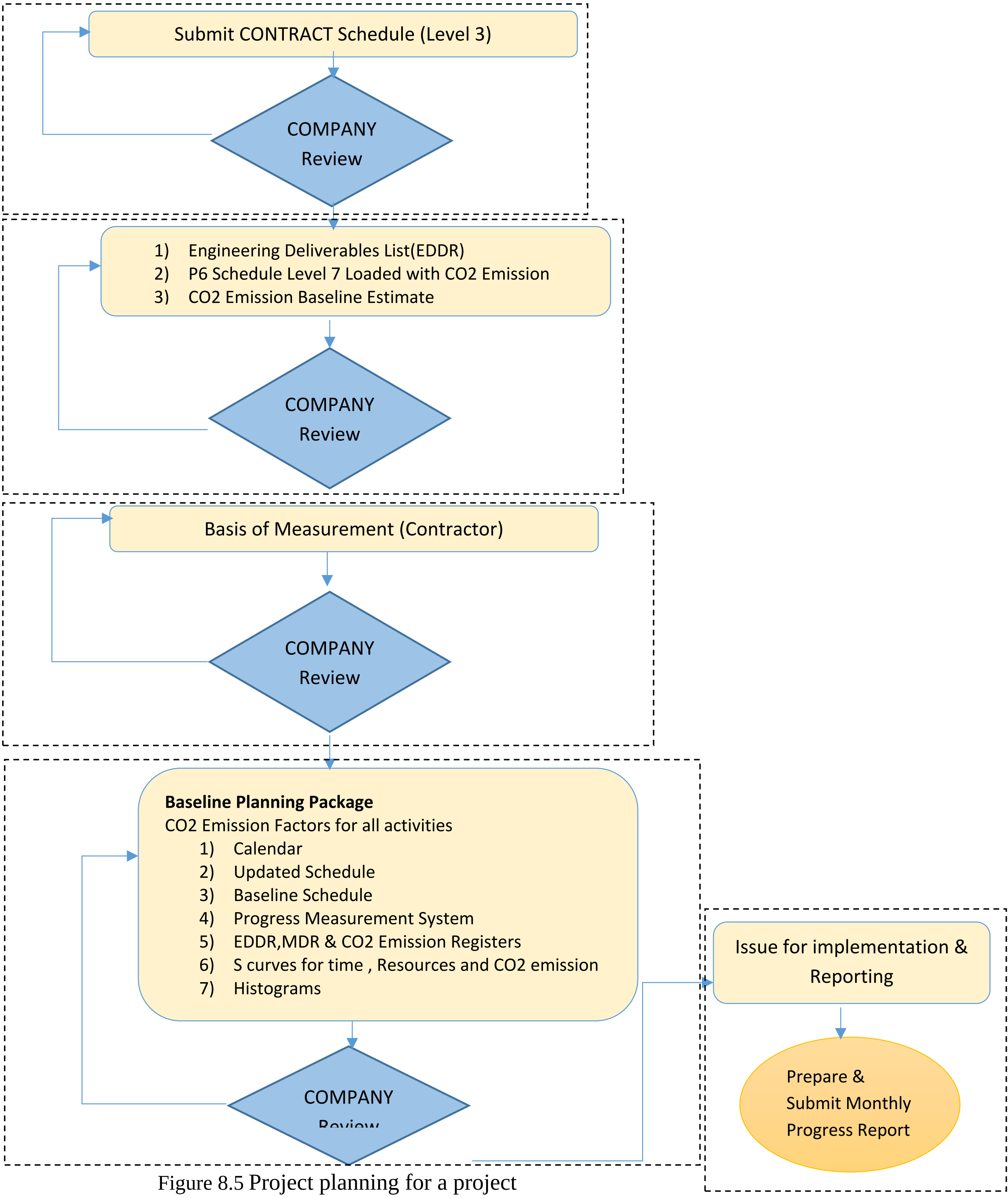


Figure 8.5 Project planning for a project

Upon approval of EDDR, the basis of measurement for all activities containing the resource information, cost information and the carbon emissions information is submitted. At this stage, carbon emissions factors will be reviewed and any justifications required for the base case carbon emissions are approved. However, as is the case with cost, the contractor would not be allowed to increase or decrease the overall carbon emissions estimate he submitted with the $COCO_2$ tender.

The contractor will later submit all the planning package requirements showing the base case and actual case template for S Curves, EDDR, construction activities, carbon emissions-loaded schedule, cost- and resource-loaded schedule, etc. as per the procedures and requirements of the project. Upon approval, this planning package will be the baseline schedule for monitoring, controlling and comparing the performance using the SIUTs (e.g., Excel and Primavera).

8.6 CO_2 Emissions Integration with Progress Reporting

Organisations have set procedures for reporting progress. As part of this research, client organisation procedures for the projects on which the case studies were conducted were used to prepare the integrated framework. After the approval of the planning package, the actual dates, resource consumption and carbon emissions expenditure are updated for every activity in the schedule. The resources consumption, man-power consumption, site activities energy, fuel consumption and transport-related data are updated based on the daily reports and inspection reports used on site. The respective contractor in charge will validate all these values before submission as a weekly or monthly report in the specified format. After submission and approval of the monthly report, the contractor, using approved values from the monthly report, submits the physical progress certificate and the CO_2 emissions saving certificate to apply for progress invoices/payments. The project performance is also monitored using CEPI and SSPI, similar to CPI and SPI of earned value management. A similar approach was adopted by researchers in many earlier studies on integrating sustainability and quality with cost and time management (Ghazvini et al., 2017; Varma et al., 2016).

Design-related savings achieved are recorded during the approval of design, and alternative material substitution is approved during the ‘material approval request submittal’. Design alternatives must be requested with complete information, including the impacts the proposed changes will have on cost, time and carbon emissions. Any design concession or deviation with carbon emissions higher than the baseline values will not be approved. Transportation savings must be justified by submission of measures taken to reduce the number of trips or the distances travelled. Similarly, the recycle and reuse measures taken during the project and the associated savings must be submitted, along with supporting evidence. Contractors also are encouraged to demonstrate the savings they can achieve for the operations phase by changing the design or material.

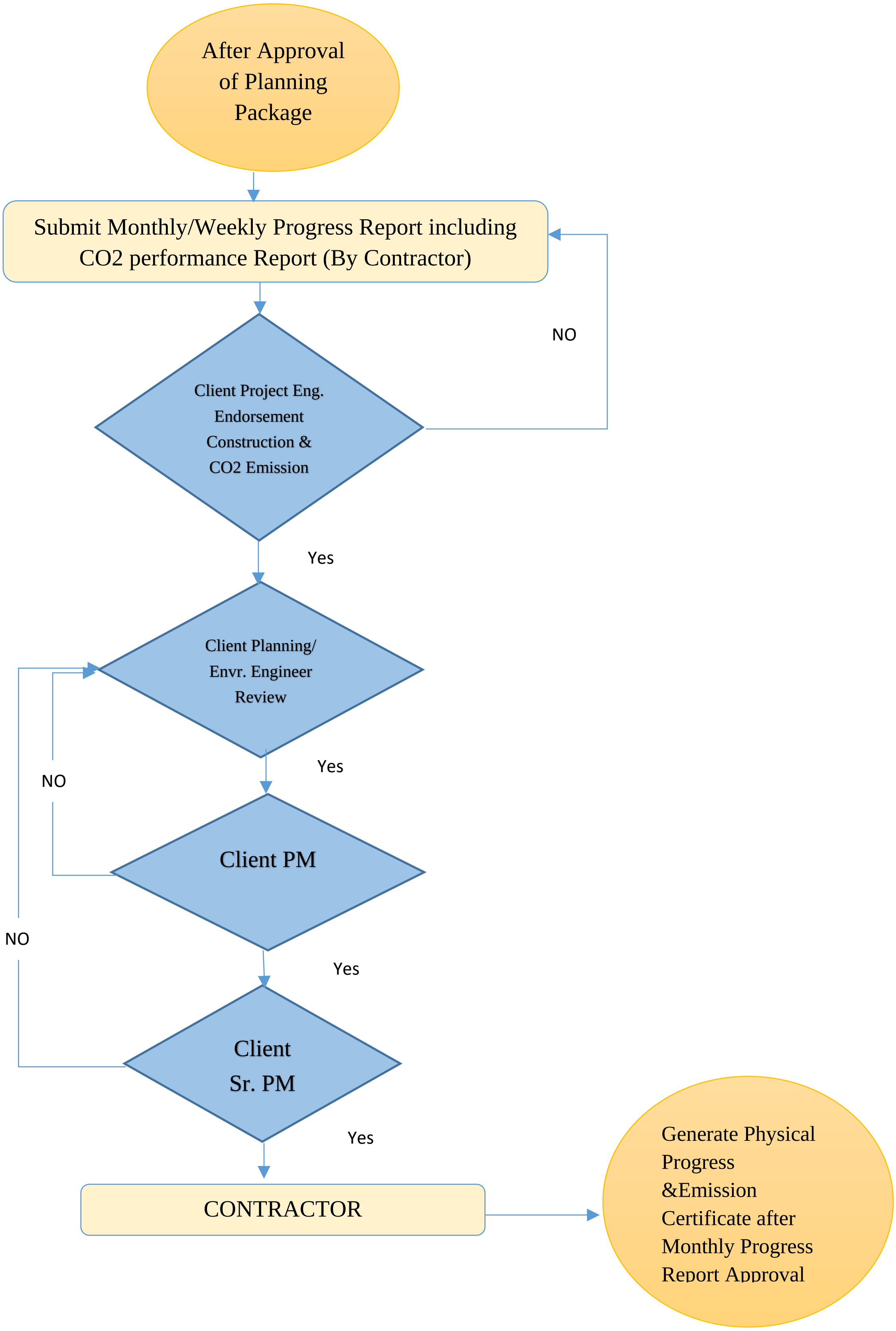


Figure 8.6 CO_2e emissions monitoring on a weekly and monthly basis

8.7 CO_2 Emissions Integration with Invoicing and Payments

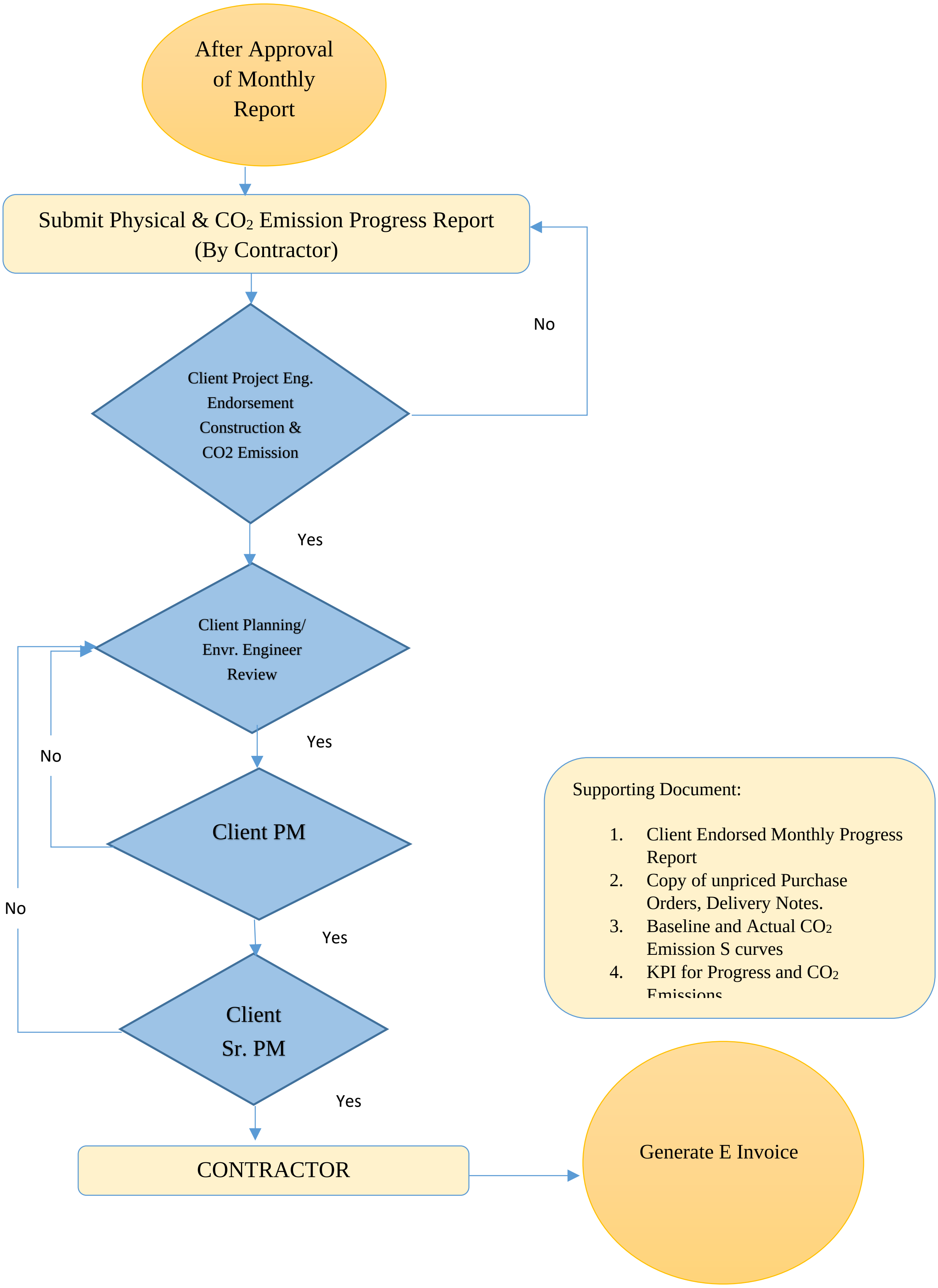


Figure 8.7 - Payment certification linked to CO_2 emission performance.

Payment certificate and the associated amount to the contractor is the sum of money paid after works have been successfully completed (Amoako, 2011). As the scope identifies the works for carbon emissions management, the payment for the contractor has a liaison with the implementation of carbon reduction measures. Furthermore, the linking of payments to carbon emissions can influence the proper execution of the works of a contractor (Darrington, 2010). Thus, selecting a suitable payment mechanism in a construction project to execute the sustainability measures is critical and requires a thorough deliberation (Walimuni et al., 2017).

Updating of progress using the daily status report, weekly reports and monthly reports are widely used in the Middle East. However, Bauman, (2013) argues that usage of daily reports may not be a suitable tool to control and manage a large number of parallel projects. So the basis for payment purpose has been taken from the monthly reports as per literature review findings, contractual clauses and existing practice of the case study organisation.

Selecting the relatively more effective payment mechanisms for contractor invoice can be used to motivate the contractor for better control of those Sustainability (Walimuni et al., 2017). Even though literature is sparsely available to link payments with environmental performance, the researcher could not find any literature linking the carbon emissions performance to payments of the contractor. Hence the carbon emissions model propose to include the linkage similarly as the progress currently is linked with payments.

Upon approval of the Monthly progress report in section 8.6, the contractor submits the 'physical progress certificate' (PPC) showing the percentage of work progress achieved and endorsed during the current month. As part of Integration of carbon emissions management with the project controls management, the CEM model proposes to add a 'carbon emissions savings certificate' along with PPC. The physical progress certificate and carbon emissions savings certificate are reviewed as per the contractual milestones, and base plan estimates. Client construction team will approve and endorse the same so that the contractor can apply for invoice payment. Such a mechanism linking it with payments improves the motivation and commitment from contractors.

8.8 Summary

Observational evidence from case studies of this research, survey findings and academic research have shown that successful implementation of carbon emissions management can provide industry organisations and project teams with the awareness, tools and means for sustainable construction. This, in turn, will help to quantify the impacts of global warming at the area, city, country and continent levels. Although every organisation has its own procedures to monitor cost and time, having conscious knowledge of carbon emissions management makes sustainable management of projects more efficient and tangible. This carbon emissions management framework sets the overall context for managing sustainability in construction projects. It helps industry practitioners to prioritise attention towards embodied carbon emissions, which is of great relevance at present due to circumstances of climate change and associated impacts. This framework provides step-by-step information on how to apply carbon emissions management using SIUTs and by adapting the $COCO_2$ tendering concept. The integrated framework for the CEM model covers stage 4 and 5 of the RIBA plan of work and commences from detailed design to construction and handover. It includes the tendering framework, planning package framework, weekly and monthly report submission framework, physical progress certificate framework and invoices submission framework. All these frameworks integrate to show the complete implementation of the CEM model. Linking the CEM model to earned value management and the invoices are intended to improve accountability, motivation for Contractors to implement CEM.

Chapter Nine: Validation and Discussion – Focus Group

9.1 Introduction

Following a review of the literature, survey and case studies, this research developed a conceptual framework for the effective implementation of carbon emissions management in a building construction project. The resultant Integrated CEM framework was developed to enhance environmental efficiency of building construction and to enable the industry to manage carbon emissions using simple-in-use tools. The purpose of this chapter is to validate the Integrated CEM framework including the CEM model using an independent expert panel in a focus group setting.

Detailed research methods, methodology and analysis methods used were explained to validate the proposed model and the justification for the focus group. This chapter also includes the comments and suggestions which were presented by the experts in the focus group session.

What follows are six individual subsections, each addressing one specific area and including a detailed analysis of that group, providing an overview of the expert feedback and their suggestions. Section 9.4.4.4 then discusses the $COCO_2$ tendering concept and analyses the feedback which was discussed during the focus group session, while Section 9.4.4.2 and 9.4.4.3 explains in detail the simple-in-use tools and the proposed outcome of the Integrated CEM, followed by the comments and suggestions provided by experts in this area. Section 9.5 focusses on the model improvement.

9.2 Focus Group Method

The focus group discussion method was chosen as a discussion technique of the expert panel to validate the proposed model. Focus groups are a useful method to explore the knowledge, expertise and perceptions of people in a particular field or area. Focus groups provide an opportunity to examine not only what people think but also how they think and why they think as they do. This ability makes focus groups a preferred tool for ideas generation, for complementing qualitative or quantitative methods, for the triangulation of findings and the validation of theories (Sagoe, 2012).

The focus group was held at the client's organisation building in the UAE with a panel of 18 experts from six different categories: cost managers (four participants), project managers (three participants), contracts managers (two participants), construction managers (three participants), planning Managers (four participants) and client representation (two participants). The participants were presented with the four key areas of research and were provided freedom to express their feedback across topics during the focus group discussion; however, the feedback was requested such that it covered the following four key areas for CEM, as shown in the focus group agenda in Table 9.1. The four key areas were:

1. The carbon emissions management (CEM) model and framework as a complete approach in managing sustainable projects.

2. The stakeholder's comfort level, ease and the efficiency of the proposed CEM model in increasing implementation levels of sustainable performance in the UAE (contractors, consultants, PMC and client).

3. The CE-EM and CE-MCM models using the SIUTs concept for improving carbon emissions management implementation and sustainability (economic, social and environmental dimensions of sustainability).

4. $COCO_2$ tendering to award contracts based on cost and carbon emissions.

Table 9.1 summarises the focus group participants and duration and the activities which took place. Before the focus group began, participants were provided with information about the concept of sustainability, challenges being faced, global warming, the role of the construction industry and the negligence towards embodied carbon emissions management by the industry. Focus group participants were also provided with the life cycle phase of building projects and the area of study being researched. This information helped the participants to focus on the concepts under discussion and to recall their ideas (Koulaidis and Christidou, 1999). Notes were taken during the focus group discussions. These were used to confirm the understanding during the data analysis.

Table 9.1 Focus group agenda

Participants	Discussion topic	Discussion time	Additional activities
Cost managers (4), project managers (3), contracts managers (2), construction managers (3), planning managers (4), client representatives (2)	Presentation of current carbon emissions management and the contract award process	60 minutes (from 8.00 AM to 9.00 AM)	A review of Estidama and LEED credit matrices
	Presentation of embodied carbon emissions and operational carbon emissions and review of current practices, tools and implementation levels	60 minutes (from 9.00 AM to 10.00 AM)	None
	Discussion on why implementation levels are low	30 minutes (from 10.00 AM to 10.30 AM)	Idea generation and shortlisting of the most prominent factors leading to lower implementation levels.
	Model and framework validation		
	Presentation of the integrated carbon emissions management framework and showing the resources to look for carbon coefficients	60 minutes (from 11.00 AM to 12.00 Noon)	Review of framework by the experts and discussions. Accessing the carbon coefficients of materials from public domain (internet resources)
	Demonstration and practice session for CO_2 estimation using simple-in-use tool (Excel)	60 minutes (from 12.00 Noon to 1.00 PM)	Calculation of embodied energy for certain activities, such as foundation and blockwork, using Excel by all participants
	Presentation on CO_2 bidding process, evaluation and award criteria	60 minutes (from 2.00 PM to 3.00 PM)	Review of current evaluation criteria and the proposed evaluation criteria
	Demonstration and practice session for CO_2 monitoring and control using simple-in-use tool (Primavera)	60 minutes (From 3.00 PM to 4.00 PM)	Monitoring and control of embodied energy. How to use resource loading options for carbon emissions monitoring and control using Primavera by 4 planning and 2 construction manager participants
	Improvements, suggestions and conclusion	30 minutes (from 4.30 PM to 5.00 PM)	Closed envelop suggestions and conclusions by all participants

The participants were from different organisations directly involved with estimation, bidding, monitoring, and controlling building projects in the UAE. Therefore, it can be expected that the focus group would express a higher rate of accurate ideas and feedback and a lower rate of misconceptions and inconsistencies.

9.3 Focus Group sampling and participants selection

A focus group is defined as a method of collecting research data through moderated group discussion based on the participants' perceptions and experience of a topic. Also, the characteristic of the focus group is homogeneity, but with sufficient variation among participants to allow for contrasting opinions. (Sage pub, 2019)

Table 9.2 Focus group Participant details

Participant	Designation	Years of Experience	Organisation
1	Cost and tendering Manager	25	Contracting Organization
2	Estimation Manager	17	Contracting Organization
3	Cost Controls Manager	19	PMC Organization
4	Senior Cost Manager	14	Design Consultancy
5	Project Manager	12	Contracting Organization
6	Sr Project Manager	21	Design Consultancy
7	Area Projects Manager	19	PMC Organization
8	Contracts Manager	12	Contracting Organization
9	Sr Contract Specialist	10	Design Consultancy
10	Construction Manager	15	Contracting Organization
11	Sr Construction Specialist	24	Design Consultancy
12	Construction Manager	26	PMC Organization
13	Planning Manager	14	Contracting Organization
14	Scheduling Manager	18	Design Consultancy
15	Planning and controls	22	Contracting Organization
16	Sr Planning Engineer	16	PMC Organization
17	Project Manager	21	Client Organization-
18	Project controls section	13	Client Organization

Focus group cannot be used to describe the entire population, so the type of sampling to describe whole populations is not necessary. The sampling method selected for validation of Integrated CEM framework is convenient sampling, as focus groups do not use probability or random samples. Nagle and Willaims (2019) also state that focus groups generally utilise convenience sampling.

Focus group participant selection plays a very important due to their inputs in developing the model or the framework (Krueger, 2014). Bruseberg and McDonagh (2002), state that the number of participants, required knowledge and willing to share

are the main criteria for selection of participants. There are different opinions regarding the focus group size. Creswell (2013), suggest the optimum number of participants in the focus group between six and eight participants while Rabiee (2004), suggests up to ten participants. Number of participants can be increased if the moderator can manage the fragmentation issue of the group. In this study, to maintain homogeneity and to have sufficient variation among participant, Eighteen construction management professional participated in the workshop with participant as moderator as shown in Table 9.2.

9.4 Focus Group Validation

9.4.1 Current carbon emissions management (CEM) and the contract award process

The CEM approach is a potential instrument to obtain environmental benefits and help to create a demand for carbon-efficient materials, products and services. This demand will increase awareness levels and boost the amounts of materials and services in the market, which have a minimal environmental footprint compared with a standard product or similar type of service. To understand these benefits, it is imperative to focus on current emissions management and the contract award process.

Table 9.3 shows that the focus group participants agreed on the practice of embodied carbon emissions management as limited and low, which is in line with the academic literature on the practice of embodied CO_2e measurement in the industry (De Wolf, Pomponi and Moncaster, 2017b). All participants agreed that Estidama and LEED requirements govern the awareness levels of the UAE construction professionals such as the awareness of calculators for operational energy and water efficiency.

Table 9.3 Validation of current carbon emissions and award process

No	Findings	Rate	Remarks
1	Current carbon emissions management and the contract award process		
a	Current practice of carbon emissions management is predominantly limited to meeting compliance requirements such as obtaining certifications of LEED and Estidama in UAE building construction.	88.9%	Two participants stated that the projects they executed in Australia and the UK required them by regulations to submit LCCEs.
b	CO_2 emissions as a unit are not prevalent in the construction industry. Instead, more emphasis is placed on energy savings, water savings and waste reduction.	78%	Participants stated that these are quick gains and can be demonstrated to the client at the onset of the project.

c	Current software is limited to energy modelling, water calculations and waste reduction.	95%	One participant did not agree and demonstrated his awareness regarding other software for CO_2 estimation.
d	Hidden data, complexity in use for the available software or compliance-based approach towards sustainability.	88.9%	Two participants stated, ‘I do not care what’s behind it as long as it is coming from a recognised software’.
e	The ultimate deciding factor in the majority of building projects in the UAE is the cost (i.e., lowest-cost bid wins the job.)	100%	All participants agreed on the common practice of awarding the project to the lowest-cost bidder.

Hidden data and complexity are identified as reasons for the lack of implementation of CEM. Item 1 (a) of Table 9.3, when compared with the survey results, shows a similarity in findings. The survey results in Figure 6.28 in section 6.7 show that 70% of respondents agree that sustainability/CEM implementation are limited to the use of rating systems in their projects.

9.4.2 Current practices, tools and implementation levels of embodied / operational carbon emissions

Table 9.4 shows that estimating and monitoring of carbon emissions is not being implemented for building projects in the UAE except the projects of the Masdar City development. This low implementation of carbon emissions management is due to emphasis and reliance of the UAE on compliance-based sustainability rating tools such as LEED and Estidama.

The current rating schemes being used for sustainable performance assessment including Estidama, LEED and BREEAM incentivise or encourage practitioners to assess the embodied CO2e of their projects but do not completely assess performance based on whole-life carbon emissions. Moreover, BREEAM and other rating tools place more emphasis on operational carbon emissions (Ariyaratne and Moncaster, 2014).

Table 9.4 Validation of carbon emissions management, its tools and implementation levels

No	Findings	Rate	Remarks
2	Embodied/operational carbon emissions review of current practices, tools and implementation levels		
a	Embodied carbon emissions estimation and monitoring is not being done.	94%	One participant gave an example of Masdar City development projects in which carbon emissions management was being implemented.
b	Embodied calculation process is complex, and tools are not available.	73%	Five participants stated it is possible with BIM and carbon calculators.
c	Embodied carbon emissions coefficients are not easily accessible at an elemental level for buildings in the UAE.	100%	A 100% acceptance was received due to the presentation provided to focus group on available data from ICE and EPDs.
d	Operational carbon emissions tools availability.	100%	Simple Excel spreadsheets, other software's compatible with BIM and IESVE are mostly used...
e	Current practices for operational carbon include power consumption savings, water consumption savings, waste diversion from landfill, use of LED and low water flow fixtures, material purchased from within 500-mile radius, concrete with high percentage of GGBS, energy-rated equipment and appliances.	78%	Four participants (2 project managers and two construction managers) stated that LCCE's are carried out as per ISO 14064 standards for reporting GHG emissions.
f	Awareness levels of operational carbon emissions are higher compared with embodied carbon emissions.	50%	Nine participants said that awareness levels are down for carbon emissions management.
g	Current tools are compliance-based, and practice is based on requirements either in LEED/Estidama/LCA or any regulations (Environmental Impact Assessment study-EIA)	100%	LEED and Estidama are more prevalent in the UAE, and the responses reflect agreement of 100%.
h	Implementation of carbon emissions management is limited to the operational phase.	94%	One respondent disagreeing on this question used masdar example.

Limited availability of free data on carbon emissions factors, the complexity of calculating material quantities and the lack of availability of EPDs, transportation modes and distances, as well as a lack of data on construction emissions, lead to lower levels of implementation of CEM. Carbon emissions estimation software and practices are evident in the industry based on the responses received on Items d and h of Table 9.4 and also as per the literature review (Mousa et al., 2016).

9.4.3 Reasons for low implementation levels of carbon emissions management in building construction industry

Table 9.5 shows that participants in the focus group agreed that there were problems of a lack of benchmarking, awareness and availability of carbon emissions factors for managing embodied CO_2e in buildings, though all agreed that several countries have started collecting data towards this goal.

Table 9.5 Validation of reasons for low CEM implementation levels in the UAE

No	Findings	Rate	Remarks
3	Discussions on why implementation levels of carbon emissions management are low		
a	Complicated software and methods to estimate and monitor embodied energy/embodied carbon of building project.	88.9%	Two participants disagree, stating that with developments in IT, software is becoming more user-friendly.
b	Low level of implementation due to lack of awareness.	100%	All participants stated that all the stakeholders should work collaboratively to increase awareness levels.
c	Clients do not specify, and regulations do not ask for it.	100%	UAE regulations do not mandate carbon emissions tracking and reporting for construction companies. Focus group participants stated that except for Masdar City, none of the clients in the UAE ask for CO_2 emissions management.
d	Lack of universal unit to measure sustainability (i.e., every industry calculates it in different ways with units).	100%	Examples given by focus group are LEED/Estidama using credits, ISO standards using compliance.
e	Carbon emissions management using simple-in-use tools for buildings is what industry needs now.	100%	All agreed to it. References were given to IESVE, SimaPro and other sustainable tools and complexities in use for construction phase.
f	Emphasis more on operational energy, water and waste savings due to product manufacturers/service providers' business interests.	100%	Focus group stated that it gives a quick win and also is easier since the market is flooded with energy-efficient fixtures and equipment. Focus group also stated that the trend or emphasis on operational carbon emissions is due to product manufacturers' benefits and to improve their sales.
g	Lack of clear guidelines, data metrics and success case studies in the industry on carbon emissions management.	100%	One of the focus group participants stated 'no one explained to us until now how simple it is'. All agreed that if clear guidelines, data metrics and case studies are available, implementation levels will increase.

When asked about the availability of emissions factors for the UAE, all participants commented that there was a lack of national, reliable and comparable benchmarks. The lack of databases is also one of the primary reasons for lack of CEM implementation in many countries. De Wolf, 2017 states that the national databases are enablers for embodied CO_2e assessments.

The focus group participants believe that governmental regulators, clients and consultants should work in collaboration with contracting companies and local non-governmental organisations to raise awareness about sustainability and carbon emissions management to improve sustainable practices in the UAE.

9.4.4 CEM using SIUTs and COCO$_2$ for Buildings: Looking Ahead.

9.4.4.1 Integration of CEM in the existing PM framework

Table 9.6 shows that the focus group acknowledged that to successfully implement carbon emissions management in construction projects, a holistic and integrated approach is required to merge sustainability with existing project management practices. Having tools for every need is increasing fatigue among construction professionals, so utilising simple-in-use tools and integrating sustainability by managing carbon emissions in the same way as time and cost is required to improve embodied carbon emissions as well as operational carbon emissions. The adoption of the carbon emissions managing method by practitioners would help produce systematic data, leading to comparable results and reliable embodied emissions statistics (Resch and Andresen, 2018).

Table 9.6 Validation of integration of CEM with PM framework

No	Findings	Rate	Remarks
4	Integration of carbon emissions management in the existing project management framework is a possibility.		
a	Carbon emissions estimates and control activities bring order to the way the resources are spent on the project.	84%	Three participants cited work-manship, expertise and procurement practices in a company as main reasons rather than CO_2 emissions control.
b	Integration of carbon emissions management can increase cost-effectiveness as each material is being recorded, travel distances are being measured, waste being monitored, etc.	100%	The unanimous answer was yes. Focus group participants stated that even the productivity of labourers increases when their outputs are linked with overtime benefits. Two focus group members stated that it would reduce waste, increase output, increase transparency and accountability.
c	Adequate resources to look for carbon coefficients (upon showing the freely available ICE database and other internet sources during presentation).	100%	These findings were contradictory to 2c in Table 9.4.
d	Tender documents will provide the carbon coefficient for a unified/single standard source for ease of comparison and tender evaluation.	100%	All participants requested that the changes in the framework include the provision of supplying the carbon coefficients as part of tender documents.

e	Carbon coefficients used in CEM are for relative comparison. The accuracy of these coefficients is not important.	50%	Nine participants disagreed and stated that accuracy will always be the top criterion during the monitoring and control phase.
f	The proposed CEM for building projects is easy to implement as minimum effort is required.	100%	This question was asked repeatedly during the focus group workshop.
g	It is superior to other descriptive sustainable rating tools, such as LEED and Estidama, with qualification in terms of kg of CO_2e.	78%	Four participants stated that having an internationally accepted certification will give more credibility than showing the savings in terms of CO_2 emissions.

9.4.4.2 CO_2 estimation using SIUT – Excel

Table 9.7 Validation of SIUT (Excel) for embodied CO_2 emissions estimation

No	Findings	Rate	Remarks
5	Demonstration and practice session for CO_2 estimation using simple-in-use tool (Excel)		
a	Embodied CO_2 emissions estimation is as simple as preparing a cost estimate (provided CO_2e for materials are readily available).	100%	Use of ICE database, knowledge of specific gravity values and awareness of calculating quantities made focus group comfortable estimating CO_2 emissions using Excel.
b	Embodied CO_2 estimates can also be prepared in cost estimation software (provided CO_2e for materials are readily available).	39%	Seven participants were aware of cost estimation tools. The remaining participant did not confirm affirmative as their companies use Excel as an estimation tool.
c	Over time, companies can build their own CO_2e coefficients similar to the rate analysis for cost estimates and use it for a competitive advantage.	50%	Nine participants disagreed, stating that in-house coefficients require third-party certification or validation. Other participants said it is possible by following the approach of rate analysis. A carbon unit analysis for 1cum concrete can be done by including coefficients of raw material, sources of energy, travel distances, percentage of recycled content, etc.
d	Data in Excel has limitations, such as retrieving the data, unauthorised changes, file size, etc. (Comparatively, the software is much more organised for storing and retrieving information.)	27%	Thirteen participants stated that Excel is a versatile tool which has a high level of acceptance in the industry. It is still in use even after the availability of Primavera and cost tools.
e	Foundation concrete carbon emissions calculations are easy with the availability of quantities and carbon coefficients.	100%	All participants agreed upon seeing the rate analysis comparison of cost and carbon emissions. Moreover, available carbon coefficients from ICE were accessed and shown to participants for variable GGBS content in concrete.
f	Optimisation of estimated carbon emissions during implementations for block work and foundation concrete is possible by changing the required quantity, reducing waste, changing method of constructions, changing travel distances, etc.	100%	All participants agreed on ease of estimation and optimisation upon review of the measures and the impacts on CO_2e emissions from these activities.

The researcher observed the preoccupation of the industry with Excel during the focus group sessions, in which the participants explained their continued use of Excel even after specialist software has become available. For example, schedule management is being done with a combination of Primavera and Excel due to the ease of preparation and generation of reports. Similarly, LEED and Estidama use excel calculators as waste and water calculators.

Item c of Table 9.7 shows a divided focus group, in which focus group participants stated that the availability of carbon emissions factors should not be limited to the ICE database or EPD, but that companies should instead be allowed to prepare and maintain their own carbon emissions databases. The focus group identified a clear opportunity for leading construction companies to collaborate on embodied CO_2e factors and uniform calculation methods.

9.4.4.3 Embodied CO_2 emissions monitoring and control using SIUT – Primavera

As Table 9.8 shows, the focus group participants stated that the CEM model will not only show the savings achieved overall and by each element of the building but will also help to identify the areas of improvement which the project team needs to focus. With high-resolution results from several representative buildings, embodied emissions values can be standardised over time and used as benchmarks for other building projects to be compared against (Resch and Andresen, 2018)

Table 9.8 Validation of SIUT – Primavera for embodied CO_2 emissions monitoring and control

No	Findings	Rate	Remarks
6	Demonstration and practice session for embodied CO_2 emissions monitoring and control using simple-in-use tool (Primavera)		
a	Embodied CO_2 emissions monitoring is as simple as time monitoring in Primavera.	84%	Three participants stated that a workaround approach is being adapted for CO_2 emission whereas Primavera is meant for time and cost control, but agreed that as the method of monitoring CO_2 emissions is the same as any resources monitoring, acceptance by users will be high.
b	Assigning embodied CO_2 as a resource to each activity and monitoring the emissions.	100%	Focus group agreed the simpler way of managing CO_2 emissions using Primavera.

c	Creating a resources directory in Primavera in the following way: Add resource and assign in cost/per unit the CO_2eq emissions factor. Go to activity and assign the resource to the activity and fill the budgeted quantity with the material Qty multiplied by the density or as applicable.	100%	Planning engineers in the focus group said that this is the usual way of creating, assigning, monitoring and controlling resources use. Adapting the same will be an advantage.
d	Managing the emissions of activity and resource CO_2 emissions and the overall emissions of the project through resource profile graphs and tabular reports.	100%	Planning and construction teams agreed on the quality of reports generated by Primavera for resource management. As CO_2 emissions are being monitored the same way, effectiveness will increase and will not add any burden on execution teams and planning teams.
e	Input process of actual quantities after optimisation: • Reduction in CO_2 emissions due to optimisation of used quantity, reduction in waste, compared with the planned quantities. • Reduction in CO_2 emissions due to the optimisation of the carbon emissions factor. • Reduction in CO_2 emissions by replacing the planned material with alternate carbon-efficient material.	100%	Enthusiasm during the focus group was greater when the options of optimisation were discussed. Participants highlighted different waste reduction strategies being adapted in their companies such as 'just-in-time' Lean, green..etc. All participants understood the IO process and agreed in converting the waste reduction outcome in CO_2 emissions as a best way to report the sustainable performance.
f	Calculation of the following: **Sustainability Planned Value (SPV)** - The sum of the carbon budget for all authorised work. Also known as sustainability performance measurement baseline. **Sustainability Earned Value (SEV)** - The authorised emissions accomplished. SEV=SPV x % of work completed **Actual Emissions (ACE)** - The total emissions to achieve the actual work performed to date. **Carbon Emission Variance (CEV)** - Determines whether the project is ahead of or behind the carbon emissions budget. CEV=SEV-SPV **Sustainability Performance Index (SPI)** - Indicates how efficiently the carbon emissions have been used when compared with the baseline SPI=SEV/SPV	88.9%	There was an agreement on ease of using these formulas for reporting; however there was disagreement in the reporting cycle. Two participants did not agree on reporting the emissions weekly, stating that shorter reporting cycles will increase the load on planning engineers and site team. Instead, they recommended monthly reporting.
g	Compared with other software or solutions available, do you think this SIUT carbon emissions management is simpler and easier?	100%	Focus group participants raised the fatigue issues related to passwords, plastic cards and various software in day-to-day life. Having one tool is preferable for ease of implementation.
h	SIUTs and $COCO_2$ tendering can increase implementation levels of carbon emissions management in building construction projects.	100%	Focus group stated that there are also other factors to consider for increasing implementation levels, such as awareness, regulations, specification, contracts and availability of data metrics. All agree that a start is required and that it should be as simple as the proposed CEM model and $COCO_2$ tendering model.
i	Estimation, monitoring and control will lead to reductions in carbon emissions (both embodied and operational CO_2 emissions).	100%	Focus group echoed the phrase 'whatever gets measured gets managed'.

9.4.4.4 $COCO_2$ bidding process, evaluation and award criteria

Adopting green procurement means committing to minimising the environmental impacts and consequences of its construction activities by optimum selection and assessment of products and services at all life cycle stages (Bohari et al., 2017). The following table shows the validation of the $COCO_2$ bidding model in which the evaluation and award criteria are cost and carbon emissions. No longer does the bid with the lowest cost win the bid but instead, the lowest CO_2 emitter shall win the bid.

Table 9.9 Validation of $COCO_2$ tendering, evaluation and award criteria

No	Findings	Rate	Remarks
7	$COCO_2$ tendering process, evaluation and award criteria		
a	Framework for cost and carbon tender is clear and concise, showing the required steps to be carried out for $COCO_2$ tendering.	100%	All participants stated that the framework clearly shows the process of $COCO_2$ tendering.
b	Submission of carbon tender will be accepted by the participating bidders unconditionally.	84%	Three participants stated that lack of awareness might be the reason for bidders to decline to participate. All participants agreed to the suggestion that a pre-bid meeting should be held to spread awareness and provide clarity in information required to bid with $COCO_2$ tendering.
c	Evaluation criteria of the $COCO_2$ bids should be issued along with the bids. Lowest carbon emitter wins the contract.	84%	Three participants objected to the idea that the lowest carbon proposal should win. Instead requested that other cost and technical criteria be given certain weightage.
d	Award letter should state the cost, time and carbon emissions values based on what performance of contractors on a project is evaluated.	100%	All participants agreed to set targets for carbon emissions similar to cost and time targets being set. Participants also recommended setting clauses for carbon emissions in the binding contract, along with penalties/rewards.
e	Evaluation and award process will become complicated and may lead to unfair practices/favours.	0%	All participants rejected this notion and stated that the bidding process would not be affected by the addition of carbon bid. They also stated and agreed that this approach of tendering would transform the way we execute sustainable projects.

A clear measurement of performance in terms of CO_2 emissions will determine how well sustainable performance has advanced in the project and what improvements need to be made. Current mechanisms in tender evaluation and the construction phase exist to ensure compliance and to track non-compliance issues. For example, tender evaluation is one of the tools used for examining the environmental performance of bidders based on the environmental requirements specified in the technical specifications (Varnäs, Balfors and Faith-Ell, 2009). Compliance with ISO standards and government legislation are another way of assessing green performance during tendering.

As Table 9.9 shows, the focus group agreed that this approach of $COCO_2$ tendering will drive the implementation of carbon emissions management. Measuring sustainability performance in terms of CO_2 emissions at the project level, organisation level, regional level and country level will provide a standard unit by which to measure the impacts of global warming and devise mitigation measures accordingly.

9.5 Other Drivers and Factors in Increasing Implementation Levels of CEM

Meanwhile, many participants mentioned the importance of CEM and explained that making it mandatory abruptly, to manage CO_2 emissions is risky in motivating the stakeholders and may cause disruption. Instead, a planned phase-wise mechanism shall be adapted to make it mandatory similar to the way Estidama has been mandated on all projects in Abudhabi. One participant suggested that although there is no mandatory requirement for CEM, the top management must impose internal policies which ensure continuous implementation in all projects. Others argued that the challenge to impose CEM on every project is difficult initially but that the company must ensure the continuity of CEM practices for at least one project every year initially and then add more projects when awareness levels improve. Besides the challenge of change, the other justifications which were also agreed by focus group members are:

1) To ensure continuous awareness sessions and on-the-job training to increase the stakeholders' levels of competency and confidence.

2) To continuously test and refine the best processes and procedures for CEM implementation.

Table 9.10 Validation of other drivers and factors in increasing CEM implementation levels

No	Findings	Rate	Remarks
8	Improvement and suggestions such as other drivers and factors to increase implementation levels		
a	Relationship between reporting and emissions reductions is indirect; the relationship is complex, with many other activities and influences coming into play.	50%	Participants were divided on this aspect, with half of them stating that in the UAE context, there exists a direct relationship.
b	Govt regulators/investor/clients are defining the need for CEM in regulations and tender enquiries and providing guidelines on the requirement details of accountability and transparency.	100%	All participants agreed to this and stated that regulations on Estidama and Al Safat had transformed the building construction industry in Abu Dhabi. The same results can be obtained with CEM implementation.
c	Reductions in emissions are likely to be influenced by senior management commitment, specific targets, the rewards for efficiency and savings, having competitive advantage and ethical reasons.	78%	Four participants stated that a bottom-up approach is more effective than a top-down approach.
d	Cost-saving or revenue-generating opportunities will drive emissions reductions.	100%	Focus group participants stated that reducing carbon emissions is also about optimising the mass/quantities and exploring alternative methods. This will result in cost savings.
e	Improving on-the-job training and awareness sessions.	100%	Focus group emphasised the importance of awareness and on-the-job training as key factors for increasing implementation levels of CEM.
f	Whatever gets measured gets managed.	100%	One of the participants stated that the case study 2 project benefitted by reducing waste as all activities and their outputs were being measured.
g	Weekly and monthly reporting of sustainable performance of an organisation in terms of CO_2 emissions should also be encouraged.	100%	All participants agreed to the fact that 'if measured can be reported'.

Therefore, two additional criteria are suggested to be introduced into the CEM model and framework: the sharing of lessons learnt and on-the-job training. As Table 9.10 shows, the focus group unanimously agreed that monitoring and reporting carbon emissions would lead to reductions in emissions. However, the research undertaken by PricewaterhouseCoopers (PwC) and the non-profit company CDP shows that the relationship between reporting and emissions reductions is indirect; the relationship is complex, with many other activities and influences coming into play.

The survey and the focus group both supported the findings of the literature review, which showed that there are several drivers which will lead a company to start measuring and reporting carbon emissions, resulting in reduction of carbon emissions on building projects:

- Meeting investor/client needs,
- Compliance with regulations,
- Senior management influence and commitment,
- Establishment of specific targets,
- Potential for cost savings,
- Brand building/market leadership and
- Ethical reasons.

The focus group emphasised cost savings or revenue generation opportunities as critical drivers in emissions reductions. The other emphasis of the focus group was on the important role of measuring emissions leading to carbon emissions reductions, stating that ‘what gets measured gets managed’.

9.6 SIUT CEM Model Testing

The SIUT model was tested on two case study projects, and the findings are in chapter 7.

9.7 Validation Findings

Following the focus group workshop, the findings of the validation process were analysed. It could be argued that the validation process indicated that the developed CEM model is fit and reliable and that improvement in the implementation of sustainability measures can be achieved as a result of adopting the CEM model. As highlighted in the focus group findings in Table 9.6, Table 9.7, Table 9.8 and Table 9.9, most of the participants in the validation process were very supportive and in agreement that the proposed CEM model, simple-in-use tools and $COCO_2$ tendering framework are of high practicality. None of the participants indicated their disagreement with any aspects of the overall model and $COCO_2$ tendering framework, but their useful comments were taken into consideration.

As noted, most of the participants in the validation process were in agreement that the developed CEM model is of high importance and fits within the building construction industry context, which is the purpose of this proposed research. Moreover, it was noted that all of the participants agreed that the developed model is clear in terms of its contents and approach. Thus, this suggests that the use of simple-in-use tools made the model simple and easy to use by the stakeholders. The participants were in full agreement on most of the themes, as presented in Table 9.6, which indicates that such a model provides a systematic and integrated approach to sustainability management by utilising the carbon emissions factor as a unit in the building construction industry. In other words, it could be argued that the developed CEM model provides a tangible unit for estimation, control and reporting of sustainability performance without adding any additional tools and offers a practical approach to sustainability management because of its transparency and responsiveness, which was proven in the validation process.

The focus group participants were also asked as part of the validation process to comment on and make suggestions for improvements of the developed model and framework. Their feedback was mainly concerned with the issue of ensuring that a regulatory framework is established for mandating carbon emissions monitoring and adoption of $COCO_2$ tendering, which is well-founded and transparent. Moreover, the participants raised the importance of sustainability reporting on each project monthly and weekly in addition to annual reports showing the sustainability indicators in terms of CO_2 emissions, which will encourage companies to quantify the impacts on global warming. Based on these indicators, stakeholders can be fully aware of the business activities and mitigation actions taken by the companies to remain sustainable.

Participants stated that the availability of carbon emissions factors should not be limited to the ICE database or EPD but that companies should be allowed to prepare and maintain their own carbon emissions databases. As the estimation and monitoring is relative, the accuracy of the carbon emissions factor does not play a major role. Moreover, as the contractors do maintain company-specific rate analyses, the carbon emission factor can also be company-specific so that companies can be competitive in bidding.

Furthermore, it was highlighted by the focus group participants and survey respondents that training and awareness are vital in ensuring that sustainable practices are implemented. It was also indicated by the participants that methodological approaches such as life cycle carbon assessments and carbon emissions environmental impact assessments should be embedded in the strategic management approaches for all building construction projects in the UAE. In particular, the participants stated that as existing SIUTs are being used as part of the CEM model, the available technical skills within companies is adequate to carry out their own carbon emissions management without the need to recruit and employ external consultants and companies to carry out these investigations. Participants raised concerns about the international role in monitoring the environmental impact of projects using LEED, BREEAM, Estidama and other rating tools which are more prescriptive. They believe that governmental regulators, clients and consultants should work in collaboration with contracting companies and local non-governmental organisations to raise awareness about sustainability and carbon emissions management to improve the sustainable practices in the UAE.

More importantly, it was highlighted by the focus group participants that further incentives and rewards from the governmental regulatory agencies should be introduced to encourage individual companies to improve their carbon emissions monitoring and performance to ensure that companies are committed to improving their sustainable performance.

In summary, the focus group validation workshop proved that the developed CEM model and $COCO_2$ tendering framework for the building construction industry is of high value and importance as it provides a systematic and integrated approach to sustainability management in this sector. Comments and suggestions for improvement were made by the focus group participants who were mainly associated with awareness, training and incentive systems, as well as the role of governmental regulatory agencies in mandating the requirements of carbon emissions management for all building construction projects. The focus group also stated that raising awareness about $COCO_2$ tendering and sustainability in terms of measuring and monitoring CO_2 emissions at the project level, organisation level, regional level and country-level is vital to improving

CEM implementation levels. The theses provides an amended version of the developed CEM model and an integrated framework in chapter 5 and 8 based on the outcomes of the validation study.

9.8 Summary

The model was validated using a focus group with an experts' review done by experienced practitioners in the building construction management industry. The opinions about the feasibility, suitability and acceptability of the model and the integrated framework provided a basis for the research to validate its structure, simple-in-use tools and role in increasing implementation levels.

The developed model of carbon emissions management (CEM) and the integrated framework showed notable acceptance by the industry experts during the case study implementation and validation and was found to be all-inclusive. The conclusions of the focus group convey that the model is practical, useful and has relative clarity. Thus, the overall feedback was positive, and comments were received as part of the focus group to increase the implementation levels of CEM.

Chapter Ten: Conclusions and Recommendations

10.1 Introduction

This chapter presents the conclusion and findings of the research. It discusses the findings from the literature review chapters, research methods chapter, data analysis chapter and validation chapters and concludes achieving the objectives of the study, as stated in chapter 1. This chapter summarises the research work undertaken as part of the study and the conclusions drawn to improve sustainable carbon emissions management for building projects. It highlights the contributions of the study to knowledge and identifies the limitations of the research. In the final section, it provides recommendations to investors, developers, clients, consultants, practitioners, research communities and policymakers and suggests areas for further research.

10.2 Conclusions

This research aimed to develop an Integrated Carbon Emissions Management framework to enhance environmental efficiency of buildings in the UAE. Environmental efficiency is enhanced through managing embodied carbon emissions and operational carbon emissions at the tendering and construction phases. The research concludes the following:

- Emphasis of the construction industry is more on 'Operational carbon emissions' such as emissions released due to use of electricity and water during the building occupation. This research shows that low energy buildings will lead to a higher ratio of embodied carbon to total carbon than a typical building over the whole life cycle. This research recommends the industry the importance of managing embodied carbon emissions in building construction.
- The current environmental assessment tools are criticized as being ineffective and inefficient in quantifying CO_2 emissions (Embodied carbon emissions) during the construction stage. This research recommends applying carbon emissions management to enhance the environmental efficiency of buildings.
- There is a lack of implementation of the standard 'unit of measure' for assessing the environmental efficiency of buildings. This research recommends the use of

CO_2e in Kilogram as a standard 'unit of measure' to manage and report the environmental efficiency of buildings.

- There is a lack of mandatory requirements to estimate and manage carbon emissions in building construction.
- The research identifies the low awareness levels for Carbon emissions management in the UAE. The research identified that increasing the CEM implementation levels and mandating the requirements as regulations will increase awareness in the industry. A similar trend is seen when sustainability rating tools (ESTIDAMA and Al safat) are mandated by the UAE, which has increased the awareness levels considerably.
- Carbon emissions management is not being implemented on building construction projects in the UAE. This research delivers an Integrated carbon emissions management framework to enhance the CEM implementation levels in UAE. Integrated CEM framework uses a holistic approach to combine time, cost and carbon emissions management of the project.
- Currently, the ultimate project award criteria do not include sustainable criteria such as CO_2 emissions levels. This research provided the industry with cost and carbon as a criteria to award the projects. $COCO_2$ tendering model is developed and used in Integrated CEM framework for industry adoption.
- UAE construction industry prefer the 'simple in use tools' to avoid the issues of hidden data, complexity and fatigue. A CEM model is required to manage carbon emissions by using the simple in use tools such as Excel and Primavera.
- The research proposed a clear and easy to use Integrated CEM framework without any addition of processes or software tools. The framework utilises the current tool being used to manage cost and time parameters of the project.
- The research verified the implementation of Integrated CEM on case study projects and benchmarked the emissions levels with other buildings. Around 20% of carbon emissions are optimized by the implementation of Integrated CEM framework on case study projects.
- The case studies of the research and literature review suggest that there are several possible ways to reduce carbon emissions by adopting simple measures. Simple measures include the use of low embodied carbon materials, reduction

of transport travel distances, efficient use of energy and water during construction activities, low carbon design, alternate material and minimising the waste during construction phase. Also, the framework gives flexibility for users to enhance the operational carbon emissions during the construction phase further.

- Lack of country-specific 'carbon emission factors' is identified as a reason for the lack of implementation of CEM in the UAE. As part of the recommendation of the research, industry is suggested to use the Inventory of Carbon Emissions (ICE) developed by the University of Bath. The research also recommends developing country-specific carbon emission factors.

The proposed Integrated CEM framework gives a comprehensive approach to enhance environmental efficiency of buildings in the UAE which takes into account the simple in use tools and simplified process. The proposed Model and framework can use other relevant simple in use tools, can also be widely utilised in other sectors and other countries.

10.3 Achievement of research objectives

The objectives of the research are achieved as detailed below:

Objective 1: To review and investigate the current practices, tools and methods of carbon emissions assessment in building construction projects.

This aspect of the literature review generated several important insights which investigate the current practices and their significant impacts on sustainability, particularly the carbon emissions from building projects and their effects on the environment, from a global perspective and in the UAE context. There were clear indications that lack of implementation of carbon emissions management is due to lack of awareness of embodied carbon emissions calculations, availability of tools, data metrics and the industry's inclination towards managing only the operational carbon emissions. The rising impacts of greenhouse gas emissions from the building construction industry and their resultant impacts on global warming could be addressed through carefully managing all the phases of the building life cycle and, in particular, the construction phase using carbon emissions management. A further study identified some drivers, which informed the need for simple-in-use tools to improve the implementation levels of carbon emissions management. The factors which limit their adoption in the building construction industry are the lack of informed knowledge and the lack of transparency of the data used by the embodied carbon calculators and tools. Findings from the study revealed that the current method of compliance-based sustainable tools, such as LEED and BREEAM, could not adequately assess the CO_2 emissions of different buildings in a quantifiable manner. These rating tools do not take into account a standard unit of embodied carbon emissions factor (i.e., ECO_2e). Hence, the need for a more appropriate resource was identified, which in turn, fulfilled objective 1 of the research.

Objective 2: To identify and evaluate the construction management methods involved in achieving efficient and low carbon buildings.

In understanding the problems associated with carbon emissions management being part of overall project management in building construction, it was envisaged that improving knowledge sharing about current best practices could be realised through publicly available data metrics and case studies. The literature review highlighted the viability of carbon emissions databases in fulfilling sustainable development principles and requirements in the material selection decision-making process, the transportation selection process and the design selection process. In this exercise, existing embodied carbon assessment tools used in both developed and developing countries were examined and found to be inadequate in improving implementation levels and in managing the carbon emissions from initiation to handover of the building project.

The findings are that companies and their management in the UAE are more confident in using the traditional cost estimation practices of Excel spreadsheet calculations and progress planning/reporting using the Primavera tool. The construction industry has a greater implementation of the Primavera tool due to clients' bidding requirements in the scope of work.

Existing environmental methods, such as LEED and Estidama, which is widely used in the UAE, do not require embodied carbon management to be carried out as a requirement under these assessments. These compliance methods, including BREEAM, place more emphasis on operational carbon, and embodied carbon is not always addressed in these assessments.

This research was subjected to a comprehensive review of both academic and industry references to sustainable manage projects, such as the tendering and construction phases. This was then further explored through a survey, of which the majority of the respondents emerged with a relatively strong degree of commitment to the need for transformation of current practices and the need to integrate carbon emissions management into project management. The responses received through surveys and the validation carried out through the focus group indicate that, in addition to these rating systems, industry should estimate, monitor and report GHG emissions using the available techniques, such as earned value analysis. This exercise also formed a significant basis upon which the model was conceptualised, hence fulfilling objective 2.

Objective 3:To develop a CEM model based on theory and expert recommendations from the industry.

The third objective was to develop the proposed conceptual framework into a scalable prototype CEM model using the data collected from the analysis. This phase provided an overview of the current simple-in-use tools, current methods, available data sources and preferences of the industry. It provided the opportunity to assess the potential capabilities of the proposed simple-in-use tools needed to develop the model to integrate carbon emissions management into the overall project management. Therefore, the development of the model into a scalable and functional prototype system enabled the fulfilment of objective 3.

Objective 4: To test and validate the CEM model using the survey and case studies.

The fourth objective of this research was to validate the applicability, effectiveness and usefulness of the developed model using case study projects located in the Western Region of Abu Dhabi, in which analysis was performed to show how carbon emissions can be managed by using simple-in-use tools and by adopting a different set of technical evaluations in awarding projects to bidders. Following the development of the CEM model, it was implemented on case study projects during the stages of the building construction to check its applicability and acceptance among practitioners. This was followed immediately after the user evaluation and validation exercise by a focus group session, as discussed in chapter 9. This procedure was useful in demonstrating the overall value and possible limitations of the model, including the integrated framework for carbon emissions management which is described in chapter 8, hence suggesting areas for further improvements. Thus, this exercise enabled the fulfilment of research objective 4.

Objective 5: To develop and validate the integrated carbon emissions management framework for tendering and construction phase of building projects in the UAE.

The fifth objective of this research was to validate the applicability, effectiveness and usefulness of the integrated framework of carbon emissions management using feedback from surveys and the literature review findings. Analysis performed shows how the current tendering practices are focussing only on economic and technical aspects, whereas the environmental aspects are not evaluated during the award of projects. The needs of industry and viable solutions are built-in as part of the integrated framework, which was validated through focus group exercises. The focus group identified an alternative solution for improving sustainable performance by adopting a different set of technical evaluation criteria for awarding the projects to the successful bidders. Optimal choices could change with changing weightings and variables in pre-qualification and tendering practices. The framework is considered a unique product which provides a foundation for efficient carbon emissions management in building construction projects and companies. The feedback received has been categorised, evaluated, analysed and considered in the updated CEM framework. Feedback received from the focus group, which included representatives of all stakeholder types, validated the applicability, functionality and advantages of this new proposed framework by highlighting the shortcomings of the existing tendering, award and management processes.

10.4 Contribution to Knowledge

The research aimed to develop an integrated CEM framework and to recommend and modify the existing procurement practices (tendering process) to base on the carbon footprint of the building in addition to cost, time and quality. The model and integrated framework will assist the decision-makers in quantifying the strategies in the building sector, in informing policy developers regarding emissions at the unit level, project level, city level and building sector level. In future, building approvals and construction can be regulated based on emissions levels. This research will also provide industry a model using simple tools and guidelines to estimate, monitor and manage carbon emissions in a similar way to existing time and cost estimate and management practices.

After summarising the feedback on the CEM model provided by the focus group, the importance of using the estimation, tendering and monitoring carbon emissions will provide a standard way of expressing the sustainable outcome in terms of CO_2e. This CEM model will show the savings achieved overall and by each element of the building but will also help to identify the areas of improvement on which the project team needs to focus. The performance in terms of CO_2 emissions which were weaker and made the overall CO_2 emissions higher for the building construction will be easily identified and thus will enable organisations to reallocate their resources towards the improvement of that particular factor or element.

The approach of $COCO_2$ tendering will drive the implementation of carbon emissions management. Measuring sustainability performance in terms of CO_2 emissions at the project level, organisation level, regional level and country level will provide a standard unit by which to measure the impacts of global warming and devise mitigation measures accordingly.

To implement carbon emissions management in construction projects, a holistic and integrated approach is required to merge the sustainability in the existing project management practices. Having tools for every need is increasing fatigue among construction professionals, so utilising ‘in-use tools’ and integrating the sustainability by managing carbon emissions in the same way as time and cost are managed is required to improve implementation levels for embodied carbon emissions as well as operational carbon emissions. Managing embodied carbon emissions needs to be seen as an important element in measuring the sustainability performance of projects and also to improve and enhance the operational performance and should not be viewed as an additional requirement. Given the above, the proposed carbon emissions management system for the building construction sector emphasises the need for commitment from all stakeholders to adopting sustainability.

The researcher trusts that the contributions of this study would be at both the academic and industry levels.

10.4.1 On the industry perspective

This study explored the building construction industry profoundly in the UAE along with its practices in managing carbon emissions. The different sources of data collection, such as surveys, case studies and focus group, ensure that all aspects are covered and that the different samples adopted in aggregate genuinely represent the building construction sector of the UAE.

Frameworks for sustainable procurement of contractors already exist (see chapter 3), but these only focus on the application of LEED, BREEAM and Estidama rating systems on projects. These rating systems cover the compliance aspect of sustainable measures such as design, materials and other prescriptive activities of the project. These conventional methods are many and too generic without focussing on one unit of measurement or standardisation. Moreover, the focus of industry is on emphasising operational carbon emissions and considering the embodied carbon emissions only during the design process.

The carbon emissions management model using the simple-in-use tools is a contribution to the industry which shows the industry how to estimate, monitor and control the carbon emissions in the same way as monitoring cost and time on projects. As the implementation of this model does not require any additional tools, solutions or awareness, the acceptance levels of industry will be high in adopting the CEM model and $COCO_2$ tendering approach.

The development of the integrated carbon emissions model allows the building construction industry to adapt to effectively managing their projects sustainably. It includes performance measures such as embodied carbon emissions in a standard unit of CO_2e in kilograms. The EVA method of benchmarking the base plan and monitoring the performance through variances is an advantage of the model.

With the use of the integrated CEM framework, organisations will have clear guidelines for reporting comprehensive performance statistics in terms of efficiency and carbon emissions savings achieved. This also will guide them to establish a solid base of structured processes and allow them to benchmark internally and externally their performance to achieve excellence and continuous improvement.

10.4.2 On the academic perspective

The research presents a detailed understanding of the challenges industry is facing to implement sustainable construction management effectively and to reduce the impacts of carbon emissions. Literature on design-related measures in reducing carbon emissions are available extensively; however, the estimation and monitoring of carbon emissions during construction at the elemental level are lacking within the current literature. Thus, this research can help to inform building practitioners on managing their projects with low-carbon emissions from the building materials, construction and transportation stages. The research will make a significant contribution to the ongoing debate regarding reducing world carbon emissions, thereby avoiding the tipping point of a temperature rise of 2°C (i.e., global warming).

This study also pursued a robust research methodology based on a triangulation of methods: quantitative and qualitative and validation of the model and framework. The three approaches involved in this study ensure the validity and reliability of the findings. The study adopted an abductive approach and proposed based on the literature review a quantitative survey, qualitative case studies and a focus group. Finally, the research validated, the proposed integrated carbon emissions management framework, including CEM Model as part of the abductive approach.

Historically, conventional literature about the UAE construction industry has largely remained peripheral to discussions on delays in project completion, time extension claims and the factors affecting project performance. Sustainability literature was focussed around the comparison of LEED and Estidama and the efficiency of operational carbon emissions. Despite an evolving culture of managing embodied carbon emissions, as a measure of sustainability in the global housing industry, there are limited studies within the context of the UAE. It is required to discuss extensively the management and synthesis of material knowledge to stimulate sustainable carbon emissions management during the tendering and construction processes. Therefore, this study enhances the current body of knowledge on the UAE element of the research.

10.5 Limitations of the Study

Similar to any other study, this research is subject to certain limitations, which are listed below:

- The study was conducted in one country only (the United Arab Emirates). Thus, differences between different markets and countries were not observed.
- Although the response rate for the survey questionnaire was high (54.9%), attention should be paid to the possible impact of non-responses. Additionally, even though the sample represents a wide range of UAE building construction practitioners in a large number of companies, it is still relatively small from a statistical point of view.
- The thesis findings are mostly applicable to small and medium-sized organisations. The majority of the construction companies in the UAE are small and medium-sized.
- The case studies were undertaken on three different commercial buildings situated in different areas comprising RCC and steel-framed structures. The research results of the case studies may only be valid for the characteristics and culture of design and building professionals in the UAE industry. There are, of

course, limitations to the case study as it is not possible to generalise with such results given the technical, cultural, environmental, social, economic, and geographical diversity of other regions.

- The research focused mainly on the tendering and construction phases, and the framework and model covered these phases; did not take into consideration other project life cycle phases in detail.
- Sample sizes which are too small or too large cannot adequately support assertions of having achieved valid conclusions and do not allow the deep, realistic and inductive analysis which characterises qualitative enquiry (Creswell, 2013). Obtaining an adequate sample size for each group of professionals for a focus group was demanding and posed a serious challenge, but the participation of 18 industry professionals satisfactorily achieved it. However, for the survey questionnaire, the sample size of 371 was adequate and well distributed across the industry. Furthermore, the sampling methods specified in chapter 4 made it possible to achieve sampling equivalence amongst professionals of the various building professions.

10.6 Recommendations

10.6.1 Recommendations for industry implementation

- Carbon emissions factors at the building element level specific to the UAE with publicly available online information should be prepared and updated for the use of industry.
- The quality and method of production of building materials and services for the construction industry should be improved. Manufacturers could make such products more carbon-efficient, thus attaining greater sustainability performance, which will improve the industry and social acceptance.
- The Environmental Product Declaration is one of the methods which helps to choose efficient materials for buildings and reduce carbon emissions. The UAE should adopt and make mandatory the EPD, which should include embodied and operational carbon emissions impacts per unit requirements for all the products used in the construction industry similar to the requirements of other developed countries such as the UK. In the case of the EU, the legal act of Construction

Products Regulation 305/2011/EU has been established, while Belgium, France and the Netherlands already have EPD requirements in place.

10.6.2 Recommendations for further research

This research identified and investigated the existing sustainability practices in the UAE construction sector and accordingly recommended the carbon emissions management model. General recommendations on how to implement carbon emissions management are provided as an integrated CEM framework in this research; however, further investigation and research on each type of construction (buildings, oil and gas, infrastructure), type of building (residential, commercial, mixed-use), type of structure (RCC, steel, composite, prefabricated), type of contract (traditional, design and build, BOT) and area of construction (location) may yield valuable outcomes for the industry.

As identified by this research, sustainability in terms of carbon emissions management is not yet effectively regulated and is considered one of the key constraints inhibiting its adoption in the UAE. The construction industry is known for its culture towards compliance with regulations rather than voluntarily contributing to the betterment of society. When Estidama and Al Safat implementation was made mandatory by Abu Dhabi and Dubai, the implementation levels increased enormously. Ras Al Khaimah also will mandate the ‘Barjeel Guide building regulations’ from year 2020. Investigation and further research in this area should be conducted to determine whether similar widespread implementation improvements can be achieved for carbon emissions management in the UAE.

References

Abanda, F.H. Tah, J.H and Cheung, F.K.T. (2013) 'Mathematical modelling of embodied energy, greenhouse gases, waste, time-cost parameters of building projects: A review', *Building and Environment*, vol. 59, January, pp. 23-37

Abdi, A., Taghipour, S. and Khamooshi, H. (2018) 'A model to control environmental performance of project execution process based on greenhouse gas emissions using earned value management', *International Journal of Project Management*, vol. *36, no.* 3, 397–413. Available from: http://doi.org/10.1016/j.ijproman.2017.12.003

Abdul-Azeez, I.A. and Ho, C.S. (2015) 'Realizing Low Carbon Emission in the University Campus towards Energy Sustainability', *Open Journal of Energy Efficiency, vol. 4, pp.* 15–27. Available from: http://doi.org/10.4236/ojee.2015.42002

Abudhabi Quality and conformity council, (2015) '*Greenhouse gas emissions factors -2015, A preliminary assessment and gap analysis report for greenhouse gas emissions factors specific to the Emirate of Abu Dhabi*', Abu Dhabi Technical Report, ADQCC

Abuzeinab, A., Arif, M., Qadri, M. and Kulonda, D. (2018), 'Green business models in the construction sector: an analysis of outcomes and benefits', *Construction Innovation*, vol. 18, no. 1, pp. 20-42. https://doi.org/10.1108/CI-07-2016-0041

Adalberth, K. (1996), 'Energy use during the life cycle of buildings: a method', *Building and Environment*, vol. 32, no. 4, pp. 317-320

Agung Wibowo, M. Aditama, S. and Zhabrinna, Z. (2018) 'Reducing carbon emission in construction base on project life cycle (PLC)', *MATEC Web of Conferences*, vol. *195*, no. 4. Available from: http://doi.org/10.1051/matecconf/201819506002

Ahn, C.R. Lewis, P. Fard, M.G. and Lee, S.H. (2013) 'Integrated Framework for Estimating, Benchmarking, and Monitoring Pollutant Emissions of Construction Operations', *Journal of Construction Engineering and Management*, vol. 139, no 12

Akadiri, P.O. Olomolaiye, P.O. and Chinyio, E.A. (2013) 'Multi-criteria evaluation model for the selection of sustainable materials for building projects', *Automation in Construction*, vol. 30, March, pp. 113-25

Akbarnezhad, A. and Xiao, J. (2017). 'Estimation and Minimization of Embodied Carbon of Buildings: A Review', *Buildings*, vol. *7*, no. 1. Available from: http://doi.org/10.3390/buildings7010005

Al Horr, Y. Arif, M. Kaushik, A. Mazroei, A. Elsarrag, E. and Mishra, S. (2017) 'Occupant productivity and indoor environment quality: A case of GSAS, *International Journal of Sustainable Built Environment*, Vol. 6, no. 2, pp.476-490. Available at: https://doi.org/10.1016/j.ijsbe.2017.11.001

Ali, H.H. and Al Nsairat, S.F. (2009) 'Developing a green building assessment tool for developing countries – Case of Jordan', *Building and Environment*, vol. 44, no. 5, May, pp. 1053-64

Alwan, Z. and Jones, P. (2014) 'The importance of embodied energy in carbon footprint assessment', *Structural Survey*, vol. 32, no. 1, April, pp. 49-60

Alzard, M. Maraqa, M.A. Chowdhury, R. Khan, Q. Albuquerque, F.B.D. Mauga, T.I. and Aljunadi, K. (2019) 'Estimation of Greenhouse Gas Emissions produced by road projects in Abu Dhabi, United Arab Emirates', *Sustainability*, *vol. 11(8), pp.* 2367. Available from: https://doi.org/10.3390/su11082367

Amoako, K.B. (2011) '*The effect of delayed payment on cash flow forecasting of Ghanaian road contractors'*, MBA thesis, Kwame Nkrumah University of Science and Technology [online] Available from: http://dspace.knust.edu.gh/bitstream/123456789/4202/1/Kwame%20Boateng%20Thesis.pdf.

Anand, C. K. and Amor, B. (2017) 'Recent developments, future challenges and new research directions in LCA of buildings: a critical review', *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 408– 416

Aouad, G. Lee, A. Marshall-Ponting, A.J. Wu, S. Koh, I. Fu, C. Cooper, R. Tah, J.H.M. Abbott, C. and Berrett, P.S. (2005). *nD modelling roadmap: A vision for nD-enabled construction*. Salford: SCRI, The University of Salford

Appolloni, A. Sun, H. Jia, F. and Li, X. (2014) 'Green procurement in the private sector: a state of the art review between 1996 and 2013', *Journal of Cleaner Production*, vol. 85, September, pp. 122-133

Ariyaratne, C.I and Moncaster, A.M. (2014) 'Stand-alone calculation tools are not the answer to embodied carbon assessment', *Energy Procedia*, vol. 62, pp. 150-159. Available from: http://doi.org/10.1016/j.egypro.2014.12.376

Asia-Pacific Economic Cooperation. (2016) 'Policy Review for APEC Low-Carbon Model Town Phase 5', Final Report, Asia-Pacific Economic Cooperation, Indonesia

Atkins, W.S. (2014) Carbon Tools [online] Available from: http://www.atkinsglobal.com/engb/corporate-sustainability/an-environment-with-a-future/a-low-carbon-economy/lower-carbon/carbon -tools (Accessed 2 October 2014)

Auriol, E. (2006) 'Corruption in procurement and public purchase', *International Journal of Industrial Organization*, vol. 24, no. 5, September, pp. 867–85

Aye, L. Ngo, T. Crawford, R.H. Gammampila, R. Mendis, P. (2012) 'Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules'. *Energy Build*. Vol.47, pp.159-168

Baldwin, A. and Bardoli, D. (2014) *A Handbook for Construction Planning and Scheduling*, 1st ed., John Wiley & Sons, Ltd

Bauman, L. (2013) '*The impact of national culture on project management in the Middle East'*, PhD thesis, Loughborough University. [online] Available from: https://dspace.lboro.ac.uk/2134/12274

BEIS UK (2018) '*2017 UK Greenhouse Gas Emissions - National Statistics'* [online]. Available from: https://www.gov.uk/government/collections/final-

Benjamin, C. and Chantale, L. (2018) *Climate Resilience - 2018 Handbook*, Marsh & McLennan Companies

Berggren, B. Hall, M. and Wall, M. (2013) 'LCE analysis of buildings – Taking the step towards Net Zero Energy Buildings', *Energy and Buildings*, vol. 62, July, pp. 381–391

Berner R.A. (2004) *The Phanerozoic Carbon Cycle: CO2 and O2*. New York: Oxford University Press

Bhosekar, S.K. and Vyas, G. (2012) 'Cost Controlling Using Earned Value Analysis in Construction Industries', *International Journal of Engineering and Innovative Technology*, vol. 1, no. 4, 324-332

Bilec, M.M. Ries, R.J. and Matthews, H.S. (2010) 'Life-cycle assessment modeling of construction processes for buildings', *Journal of Infrastructure Systems*, vol. 16, no. 3, September, pp. 199-205

BMW (2016). Sustainable Value Report 2016 [online] Available from: https://www.bmwgroup.com /content/dam/bmw-group-websites/bmwgroupcom /ir/downloads/en/2016/2016-BMW-Group-Sustainable-Value-Report.pdf. (Accessed: 4 May 2018)

Bohari, A.M. Skitmore, M. Xia, B. and Teo, M (2017) 'Green oriented procurement for building projects: Preliminary findings from Malaysia', *Journal of Cleaner Production*, vol. 148, February, pp. 690-700. Available from: http://doi.org/10.1016/j.jclepro.2017.01.141

BP (2018) *BP Statistical Review of World Energy 2018*, London, UK: BP

Bratt, C. Hallstedt, S., Robert, K.H. Broman, G. and Oldmark, J. (2013) 'Assessment of criteria development for public procurement from a strategic sustainability perspective', *Journal of Cleaner Production*, vol. 52, pp. 309-316

BRE (1996) 'Potential carbon emission savings from energy efficiency in commercial buildings', Watford, *Building Research Establishment*

Bruseberg, A. and McDonagh, D. C. (2002) Organising and conducting a focus group: The logistics. In J. Langford, & D. McDonagh (Eds.), *Focus groups: Supporting effective product development* (pp. 19-46). New York: Taylor and Francis.

Bryman, A (2004) *Social Research Methods, 2nd ed.*, Oxford, UK: Oxford University Press

Building (2006) Reducing UK emissions 2018 Progress Report to Parliament. [online] Available from: https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress Report-to-Parliament.pdf (Accessed: 8 May 2018)

Building Radar (2018) Construction sector in Europe 2018 - Building Radar. [online] Available from: https://buildingradar.com/construction-blog/eu-construction-sector-2018/ (Accessed: 8 May 2018)

Bull, R. Ozawa-Meida, L. Brockway, P. and Holland, C. (2013) 'Integrating an ICT carbon calculator tool into procurement processes at De Montfort University: lessons learned', *Carbon Management,* vol. 4, no. 2, April, pp. 143-157

Busch, T. and Wolfensberger, C. (2011) 'The virtue of corporate carbon management', *International Journal of Sustainable Strategic Management*, vol. 3, no. 2, pp. 142-157

Cabeza, L.F. Barreneche C. Miro L, Morera J.M. Bartoli E. and Fernandez A.I. (2013) 'Low carbon and low embodied energy materials in buildings: A review', *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 536-542

Celentani, M. and Ganuza, J.J. (2002) Corruption and competition in procurement. *European Economic Review*, vol. 46, no. 7, July, pp. 1273–303

Chau, C.K. Leung, T.M. and Ng, W.Y. (2015) 'A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings', *Applied Energy*, vol. 143, no. 1, April, pp. 395–413

Chen, Y. and Ng, S.T (2015) Integrate an Embodied GHG Emissions Assessment Model into Building Environmental Assessment Tools', in *International Conference on Sustainable Design, Engineering and Construction*. *Procedia Engineering,* Vol.118, pp. 318-325

Chhatwani, M. (2015) *Model-Driven Management of Construction Carbon Footprint: Case Study*. *Construction Research Congress 2016*, PhD thesis, Urbana-Champaign: University of Illinois at Urbana-Champaign. Available from: http://ascelibrary.org/doi/10.1061/9780784479827.121

Clayson, D.S. Thal, A.E. and White E.W. (2018). 'Cost performance index stability: insights from environmental remediation projects', *Journal of Defense Analytics and Logistics*, vol. *2*, no. 2, pp. 94–109. Available from: http://doi.org/10.1108/JDAL-11-2017-0024

Climate Central (2018) *Rising Global Temperatures and CO_2* [online]. Available from: http://www.climatecentral.org/gallery/graphics/co2-and-rising-global-temperatures (Accessed 15 December 2018)

Climate Resilience 2018 Handbook (2018) Marsh & McLennan Companies [online]. Available from: *https://www.mmc.com/content/dam/mmc.../climate-resilience-handbook-2018.pdf (*Accessed 15 September 2018)

ClimateWorks Australia (2018) '*Could innovation in buildings help change our decarbonisation trajectory? Innovative technologies and new ways of doing things will enable and strengthen the rapid shift required for transformative action'*. Melbourne. [online] Available from: https://www.climateworksaustralia.org/sites/default/files/documents/publications/decarb-futures-buildings.pdf *(*Accessed 05 November 2018)

Committee on Climate Change. (2018). Reducing UK emissions 2018 Progress Report to Parliament. [online] Available from: https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf. *(*Accessed 12 December 2018)

Condeixa, K. Haddad, A. and Boer, D. (2014) 'Life Cycle Impact Assessment of masonry system as inner walls: A case study in Brazil', *Construction and Building Materials*, vol. 70, 15 November, pp. 141-147

Correia, F. Howard, M. Hawkins, B., Pye, A. and Lamming, R (2013). 'Low Carbon Procurement: An emerging Agenda', *Journal of Purchasing and Supply Management*, vol. 19, March, pp. 58–64

Crawford R H. (2009) 'Life cycle energy and greenhouse gas emissions analysis of wind turbines and the effect of size on energy yield', *Renewable and Sustainable Energy Reviews*, vol. 13, no. 9, December, pp. 2653-60

Crawford, R. H. (2011). *Life Cycle Assessment in the Built Environment*, 1st ed. London and New York, Spon Press

Crawford, R.H. and Treloar, G.J. (2005) 'An assessment of the energy and water embodied in commercial building construction', in *Proceedings of 4th Australian LCA Conference*, Sydney, Australia

Creswell, J.W. (2013) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, 4th ed. Thousand Oaks, CA: Sage Publications

Crishna, N. Banfill, P.F.G and Goodsir, S. (2011) 'Embodied energy and CO2 in UK dimension stone', *Resources Conservation and Recycling*, vol. 55, no. 12, October, pp. 1265-1273

Crotty, M. (1998) *The Foundation of Social Research: Meaning and perspectives in the Research Process*, London: SAGE Publications

Cushman, B.R. (2017) Energy consumption, energy type, [online]. Available from: from http://www.dartmouth.edu/~cushman/books/Numbers/Chap1-Materials.pdf (Accessed 02 December 2017)

Darrington, J.W. (2010) 'Addressing human motivation', *The Voice of the Construction Industry*, vol. 40 (2), pp. 18-19

Davies, P.J. Emmitt, S. and Firth, S.K. (2014) 'Challenges for capturing and assessing initial embodied energy: a contractor's perspective', *Construction Management and Economics*, vol. 32, no. 3, March, pp. 290-308, https://DOI.org/10.1080/01446193.2014.884280

De Wever, B. Schellens, T. Valcke, M. and Van Keer, H. (2006) 'Content analysis schemes to analyze transcripts of online asynchronous discussion groups: A review', *Computers & Education*, vol. 46, January, pp. 6-28

De Wolf, C. Pomponi, F. and Moncaster, A. (2017) 'Measuring embodied carbon dioxide equivalent of buildings: A review and critique of current industry practice', *Energy and Buildings*, vol. 140, February, pp. 68–80. Available from: http://doi.org/10.1016/j.enbuild.2017.01.075

DEFRA (2008) *Development of an Embedded Carbon Emissions Indicator*, Department of Environment, Food and Rural Affairs, London, UK

Denscombe, M. (2010) The Good Research Guide: For small-scale social research projects, 4th ed., London: McGraw-Hill

Devi, P.L. and Palaniappan, S. (2014) 'A case study on life cycle energy use of residential building in Southern India', *Energy and Buildings*, *80*, September, pp. 247–259. Available from: http://doi.org/10.1016/j.enbuild.2014.05.034

Ding, G.K.C. and Shen, L.Y. (2010) 'Assessing sustainability performance of built projects: a building process approach', *International Journal of Sustainable Development*, vol. 13, no. 3, pp. 267-77

Dixit, M.K. Culp, C.H. and Fernández-Solís L.J. (2013) 'System boundary for embodied energy in buildings: A conceptual model for definition', *Renewable and Sustainable Energy Reviews*, vol. 21, pp. 153–164. Available from: http://doi.org/10.1016/j.rser.2012.12.037

Dixit, M.K. Solis J.L. Lavy S. and Culp C.H. (2010) 'Identification of Parameters for embodied energy measurement: a literature review', Energy *and Buildings*, vol. 42, no. 8, August, pp. 1238-1247

Dixit, M.K., Solis J.L. Lavy S. and Culp C.H. (2012) 'Need for an embodied energy measurement protocol for buildings: A review Paper'. *Renewable and Sustainable Energy Reviews* vol. 16, no. 6, August, pp. 3730-3743

Dobrovolskienė, N. and Tamošiūnienė, R. (2016) 'Sustainability-Oriented financial resource allocation in a project portfolio through multi-criteria decision-making' *Sustainability*, vol.

8, no. 5, pp. 1–18. Available from: http://doi.org/10.3390/su8050485

Doda, B. Gennaioli, C. Goundson, A. Grover, D. and Sullivan, R (2015) ‘Are corporate carbon management practices reducing corporate carbon emissions?’ *Corporate Social Responsibility and Environmental Management*. ISSN 1535-3966

Dubai Municipality (2019) Al Sa'fat - Dubai Green Building Evaluation system. [online] Available from: https://www.dm.gov.ae/en/Business/DubaiCentralLaboratory/Laws%20and%20Legislation/Documents/Inspection%20Certification/07_DCL_LawsLegislation_InspectionCertification_AlSafat_2017_Eng.pdf. (Accessed 5 May 2019).

Estidama (2019) Pearl Building Rating System (PBRS), Urban Planning Council, Abu Dhabi, United Arab Emirates [online]. Available from: https://www.dpm.gov.abudhabi/en/Urban-Planning/Pearl-Building-Rating-System (Accessed 20 January 2019)

Fisher, C. (2003) *Research and Writing a Dissertation for Business Students*, FT Prentice Hall

Fong, Yan, Z.S. (2009) Design of a Web-based Tendering System for e-Government Procurement, in *ICE GOV2009*. Bogota, Colombia, November 10-13, Colombia: ACM, pp. 558-663

Fouché, M. and Crawford, R. (2015) ‘The Australian construction industry’s approach to embodied carbon assessment: a scoping study, in proceedings of *Living and Learning: Research for a Better Built Environment: 49thInternational Conference of the Architectural Science Association*, University of Melbourne, pp. 578–587

Fu, F. Luo, H. Zhong, H. and Hill, A. (2014) ‘Development of a Carbon Emission Calculations System for Optimizing Building Plan Based on the LCA Framework’, *Mathematical Problems in Engineering*

G.F. Menzies, S. Turan and P.F.G. Banfill (2007) ‘Life-cycle assessment and embodied energy: a review’, *Construction Materials*, vol. 160, no. 4, January, pp. 135-143

Gangolells, M. Casals, M. Gassó, S. Forcada, N. Roca, X. and Fuertes, A. (2009) ‘A methodology for predicting the severity of environmental impacts related to the construction process of residential buildings’, *Building and Environment*, vol. 44, no. 3, March, pp. 558-71

Gareis, R. Huemann, M. and Martinuzzi, A. (2014) 'Project Management and Sustainable Development Principles', *From Academia: Summaries of New Research for the Reflective Practitioner*, October, pp. 1–4. Available from: http://doi.org/10.1016/j.jembe.2005.12.017

Gavotsis, E. and Moncaster A. (2015) ‘Improved embodied energy and carbon accounting: recommendations for industry and policy’, *Athens Journal of Technological Engineering*, vol. 2 (1), pp. 09–23

Ghazvini, M.S. Ghezavati, V. Raissi, S. and Makui, A. (2017) 'An integrated efficiency-risk approach in sustainable project control', *Sustainability*, vol. *9, no.* 9. Available from: http://doi.org/10.3390/su9091575

Giesekam, J.J. Barrett, R and Taylor, P. (2016) ‘Construction sector views on low carbon building materials’, *Building Research and Information*. vol. 44 (4), pp. 423–444

Giné, M.A.C. (2012) *Development of a Sustainable Management System for Rural Road*

Networks in Developing Countries, PhD thesis, Ontario: University of Waterloo, Ontario

GPP-2020 (2017) *Tender Compilation - Mainstreaming Low-carbon Procurement*. [online] Available from: http://www.gpp2020.eu/low-carbon-tenders/ (Accessed 12 January 2017)

Gray, D.E. (2004) *Doing Research in the Real World*, London, UK: SAGE Publications

Greater London Authority (2018) Zero carbon London: A 1.5ºC compatible plan (December). [online] Available from: https://www.london.gov.uk/sites/default/files/1.5c_compatible_plan.pdf (Accessed 22 August 2018)

Gu, N. and London, K. (2010) 'Understanding and facilitating BIM adoption in the AEC industry', *Automation in Construction*, vol. 19, pp. 988–999

Guthrie, P. Konaris, T. French, G. Boyd, J. Felix, J. Vink, E. and Baillon, F. (2012) *State of the World Report 2012: Sustainable Infrastructure*. Report prepared for the International Federation of Consulting Engineers (FIDIC) [online]. Available from: https://fidic.org/node/803 (Accessed 27 Mar 2016)

Haapio, A. and Viitaniemi, P. (2008) 'A critical review of building environmental assessment tools', *Environmental Impact Assessment Review*, vol. 28, no. 7, October, pp. 469-482

Hajibabai, L. Aziz, Z. and Peña-Mora, F. (2011) 'Visualizing greenhouse gas emissions from construction activities', *Construction Innovation*, vol. 11, no. 3, pp. 356-370

Hammond, G. and Jones, C. (2011) A BSRIA Guide. Embodied Carbon: The Inventory of Carbon and Energy, University of Bath, UK. *ICE* 136. Available from: http://doi.org/10.1680/ener.2011.164.4.206

Hammond, G.P. and Jones, C.I. (2008) 'Embodied energy and carbon in construction materials', *Proceedings of the Institution of Civil Engineers – Energy*, vol. 161, no. 2, May, pp. 87-98

Harmouch, N. Srour, I. Chehab, G. and Hamade, R. (2012) 'A Comparison of CO2 calculators for building Construction', CIB W78 2012, 29th International Conference, Beirut, Lebanon, 17-19 October. [online] Available from: https://itc.scix.net/data/works /att/w78-2012-Paper-32.pdf (Accessed 20 May 2014)

Heap, Y.C. and Christopher, N.P. (2014) 'Improving Construction Procurement Systems using Organizational Strategies', *Acta Polytechnica Hungarica*, vol. 11, no. 1, pp. 5-20

HM Treasury (2013) *Infrastructure Carbon Review*. London

Hoffman, A.J. (2007) *Carbon strategies: How leading companies are reducing their climate change footprint*, Michigan, University of Michigan Press

Hofmann, D.A. and Stetzer, A. (1998) 'The role of safety climate and communication in accident interpretation: Implications for learning from negative events', *Academy of Management Journal*, vol. 41, no. 6, 644-657

Hong, J. Feng, Y. Mao, C. Peng, Y. and Shen, G.Q. (2016) 'Uncertainty analysis for measuring greenhouse gas emissions in the building construction phase: a case study in China', *Journal of Cleaner Production*, vol. *129*, pp. 183–195. Available from: http://doi.org/10.1016/j.jclepro.2016.04.085

Howard R. and Bjork B. (2008) 'Building information modelling - experts' views on standardisation and industry deployment', *Advanced Engineering Informatics*, vol. 22(2), pp. 271-280

Huang, W. Gao, Q.X. Cao, G.L. Ma, Z.Y. Zang, W.D. and Chao, Q.C. (2016) 'Effect of urban symbiosis development in China on GHG emissions reduction', *Advances in Climate Change Research*, vol. 7, no. 4, December, pp. 247–252

Hughes, W. and Laryea, S. (2013) *Organizing for sustainable procurement: theories, institutions, and practice. Design and Management of Sustainable Built Environments*, London: Springer

Hwang, B. and Ng, W. (2013) 'Project management knowledge and skills for green construction: Overcoming challenges', *International Journal of Project Management*, vol. 31, February, pp. 272-284

Ibn-Mohammed, T. Greenough, R. Taylor, S. Ozawa-Meida, L. and Acquaye, A. (2013) 'Operational vs embodied emissions in buildings-A review of current trends', *Energy and Buildings*. Vol. 66, pp. 232–245

ICE. (2013) '*CESMM4 – Civil Engineering Standard Method of Measurement'*, Institution of Civil Engineers, London

Iddon, C.R. and Firth S.K. (2013) 'Embodied and operational energy for new-build housing: A case study of construction methods in the UK', *Energy and Buildings*, vol. 67, December, pp. 479-488

Intergovernmental Panel for Climate Change (2013) *Synthesize Report Climate Change 2001*, IPCC website publications, Available from: https://www.ipcc.ch/report /ar3/syr/

Intergovernmental Panel on Climate Change (2013) 'Climate Change 2007: Synthesis Report', *Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Core Writing Team, Pachauri, R.K and Reisinger, A (eds.)*, IPCC, Geneva, Switzerland

International Energy Agency (2015) IEA Statistics: CO2 Emissions from Fuel Combustion

International Energy Agency (IEA). CO2 Emissions from Fuel Combustion 2018. [online] Available from: https://webstore.iea.org/co2-emissions-from-fuel-combustion-2018-highlights (accessed on 29 March 2019)

International Energy Agency, (2018) 'CO2 Emissions from Fuel Combustion highlights', pp.1–134. [online] Available from: http://doi.org/10.1787/co2_fuel-2014-en (accessed on 29 March 2019)

International Organization for Standardization (2014) ISO 14000: 2004 Environment Management

International Organization for Standardization (2015) ISO 14001: 2015 Environment Management

International Organization for Standardization (2015) ISO 14031: 2013 Environmental Management - Environmental Performance Evaluation- Guidelines

ISO (2009) *Environmental management The ISO 14000 family of International Standards:* International Standards Organisation: Geneva, Switzerland

Jeppesen, S. (2005) 'Critical realism as an approach to unfolding empirical findings: thoughts on fieldwork in South Africa on SMEs and environment*' The Journal of Transdisciplinary Environmental Studies*, vol. 4, no. 1

Jiang, P. Keith Tovey, N. (2009) ‘Opportunities for low carbon sustainability in large commercial buildings in China’, *Energy Policy*, doi:10.1016/j.enpol.2009.06.059

Kara, S. and Ibbotson, S. (2011). ‘Embodied energy of manufacturing supply chains’, *CIRP Journal of Manufacturing Science and Technology*, pp. 317-323

Kenley, R., Harfield, T. and Pirzadeh, P. (2012) ‘Mass-haul Environmental Impact Minimisation. A practical method for greening road procurement’, Industry Report, *Sustainable Built Environment National Research Centre (SBEnrc)*, Brisbane [online]. Available from: https://www.sbenrc.com.au/research-publications (Accessed 20 April 2016)

Khasreen M.M., Banfill P.F.G. and Menzies G.F. (2009) ‘Life Cycle Assessment and the environmental impacts of buildings: a review’, *Sustainability*, vol. 1, no. 3, September, pp. 674-701

Khasreen, M.M. (2013) ‘*Carbon Dioxide Emissions of Office Buildings in Scotland: Life-Cycle Assessment of New-Build Offices’*, PhD thesis, Heriot-Watt University

Kim, J. Hong, T. Park, H. S. Kim, C.-J. and Koo, C. (2014) 'Integrated CO2, cost, and schedule management system for building construction projects using the earned value management theory', *Journal of Cleaner Production*, vol. 103, pp. 275–285. Available from: http://doi.org/10.1016/j.jclepro.2014.05.031

Kim, S. Lee, S. Na, Y.J. and Kim, J.T. (2013) ‘Conceptual model for LCC-based LCCO2 analysis of apartment buildings’, *Energy Buildings*, vol. 64, September, pp. 285–291

Knight, D. and Addis, B. (2011) ‘Embodied carbon dioxide as a design tool – a case study’, *Proceedings of ICE Civil Engineering*, vol. 164, no. 3, November, pp. 171-176

Kofoworola O.F. and Gheewala S.H. (2008) ‘Environmental life cycle assessment of a commercial office building in Thailand’. *International Journal of Life Cycle Assessment* Vol 13(6), pp. 498 – 511

Krantz, K. Larsson, J. Lu, W. and Olofsson, T. (2015) ‘Assessing Embodied Energy and Greenhouse Gas Emissions in Infrastructure Projects’, *Buildings*, vol. 5, October, pp. 1156-1170

Kravari, M. (2017) *Environmental impact assessment of building materials in BIM models*, Construction Management and Engineering, PhD thesis, Eindhoven, The Netherlands: Eindhoven University of Technology

Krueger, R. and Casey, M.A. (2015). *Focus groups: a practical guide for applied research*, 5th ed., London, UK: Sage Publications

Krueger, R.A. and Casey, M.A. (2014) *Focus Groups: A Practical Guide for Applied Research*, 5th ed. London, UK: Sage Publications.

Kumanayake, R. and Luo, H. (2018) ‘Life cycle carbon emission assessment of a multi-purpose university building: A case study of Sri Lanka’, *Frontiers of Engineering Management*, vol. 5, no. 3, September, pp. 381–393

Kumanayake, R. and Luo, H. (2018) 'A tool for assessing life cycle CO2 emissions of buildings in Sri Lanka', *Building and Environment*, vol. *128*, December, pp. 272–286. Available from: http://doi.org/10.1016/j.buildenv.2017.11.042

Kumanayake, R. Luo, H.B. and Bandara, R.M.P.S. (2017). ‘A conceptual tool for assessing building life cycle carbon emissions in the context of Sri Lanka', conference paper, 111th *Annual Sessions of the Institution of Engineers Sri Lanka*, Colombo, Sri Lanka, October 2017

Kumar, R. (2011) *Research Methodology: A step by step guide for beginners*, 3rd ed., Thousand Oaks, CA: Sage Publications

Lam, K. and Yu, C. (2011) 'A multiple kernel learning-based decision support model for contractor pre-qualification', *Automation in Construction*, vol. 20, no. 5, August, pp. 531-536

Langdon, D and Rawlinson, S 2006, Procurement: *Two-stage tendering.* [online] Available from: https://www.building.co.uk/data/procurement-two-stagetendering/3067103.article. (Accessed 20 April 2013)

Langston, C. Chan, E.H.W. and Yung, E.H.K. (2018) Embodied Carbon and Construction Cost Differences between Hong Kong and Melbourne Buildings, *Construction Economics and Buildings*, vol. *18, no.* 4, December, pp. 84–102

Langston, Y.L. and Langston, C.A. (2008) 'Reliability of building embodied energy modelling: an analysis of 30 Melbourne case studies', *Construction Management and Economics*, vol. 26, February, pp. 147–60

Lenzen, M. Dey, C. and Foran, B. (2004) 'Energy requirements of Sydney households', *Ecological Economics*, vol. 49, no. 3, July, pp. 375-399

Lewis, E. (2018) *Embodied Carbon - Example Client Brief, UK Green Building Council.* [online] Available from https://www.ukgbc.org/wp-content/uploads/2018/01/08476-Embodied-Carbon-4pp-WEB-SPREADS_0.pdf (Accessed 12 January 2019)

Li, D., Cui, P. and Lu, Y. (2016) 'Development of an automated estimator of life-cycle carbon emissions for residential buildings: A case study in Nanjing, China,' *Habitat International*, vol. *57*, pp. 154–163. Available from: http://doi.org/10.1016/j.habitatint. 2016.07.003

Life Cycle Databases, a list of third-party databases, Greenhouse Gas Protocol [online]. Available from: https://www.ghgprotocol.org/Third-Party-Databases (Accessed on 14 October 2014)

Lin, H.T. (2016) 'GHG emission reduction performance of state-of-the-art green buildings: Review of two case studies', *Renewable and Sustainable Energy Reviews*, vol. 56, pp. 484–493

Lindfors, L.G. Christiansen, K. Hoffman, L. Virtanen, Y. Juntilla, V. Hanssen, O.J. Rønning, A. Ekvall, T. and Finnveden, G. (1995) 'Nordic guidelines on life cycle assessment', Nord 1995:20. Nordic Council of Ministers, Copenhagen, Denmark

Lützkendorf, T. Foliente, G. Balouktsi, M. and Wiberg, A. H. (2015) 'Net-zero buildings: incorporating embodied impacts', *Building Research & Information.* vol. 43(1), pp. 62-81

Mansah, G.M. Knight, A. and Coffey, C. (2012) '4Es and 4 Poles model of sustainability', *Structural Survey*, vol. 30, no. 5, pp. 426-442

Mao, C. Shen, Q.P. Shen, L.Y. and Tang, L.N. (2013) 'Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects', *Energy and Buildings*, vol. 66, November, pp. 165–176

Marchman M. and Clarke S.N. (2011) ‘Overcoming the barriers to sustainable construction and design through a cross-reference of west coast practices’. *47th ASC Annual International Conference Proceedings*, Associated Schools of Construction, Clemson, South Carolina

Markiv, T. Sobol, K. Franus, M. and Franus, W. (2016) ‘Mechanical and durability properties of concretes incorporating natural zeolite’, *Arch. Civ. Mech. Eng*., vol. 16, pp. 554–562

McEvoy, P. and Richards, D. (2006) ‘A critical realist rationale for using a combination of quantitative and qualitative methods’, *Journal of Research in Nursing*, vol. 11, no. 1, January, pp. 66-78

McMurray, A.J. Islam, M.M. Siwar, C. and Fien, J. (2014) ‘Sustainable procurement in Malaysian organizations: practices, barriers and opportunities’, J. Purchase Supply Management, vol. 20, no. 3, September, pp. 195-207

McQueen, R.A. and Knussen, C. (2002) *Research Methods for Social Science: A Practical Introduction*, Essex, UK: Pearson Education Limited

Miles, M. and Huberman, A.M. (1994) *Qualitative Data Analysis*, Thousand Oaks, CA: Sage Publications

Minichiello, V. Aroni, R. and Hays, T. N (2008) *In-Depth Interviewing: Researching People*, 3rd ed., Australia: Pearson Education

MoEW (UAE Ministry of Environment and Water) (2015) *United Arab Emirates State of Green Economy Report 2014*, MoEW, Dubai [online]. Available from: https://www.beeatna.ae/ (Accessed on 26 May 2016)

Moncaster, A. M. and Ariyaratne, C.I. (2014) ‘Standalone calculation tools are not the answer to embodied carbon assessment’, *Energy and Buildings*, vol. 62, pp. 150-159

Moncaster, A. M. and Symons, K.E. (2013) ‘A method and tool for ‘cradle to grave’ embodied carbon and energy impacts of UK buildings in compliance with the new TC350 standards’, *Energy and Buildings*, vol. 66, November, pp. 514-523

Moncaster, A.M. and Song, J.Y. (2012) ‘A comparative review of existing data and methodologies for calculating embodied energy and carbon of buildings’, *International Journal of Sustainable Building Technology and Urban Development*, vol. 3(1), pp. 26-36

Motawa, I. and Carter, K. (2013). 'Sustainable BIM-based Evaluation of Buildings', *Procedia — Social and Behavioral Sciences*, vol. *74*, March, pp. 419–428. Available from: http://doi.org/10.1016/j.sbspro.2013.03.015

Mousa, M. Luo, X. and McCabe, B. (2016) 'Utilizing BIM and Carbon Estimating Methods for Meaningful Data Representation', *Procedia Engineering*, vol. *145*, pp. 1242–1249. Available from: http://doi.org/10.1016/j.proeng.2016.04.160

Nagle, B. and William, N. (2019). Methodology Brief: Introduction to Focus Groups. *Center of Assessment, Planning and Accountability*, [Online]. Pp: 1-12. Available at: http://www.mmgconnect.com/projects/userfiles/File/FocusGroupBrief.pdf [Accessed 20 August 2019].

Nawarathna, A. Fernando, N. and Alwan, Z. (2018) 'Reasons for the Slow Uptake of Embodied Carbon Estimation in the Sri Lankan Building Sector,' *International Journal of Civil and Environmental Engineering*, vol. *12*, no. 2, pp. 102–107. Available from:

http://doi.org/10.1999/1307-6892/10008556

Nawarathna, R. and Fernando, N G. (2017) 'Estimating whole life cycle carbon emissions of buildings: A literature review', in *The 6th World Construction Symposium 2017: What's New and What's Next in the Built Environment Sustainability Agenda?, Colombo, Sri Lanka*, 30 June-2 July 2017, pp. 188–196

Network Rail. (2018) *Carbon Capital - Guidance Note - Environment, Network Rail*

Newell, G. (2008) 'The strategic significance of environmental sustainability by Australian-listed property trusts', Journal of Property Investment and Finance, vol. 26, no. 6, pp. 522-540

Ng, S.T, (2015) 'Reducing the embodied carbon of construction projects through a carbon emission encompassed tender', *Energy and Sustainability*, vol. 403

Ng, S.T. (2014) 'Towards a Carbon Emission-Encompassed Tender for Construction Projects', *Zero Carbon Building Journal*, vol. *2*, pp. 6–13

Ng, S.T. Wong, J. and Skitmore, M. (2013) 'Challenges facing carbon dioxide labelling of construction materials', *Proceedings of the Institution of Civil Engineers: Engineering Sustainability*, Vol. 166, pp. 20–31

Ochieng E.G, Wynn T.S, Zuofa T, Ruan X, Price A.D.F. et al. (2014) 'Integration of Sustainability Principles into Construction Project Delivery', *Journal of Architectural Engineering* Technology, vol. 3, no. 1: 116. https://doi.org/10.4172/2168-9717.1000116

OECD, Eco-Innovation in Industry: Enabling Green Growth [online]. Available from: http://www.oecd.org/sti/ind/eco-innovationinindustryenablinggreengrowth.htm (Accessed on 1 January 2018)

Ortiz, O. Castells, F. and Sonnemann, G. (2009) 'Sustainability in the construction industry: A review of recent developments based on LCA', *Construction and Building Materials*, vol. 23, no. 1, pp. 28-39

Pen-Mora F, Ahn C. Golparvar-Fard M. Hajibabai L. Shiftwehfar R, An S. Aziz Z. and Song, S.H. (2009) 'Application of Visualization for Construction emissions monitoring', *Proceedings of the Construction Research Congress*, Banff, Canada, May 8-11

Pomponi, F. and Moncaster, A. (2017) 'Scrutinising embodied carbon in buildings: The next performance gap made manifest', *Renewable and Sustainable Energy Reviews*, June, pp. 2431–2442. Available from: http://doi.org/10.1016/j.rser.2017.06.049

Presley, A. and Meade, L. (2010) 'Benchmarking for sustainability: an application to the sustainable construction industry', *Benchmarking: An International Journal*, vol. 17, no. 3, pp. 435-451

Primavera Earned Value Management, Oracle Data Sheet [online]. Available from: http://www.oracle.com/us/industries/aerospace/042529.pdf (Accessed 28 October 2014)

Pullen, S. (2000) 'Energy used in the construction and operation of houses', *Architectural Science Review*, vol. 43, no. 2, October, pp. 87-94

Rabiee F. (2004) 'Focus-group interview and data analysis', *Proceedings of the Nutrition Society*, vol. 63, pp. 655–660

Radhi, H. (2010) ‘On the Effect of Global Warming and UAE Built Environment’, in Harris, S.A. (ed.). Global Warming, Croatia: SCIYO, pp. 95-110

Ras Al Khaimah Municipality (2019) Barjeel – Ras Al Khaimah Green Building Regulations. [online] Available from: https://mun.rak.ae/Documents/EER/Barjeel%20-%20Green%20Building%20Regulations.pdf. (Accessed 10 July 2019).

Remenyi, D. Williams, B. and Money, A. (1998) *Doing Research in Business and Management: An Introduction to Process and Method*, London: Sage Publications

Resch, E. & Andresen, I. (2018) 'A Database Tool for Systematic Analysis of Embodied Emissions in Buildings and Neighborhoods', *Buildings*, vol. *8*, p. 106. Available from: http://doi.org/10.3390/buildings8080106

Ritchie, J. and Lewis, J. (2003) *Qualitative Research Practice: A Guide for Social Science Students and Researchers*, London: Sage Publications

Robson, C. (2002) *Real World Research*, Oxford, UK: Blackwell

Robson, C. (2011) *Real World Research*, 3rd ed., Chichester, UK: John Wiley & Sons

Roh, S. Tae, S. and Kim, R. (2018) 'Analysis of embodied environmental impacts of Korean apartment buildings considering major building materials', *Sustainability*, vol. *10*, no. 6. Available from: http://doi.org/10.3390/su10061693

Rowley, J. (2002) ‘Using case studies in research’, *Management Research News*, vol. 25, no. 1, pp. 16-27

Royal Institute of British Architects (2018) *Embodied and whole life carbon assessment for architects*, London [online]. Available from: from https://www.architecture.com/-/media/gathercontent/whole-life-carbon-assessment-for-architects/additional-documents/11241wholelifecarbonguidancev7pdf.pdf (Accessed 05 January 2019)

Royal Institute of British Architects and Sinclair, D. (2013) RIBA Plan of Work 2013: Overview [online]. Available from: http://doi.org/ISBN.978.1.85946.519.6 (Accessed 18 December 2013)

Rubio Gomez, M.C. Martínez, G. Baena, L. Moreno-Navarro, F. (2012) ‘Warm mix asphalt: An overview’, *Journal of Cleaner Production*, vol. 24, pp. 76–84

Ruparathna, R. and Hewage, K. (2015) ‘Sustainable procurement in the Canadian construction industry: challenges and benefits’, *Canadian Journal of Civil Engineering*, vol. 42, no. 6, May, pp. 417-426

Ruth, M. Worrell, E. and Price, L. (2000) Evaluating Clean Development Mechanism Projects in the Cement Industry Using a Process-Step Benchmarking Approach, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA

Sacks, R. & Barak, R. (2010) ‘Teaching building information modeling as an integral part of freshman year’, *Journal of Civil Engineering Education*, vol.136 (1), pp. 30-38

Sagepub (2019) Participants in a Focus Group. [online] Available at https://www.sagepub.com/sites/default/files/upm-binaries/24056_Chapter4.pdf. [Accessed 9 August 2019].

Sagoe, D. (2012) ‘Precincts and prospects in the use of focus groups in social and behavioural science research’, *Qualitative Report*, vol. 17, no, 29, April, pp. 1-16

Sandalow, D. (2018) *Guide to Chinese Climate Policy 2018*, Columbia University School of International and Public Affairs, Center on Global Energy Policy

Sandanayake, M. Zhang, G. and Setunge, S. (2016) 'Environmental emissions at foundation construction stage of buildings - Two case studies', *Building and Environment*, vol. *95*, pp. 189–198. Available from: http://doi.org/10.1016/j.buildenv.2015.09.002

Sansom, M. and Pope R.J. (2012) 'A comparative embodied carbon assessment of commercial buildings', *Structural Engineer,* vol. 90, no. 10, October, pp. 38-49

Sarkar, D. Datta, R. Mukherjee, A. and Hannigan, R. (2015) *An Integrated Approach to Environmental Management*, John Wiley & Sons

Sattary, S. (2017) *Sustainable Construction Potential Carbon Emission Reductions (PCER) in Australian Construction Systems through the Use of Bioclimatic Design Principles*, PhD thesis, Queensland: University of Southern Queensland

Saunders, M. Lewis, P. and Thornhill, A. (2003) *Research methods for business students*, 3rd ed., Ashford, UK: Pearson Education

Saunders, M. Lewis, P. and Thornhill, A. (2012) *Research methods for business students*, 6th ed., Essex, UK: Pearson Education

Säynäjoki, E.S., Korba, P., Kalliala, E. and Nuotio, A.K. (2018) 'GHG emissions reduction through urban planners' improved control over earthworks: A case study in Finland', *Sustainability*, vol. 10, no. 8, pp. 16–18. Available from: http://doi.org/10.3390/su10082859

Schilling, J. (2006) 'On the pragmatics of qualitative assessment: Designing the process for content analysis,' *European Journal of Psychological Assessment*, vol. 22, no. 1, January, pp. 28-37

Sharpe, D. (2015) 'Your Chi-Square Test is Statistically Significant: Now What?', *Practical Assessment, Research & Evaluation*, vol. 20, no. 8, April, p. 1 [online]. Available from: https://pareonline.net/getvn.asp?v=20&n=8 (Accessed 18 Jan 2017)

Shiftwehfar R. Golparvar-Fard M. Pen-Mora F. Karahalios K. and Aziz Z. (2010) 'Application of Visualization for Construction emissions monitoring', *Proceedings of the Construction Research Congress*, Banff, Canada, May 8-11 pp. 1396-1405 [online] https://doi.org/10.1061/41109(373)140 (Accessed 16 November 2013)

Shrivastava, S. and Chini, A. (2014) 'Using Building Information Modeling to Assess the Initial Embodied Energy of a Building', *International Journal of Construction Management*, vol. 12, no. 1, February, pp. 51-63

Silvius, A.J.G. Schipper, R. and Nedeski, S. (2013) 'Sustainability in Project Management : Reality Bites', in *PM World Journal*, vol. 2, pp. 1–183. Available from: http://doi.org/10.1002/pmj

Simonen, K. Rodriguez, B. Barrera, S. Huang, M. McDade, E. and Strain, L. (2017) *Embodied Carbon Benchmark Study: LCA for Low Carbon Construction*. The Carbon Leadership Forum, Department of Architecture, University of Washington. [online] Available from: http://hdl.handle.net/1773/38017. (Accessed 09 February 2018)

Sinha, R. Lennartsson, M. Frostell, B. (2016) 'Environmental footprint assessment of building structures: a comparative study'. *Build. Environ*. Vol. 104, 162–171

Skanska, A.B. '*Carbon Foot-printing in Construction – examples from Finland, Norway'*, Sweden, UK and US, Case study 76

Smith, R.A., Kersey, J.R. and Griffiths, P.J. (2003) *The Construction Industry Mass Balance: Resource Use, Wastes and Emissions*, Viridis and CIRIA, UK

Software Process and Measurement. (2016) *Basics: Difference Between Models, Frameworks, and Methodologies.* [online] Available from: https://tcagley.wordpress.com /2016/03/24/basics-difference-between-models-frameworks-and-methodologies/ (Accessed 19 Jul. 2019)

Sourani A. and Sohail M. (2011) 'Barriers to addressing sustainable construction in public procurement strategies', *Proceedings of the Institute of Civil Engineers — Engineering Sustainability*, vol. 164, no. 4, December, pp. 229-237

Sreedhara, S. Jichkarb, P. and Biligiric, K.P. (2016) 'Investigation of Carbon Footprints of Highway Construction Materials in India', *Transportation Research Procedia*, vol. 17, pp. 291-300

SteelConstruction.info (2018) *Life cycle assessment and embodied carbon* [online]. Available from: https://www.steelconstruction.info/Life_cycle_assessment_ and_embodied_carbon #Further_reading. (Accessed 9 November 2018)

Strauss, A.L. and Corbin, J. (1998) *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*, 2nd ed., London: Sage Publications

Sturgis, S. (2018) 'Whole-life carbon: RIBA and RICS guidance, March, pp. 1–8. [online] Available from https://www.building.co.uk/whole-life-carbon/whole-life-carbon-riba-and-rics-guidance/5092522.article#.WqZbXkQCRZc.twitter (Accessed 9 November 2018)

Subramaniam, N. et al. (2015) 'Integration of carbon risks and opportunities in enterprise risk management systems: evidence from Australian firms', *Journal of Cleaner Production*, vol. 96, June, pp. 407-417

Syngros, G. Balaras, C.A. and Koubogiannis, D.G. (2017) 'Embodied CO_2 Emissions in Building Construction Materials of Hellenic Dwellings', *Procedia Environmental Sciences*, vol. 38, pp. 500–508. Available from: https://doi.org/10.1016/ j.proenv.2017.03.113

Tam, V.W.Y. Tam, C.M. (2006) 'Evaluations of existing waste recycling methods: a Hong Kong study'. *Building and Environment*, vol. 41, pp.1649–1660

Tan, Y. Shen, L. and Yao, H. (2011) 'Sustainable construction practice and contractor's competitiveness: A preliminary study', *Habitat International*, vol. 35, no. 2, April, pp. 225-230

The Embodied Carbon Review (2018) 'Embodied carbon reduction in 100+ regulations & rating systems globally' [online]. Available from https://www.oneclicklca.com/wp-content/uploads/2018/12/Embodied_Carbon_Review_ 2018.pdf (Accessed 19 December 2018)

Treloar G.J. (1996) 'Completeness and accuracy of embodied energy data: A national module of residential buildings', in *Proceedings of Embodied Energy* State-*of-Play Seminar*, Deakin University, Geelong, 28-29 November, pp 51-60

Treloar, G.J. (1997) 'Extracting Embodied Energy Paths from Input-Output Tables: Towards an Input–Output-based Hybrid Energy Analysis Method', *Economic Systems Research*, vol. 9, no. 4, February, pp. 375-391

Treloar, G.J. and Crawford, R. (2005) 'An assessment of the energy and water embodied in commercial building construction', peer-reviewed paper presented at the *4th Australian LCA Conference*, Sydney

Tutu, K.A. and Tuffour, Y.A. (2016) 'Warm-Mix Asphalt and Pavement Sustainability: A Review', *Journal of Civil Engineering*, vol. 6, pp. 84–93

UK Department for Environment Food & Rural Affairs (2011) 'Sustainable Procurement in Government: Guidance to the Flexible Framework'. [online] Available from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69471/pb13423-flexible-framework-guidance-110928.pdf (Accessed 05 May 2013)

UNEP-SBCI (2013) 'Join the Global Platform for Sustainable Buildings' [online]. Available from www.unep.org/sbci (Accessed 05 May 2013)

United Nations Framework on Climate Change (2006) Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol, etc., FCCC/KP/CMP/2005/8/Add.1., Montreal 2005 [online]. Available from: http://www.scientia.hu/klimavaltozas/dok/08a01.pdf (Accessed 3 January 2018)

United Nations Framework on Climate Change (2011) Report of the Conference of the Parties on its sixteenth sessions held in Cancun from 29 November to 10 December 2010, FCCC/CP/2010/7/Add.1., Cancun 2010 [online]. Available from: https://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf (Accessed 3 January 2018)

Varma, S.S. Sujith, T.P. Amrutha, K. Hadiya, K. and Jacob, J. (2016) 'Project tracking using Earned Value Management on cost, time and carbon footprint', *International Research Journal of Engineering and Technology (IRJET), vol. 3,* no. 4

Varnäs, A. Balfors, B. and Faith-Ell, C. (2009) 'Environmental consideration in procurement of construction contracts: current practice, problems and opportunities in green procurement in the Swedish construction industry', *Journal of Cleaner Production*, vol. 17, no. 13, pp. 1214–1222. Available from: http://doi.org/10.1016/j.jclepro.2009.04.001

Varun S.A. Sharma A. Shree, V. and Nautiyal, H. (2012) 'Life cycle environmental assessment of an educational building in Northern India: A case study', *Sustainable Cities and Society*, vol. 4, no. 1, October, pp. 22–28

Verbrugge, B. (n.d.). *Best Practice, Model, Framework, Method, Guidance, Standard: towards a consistent use of terminology – revised*. [online] Available from https://www.vanharen.net/blog/van-haren-publishing/best-practice-modelframework-method-guidance-standard-towards-consistent-use-terminology/ (Accessed July 18, 2019)

Victoria, M. F. and Perera, S. (2018) 'Parametric embodied carbon prediction model for early-stage estimating', *Energy and Buildings*, vol. 168, pp. 106–119. Available from: http://doi.org/10.1016/j.enbuild.2018.02.044

Vijayaraghavan, K. (2016) 'Green roofs: A critical review on the role of components, benefits, limitations and trends', Renewable and Sustainable Energy Reviews, vol. 57, May, pp. 740–752

Waara, F. and Brochner, J. (2006) 'Price and non-price criteria for contractor selection', *Journal of Construction Engineering and Management*, vol. 132, no. 8, August, pp. 797–804

Walimuni, P.C. Samaraweera, A. and De Silva, L. (2017) 'Payment mechanisms for contractors for better environmental hazard controlling in road construction projects', *Built Environment Project and Asset Management*, Vol. 7(4), pp.426-440, https://doi.org/10.1108/BEPAM-11-2016-0069

Wang E. Shen Z. Berryman C. (2011) 'A Building LCA Case study using Autodesk Ecotect and BIM Model', *47th ASC Annual International Conference Proceedings* [online] Available from: *https://digitalcommons.unl.edu/constructionmgmt/6/* (Accessed 3 September 2013)

Wang, X. Duan, Z. Wu, L. and Yang, D. (2015) 'Estimation of carbon dioxide emission in highway construction: A case study in southwest region of China'. *Journal of Cleaner Production*, vol. 103, pp. 705–714. Available from: http://doi.org/10.1016/j.jclepro.2014.10.030

Watermeyer, R. (2012) 'Changing the construction procurement culture to improve project outcomes', *Joint CIB*, vol. 70, no. 1, pp. 2-11

Webb, R. (2000) Sustainable Architecture — Cities, Buildings and Technology, paper for presentation at *International Conference on Sustainable Building*, Maastricht

Weidema, B.P. (1998). 'Multi-user test of the data quality matrix for product life cycle inventory data', *International Journal of Life Cycle Assessment*, vol. 3, no. 5, pp. 259-265

Weidema, B.P. and Wesnæs, M. (1996). 'Data quality management for life cycle inventories - An example for using data quality indicators', *Journal of Cleaner Production*, vol. 4, nos. 3-4, pp. 167-174

Werner, F. Althaus, H.-J. Künniger, T. Richter, K. and Jungbluth, N. (2007) Life Cycle Inventories of Wood as Fuel and Construction Material, *Ecoinvent*, Report No. 9, January, pp. 1-165

Wheating, N.C. (2017) *'Embodied carbon: A framework for prioritizing and reducing emissions in the building industry'*, Master's dissertation, San Francisco: The University of San Francisco

White, P. Golden, J.S. Biligiri, K.P. Kaloush, K. (2010) 'Modeling Climate Change Impacts of Pavement Production and Construction', *Resources, Conservation and Recycling*, vol. 54, no. 11, September, pp. 776-782

Wiese. F, Hilpert. S,Kaldemeyer. C, Plebmann, G (2018), 'A qualitative evaluation approach for energy system modelling frameworks', Energy, *Sustainability and Society*, Vol. 8, pp.13.

Wilkinson, S. and Reed, R. (2006) 'Delivering Sustainability: Improving energy efficiency of the CBD', *RICS Education Trust Golden Jubilee Project Final Report*, London: RICS

Wittneben, B.B. and Kiyar, D. (2009) 'Climate change basics for managers', *Management Decision*, vol. 47, no. 7, pp. 1122-1132

Wong, J.K.W. Li, H. Wang, H. Huang, T. Luo, E. and Li, V. (2013) 'Toward low-carbon construction processes: the visualisation of predicted emission via virtual prototyping technology', *Automation in Construction*, vol. 33, pp. 72-78

Worldwatch Paper #124: *A Building Revolution: How Ecology and Health Concerns Are Transforming Construction*, March 1995 [online]. Available from: https://www.worldwatch.org/node/866 (Accessed 3 Jan 2012)

Woszuk, A. and Franus, W. (2016) 'Properties of the Warm Mix Asphalt involving clinoptilolite and Na-P1 zeolite additives', *Construction and Building Materials*, vol. 114, March, pp. 556–563

Woszuk, A. and Franus, W. (2017) 'A review of the application of zeolite materials in Warm Mix Asphalt technologies', *Applied Sciences*, vol. 7, no. 3, 293

WRAP. (2011) '*Information sheet for construction clients and designers: Cutting embodied carbon in construction projects*'. [online] Available from: https://www.wrap.org.uk/.../FINAL/20PRO095/009/20Embodied/20Carbon/20Annex.pdf. (Accessed 3 Jan 2012)

WRAP. (n.d.) *Cutting embodied carbon in construction projects.* [online] Available from https://www.papers3://publication/uuid/A4271964-6EDE-44A9-8A87-18796648707F (Accessed 3 Jan 2012)

Xie Xia, A. (2015) *Integrated Design for Green Building in China: the obstacles and the way forward*, PhD thesis, Hong Kong: The University of Hong Kong

Yeo, Z. Ng, R. and Song, B. (2016) 'Technique for quantification of embodied carbon footprint of construction projects using probabilistic emission factor estimators', *Journal of Cleaner Production*, vol. 119, pp. 135–151. Available from: http://doi.org/10.1016/j.jclepro.2016.01.076

Yin, R.K. (2014) *Case study research: Design and methods,* 5th ed., Thousand Oaks, CA: Sage Publications

Yu, W. Der, Cheng, S.T., Ho, W.C. and Chang, Y.H. (2018) 'Measuring the sustainability of construction projects throughout their lifecycle: A Taiwan Lesson', *Sustainability*, vol. 10, no. 5. Available from: http://doi.org/10.3390/su10051523

Yu, W.D. Chang, Y.H. and Liu, D.G. (2014) 'A Generic Eco-Innovation Model to Improve Building Sustainability', in *Proceedings of the Innovation for Sustainability 2014*. Porto, Portugal, 10–11 July 2014; pp. 165-1–12.

Yu, W.D. Cheng, S.T. Miao, C.M. and Perng, G.Y. (2017) 'Green innovation of green roof technology—A case study', *Materials Science & Engineering Technology*, vol. 48, May, pp. 420–429

Zhang, Y. Zheng, X. Zhang, H. Chen, G, and Wang, X. (2016) 'Carbon emission analysis of a residential building in China through life cycle assessment', *Frontiers of Environmental Science & Engineering*, vol. 10, no. 1, February, pp. 150–158

Appendix A – Survey 1 Questionnaire

Survey 1 - Preliminary Data collection

Exploring the current practices(sustainabiliy, CO2 emission management) of UAE construction industry

1. Please specify the nature of your organization

- ○ Contractor-A
- ○ Contractor-B
- ○ Client-A
- ○ Client-B
- ○ Architectural & Design Consultant-A
- ○ Architectural & Design Consultant-B
- ○ Project Management Consultant-A
- ○ Project Management Consulant-B
- ○ Manufacturer-A
- ○ Manufacturer-B

2. Please specify your position

- ☐ General Manager
- ☐ Construction Manager
- ☐ Project Manager
- ☐ Estimation Manager
- ☐ Procurement Manager
- ☐ Design Manager
- ☐ Planning and Controls Manager
- ☐ Safety and Environmental Manager
- ☐ Contracts Manager
- ☐ Other (please specify)

3. Please specify your work experience in building construction industry

- ○ < 5 Years
- ○ 5 to 10 Years
- ○ 10 to 20 Years
- ○ > 20 Years

4. What is your academic Qualification level?

- ○ Under graduation
- ○ Graduate
- ○ Post graduate
- ○ Doctorate
- ○ Other (please specify)

5. Which of the following Professional qualifications you have?

- [ ] PMP - Project Management Professional
- [ ] BREEAM Assessor
- [ ] MRICS - Member Royal Institute of Chartered Surveyors
- [ ] PQP - Pearl Qualified Professional
- [ ] CCS - Certified Cost Specialist
- [ ] Certified Carbon Auditor
- [ ] LEED AP
- [ ] Other (please specify)

6. Have you worked on sustainable (Green) building construction projects

- ( ) Yes
- ( ) No

7. Which of the following were used on the sustainable projects you worked on?

- [ ] LEED
- [ ] BREAAM
- [ ] ESTIDAMA

8. Are you aware of following terms

	Fully aware	Aware	Not aware
Green house gas emissions (GHG)	( )	( )	( )
Carbon (CO2) emissions	( )	( )	( )
Embodied CO2 emissions	( )	( )	( )

9. Are you aware of carbon emission factors and carbon emission estimates

- ( ) Extremely aware
- ( ) Very aware
- ( ) Somewhat aware
- ( ) Not so aware
- ( ) Not at all aware

10. Is CO2 emissions estimated and tracked in any projects you worked with?

- ( ) Always
- ( ) Usually
- ( ) Sometimes
- ( ) Rarely
- ( ) Never

11. What software / tools you use for estimation while bidding for a project

- [ ] Excel spreadsheet (with In-house rate analysis)
- [ ] B2W estimate
- [ ] Sage Estimating
- [ ] Pro Est Estimating
- [ ] Other (please specify)

12. What software tools you use for planning and control for a project

	Never	Rarely	Sometimes	Often	Always
Only Primavera	○	○	○	○	○
Only MS Project	○	○	○	○	○
A combination of Excel and the planning software (primavera, MS project)	○	○	○	○	○
In house developed company software	○	○	○	○	○

13. Which of the following your company use to estimate cost while bidding for a project in UAE ?

- ○ BCIS
- ○ Government rate indices
- ○ In house cost indices
- ○ Other (please specify)

14. Do you agree with the following issues faced while working with cost estimation soft-wares

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Hidden data	○	○	○	○	○
Complexity	○	○	○	○	○
Training and awareness requirements	○	○	○	○	○
Un reliable results	○	○	○	○	○
Additional costs	○	○	○	○	○

15. Which of the following tools you use on your projects for carbon assessment?

- [ ] SimaPro
- [ ] Envest
- [ ] IES VE
- [ ] None of the above
- [ ] Other (please specify)

16. Do you agree, project performance in UAE is being monitored by the following:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
EVA Technique via Excel S curves to monitor weekly/monthly performance	○	○	○	○	○
Use of only Primavera/MS Project	○	○	○	○	○
Last Planer Methods	○	○	○	○	○

17. Due to you feel fatigue due to various number of tools for managing projects

- ○ Yes
- ○ No
- ○ Other (please specify)
- ○ Depends upon complexity of tool

18. Out of the four below, which one was the ultimate governing factor for award of building projects?

- ○ Purely technical (Awarded based on only technical capability of the bidder)
- ○ Purely commercial (Lowest Bid wins the contract)
- ○ Purely environmental (based on Life cycle carbon emissions proposed by each bidder)
- ○ Purely safety and integrity (based on the safety record of the bidder only)

19. Were you involved on a project which was awarded only on environmental basis?

- [ ] Yes
- [ ] No

Appendix B – Survey 2 Questionnaire

Title:A study on effective implementation of carbon emission management in UAE construction industry

Dear All,

I am approaching you in relation to the research being conducted as a part of fulfillment of the requirements for the PhD in Construction Management at Heriot Watt University. My research is a study on effective implementation of carbon emission management in UAE construction industry. Survey objective is find out the current sustainable practices, reasons for lack of implementation of Carbon emission management systems.

I would be grateful for your participation in completing this Questionnaire. Your valuable information will provide a great insight to understand the current situation of sustainable construction and its impact in UAE.

Thank you for your valuable time and participation to complete this questionnaire. Your input is highly appreciated.

Regards,
Mohammed Azharuddin,
PhD student

1. Please specify the nature of your organization

- ○ Contractor
- ○ Client
- ○ Real Estate Developer
- ○ Architectural & Design Consultancy
- ○ Project Management Consultancy
- ○ Manufacturer
- ○ Vendor/Supplier
- ○ Other (please specify)

[ ]

2. Please specify your position

- [ ] General Manager
- [ ] Construction Manager
- [ ] Project Manager/Engineer
- [ ] Estimation Manager/Engineer/Quantity Surveyor/Cost Engineer
- [ ] Procurement Manager/Engineer/Officer
- [ ] Design Manager/Engineer
- [ ] Planning and Controls Manager/Engineer
- [ ] Safety and Environmental Manager/Engineer/Officer
- [ ] Contracts Manager/Engineer/Adminstrator
- [ ] Other (please specify)

[ ]

3. Please specify your work experience in building construction industry

- ◯ < 5 Years
- ◯ 5 to 10 Years
- ◯ 10 to 20 Years
- ◯ > 20 Years

4. What is your academic Qualification level?

- ◯ Under graduation
- ◯ Post graduate
- ◯ Graduate
- ◯ Doctorate
- ◯ Other (please specify)

5. Which of the following Professional qualifications you have?

- ☐ PMP - Project Management Professional
- ☐ PQP - Pearl Qualified Professional
- ☐ MRICS - Member Royal Institute of Chartered Surveyors
- ☐ Carbon Auditor
- ☐ CCS - Certified Cost Specialist
- ☐ CEM
- ☐ LEED AP
- ☐ None of the above
- ☐ BREEAM Assessor
- ☐ Other (please specify)

6. What is the maximum value of Projects handled in this year?

- ◯ < 1 M USD
- ◯ 20 M USD to 50 M USD
- ◯ 1 M USD to 5 M USD
- ◯ 50 M USD to 100 M USD
- ◯ 5 M USD to 20 M USD
- ◯ > 100 M USD

7. SECTION B

Please select the procurement route of the above project.

- ◯ Traditional procurement route
- ◯ Project Management contract
- ◯ Design & Build (including variants)
- ◯ PPP - Public Private Partnership
- ◯ Other (please specify)

8. Out of the four below, which one was the ultimate deciding factor for award of building projects?

- ◯ Purely technical
- ◯ Purely commercial
- ◯ Purely environmental
- ◯ Purely safety and integrity

9. Have you been part of any project which was awarded only on environmental basis (not on cost basis i.e. lowest bid wins the job)

- ☐ Yes
- ☐ No

10. Have you worked on sustainable (Green) building construction projects

- ◯ Yes
- ◯ No

11. Do you agree the adverse impacts of carbon emissions are one of the reasons for global warming effects

- ◯ Strongly agree
- ◯ Agree
- ◯ Neither agree nor disagree
- ◯ Disagree
- ◯ Strongly disagree

12. Which one of the following factors do you think is limiting the sustainable construction management practice in UAE?

- ◯ Lack of Awareness
- ◯ Lack of Experience
- ◯ Non availability of Data sources and metrics
- ◯ Hurdles in getting certified
- ◯ Increased first costs
- ◯ Lenient Regulations
- ◯ Developers focus on low first costs
- ◯ Fast track construction in UAE

13. Which of the following were used on the sustainable projects you worked on?

- ☐ LEED
- ☐ BREAAM
- ☐ Green Star
- ☐ Other (please specify)
- ☐ ESTIDAMA
- ☐ LCA based on ISO 14000 series

____

14. Do you think sustainability related clauses shall be mandatory in the contractual arrangements in UAE?

- ☐ Strongly agree
- ☐ Agree
- ☐ Neither agree nor disagree
- ☐ Disagree
- ☐ Strongly disagree

15. SECTION C

What basis your company follows to estimate cost while bidding for a project in UAE

- ○ BCIS
- ○ In house cost indices
- ○ Other (please specify)
- ○ Government rate indices

16. What software / tools you use for estimation while bidding for a project

- ○ Excel spreadsheet (with In-house rate analysis)
- ○ Pro Contracting Estimating
- ○ B2W estimate
- ○ Sage Estimating
- ○ Other (please specify)
- ○ Pro Est Estimating
- ○ WinEst
- ○ BSE Estimator

17. Rate the extent of usage of the following software / tools for planning and controlling a project (1= extensively used, 5= very low usage or not used)

☐	Primavera
☐	Microsoft Project
☐	Bar charts using Excel Spreadsheets
☐	PMWeb
☐	SAP PPM and SAP PS

18. What is your awareness level and proficiency in the above (Q14 & Q15) selected tools

- ○ Not at all professional
- ○ Not so professional
- ○ Somewhat professional
- ○ Very professional
- ○ Extremely professional

19. Do you agree with the following issues faced while working with cost estimation and Carbon estimating software

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Hidden data	○	○	○	○	○
Complexity	○	○	○	○	○
Training and awareness requirements	○	○	○	○	○
Un reliable results	○	○	○	○	○
Additional costs	○	○	○	○	○

20. Are you aware of following terms

	Fully aware	Aware	Not aware
Green house gas emissions (GHG)	○	○	○
Carbon (CO2) emissions	○	○	○
Life cycle assessment based on CO2 emissions	○	○	○
Embodied energy	○	○	○
Embodied CO2 emissions	○	○	○
NONE OF THE ABOVE	○	○	○

21. Which of the following tools you use on your projects for carbon assessment?

- ☐ GABI
- ☐ Athena
- ☐ SimaPro
- ☐ Envest
- ☐ BEES
- ☐ None of the above
- ☐ Other (please specify)

22. How would you prefer to estimate life cycle carbon emissions on your project (1 = high, 3 = low)

- ☐ Using standalone software tools available in market
- ☐ Using software integrated with your current tools such as BIM
- ☐ Using simple in use tools, which are most familiar to you

23. How do you monitor the project performance

- Cash Flow & EVA Technique via S curves
- Accounting softwares, Tally
- CPM techniques via Primavera/MS Project
- Balance score card
- Last Planer Methods
- Other (please specify)

24. Do you agree that carbon emissions assessment shall be made mandatory?

- Strongly agree
- Disagree
- Agree
- Strongly disagree
- Neither agree nor disagree

25. What do you prefer for assessing and monitoring carbon emissions

- In Use tools like excel, primavera, MS Project
- In use tools like SimaPro, Envest,
- New tools specific to estimation and monitoring of carbon emissions
- Energy Modelling

26. Do you feel fatigue due to various number of tools and software for managing projects

- Yes
- Depends upon quality of the tool interface
- No
- Depends upon complexity of tool
- Other (please specify)

27. Which ONE the following statements BEST describes your Carbon Emissions Management (CEM) implementation experience over the last few years:

- CEM is limited to certifying the Project under LEED, ESTIDAMA and similar rating system
- Scope of our CEM are ONLY defined with SMART objectives and focused programs but not implemented
- CEM is limited to certifying the Project for Energy rating
- CEM approach and elements have been formalized and documented only but not implemented in totality
- CEM is limited to carrying out Life Cycle Assessment for Energy consumed
- Have never seen CEM implementation

28. Rank the measures to improve the implementation of Carbon emissions management in UAE building construction projects (1=very important, 5=not important)

☐	Mandate the Carbon emission for all projects in UAE
☐	Integrate carbon emissions management in Project management systems
☐	Upon technically qualifying the bidders, Carbon and cost bids shall be criteria for award
☐	Spread awareness and knowledge in using simple in-use software to improve the implementation
☐	Make Carbon emission factors freely available to industry for estimation and monitoring

29. What are the drivers for carbon management in your Organization? (Please rate as per their importance, (1 = Very important, 5 = Not important

	1	2	3	4	5
Climate change	○	○	○	○	○
Do the right thing	○	○	○	○	○
Comply with government laws and regulations	○	○	○	○	○
Energy prices and Financial savings	○	○	○	○	○
Reputation and market position	○	○	○	○	○

30. If you are a contractor, will you bid for projects with carbon emissions and cost as criteria for award of contract.

- ☐ Yes
- ☐ No

31. Will you execute a project which requires carbon emissions (embodied and operational) estimation and controlling same as cost and time.

- ☐ Yes
- ☐ No

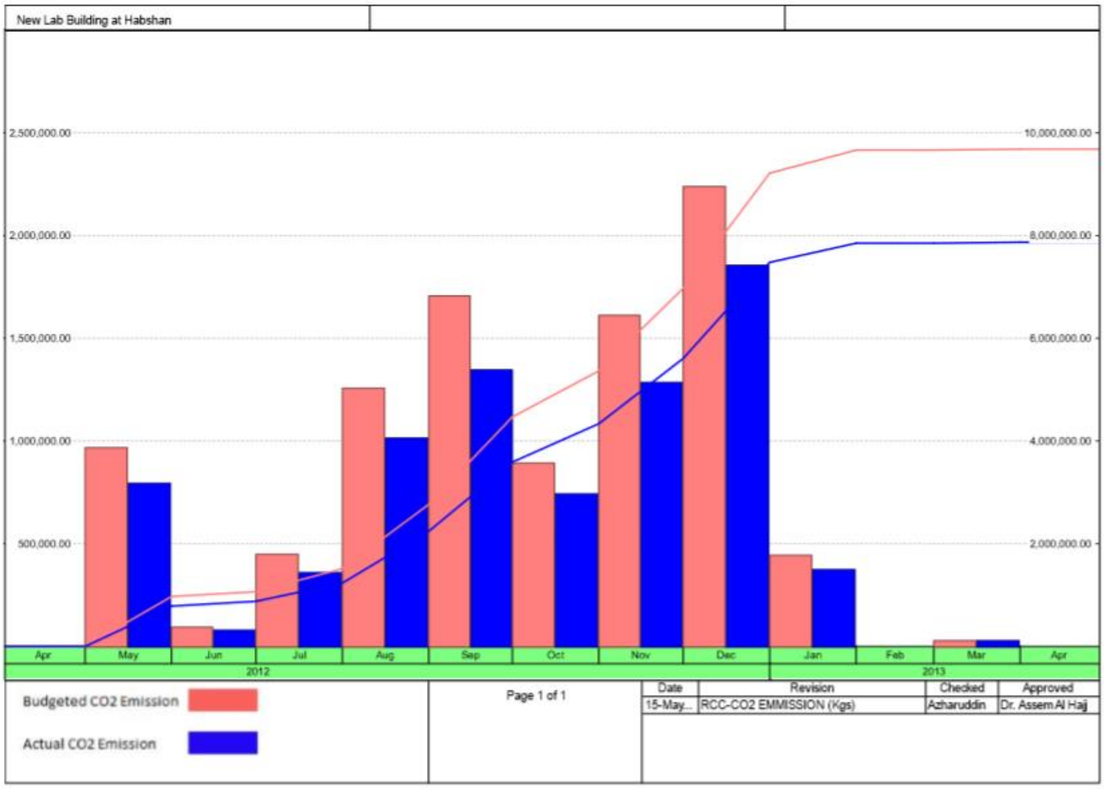
32. If you are a contractor, Will you submit the carbon emissions bid in addition to cost bids during the tendering phase (carbon and cost tendering bids)

- ☐ Very likely
- ☐ Likely
- ☐ Neither likely nor unlikely
- ☐ Unlikely
- ☐ Very unlikely

33. In your opinion what could be done to promote sustainable construction by implementing carbon emissions management in UAE ?

- [ ] Validation of cost and environmental benefits of Buildings by integrating Carbon Emission management(CEM) with traditional Project management process.
- [ ] Case studies of successful CEM projects to be published
- [ ] Increase awareness through training and promotional programs
- [ ] Project selection shall emphasize on whole life cycle carbon emissions of the project
- [ ] Easy availability of carbon emissions factors for all Materials
- [ ] Government regulation – “Carrot and stick” type
- [ ] Allocation of funds for research and innovation
- [ ] Project Selection shall emphasize on environmental impact such as the amount of CO_2eq emitted.

Appendix C - Case study 1 data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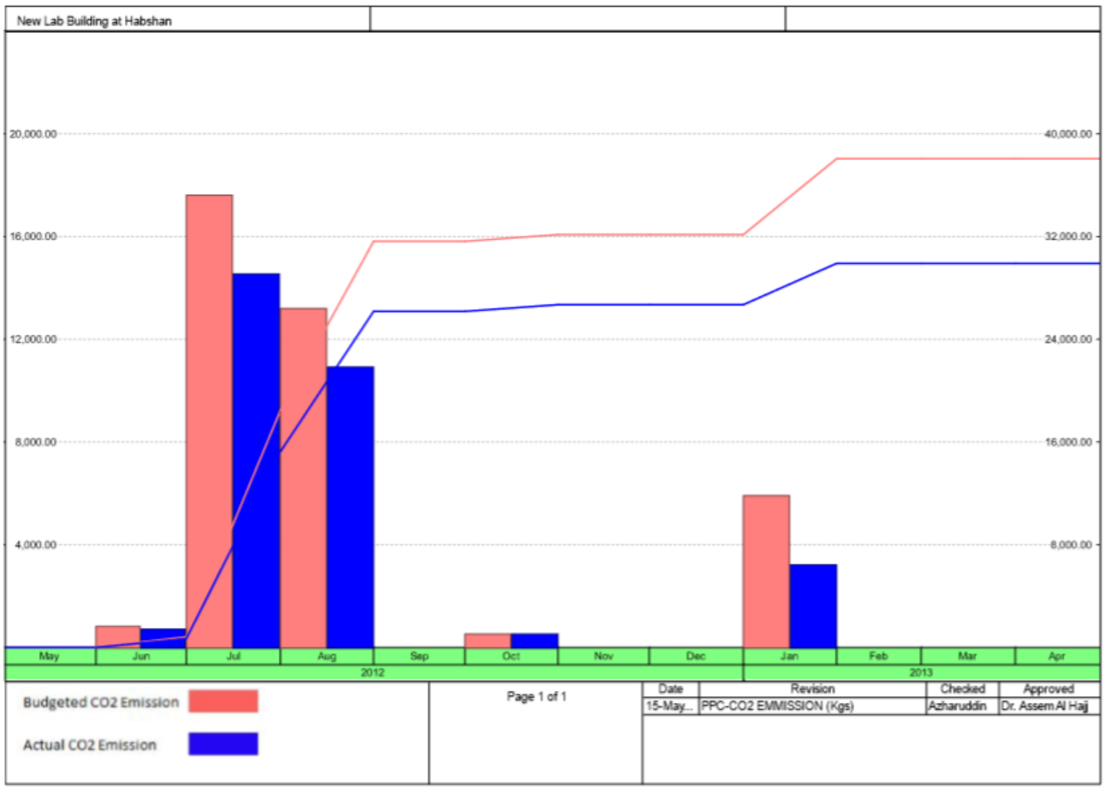
Dr. Assem Al Hajj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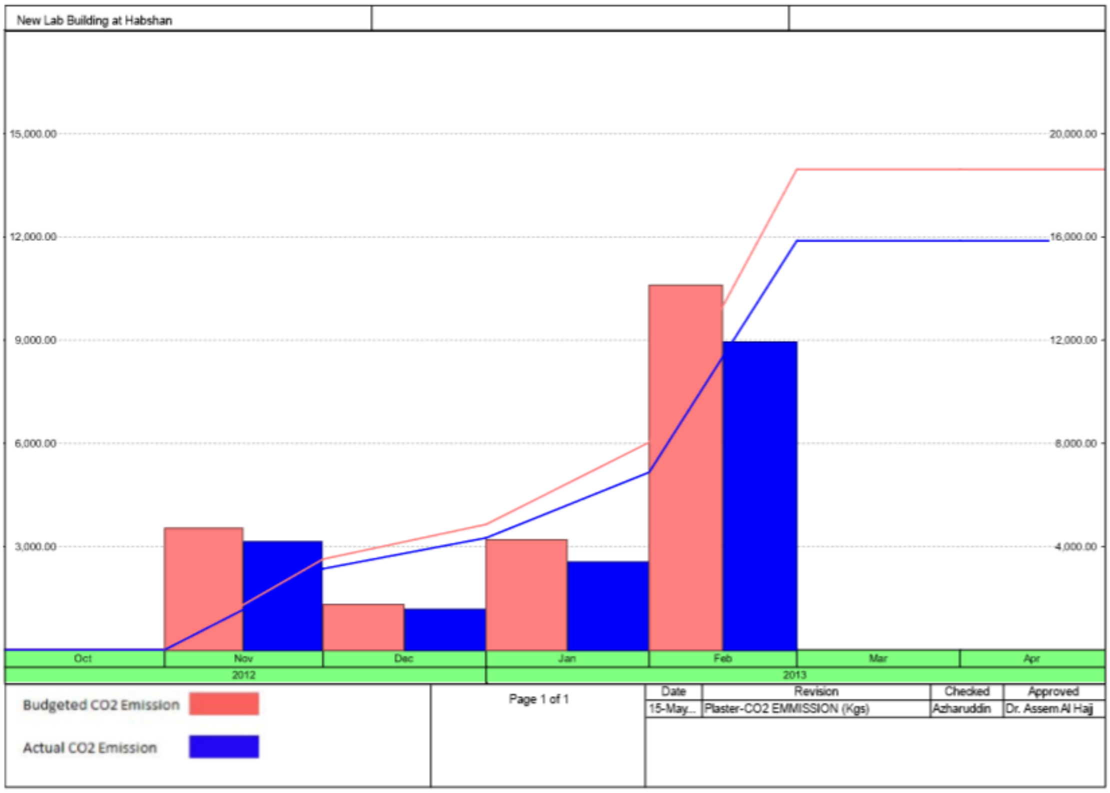
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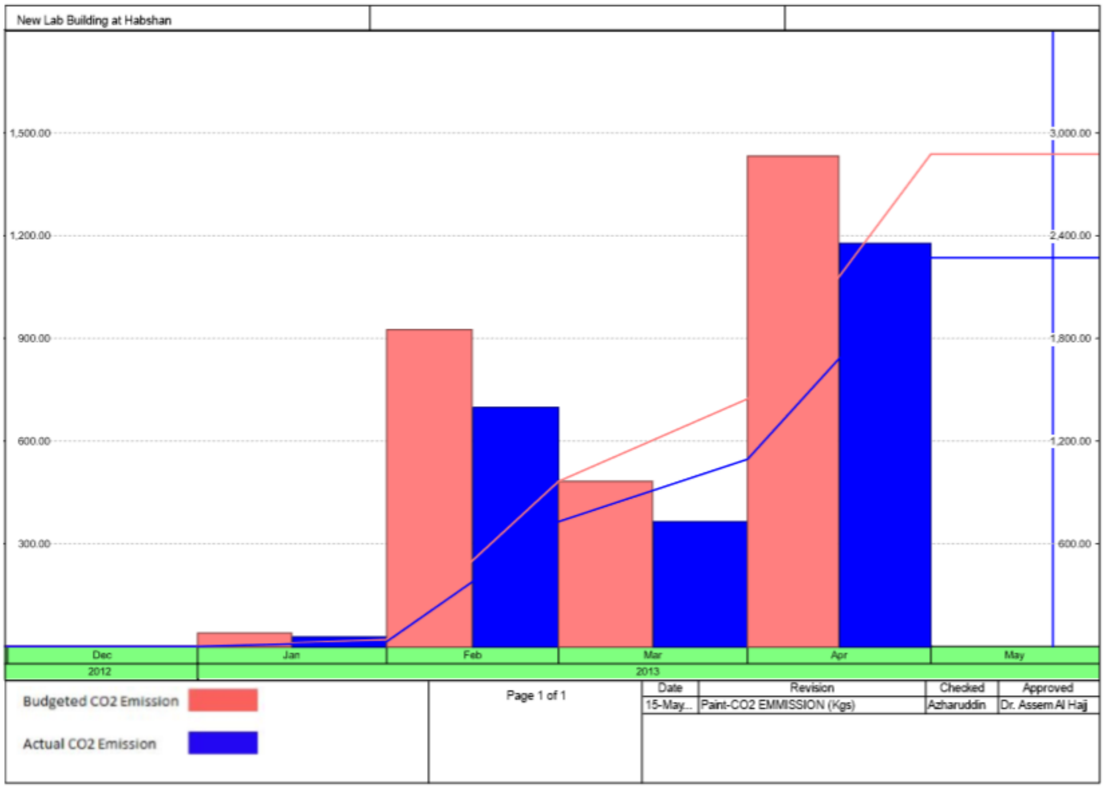
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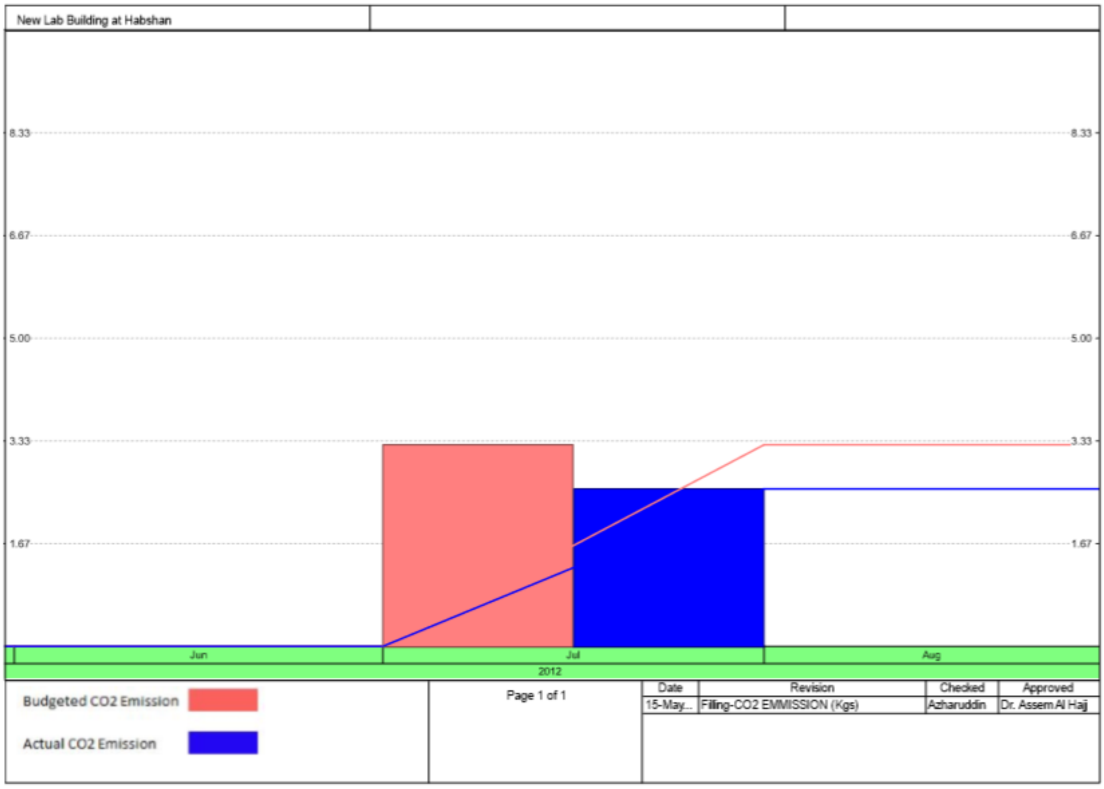
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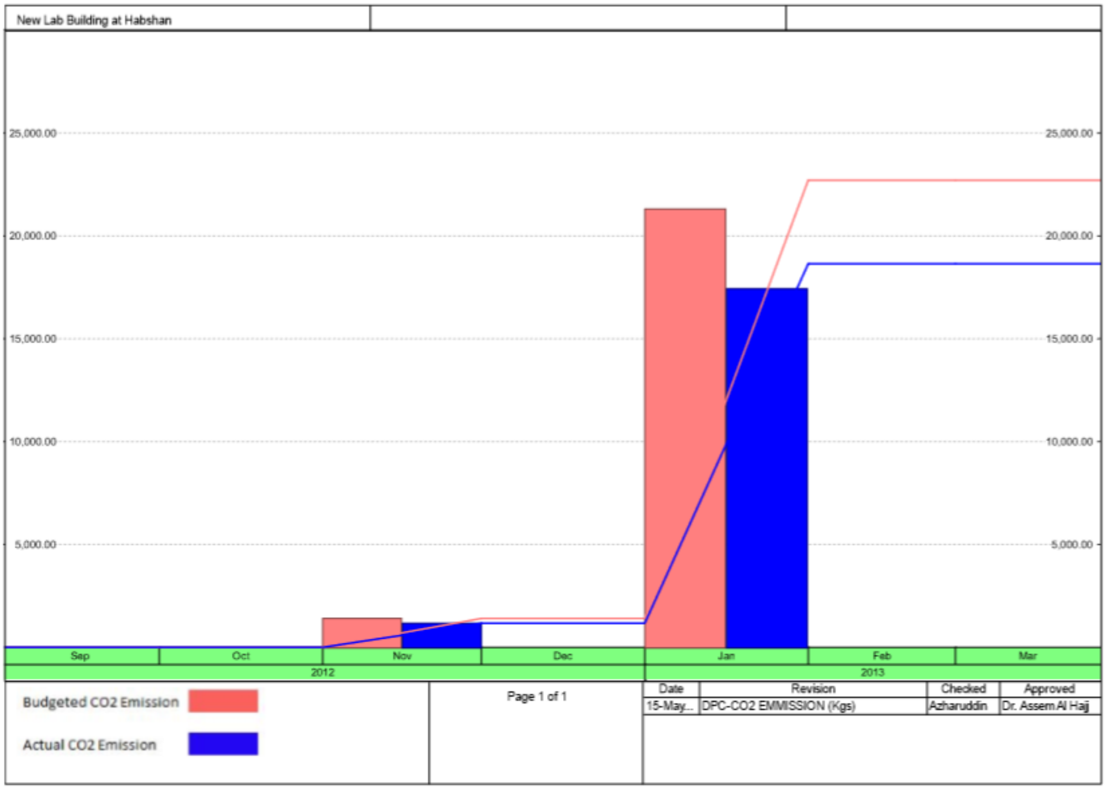
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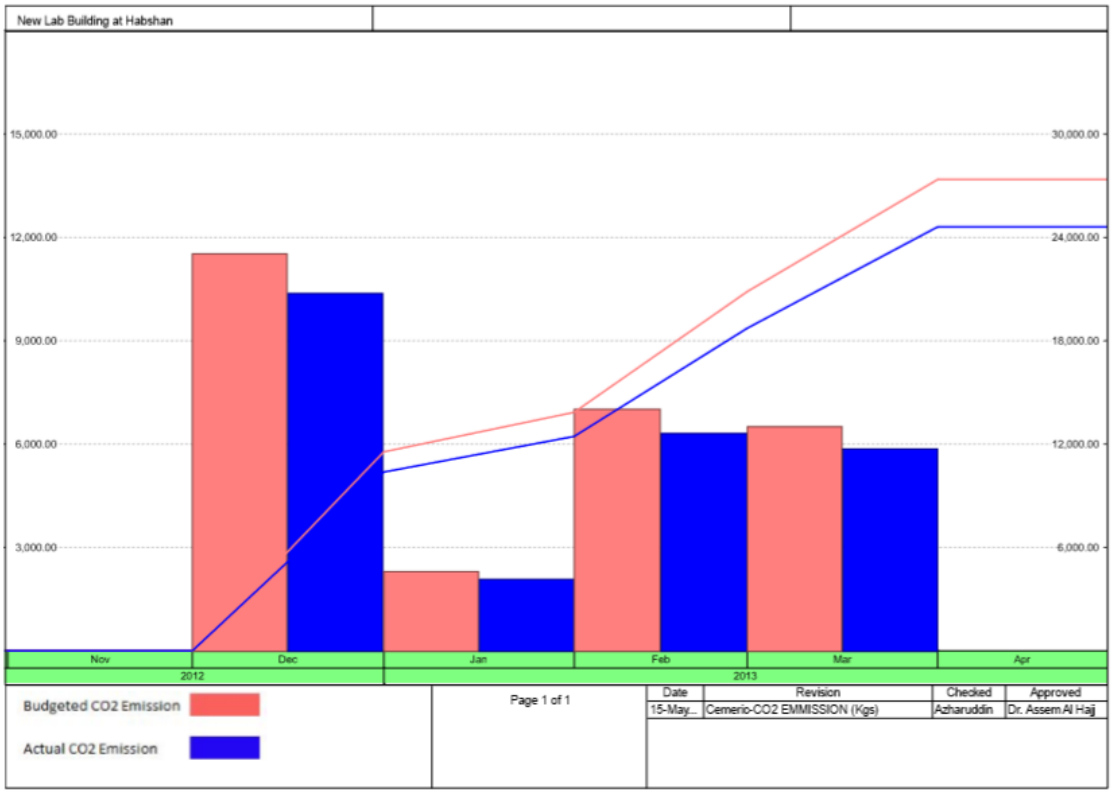
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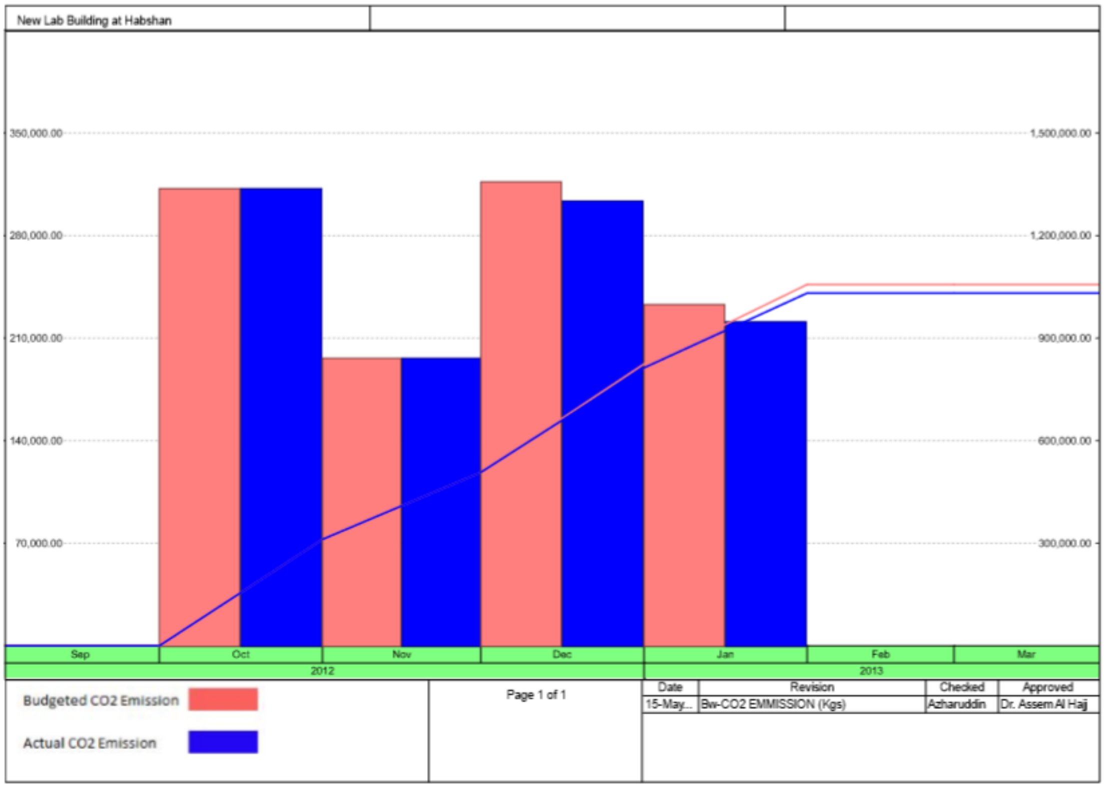
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Bw-CO2 EMMISSION (Kgs)
Azharuddin
Dr. Assem Al Hajj

Project: Construction of New Lab Building at Habshan
Sheet: Contractor Staff - travel emissions - Toyota cars

S.No	Manpower	Month	Product manufacturer Name	No of Cars	No of trips required	Is EPD available?	Location of Accomodation	Avg Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumption (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Manpower	Jan-12	Toyota 1.8 L	2	25	Yes	Buhasa Road	80	Road	Petrol	0.125	2.3307	1,165.35
2	Manpower	Feb-12	Toyota 1.8 L	2	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	1,165.35
3	Manpower	Mar-12	Toyota 1.8 L	2	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	1,165.35
4	Manpower	Apr-12	Toyota 1.8 L	4	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	2,330.70
5	Manpower	May-12	Toyota 1.8 L	4	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	2,330.70
6	Manpower	Jun-12	Toyota 1.8 L	4	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	2,330.70
7	Manpower	Jul-12	Toyota 1.8 L	4	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	2,330.70
8	Manpower	Aug-12	Toyota 1.8 L	4	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	2,330.70
9	Manpower	Sep-12	Toyota 1.8 L	4	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	2,330.70
10	Manpower	Oct-12	Toyota 1.8 L	4	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	2,330.70
11	Manpower	Nov-12	Toyota 1.8 L	4	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	2,330.70
12	Manpower	Dec-12	Toyota 1.8 L	6	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	3,496.05
13	Manpower	Jan-13	Toyota 1.8 L	6	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	3,496.05
14	Manpower	Feb-13	Toyota 1.8 L	6	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	3,496.05
15	Manpower	Mar-13	Toyota 1.8 L	6	26		Buhasa Road	80	Road	Petrol	0.125	2.3307	3,635.89
16	Manpower	Apr-13	Toyota 1.8 L	6	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	3,496.05
17	Manpower	May-13	Toyota 1.8 L	8	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	4,661.40
18	Manpower	Jun-13	Toyota 1.8 L	8	29		Buhasa Road	80	Road	Petrol	0.125	2.3307	5,407.22
19	Manpower	Jul-13	Toyota 1.8 L	8	25		Buhasa Road	80	Road	Petrol	0.125	2.3307	4,661.40
20	Manpower	Aug-13	Toyota 1.8 L	6	30		Buhasa Road	80	Road	Petrol	0.125	2.3307	4,195.26
21	Manpower	Sep-13	Toyota 1.8 L	2	30		Buhasa Road	80	Road	Petrol	0.125	2.3307	1,398.42
22	Manpower	Oct-13	Toyota 1.8 L	2	30		Buhasa Road	80	Road	Petrol	0.125	2.3307	1,398.42
												Total	61,483.87

Note: Car Trip from Accomodation
DEFRA GHG conversion factors - http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

Private T	Petrol		Assumption
Fuel Effic	8.9800	l/100km	Car Magazine - Toyota Corolla 1.8l
	0.111358575	l/km	say 0.125

Project: Construction of New Lab Building at Habshan
Sheet: Contractor labour - travel emissions - bus

S.No	Manpower Quantity	Month	Product manufacturer Name	Avg Number of labours per month	No of Buses/ day	No of Days	Is EPD available?	Location of Plant/wareh ouse	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumpt ion (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Manpower 9	Jan-12	Ashok Leyland	9	1	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	1,065.60
2	Manpower 29	Feb-12	Ashok Leyland	29	1	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	1,065.60
3	Manpower 34	Mar-12	Ashok Leyland	34	1	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	1,065.60
4	Manpower 35	Apr-12	Ashok Leyland	35	1	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	1,065.60
5	Manpower 67	May-12	Ashok Leyland	67	2	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	2,131.20
6	Manpower 84	Jun-12	Ashok Leyland	84	3	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	3,196.80
7	Manpower 89	Jul-12	Ashok Leyland	89	3	27	yes	Buhasa Road	80	Road	diesel	0.2	2.664	3,452.54
8	Manpower 89	Aug-12	Ashok Leyland	89	3	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	3,196.80
9	Manpower 134	Sep-12	Ashok Leyland	134	4	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	4,262.40
10	Manpower 134	Oct-12	Ashok Leyland	134	4	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	4,262.40
11	Manpower 156	Nov-12	Ashok Leyland	156	5	24	yes	Buhasa Road	80	Road	diesel	0.2	2.664	5,114.88
12	Manpower 156	Dec-12	Ashok Leyland	156	5	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	5,328.00
13	Manpower 156	Jan-13	Ashok Leyland	156	5	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	5,328.00
14	Manpower 203	Feb-13	Ashok Leyland	203	7	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	7,459.20
15	Manpower 203	Mar-13	Ashok Leyland	203	7	26	yes	Buhasa Road	80	Road	diesel	0.2	2.664	7,757.57
16	Manpower 234	Apr-13	Ashok Leyland	234	8	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	8,524.80
17	Manpower 284	May-13	Ashok Leyland	284	9	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	9,590.40
18	Manpower 291	Jun-13	Ashok Leyland	291	9	29	yes	Buhasa Road	80	Road	diesel	0.2	2.664	11,124.86
19	Manpower 299	Jul-13	Ashok Leyland	299	10	25	yes	Buhasa Road	80	Road	diesel	0.2	2.664	10,656.00
20	Manpower 281	Aug-13	Ashok Leyland	281	9	30	yes	Buhasa Road	80	Road	diesel	0.2	2.664	11,508.48
21	Manpower 281	Sep-13	Ashok Leyland	281	9	30	yes	Buhasa Road	80	Road	diesel	0.2	2.664	11,508.48
22	Manpower 281	Oct-13	Ashok Leyland	281	9	30	yes	Buhasa Road	80	Road	diesel	0.2	2.664	11,508.48
													Total	**130,173.70**

Note: Each day 2 trips by 40 Seater Bus
DEFRA GHG conversion factors - http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

fuel	Diesel		Assumption
Fuel Efficiency - bus		l/100km	
	0.2	l/km	

Project: Construction of New Lab Building at Habshan
Sheet: Client Staff - travel emissions - Toyota cars

S.No	Manpower	Month	Product manufacturer Name	No of Cars	No of trips required	Is EPD available?	Location of Plant/warehouse	Avg Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumption (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Manpower	Jan-12	Toyota	1	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	2,185.03
2	Manpower	Feb-12	Toyota	1	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	2,185.03
3	Manpower	Mar-12	Toyota	1	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	2,185.03
4	Manpower	Apr-12	Toyota	1	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	2,185.03
5	Manpower	May-12	Toyota	1	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	2,185.03
6	Manpower	Jun-12	Toyota	1	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	2,185.03
7	Manpower	Jul-12	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
8	Manpower	Aug-12	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
9	Manpower	Sep-12	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
10	Manpower	Oct-12	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
11	Manpower	Nov-12	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
12	Manpower	Dec-12	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
13	Manpower	Jan-13	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
14	Manpower	Feb-13	Toyota	3	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	6,555.09
15	Manpower	Mar-13	Toyota	3	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	6,555.09
16	Manpower	Apr-13	Toyota	3	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	6,555.09
17	Manpower	May-13	Toyota	3	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	6,555.09
18	Manpower	Jun-13	Toyota	3	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	6,555.09
19	Manpower	Jul-13	Toyota	3	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	6,555.09
20	Manpower	Aug-13	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
21	Manpower	Sep-13	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
22	Manpower	Oct-13	Toyota	2	25	Yes	Buhasa Road	300	Road	Petrol	0.125	2.3307	4,370.06
												Total	**96,141.38**

Note: Car Trip from HQ in Saloon Car
DEFRA GHG conversion factors - http://www.defra.gov.uk/environment/business/reporting/conversion-factors.htm

Private Ta	Petrol		Assumption
Fuel Effici	8.9800	l/100km	Car Magazine - Toyota Corolla 1.8l
	0.111358575	l/km	say 0.125

Project: **Construction of New Lab Building at Habshan**
Material Sheet: Transportation for Waterproofing material

S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD available?	Location of Plant/ware house	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumption (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Wet Areas	Nov-12	Polybit	Sqm	2150	1	No	Abu Dhabi	160	Road	diesel	0.2	2.664	85.248
2	Wet Areas+Roof	Jan-13	Polybit	Sqm	3500	1	No	Abu Dhabi	160	Road	diesel	0.2	2.664	85.248
													Total	**170.50**

Project: **Construction of New Lab Building at Habshan**
Material Sheet: Transportation for Rebar material

S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD availabl e?	Location of Plant/ware house	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumptio n (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Foundations	May-12	Emirates steel	Ton	55	2	Yes	Dubai	240	Road	diesel	0.2	2.664	255.74
2	Footings	Jun-12	Emirates steel	Ton	70	3	Yes	Dubai	240	Road	diesel	0.2	2.664	383.62
3	Footing	Jul-12	Emirates steel	Ton	75	3	Yes	Dubai	240	Road	diesel	0.2	2.664	383.62
4	Tiebeams	Aug-12	Emirates steel	Ton	20	1	Yes	Dubai	240	Road	diesel	0.2	2.664	127.87
5	Blinding for Grade Slab	Sep-12	Emirates steel	Ton	20	1	Yes	Dubai	240	Road	diesel	0.2	2.664	127.87
6	Staircase, Beam, Slab	Oct-12	Emirates steel	Ton	30	2	Yes	Dubai	240	Road	diesel	0.2	2.664	255.74
7	Column FF	Nov-12	Emirates steel	Ton	75	3	Yes	Dubai	240	Road	diesel	0.2	2.664	383.62
8	Beam, Roof Slab	Dec-12	Emirates steel	Ton	81	4	Yes	Dubai	240	Road	diesel	0.2	2.664	511.49
9	Column above Roof Slab, Head Roof Parapet	Jan-13	Emirates steel	Ton	3	1	Yes	Dubai	240	Road	diesel	0.2	2.664	127.87
10	Head Roof Parapet Wall	Feb-13	Emirates steel	Ton	8	1	Yes	Dubai	240	Road	diesel	0.2	2.664	127.87
11	Head Roof Parapet Wall	Mar-13	Emirates steel	Ton	9	1	Yes	Dubai	240	Road	diesel	0.2	2.664	127.87
													Total	**2,813.18**

Project: Construction of New Lab Building at Habshan
Material Sheet: Transportation for Concrete ready mix

S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD available?	Location of Plant/warehouse	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumption (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
2	Foundations	May-12	Ready Mix Beaton	M3	150	21		Madinat Zayed	55	Road	Diesel	0.2	2.664	627.94
3	Footings	Jun-12	Ready Mix Beaton	M3	50	7		Madinat Zayed	55	Road	Diesel	0.2	2.664	209.31
4	Footing&Neck Column	Jul-12	Ready Mix Beaton	M3	250	36		Madinat Zayed	55	Road	Diesel	0.2	2.664	1,046.57
5	Blinding Tie Beams & Tiebeams	Aug-12	Ready Mix Beaton	M3	370	53		Madinat Zayed	55	Road	Diesel	0.2	2.664	1,548.93
6	Blinding for Grade Slab	Sep-12	Ready Mix Beaton	M3	480	69		Madinat Zayed	55	Road	Diesel	0.2	2.664	2,009.42
7	Blinding for Grade Slab & Retaining Wall	Oct-12	Ready Mix Beaton	M3	230	33		Madinat Zayed	55	Road	Diesel	0.2	2.664	962.85
8	Grade Slab,First Floor Slab & Staircase	Nov-12	Ready Mix Beaton	M3	550	79		Madinat Zayed	55	Road	Diesel	0.2	2.664	2,302.46
9	Column upto Roof Slab	Dec-12	Ready Mix Beaton	M3	600	86		Madinat Zayed	55	Road	Diesel	0.2	2.664	2,511.77
10	Beam, Roof Slab & Parapet	Jan-13	Ready Mix Beaton	M3	210	30		Madinat Zayed	55	Road	Diesel	0.2	2.664	879.12
11	Head Roof Parapet Wall	Feb-13	Ready Mix Beaton	M3	70	10		Madinat Zayed	55	Road	Diesel	0.2	2.664	293.04
12	Head Roof Parapet Wall	Mar-13	Ready Mix Beaton	M3	20	3		Madinat Zayed	55	Road	Diesel	0.2	2.664	83.73
													Total	**12,475.13**

Project: Construction of New Lab Building at Habshan
Material Sheet: Transportation for plaster material

S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD available?	Location of Plant/warehouse	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumption (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Ground Floor Internal	Nov-12	AL AIN Cement & Sand from Quarry in Hatta	Sqm	700	2	Yes	Al Ain	180	Road	diesel	0.2	2.664	191.81
2	Ground Floor Internal	Dec-12	AL AIN Cement & Sand from Quarry in Ain	Sqm	600	2	Yes	Al Ain	180	Road	diesel	0.2	2.664	191.81
3	Gr. Floor External+Fist Floor Internal	Jan-13	AL AIN Cement & Sand from Quarry in Ain	Sqm	750	2	Yes	Al Ain	180	Road	diesel	0.2	2.664	191.81
4	Gr. Floor External+Fist Floor Internal	Feb-13	AL AIN Cement & Sand from Quarry in Ain	Sqm	550	2	Yes	Al Ain	180	Road	diesel	0.2	2.664	191.81
													Total	**767.23**

Project: Construction of New Lab Building at Habshan
Material Sheet: Transportation for Concrete ready mix for PCC

S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD availabl e?	Location of Plant/warehou se	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumpti on	Emission factor (kg CO2 eg/	Total CO2 emissions (kg CO2 eq)
1	Blinding for Foundations	Jun-12	Ready Mix Beaton	M3	10	2	No	Madinat Zayed	55	Road	diesel	0.2	2.664	58.61
2	Foundations	Jul-12	Ready Mix Beaton	M3	50	7	No	Madinat Zayed	55	Road	diesel	0.2	2.664	205.13
3	Blinding Tie Beams & Tiebeams	Aug-12	Ready Mix Beaton	M3	40	6		Madinat Zayed	55	Road	diesel	0.2	2.664	175.82
4	Blinding for Grade Slab	Oct-12	Ready Mix Beaton	M3	10	2		Madinat Zayed	55	Road	diesel	0.2	2.664	58.61
5	Retaining Wall	Jan-13	Ready Mix Beaton	M3	30	4		Madinat Zayed	55	Road	diesel	0.2	2.664	117.22
													Total	**615.384**

To and fro distances considered eq 55 km

Project: **Construction of New Lab Building at Habshan**
Material Sheet: Transportation for painting material

S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD available?	Location of Plant/warehouse	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumption (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Ground Floor	Jan-13	JOTUN	Sqm	400	1	Yes	Dubai	300	Road	diesel	0.2	2.664	159.84
2	Ground & First Floor	Feb-13	JOTUN	Sqm	700	1	Yes	Dubai	300	Road	diesel	0.2	2.664	159.84
3	Gr. Floor+Fist Floor	Mar-13	JOTUN	Sqm	600	1	Yes	Dubai	300	Road	diesel	0.2	2.664	159.84
4	Gr. Floor+Fist Floor	Apr-13	JOTUN	Sqm	900	1	Yes	Dubai	300	Road	diesel	0.2	2.664	159.84
													Total	639.36

Project: **Construction of New Lab Building at Habshan**
Material Sheet: Transportation for Ceramic material

S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD available?	Location of Plant/ware house	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumption (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Floor and Wall	Dec'12	RAK Cemaric	Sqm	3,400.00	2	No	Ras Al Khaimah	350	Road	diesel	0.2	2.664	372.96
													Total	**372.96**

Project: Construction of New Lab Building at Habshan
Material Sheet: Transportation for Block work material

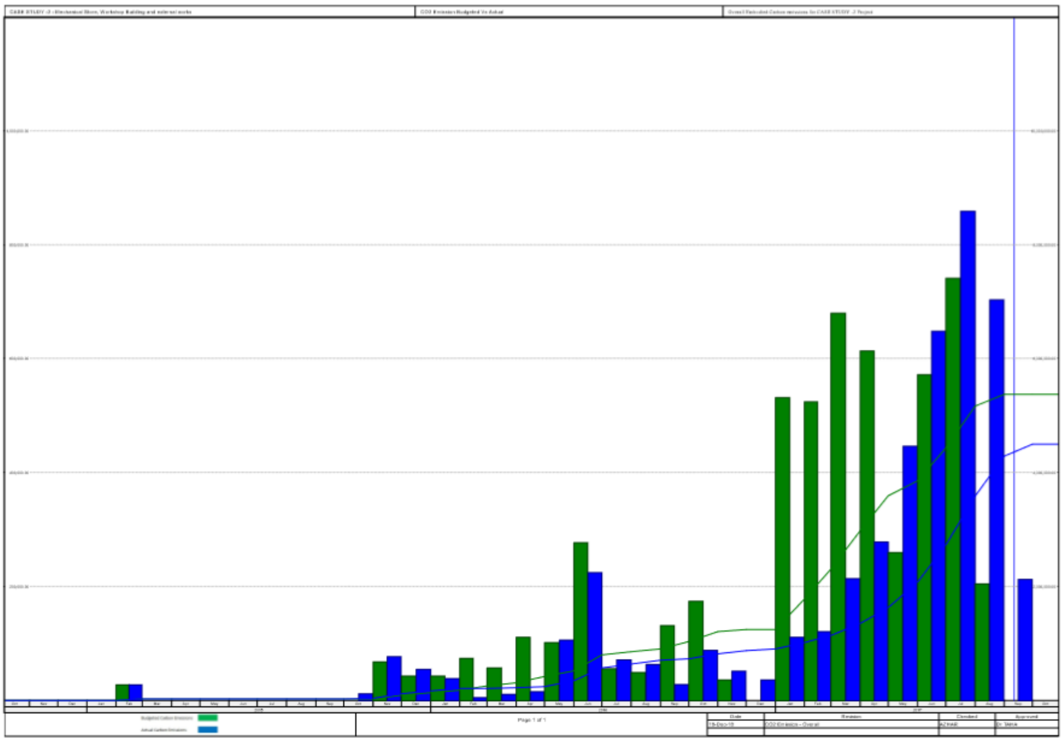
S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD availabl e?	Location of Plant/warehou se	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumptio n (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Ground Floor Internal	Oct-12	Emirates Block	Sqm	800	10	No	Abudhabi	140	Road	diesel	0.2	2.664	745.92
2	Ground Floor Internal	Nov-12	Emirates Block	Sqm	300	4	No	Abudhabi	140	Road	diesel	0.2	2.664	298.37
3	Gr. Floor External+Fist Floor Internal	Dec-12	Emirates Block	Sqm	800	10	No	Abudhabi	140	Road	diesel	0.2	2.664	745.92
4	Gr. Floor External+Fist Floor Internal	Jan-13	Emirates Block	Sqm	350	5	No	Abudhabi	140	Road	diesel	0.2	2.664	372.96
													Total	**2163.168**

Project: **Construction of New Lab Building at Habshan**
Material Sheet: transportation for Backfill material

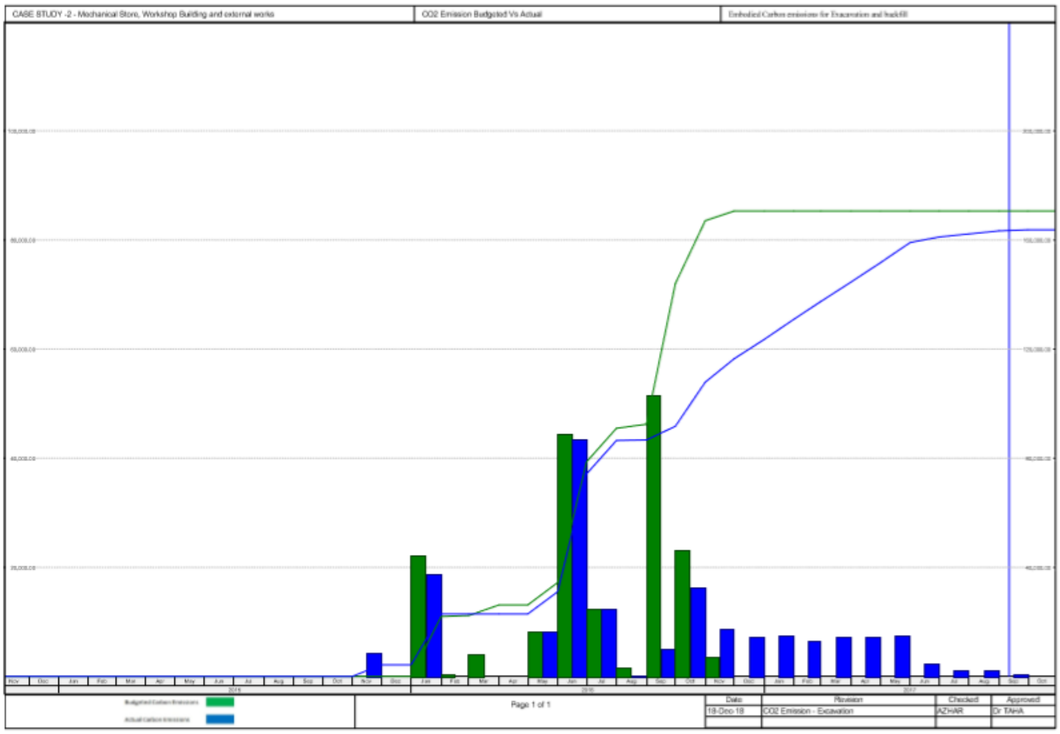
S.No	Description of Material	Month	Product manufacturer Name	Unit	Quantity	No of trips required	Is EPD available?	Location of quarry	Distance from site (Km)	Mode of transport	fuel type	Avg fuel consumption (Lts)/km	Emission factor (kg CO2 eg/ litre)	Total CO2 emissions (kg CO2 eq)
1	Filling	July'12	Raw Material fro	CUM	4,520.00	234	No	Quarry Madinat	70	Road	diesel	0.2	2.664	8,727.26
													Total	**8,727.26**

Note:
Distance from site to quarry was 35 km. to & fro distances taken as 70 km

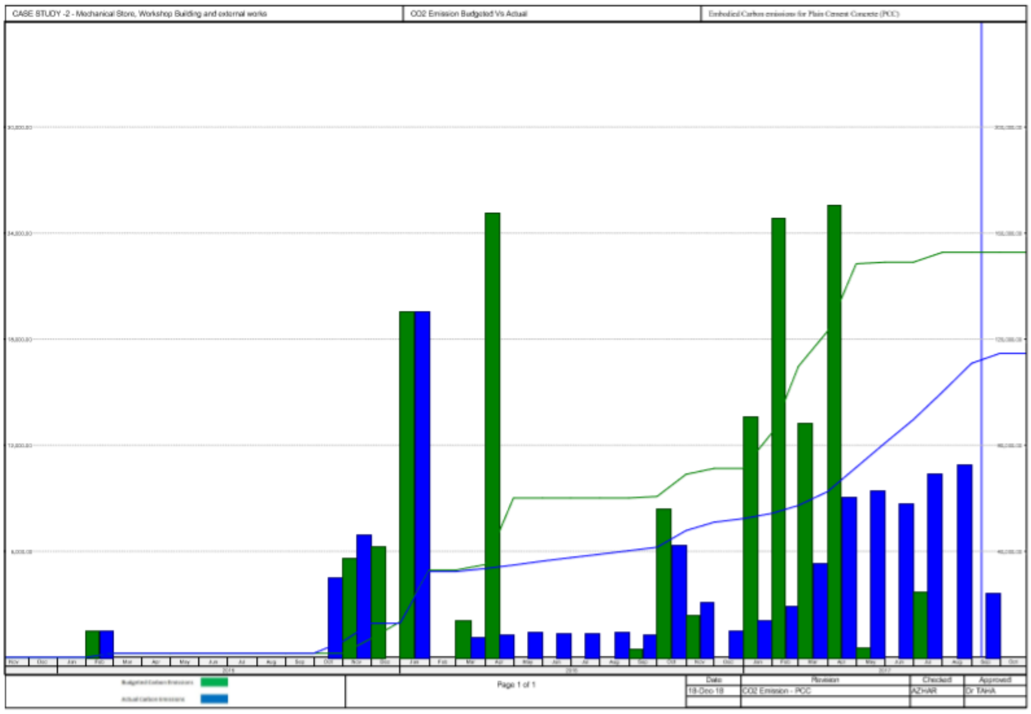
Appendix D – Case study 2 data



CASE STUDY -2 - Mechanical Store, Workshop Building and external works
CO2 Emission Budgeted Vs Actual



CASE STUDY -2 - Mechanical Store, Workshop Building and external works
CO2 Emission Budgeted Vs Actual
Embodied Carbon emissions for Excavation and backfill
Page 1 of 1
Date
Revision
Checked
Approved
18-Dec-18
CO2 Emission - Excavation
AZHAR
Dr TAHA


CASE STUDY -2 - Mechanical Store, Workshop Building and external works
CO2 Emission Budgeted Vs Actual
Embodied Carbon emissions for Plain Cement Concrete (PCC)
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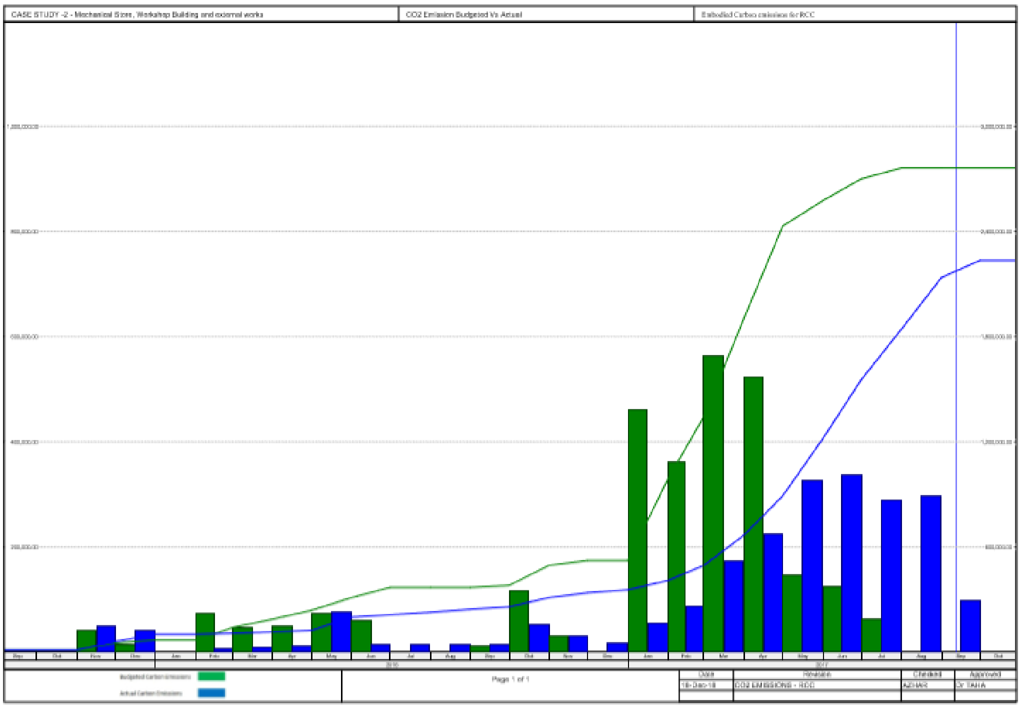
Approved
18-Dec-18
CO2 Emission - PCC
AZHAR
Dr TAHA


CASE STUDY -2 - Mechanical Store, Workshop Building and external works
CO2 Emission Budgeted Vs Actual
Embodied Carbon emissions for RCC
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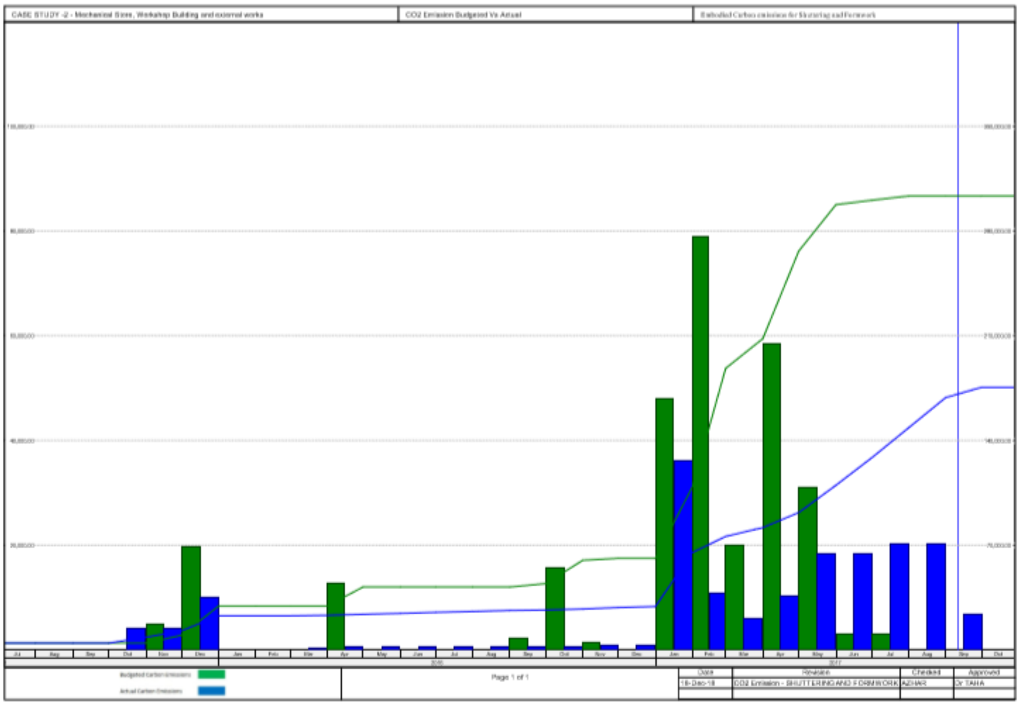
Approved
18-Dec-18
CO2 EMISSIONS - RCC
AZHAR
Dr TAHA


CASE STUDY -2 - Mechanical Store, Workshop Building and external works
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CO2 Emission - SHUTTERING AND FORMWORK
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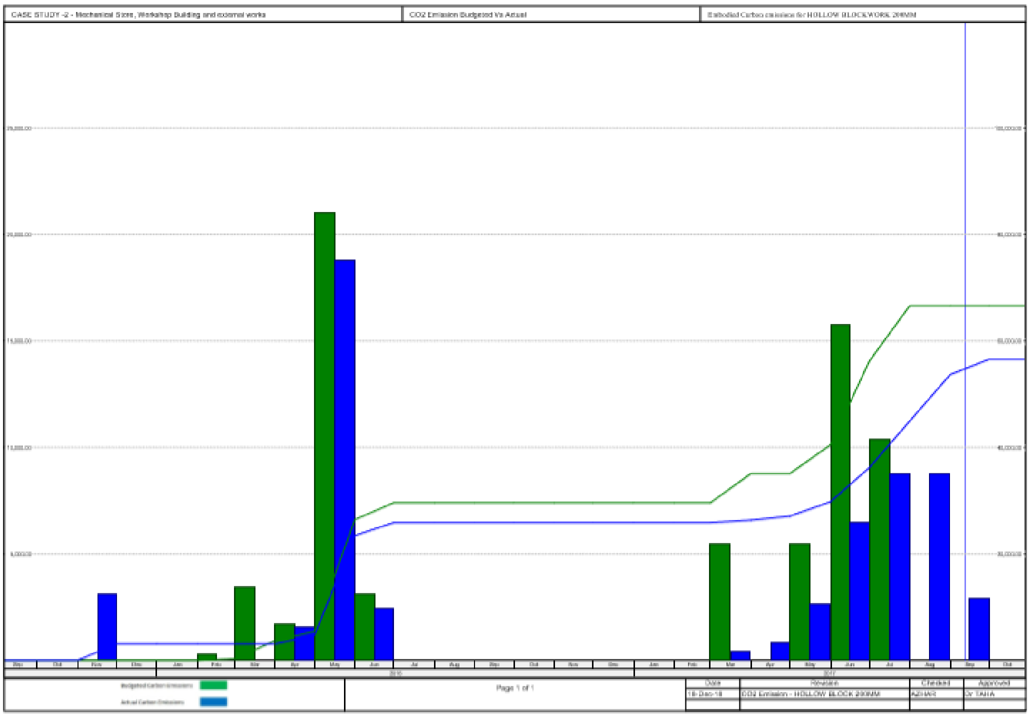
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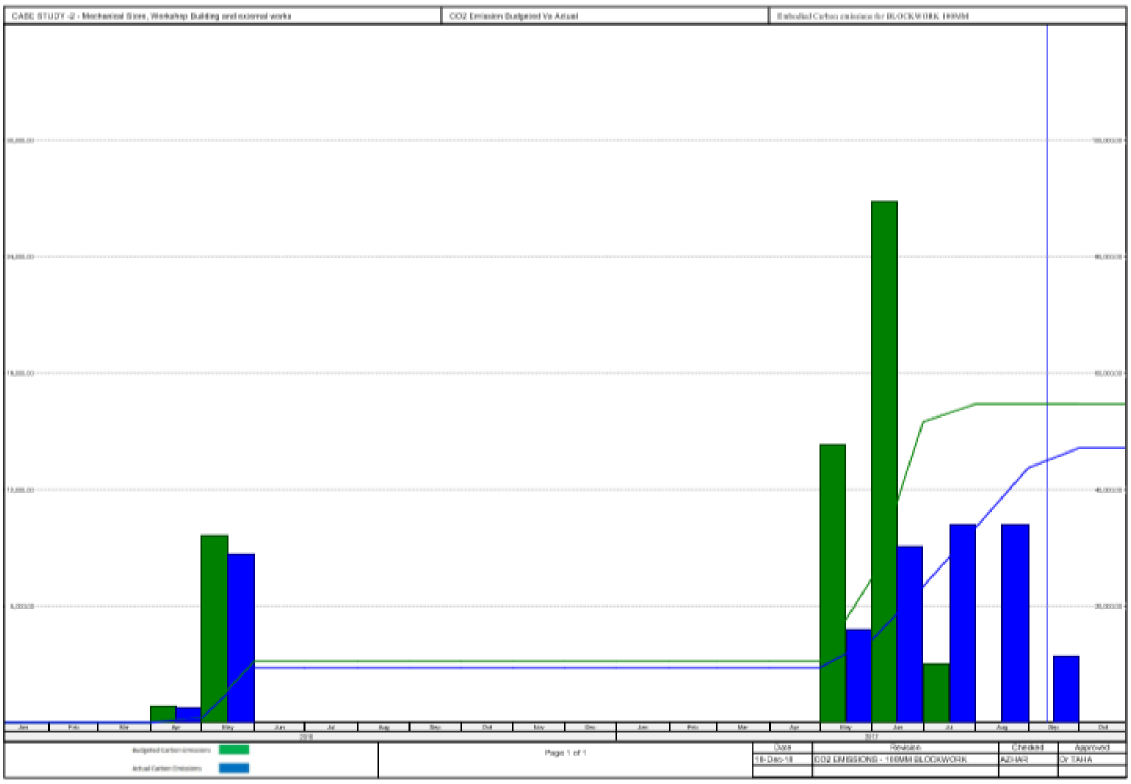
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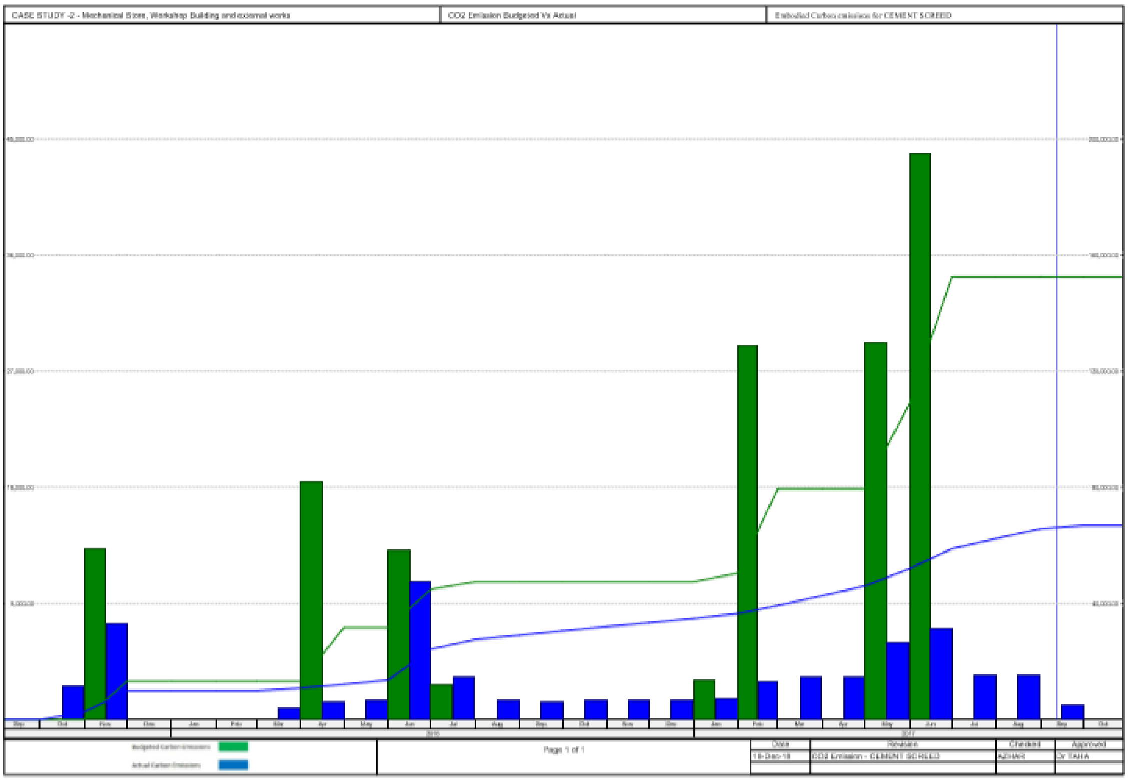
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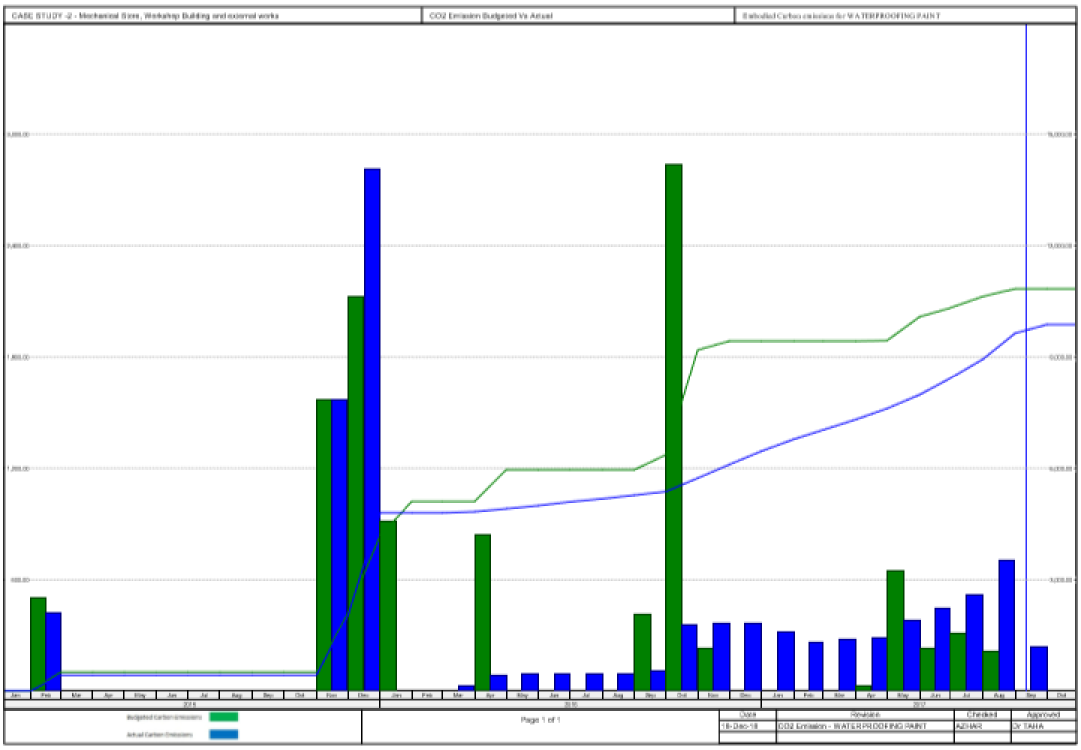
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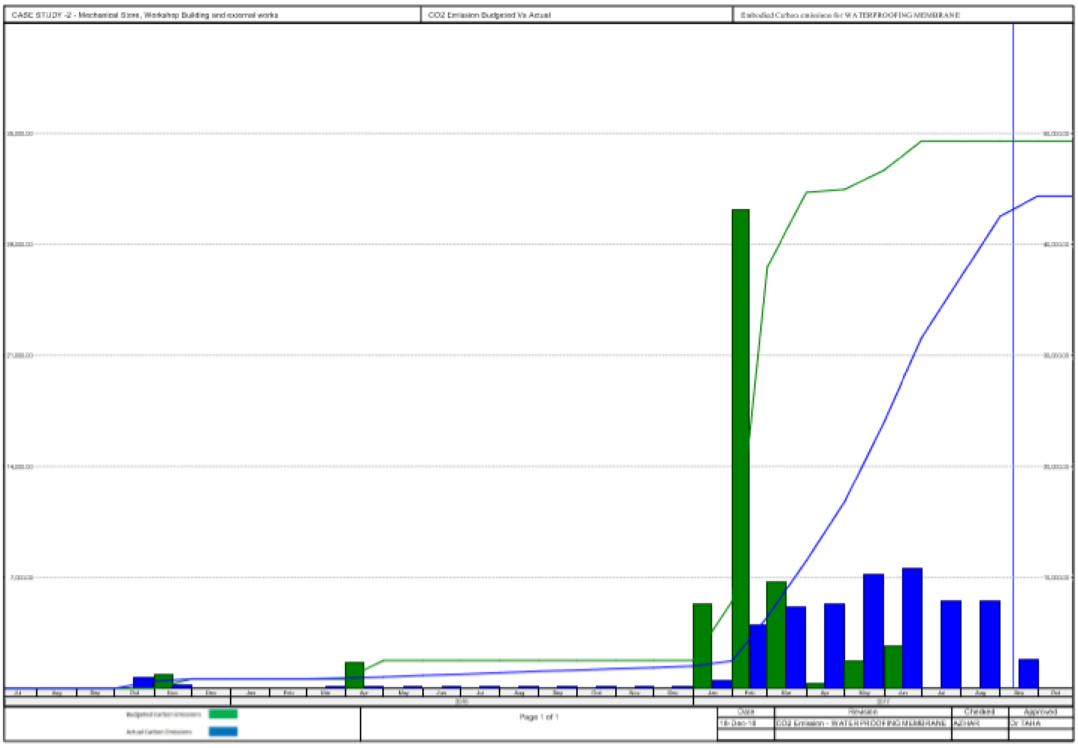
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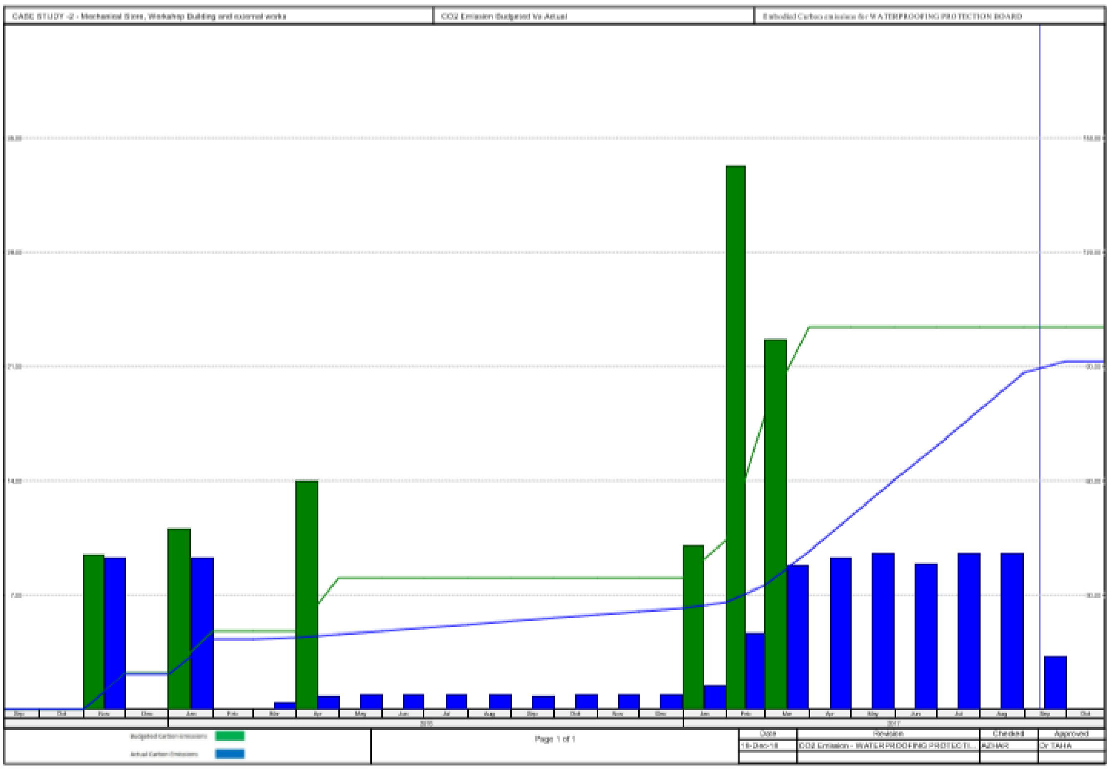
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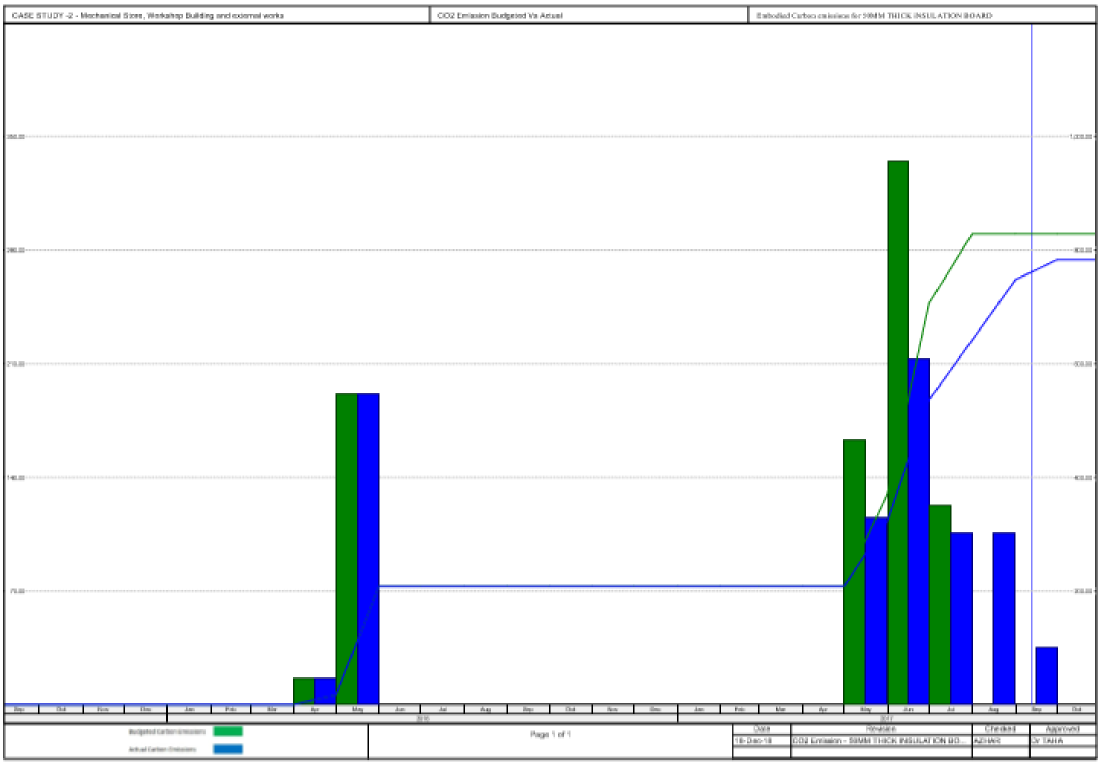
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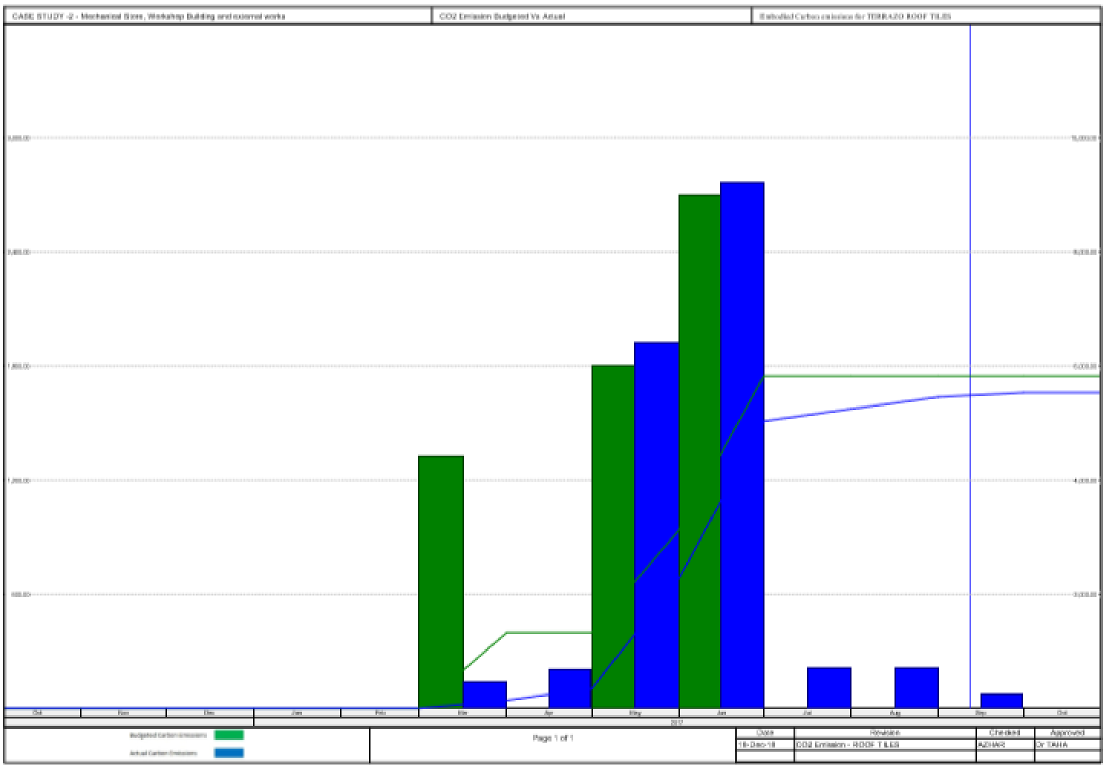
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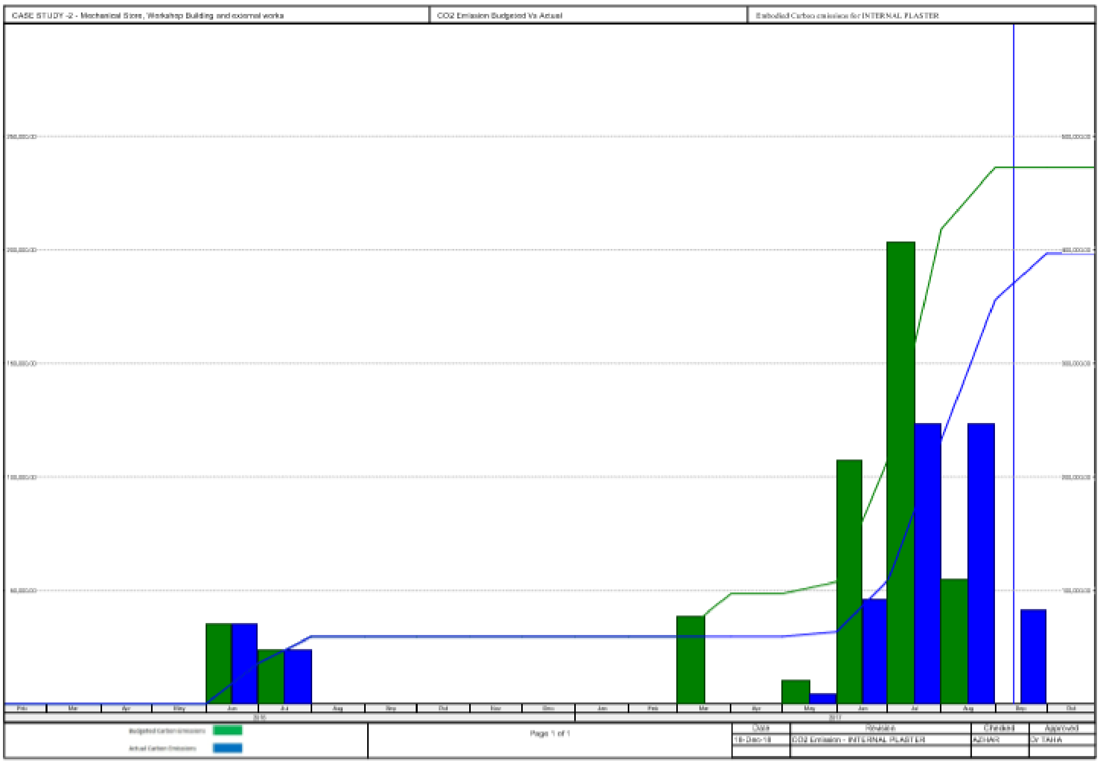
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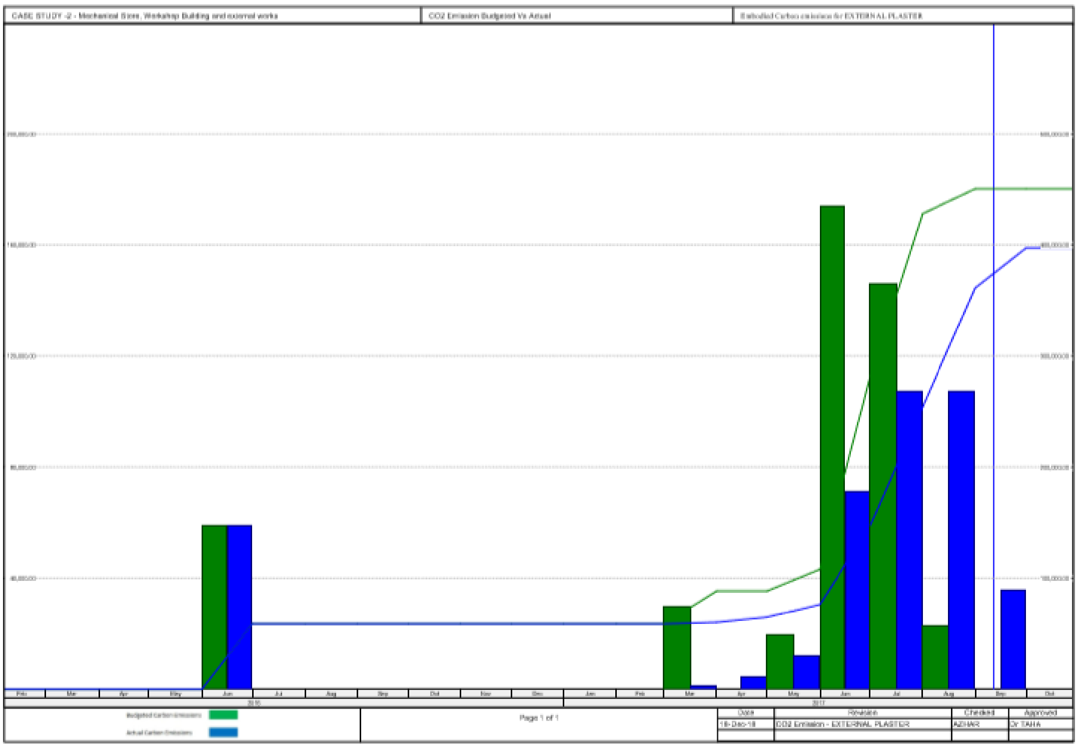
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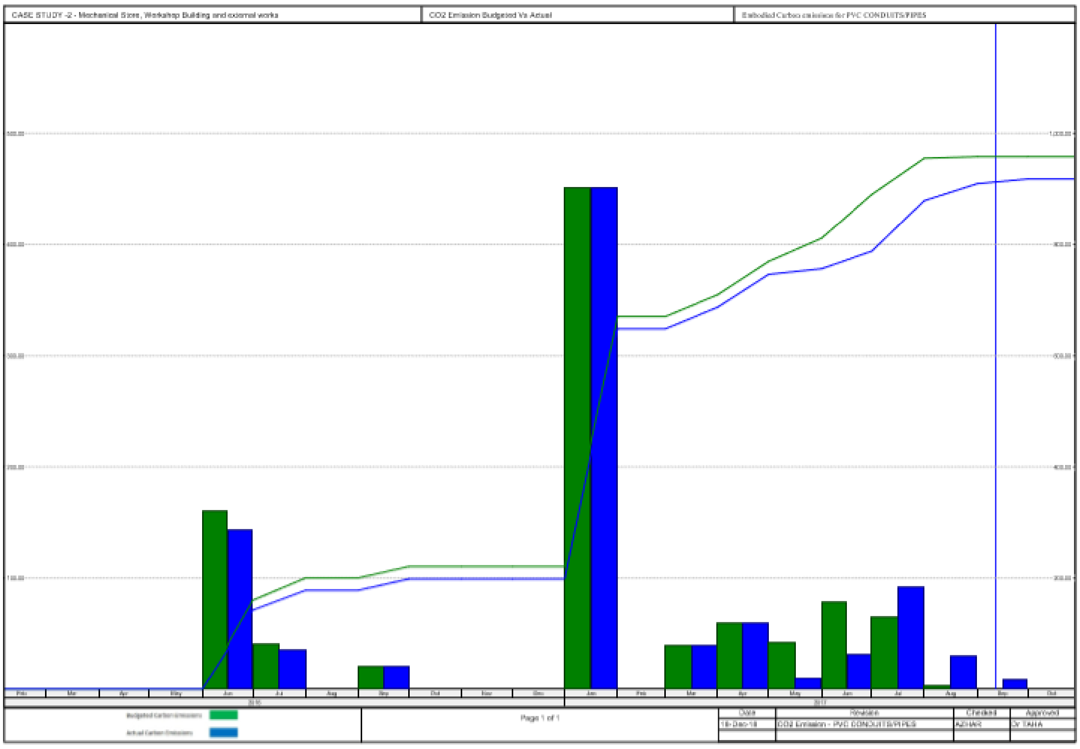
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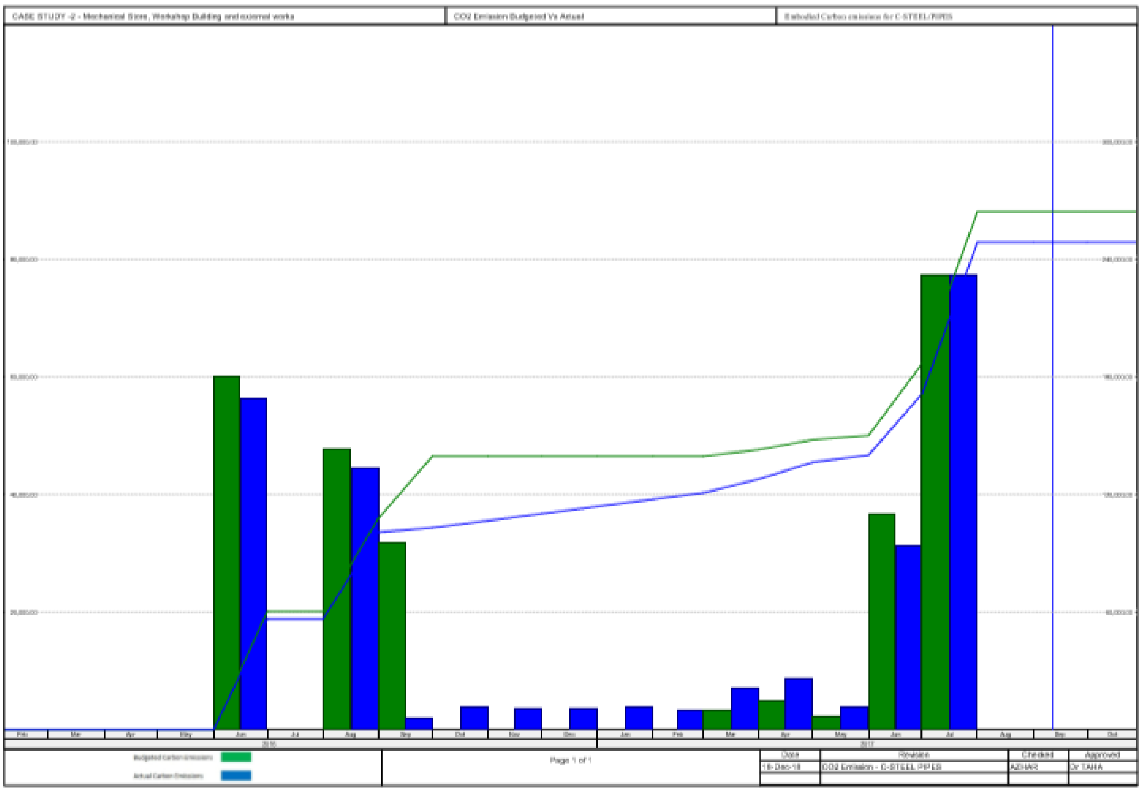
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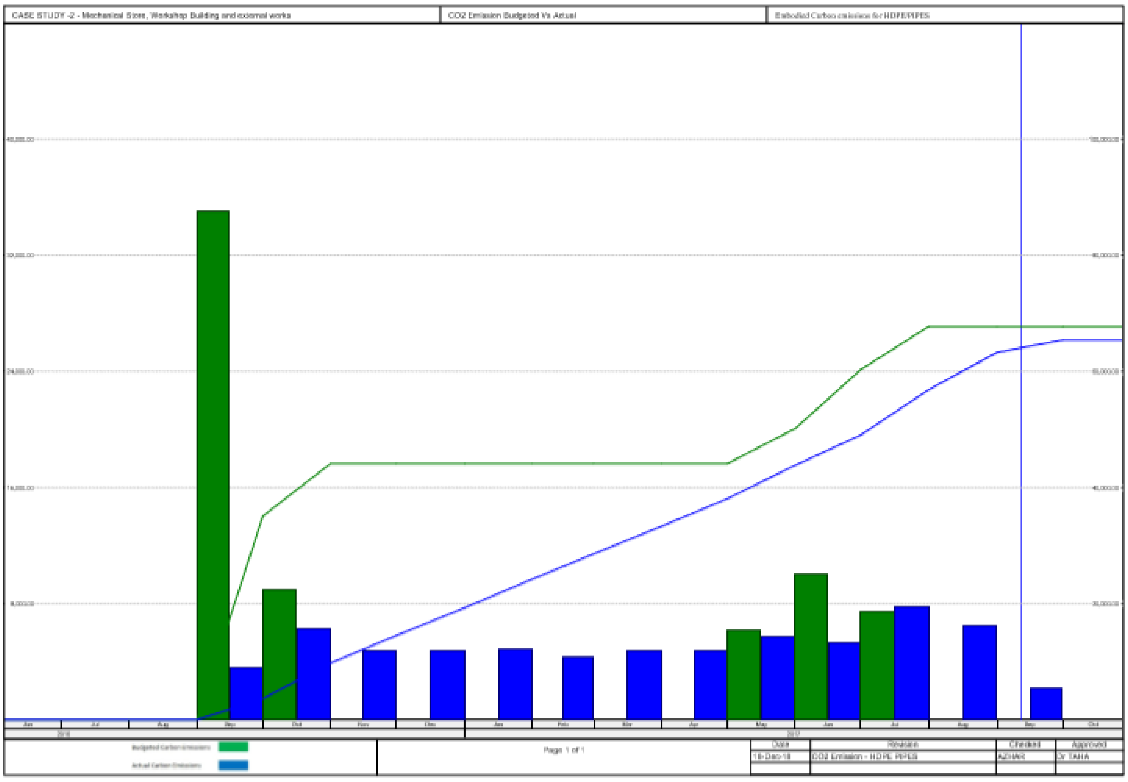
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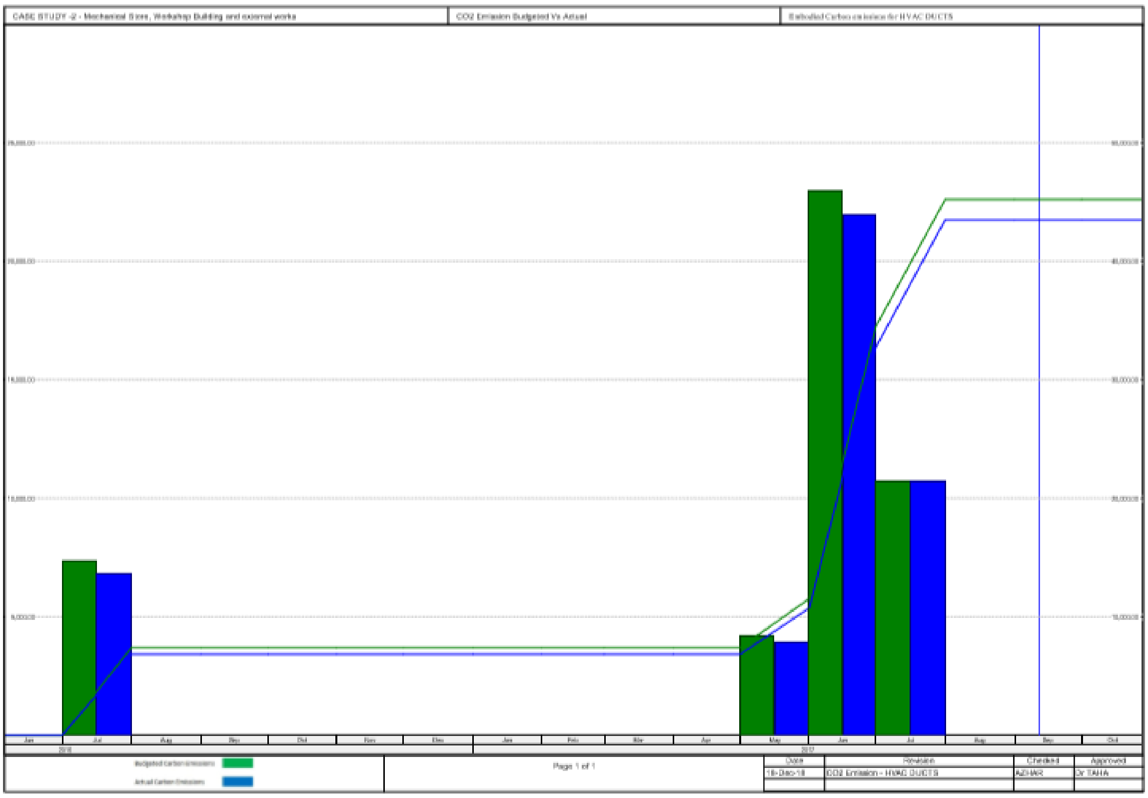
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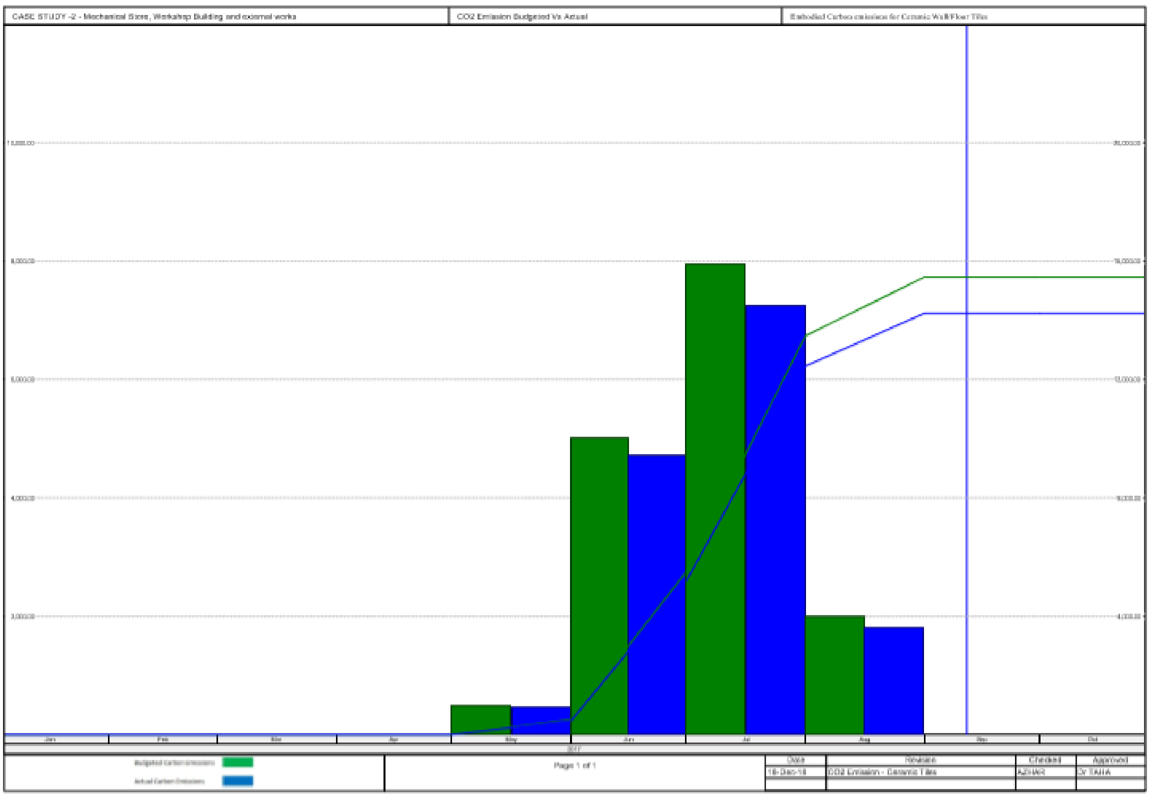
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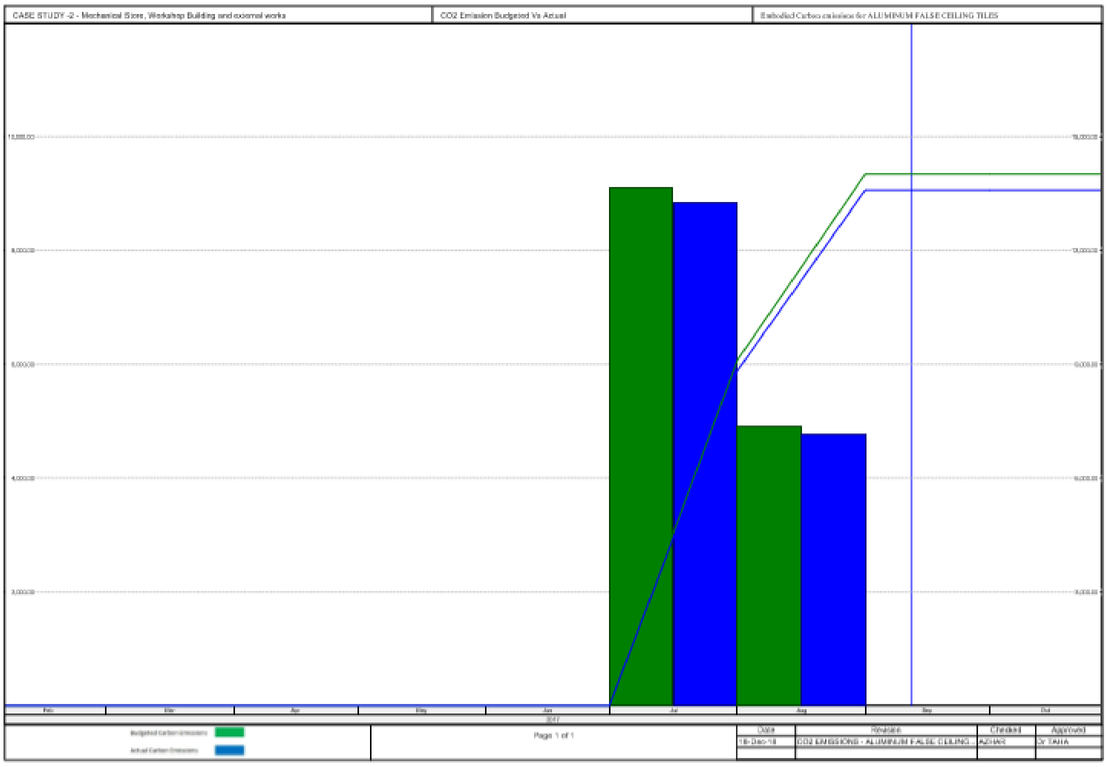

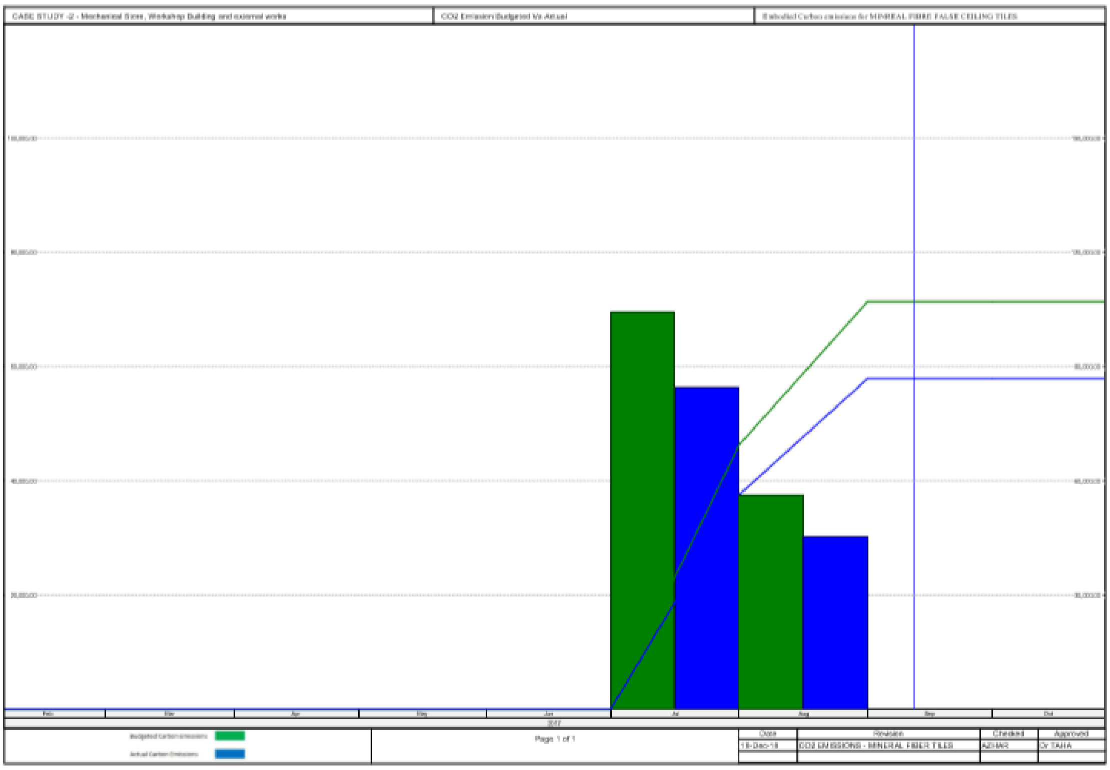

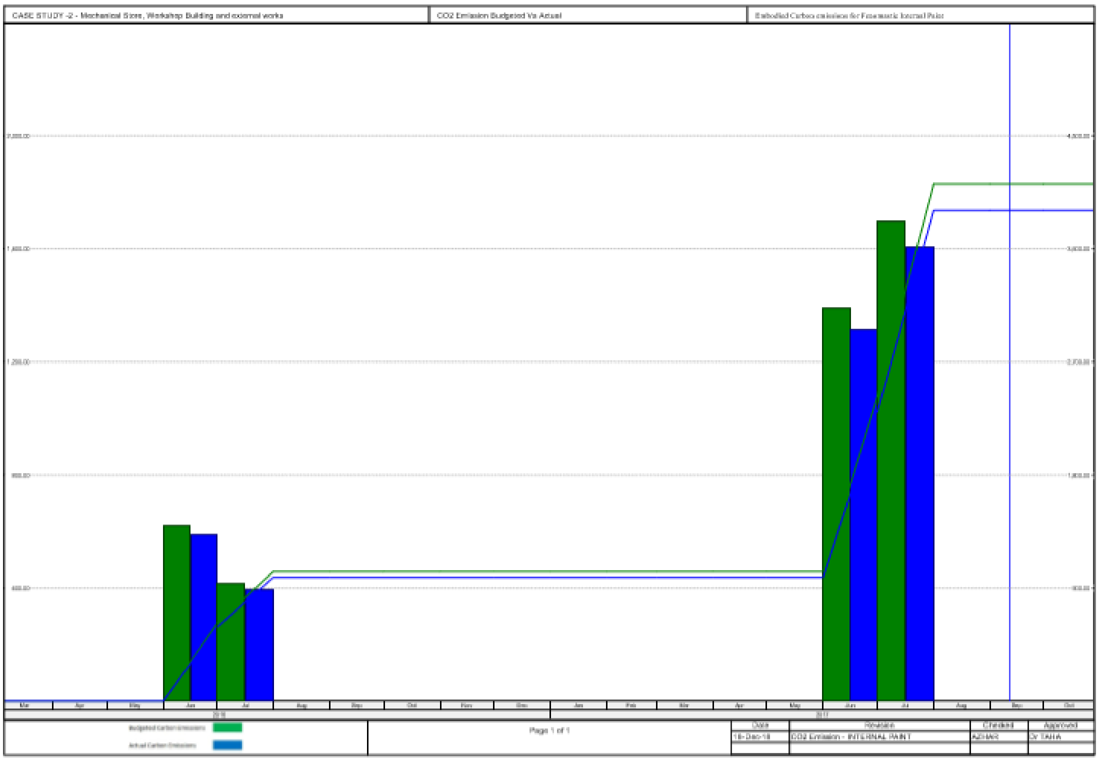
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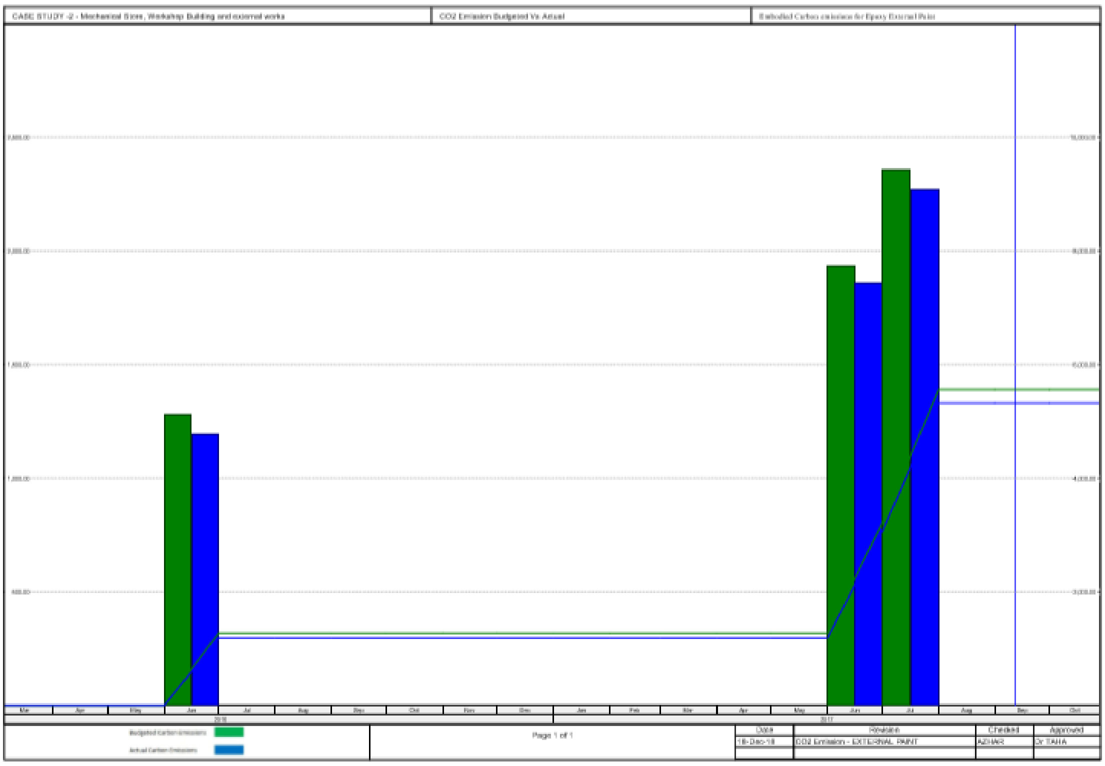
CO2 Emission - INTERNAL PAINT
AZHAR
Dr TAHA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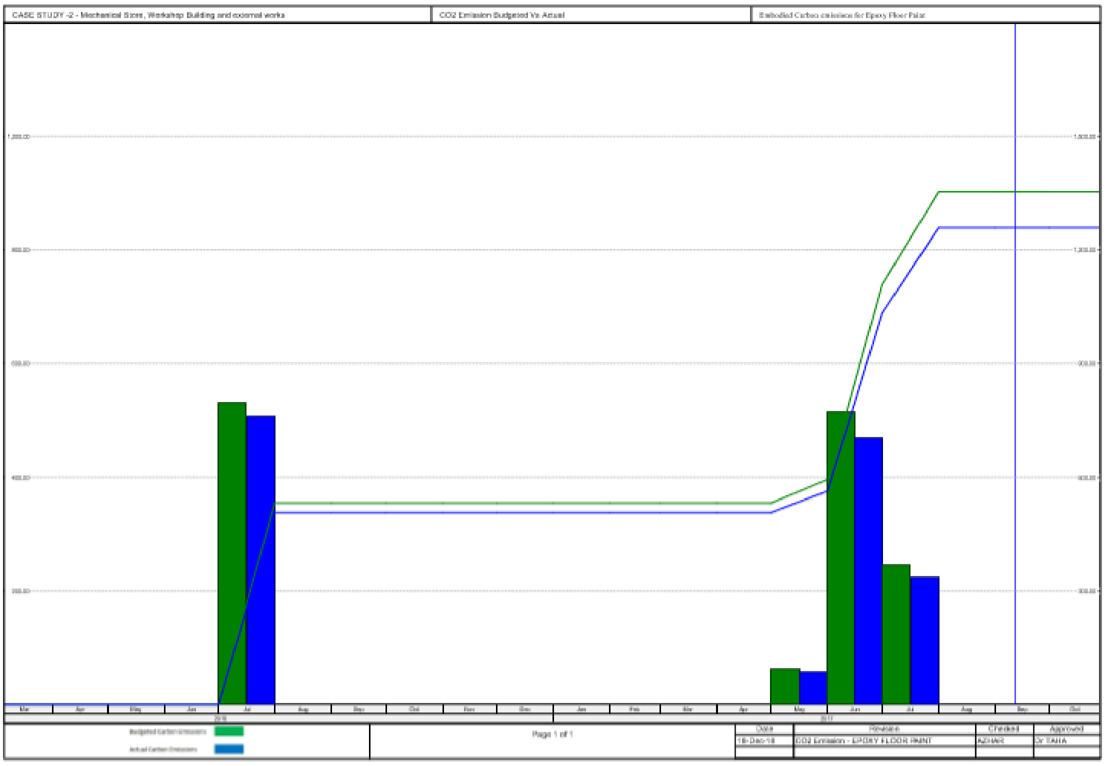
AZHAR
Dr TAHA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CO2 Emission - EPOXY FLOOR PAINT
AZHAR
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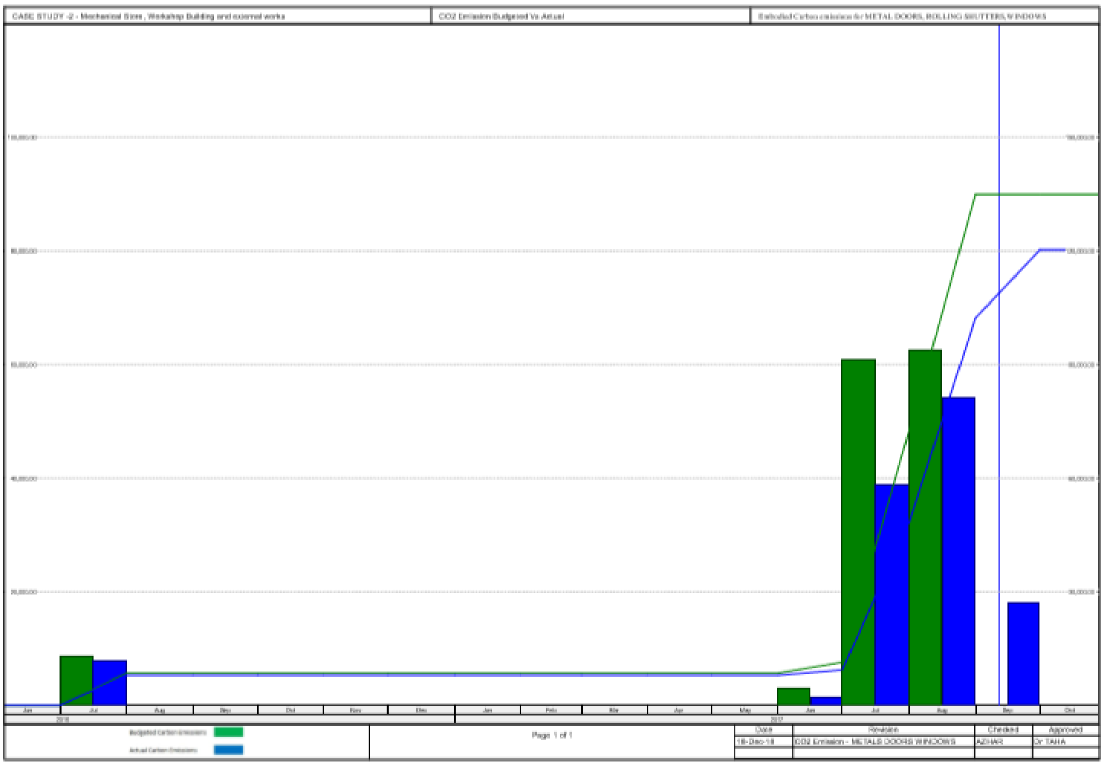
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CO2 Emission - METALS DOORS WINDOWS
AZHAR
Dr TAHA

Carbon Emisisons for steel structure - Case Study-2

MAINTENANCE WORKSHOP - STEEL STRUCTURE QUANTITY														
Refrenece drawing No :5620-BUH-41-20-45-060-A1 SHEET (1 TO 5)														
S.no	**Type**	**Size**	**Units**	**Nos**	**L**	**H**	**W**	**TK**	**Density kg/m3**	**KG per Length**	**Weight in kg**	**ECC kgCO2e/kg**	**Carbon emissions in kg/CO2e**	**Remark**
1	ANCHOR BOLT - 01	8- M56 GRADE 4.6	NOS	32	8.00	-	-	-		33.400	8,550	3.77	32,235	Ø 56 mm
2	ANCHOR BOLT - 02	4 - M36 GRADE 4.6	NOS	4	4.00	-	-	-		11.000	176	3.77	664	Ø 36 mm
3	BASE PLATE - 01	1000 X 950 X 40	NOS	32	1.00	1.000	0.950	0.040	7,850	298.300	9,546	3.77	35,987	
4	BASE PLATE - 02	400 x 400 x 20	NOS	4	1.00	0.600	0.400	0.020	7,850	37.680	151	3.77	568	
5	STUB COLUMN - 01	UB - 610 X 229 X 125	NOS	32	10.00	0.610	0.229	0.125		125.000	40,000	3.77	150,800	
6	STUB COLUMN - 02	UB - 533 X 210 X 45	NOS	4	10.18	0.533	0.210	0.045		45.000	1,832	3.77	6,905	
7	RAFTER	UB - 610 X 229 X 101	NOS	16	17.89	0.610	0.229	0.101		101.000	28,913	3.77	109,004	
8	"C" PURLIN SIDE	CH-305 X 89 X 42	NOS	1	294.60	-	-	-		41.800	12,314	3.77	46,425	
9	FALSE RAFTER	L - 50 X 50 X 6	NOS	1	34.50	0.050	0.050	0.006		4.470	154	3.77	581	
10	BEAM	UB - 356 X 171 X 45	NOS	8	75.20	0.356	0.171	0.045		45.000	27,072	3.77	102,061	
11	BEAM	UB - 356 X 171 X 45	NOS	8	4.23	0.356	0.171	0.045		45.000	1,524	3.77	5,744	
12	EOT CRANE GRIDER	UC - 356 X 368 X 125	NOS	2	75.20	0.356	0.368	0.125		125.000	18,800	3.77	70,876	
13	EOT CRANE GRIDER SUPPORT	UC - 406 X 178 X 74	NOS	32	0.25	0.406	0.178	0.074		74.000	592	3.77	2,232	
14	EOT CRANE SELF WEIGHT	EOT CRANE - 20 TON	NOS	2							10,000	3.77	37,700	
15	BREACHING	UB - 305 x 165 x40	NOS	76	6.16	0.305	0.165	0.040		40.000	18,726	3.77	70,599	
16	ZED PURLIN ON TOP	Z25225	NOS	22	75.20	-	-	-		7.930	13,119	3.77	49,460	
17	SAG ROD INCLUDING BRACING	16 MM DIA	Rmt	1	439.20	-	-	-		1.580	694	3.77	2,616	
18	ROOF SHEETING & FASTERES	0.9 MM X 85MM CORE X 130 MM TK	M^2	1	1297.20	-	-	-		19.400			90,609	CO2e from data sheet
19	ROOF SHEE FLASHING	0.9 MM X 85MM CORE X 130 MM TK	M^2	1	527.00	-	-	-		19.400			14,329	CO2e from data sheet

Carbon Emisisons for steel structure - Case Study-2

20	RAFTER TO PURLIN SUPPROT	UA - 50 X 50 X 6	NOS	1	660	0.050	0.050	0.006		4.500	2,970	3.77	11,197	
21	WELDED PLATE ON RAFTER	130 X 190 X 12	NOS	1	352.00	0.130	0.190	0.120		2.327	819	3.77	3,088	
22	JOINT BOLTS ALL M20	M20 GRADE 8.8	NOS	1	1296.00	-	-	-		0.280	363	3.77	1,368	
23	JOINT BOLTS AL M16	M16 GRADE 4.4	NOS	1	4048.00	-	-	-		0.123	498	3.77	1,877	
24	JOINT BOLTS AL M24	M24 GRADE 8.8	NOS	1	316.00	-	-	-		0.418	132	3.77	498	
25	JOINT BOLTS AL M30	M30 GRADE 8.8	NOS	1	768.00	-	-	-		0.716	550	3.77	2,073	
TOTAL WEIGHT IN METRIC TON											197,495		849,496	

Virgin material-sections Embodied CO2eq (source IPCC (2016) and WSI)	3.77	kg CO2eq/kg
Hot rolled Sections - Embodied CO2eq values with recycle content (ICE)	2.03	kg CO2eq/kg
Planned Embodied CO2eq emissions	**849,495.83**	kg/CO2eq
Considering 50% of the material supplied with recycled content, the Actual Embodied CO2eq emissions (after optimization during EPC phase)	**677,674.92**	kg/CO2eq
% savings achieved	**20%**	

Transporatation emissions - Case study -2

S.No	Description	Base case CO_2 emissions for travel	Actual CO_2 emissions (kg CO_2 eq)	Percentage
1	Backfill Material	43,860.10	2,193.00	0.46%
2	Blinding concrete	5,338.23	4,305.02	0.90%
3	RCC concrete	36,505.68	29,440.07	6.18%
4	Formwork and shuttering	116,278.27	93,772.80	19.69%
5	Structural and rebar steel	14,850.20	11,423.23	2.40%
6	Block work	8,533.32	6,564.10	1.38%
7	Plastering- OPC cement	7,135.26	5,754.24	1.21%
8	Painting	1,189.21	959.04	0.20%
9	Waterproofing	2,906.96	2,344.32	0.49%
10	Ceramic	3,845.11	3,100.90	0.65%
11	Manpower transportation of contractor	100,580.71	81,113.47	17.03%
12	Transportation of PMT(Contractor)	170,362.28	137,388.94	28.85%
13	Transportation of PMT(Client)	121,310.60	97,831.13	20.54%
	Total Transportation emisisons	632,695.94	476,190.26	100.00%

Project: Case Study - 2

Material Sheet: Transportation for Backfill I Actual CO_2 emissions (kg CO_2 eq)

S.No	Description of Material	manufacturer Name	Unit	Quantity	trips required	Plant/warehouse	from site (Km)	Mode of transport	fuel type	consumption	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Backfill Material - Mech store	Natural soil	M3	909.33	51	Muncipality bur	4	Road	diesel	0.2	2.664	108.69
2	Backfill Material - Workshop	Natural soil	M3	7255.63	403	Muncipality bur	4	Road	diesel	0.2	2.664	858.87
3	Backfill Material - External works	Natural soil	M3	10347.58	575	Muncipality bur	4	Road	diesel	0.2	2.664	1,225.44
											Total	**2,193.00**

Project: **Case study -2**

Material Sheet: Transportation for Plain cer **Actual CO_2 emissions (kg CO_2 eq)**

S.No	Description of Material	manufacturer Name	Unit	Quantity	trips required	ready mix plant	from site (Km)	Mode of transport	fuel type	consumption	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	PCC - Mech store	Ready Mix Beaton	M3	113.76	19	Madinat Zayed	80	Road	diesel	0.2	2.664	809.86
2	PCC - Workshop	Ready Mix Beaton	M3	439.29	73	Madinat Zayed	80	Road	diesel	0.2	2.664	3,111.55
3	PCC - External works	Ready Mix Beaton	M3	51.3	9	Madinat Zayed	80	Road	diesel	0.2	2.664	383.62
											Total	**4305.024**

Project: Case study-2

Material Sheet: Transportation for Concret Actual CO_2 emissions (kg CO_2 eq)

S.No	Description of Material	manufacturer Name	Unit	Quantity	No of trips required	Plant/warehouse	from site (Km)	Mode of transport	fuel type	consumption (Lts)/km	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	RCC for Mech store	Ready Mix Beaton	M3	515.69	86	Madinat Zayed	55	Road	Diesel	0.2	2.664	2,518.63
2	RCC for Workshop	Ready Mix Beaton	M3	4135.57	689	Madinat Zayed	55	Road	Diesel	0.2	2.664	20,198.12
3	RCC for external works	Ready Mix Beaton	M3	1376.6	229	Madinat Zayed	55	Road	Diesel	0.2	2.664	6,723.31
											Total	**29,440.07**

Project: Case study-2
Material Sheet: Transportation for Rebar m **Actual CO_2 emissions (kg CO_2 eq)**

S.No	Description of Material	manufacturer Name	Unit	Quantity in ton	trips required	Plant/ware house	from site (Km)	Mode of transport	fuel type	consumptio n (Lts)/km	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Shuttering and formwork- Mech store	Danube/Scaffold	M3	83.425	6	Dubai/Abu dhabi	440	Road	diesel	0.2	2.664	1,406.59
2	Shuttering and formwork- Workshop	Danube/Scaffold	M3	5358	357	Dubai/Abu dhabi	440	Road	diesel	0.2	2.664	83,692.22
3	Shuttering and formwork- External works	Danube/Scaffold	M3	555.5	37	Dubai/Abu dhabi	440	Road	diesel	0.2	2.664	8,673.98
											Total	**93,772.80**

Note:

average total distance is (220 x 2)+2 440

Buhasa - 220 km is considered for all materials. Distances

sharjah, hence distance is multiplied by 2

on the project. One truck avg capacity is 15cum

Project: **Ccase study-2**

Material Sheet: Transportation for Rebar m **Actual CO_2 emissions (kg CO_2 eq)**

S.No	Description of Material	manufacturer Name	Unit	Quantity in ton	trips required	Plant/ware house	from site (Km)	Mode of transport	fuel type	consumption (Lts)/km	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Base plate and anchor bolts	Fabricator/Emirates steel	Ton	18.5	2	Abudhabi	440	Road	diesel	0.2	2.664	468.86
2	Columns	Fabricator/Emirates steel	Ton	41.8	4	Abudhabi	440	Road	diesel	0.2	2.664	937.73
3	Rafter	Fabricator/Emirates steel	Ton	32.8	3	Abudhabi	440	Road	diesel	0.2	2.664	703.30
4	Tiebeams	Fabricator/Emirates steel	Ton	47.98	5	Abudhabi	440	Road	diesel	0.2	2.664	1,172.16
5	Bracings	Fabricator/Emirates steel	Ton	19.42	2	Abudhabi	440	Road	diesel	0.2	2.664	468.86
6	Purlin, sag rods and other accessories	Fabricator/Emirates steel	Ton	26.2	2	Abudhabi	440	Road	diesel	0.2	2.664	468.86
7	Roof sheeting	RMI sharjah	M2	1824	8	Sharjah	590	Road	diesel	0.2	2.664	2,514.82
8	Rebar for the project	Emirates steel	Ton	391.76	20.00	Abudhabi	440	Road	diesel	0.2	2.664	4,688.64
											Total	**11,423.23**

Total distance is (220 x 2) for abudhabi and 590 for sharjah
Distance from Mussafah to Buhasa - 220 km
Distance from Emirates steel to Quality fabricator - 2 km
For roof sheeting the trucks will go empty back to sharjah

Project: Case study-2

Material Sheet: Transportation for Block w **Actual CO_2 emissions (kg CO_2 eq)**

S.No	Description of Material	manufacturer Name	Unit	Quantity	No of trips required	Plant/warehou se	from site (Km)	Mode of transport	fuel type	consumptio n (Lts)/km	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Blockwork Mech Store	Emirates Block	M3	526	10	Abudhabi	440	Road	diesel	0.2	2.664	2,344.32
2	Blockwork Workshop	Emirates Block	M3	679.58	4	Abudhabi	440	Road	diesel	0.2	2.664	937.73
3	Sand for Mortar	Al Ahli	M3	180.837	10	Abudhabi	440	Road	diesel	0.2	2.664	2,344.32
4	Cement for mortar	Al Ain cement	M3	41.83	4	Abudhabi	440	Road	diesel	0.2	2.664	937.73
											Total	**6564.096**

Average CO2 consumption due to tranportation

Project: Case study-2

Material Sheet: Transportation for plaster r **Actual CO_2 emissions (kg CO_2 eq)**

S.No	Description of Material	manufacturer Name	Unit	Quantity	No of trips required	of Plant/war	from site (Km)	Mode of transport	fuel type	consumpti on	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Plaster - Mech store	Sand from Quarry in Hatta	Sqm	2550								
2	Plaster - Workshop	Sand from Quarry in Ain	Sqm	9800								
3	Sand	Sand from Quarry in Ain	cum	494	27	Al Ain	360	Road	diesel	0.2	2.664	5,178.82
4	Cement	Sand from Quarry in Ain	bag	550	3	Al Ain	360	Road	diesel	0.2	2.664	575.42
											Total	**5,754.24**

cement- 50 kg 0.21 bags /sqm 1 bag 0.0347

sand .04 cum/sqm

Project: **Construction of New Workshop Building at Buhasa**

Material Sheet: Transportation for painting Actual CO_2 emissions (kg CO_2 eq)

S.No	Description of Material	manufacturer Name	Unit	Quantity	No of trips required	Plant/warehouse	from site (Km)	Mode of transport	fuel type	consumption	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Paint - Mech store	JOTUN	Sqm	1490	2	Dubai	300	Road	diesel	0.2	2.664	319.68
2	Paint- workshop	JOTUN	Sqm	7087	4	Dubai	300	Road	diesel	0.2	2.664	639.36
											Total	**959.04**

Project: Construction of New Workshop Building at Buhasa
Material Sheet: Transportation for Waterpr **Actual CO_2 emissions (kg CO_2 eq)**

S.No	Description of Material	manufacturer Name	Unit	Quantity	No of trips	Plant/ware house	from site (Km)	Mode of transport	fuel type	consumpti on	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Mech store	Polybit	LS	Actual trips logged	2	Abu Dhabi	440	Road	diesel	0.2	2.664	468.864
2	Workshop	Polybit	LS		5	Abu Dhabi	440	Road	diesel	0.2	2.664	1172.16
3	External works	Polybit	LS		3	Abu Dhabi	440	Road	diesel	0.2	2.664	703.296
											Total	**2,344.32**

Project: **Construction of New Workshop Building at Buhasa**

Material Sheet: Transportation for Ceramic, Actual CO_2 emissions (kg CO_2 eq)

S.No	Description of Material	manufacturer Name	Unit	Quantity	No of trips required	Plant/warehouse	from site (Km)	Mode of transport	fuel type	consumption (Lts)/km	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Ceramic tiles	RAK Cemaric	cum	2,900.00	6	Ras Al Khaimah	750	Road	diesel	0.2	2.664	2,397.60
2	False ceiling	Abudhabi supplier	sqm	2100	3	Abudhabi	440	Road	diesel	0.2	2.664	703.30
											Total	**3100.896**

Project **Construction of New Workshop Building at Buhasa**

Sheet: Contractor labour - travel emissio **Base case (** **Actual CO_2 emissions (kg CO_2 eq)**

S.No	Manpower Quantity	Month	manufacturer Name	of labours per month	Buses/ day	No of Days	Is EPD available?	Plant/warehouse	from site (Km)	Mode of transport	fuel type	consumption	factor (kg CO2 eg/ litre)	emissions (kg CO2 eq)
1	Manpower	Apr-15	Ashok Leyland	20	1	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	1,065.60
2	Manpower	May-15	Ashok Leyland	32	1	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	1,065.60
3	Manpower	Jun-15	Ashok Leyland	35	1	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	1,065.60
4	Manpower	Jul-15	Ashok Leyland	40	1	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	1,065.60
5	Manpower	Aug-15	Ashok Leyland	54	2	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	2,131.20
6	Manpower	Sep-15	Ashok Leyland	52	2	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	2,131.20
7	Manpower	Oct-15	Ashok Leyland	45	2	27	yes	Madinazayed	80	Road	diesel	0.2	2.664	2,301.70
8	Manpower	Nov-15	Ashok Leyland	65	2	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	2,131.20
9	Manpower	Dec-15	Ashok Leyland	80	2	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	2,131.20
10	Manpower	Jan-16	Ashok Leyland	80	2	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	2,131.20
11	Manpower	Feb-16	Ashok Leyland	80	2	24	yes	Madinazayed	80	Road	diesel	0.2	2.664	2,045.95
12	Manpower	Mar-16	Ashok Leyland	109	3	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	3,196.80
13	Manpower	Apr-16	Ashok Leyland	104	3	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	3,196.80
14	Manpower	May-16	Ashok Leyland	145	5	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	5,328.00
15	Manpower	Jun-16	Ashok Leyland	145	5	26	yes	Madinazayed	80	Road	diesel	0.2	2.664	5,541.12
16	Manpower	Jul-16	Ashok Leyland	145	5	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	5,328.00
17	Manpower	Aug-16	Ashok Leyland	198	7	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	7,459.20
18	Manpower	Sep-16	Ashok Leyland	198	7	24	yes	Madinazayed	80	Road	diesel	0.2	2.664	7,160.83
19	Manpower	Oct-16	Ashok Leyland	215	8	25	yes	Madinazayed	80	Road	diesel	0.2	2.664	8,524.80
20	Manpower	Nov-16	Ashok Leyland	220	8	29	yes	Madinazayed	80	Road	diesel	0.2	2.664	9,888.77
21	Manpower	Dec-16	Ashok Leyland	150	4	29	yes	Madinazayed	80	Road	diesel	0.2	2.664	4,944.38
22	Manpower	Jan-17	Ashok Leyland	40	1	30	yes	Madinazayed	80	Road	diesel	0.2	2.664	1,278.72
													Total	**81,113.47**

Project: Construction of New Workshop Building at Buhasa

Sheet: Contractor Staff - travel emissions · Base case (Actual CO_2 emissions (kg CO_2 eq)

S.No	Manpower	Month	manufacturer Name	No of Cars	No of trips required	available ?	Location of Accomodation	Distance from site	Mode of transport	fuel type	consumpti on	factor (kg CO2 eg/	emissions (kg CO2 eq)
1	Manpower	Oct-14	Toyota 1.8 L	1	25	Yes	Habshan Road	60	Road	Petrol	0.125	2.3307	437.01
2	Manpower	Nov-14	Toyota 1.8 L	1	25		Habshan Road	60	Road	Petrol	0.125	2.3307	437.01
3	Manpower	Dec-14	Toyota 1.8 L	1	25		Habshan Road	60	Road	Petrol	0.125	2.3307	437.01
4	Manpower	Jan-15	Toyota 1.8 L	1	25		Habshan Road	60	Road	Petrol	0.125	2.3307	437.01
5	Manpower	Feb-15	Toyota 1.8 L	1	25		Habshan Road	60	Road	Petrol	0.125	2.3307	437.01
6	Manpower	Mar-15	Toyota 1.8 L	2	25		Habshan Road	60	Road	Petrol	0.125	2.3307	874.01
7	Manpower	Apr-15	Toyota 1.8 L	2	25		Habshan Road	60	Road	Petrol	0.125	2.3307	874.01
8	Manpower	May-15	Toyota 1.8 L	2	25		Habshan Road	60	Road	Petrol	0.125	2.3307	874.01
9	Manpower	Jun-15	Toyota 1.8 L	4	25		Habshan Road	60	Road	Petrol	0.125	2.3307	1,748.03
10	Manpower	Jul-15	Toyota 1.8 L	4	25		Habshan Road	60	Road	Petrol	0.125	2.3307	1,748.03
11	Manpower	Aug-15	Toyota 1.8 L	4	25		Habshan Road	60	Road	Petrol	0.125	2.3307	1,748.03
12	Manpower	Sep-15	Toyota 1.8 L	4	25		Habshan Road	60	Road	Petrol	0.125	2.3307	1,748.03
13	Manpower	Oct-15	Toyota 1.8 L	4	25		Habshan Road	60	Road	Petrol	0.125	2.3307	1,748.03
14	Manpower	Nov-15	Toyota 1.8 L	4	25		Habshan Road	60	Road	Petrol	0.125	2.3307	1,748.03
15	Manpower	Dec-15	Toyota 1.8 L	4	25		Habshan Road	60	Road	Petrol	0.125	2.3307	1,748.03
16	Manpower	Jan-16	Toyota 1.8 L	4	25		Habshan Road	60	Road	Petrol	0.125	2.3307	1,748.03
17	Manpower	Feb-16	Toyota 1.8 L	6	25		Habshan Road	60	Road	Petrol	0.125	2.3307	2,622.04
18	Manpower	Mar-16	Toyota 1.8 L	6	25		Habshan Road	60	Road	Petrol	0.125	2.3307	2,622.04
19	Manpower	Apr-16	Toyota 1.8 L	6	25		Habshan Road	60	Road	Petrol	0.125	2.3307	2,622.04
20	Manpower	May-16	Toyota 1.8 L	6	26		Habshan Road	60	Road	Petrol	0.125	2.3307	2,726.92
21	Manpower	Jun-16	Toyota 1.8 L	6	25		Habshan Road	60	Road	Petrol	0.125	2.3307	2,622.04
22	Manpower	Jul-16	Toyota 1.8 L	8	25		Habshan Road	60	Road	Petrol	0.125	2.3307	3,496.05
23	Manpower	Aug-16	Toyota 1.8 L	8	29		Habshan Road	60	Road	Petrol	0.125	2.3307	4,055.42
24	Manpower	Sep-16	Toyota 1.8 L	8	25		Habshan Road	60	Road	Petrol	0.125	2.3307	3,496.05
25	Manpower	Oct-16	Toyota 1.8 L	6	30		Habshan Road	60	Road	Petrol	0.125	2.3307	3,146.45
26	Manpower	Nov-16	Toyota 1.8 L	2	30		Habshan Road	60	Road	Petrol	0.125	2.3307	1,048.82
27	Manpower	Nov-16	Toyota 1.8 L	2	30		Habshan Road	60	Road	Petrol	0.125	2.3307	1,048.82
28	Manpower		Toyota 1.8 L	1	695		Abudhabi office	440	Road	Petrol	0.125	2.3307	89,091.01

Project: Construction of New Workshop Building at Buhasa

Sheet: Client Staff - travel emissions - Toyo **Base case (** **Actual CO_2 emissions (kg CO_2 eq)**

S.No	Manpower	Month	manufacturer Name	No of Cars	No of trips required	Is EPD available?	Plant/warehouse	Distance from site	Mode of transport	fuel type	consumption (Lts)/km	factor (kg CO2 eg/ litre)	emissions (kg CO2 eq)
1	Manpower	Oct-14	Toyota	1	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	2,010.23
2	Manpower	Nov-14	Toyota	2	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
3	Manpower	Dec-14	Toyota	2	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
4	Manpower	Jan-15	Toyota	2	20	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	5,360.61
5	Manpower	Feb-15	Toyota	2	20	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	5,360.61
6	Manpower	Mar-15	Toyota	2	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	2,680.31
7	Manpower	Apr-15	Toyota	3	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
8	Manpower	May-15	Toyota	3	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
9	Manpower	Jun-15	Toyota	2	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	2,680.31
10	Manpower	Jul-15	Toyota	2	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
11	Manpower	Aug-15	Toyota	3	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	6,030.69
12	Manpower	Sep-15	Toyota	2	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
13	Manpower	Oct-15	Toyota	2	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
14	Manpower	Nov-15	Toyota	2	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	2,680.31
15	Manpower	Dec-15	Toyota	2	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	2,680.31
16	Manpower	Jan-16	Toyota	2	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	2,680.31
17	Manpower	Feb-16	Toyota	2	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	2,680.31
18	Manpower	Mar-16	Toyota	2	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	2,680.31
19	Manpower	Apr-16	Toyota	3	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
20	Manpower	May-16	Toyota	3	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
21	Manpower	Jun-16	Toyota	3	10	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	4,020.46
22	Manpower	Jul-16	Toyota	3	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	6,030.69
23	Manpower	Aug-16	Toyota	3	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	6,030.69
24	Manpower	Sep-16	Toyota	3	15	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	6,030.69
25	Manpower	Oct-16	Toyota	2	20	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	5,360.61
26	Manpower	Nov-16	Toyota	2	20	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	5,360.61
27	Manpower	Dec-16	Toyota	2	20	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	5,360.61
28	Manpower	Jan-17	Toyota	2	25	Yes	Buhasa Road	460	Road	Petrol	0.125	2.3307	6,700.76
												Total	**97,831.13**