Designing a Lean and Green framework for the reduction of GHG emissions in the South African manufacturing industry

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ABSTRACT

Lean and Green is a hybrid philosophy that combines the operational efficiencies of Lean with the environmental consciousness instilled by Green philosophy. However, the South African manufacturing industry experiences challenges in addressing their GHG emissions. Therefore, this study aims to conceptualise and guide GHG reduction using Lean and Green. This is achieved by designing a Lean and Green framework for GHG reduction in the South African manufacturing industry.

Within the paradigm of design science research (DSR), a qualitative systematic literature review (SLR) and applied thematic analysis (ATA) were used to code quotations (design elements) from various literature sources in Atlas.ti. From these elements, five themes were categorised and used to create a literature-based conceptual Lean and Green framework.

Deployment of design science research and surveys, built-in verification and validation further developed the framework to increase relevance to the South African manufacturing industry.

Finally, this study presents a Lean and Green GHG reduction framework for the South African manufacturing industry. This framework provides researchers and practitioners with the essential elements and themes for achieving GHG reduction within the Lean and Green paradigm.

Keywords: Lean and Green, GHG emissions, systematic literature review, applied thematic analysis

PREFACE

This dissertation was compiled and presented in **article** format in accordance with the academic rules of the North-West University (approved on 21 September 2017).

Rule A.4.10.5 states: "*Where a candidate is allowed to submit the research product in the form of research articles, such research product must be presented for examination purposes as an integrated unit, supplemented with a problem statement, an introduction and a synoptic conclusion as prescribed by faculty rules and the manuscript submission guidelines, or the url link to the manuscript guidelines of the journal or journals concerned*."

Rule A.4.10.8. states: "*Where any research article or internationally examined patent to which the candidate for a master's degree and other authors or inventors have contributed is submitted as the research product of a master's degree programme, the candidate must obtain a written statement from each co-author and co-inventor in which it is stated that such co-author or co-inventor grants permission for the research product to be used for the stated purpose, and in which it is further indicated what each co-author's or co-inventor's academic contribution to the research product concerned was.*"

Rule A.4.10.9. states: "*Where co-authors or co-inventors as contemplated in rule 4.10.8 were involved in the development of the research product, the candidate must mention this fact in the preface, and must include the statement of each co-author or co-inventor immediately following the preface to the research product.*"

The following manuscript has been submitted to the *Journal of Cleaner production* with reviewer comments incorporated and presented in Chapter 3:

- M. Roopa, R. Coetzee and E. Davies, "*A Literature-based Conceptual Lean and Green framework for GHG emission reduction in the manufacturing industry*".

The following research paper has been published in the *SAIIE31 Green conference* proceedings and is presented in chapter 4:

- M. Roopa, R. Coetzee and E. Davies, "*Designing a Lean and Green framework for GHG reduction in the South African manufacturing industry*". SAIIE31 Green conference proceeding pg 656-676.

LAYOUT, NUMBERING AND REFERENCING

The two research papers that have been submitted and/or published have adhered to the author guidelines as stipulated by each journal/proceeding. These papers are in a different format from the remainder of this dissertation. For this reason, the header, footer, page numbers and formatting appear differently in Chapter 3 and Chapter 5. The headings and original content of the publications cannot be modified.

STATEMENT OF CO-AUTHORS

To whom it may concern,

The listen co-authors hereby give consent that **Meelan Roopa** may submit the manuscript(s) as part of his dissertation titled, **"*Designing a Lean and Green framework for GHG reduction in the South African manufacturing industry*"** for the degree Master of Engineering in Industrial Engineering, at the North-West University (NWU):

(This letter of consent complies with rules A4.10.8 and A4.10.9 of the academic rules, as stipulated by the North-West University)

Dr. Rojanette Coetzee	17 December 2020	Potchefstroom
	Date	Signed at

Dr. Edward Davies	17 December 2020	Fourways
	Date	Signed at

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Chapter 1

Introduction

This chapter provides context on the research problem addressed by the aim, objectives and methodology of this study. The research contribution and ethical considerations are also presented in this chapter.

1 Introduction

1.1 Background

Manufacturing companies are always competing to provide products to customers in the fastest and most cost-effective manner possible (Linder, 2019). To produce these products, resource consumption becomes vital. Throughout the manufacturing process, of various products, energy is used to run auxiliary support systems or convert raw materials into products (Barrett *et al.*, 2018). During this conversion process, greenhouse gases (GHGs) are often emitted. Examples of such gases include carbon dioxide (CO_2), ozone (O_3), nitrous oxide (N_20) and methane (CH_4) (Gohar & Shine, 2007:1).

According to Weisser (2007:8), the Global Warming Potential (GWP) is the ability of a GHG to trap heat within the atmosphere, relative to an equal amount of (CO_2). Each GHG therefore possesses a global warming potential and poses a threat to the environment. Each GHG has established values for GWP set out by the Intergovernmental Panel on Climate Change (IPPC) (Svensson, 2011:3). These standardised values can be converted into a carbon dioxide Equivalent (CO_2e), which has become the standard unit for measuring the carbon footprint of organisations around the globe. With growing consumer needs, anthropogenic activities give rise to increased levels of GHG emissions and other pollutants.

South Africa is the most significant energy consumer and the largest source of pollution emissions on the African continent (Ndoricimpa, 2017), with coal generating 29% of the primary energy. Unsurprisingly, this has led to South Africa being one of the countries with the highest CO_2 emissions per capita and the most carbon-intensive non-oil producing developing country (Kohler, 2013). In order to draw a comparison to other countries, the CO_2 emissions of various countries, between 1951 and 2017 are encapsulated in Figure 1.

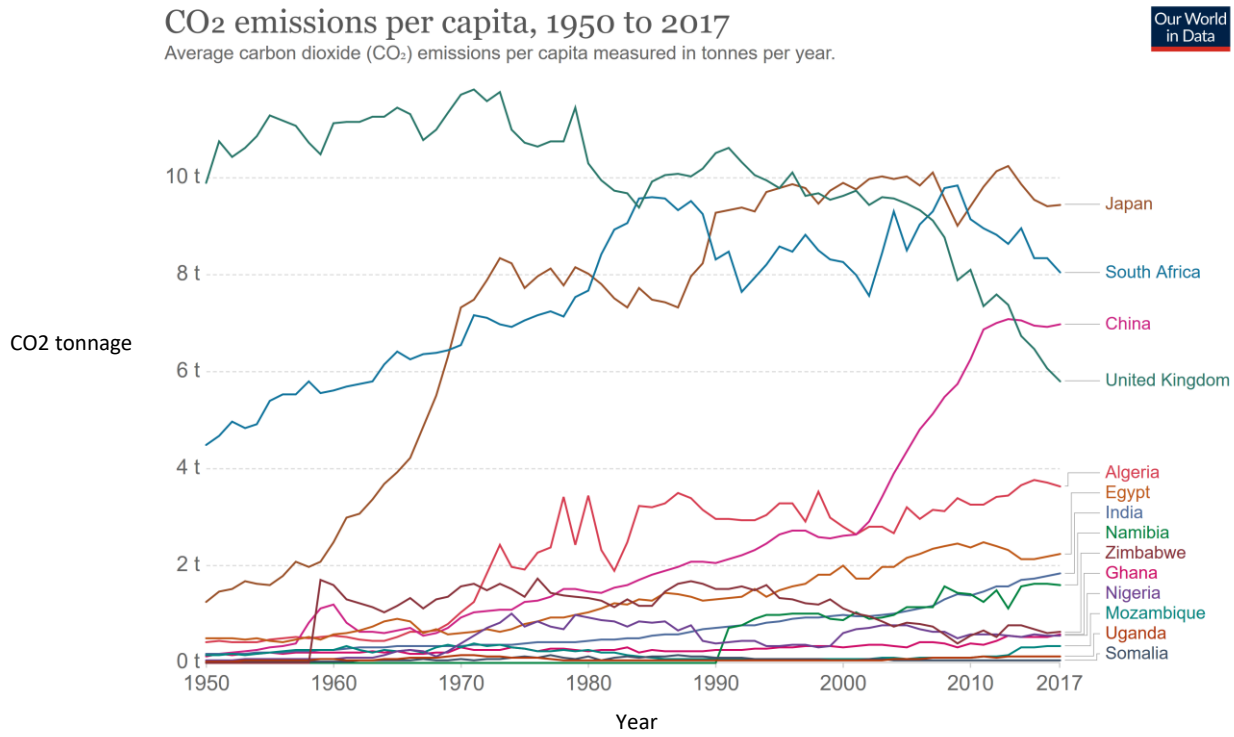


Figure 1 CO2 emissions per capita between 1950 and 2017 (Oxford, 2017)

As substantiated by Figure 1, South Africa also has a larger CO_2 emission per capita than the United Kingdom and China. The vast CO_2 emissions indicate that South Africa is a profligate emitter of GHGs. In broader contexts, South Africa ranked as the 13th highest CO_2 emitter per capita, and 12th highest source of emissions in the world (UCSUSA, 2018).

Despite these trends, the country does recognise its obligation to preserve the environment. The South African government believes that the country must reduce GHG emissions while providing economic growth and increasing employment to reduce poverty and inequality (Ndoricimpa, 2017). The South African carbon tax act is a recent form of legislation aimed at relieving its environmental impact. Various other forms of legislation and policies are used to standardise sustainable environmental practices across multiple industries in the country.

The South African Department of Energy enforces regulations to control GHG emissions and reduce other harmful environmental effects. According to the 2018/2019 annual report from the South African Department of Energy (DOE, 2018/19), R7.09 billion was used to fund programmes for energy policies, planning, electrification, nuclear energy and clean energy. While improvement initiatives have been undertaken, organisations are still challenged with identifying opportunities for future reductions. Carbon tax policies and regulations have also served as an approach to remedy these unwanted effects on the environment. South Africa has deployed the Carbon Tax

act, which was assented in May 2019 and signed into law by the South African President. The Carbon Tax act took effect from 1 June 2019 (RSA, 2019).

As a result, organisations which deviate beyond the allocated CO_2e emissions are taxed R120 per CO_2e ton. Beyond this effort to address carbon emissions, further initiatives are needed to reduce GHG emissions in South Africa.

As previously mentioned, South Africa is the highest energy consumer and the largest contributor of pollution emissions (GHG emissions) in Africa (Ndoricimpa, 2017). South Africa also has one of the highest CO_2 emissions per capita (Kohler, 2013). Furthermore, the manufacturing industry within South Africa is renowned for being the largest sector for carbon emissions. This industry must also abide by the carbon tax policies, leaving organisations challenged with the inability to effectively identify and address GHG emissions with growing concerns regarding their carbon footprint (CF) (Allwood & Cullen, 2009; Jeswiet & Kara, 2008; Júnior *et al.*, 2018). The South African manufacturing industry therefore needs an initial steppingstone to identify, conceptualise, and navigate the process of reducing GHG emissions. With the manufacturing industry of South Africa being the more profligate industry that is unable to address environmental challenges, the reduction of GHG emissions is of greater concern now than ever before (Allwood & Cullen, 2009; Júnior *et al.*, 2018).

1.2 Research problem

GHG emissions are an ever-increasing environmental concern due to anthropogenic activities around the world. Across industries, mechanisms have been introduced to try and mitigate this, but a larger effort is needed to reduce GHG emissions. The same can be said for South Africa.

More specifically, the South African manufacturing industry is challenged with reducing their GHG emissions.

1.3 Research opportunity

Literature discusses the relationship between lean and green principles and highlights the environmental performance and operational efficiency delivered by this paradigm (Diaz-Elsayed *et al.*, 2013; Galeazzo *et al.*, 2014). Researchers have further investigated implementation models used to facilitate the adoption of this paradigm (Cherrafi *et al.*, 2017; David & Found, 2016). Much of this academic interest stems from the manufacturing sector (Fercoq *et al.*, 2016; Zokaei *et al.*, 2017a:4). With the increased interest in these two paradigms, the academic community has investigated their interactions and applicability in various industries. This focus stems beyond

manufacturing sectors, and can be applied to business models, small, medium and micro enterprises (SMMEs) and supply chain management (Carvalho *et al.*, 2017; Duarte & Cruz-Machado, 2013; Oliveira *et al.*, 2018)

There is recognition of the range of literature on these topics leading to synthesis of ideas that also identify future research streams. This analysis includes systematic literature reviews that integrate Lean, Green and Six Sigma, barriers to Lean and Green integration, integrative Lean and sustainability synergies and the state of the art regarding the Lean and Green paradigm (Caiado *et al.*, 2018; Cherrafi *et al.*, 2017; de Carvalho *et al.*, 2017; Garza-Reyes, 2015).

Lean and Green has demonstrated its capabilities in reducing GHG emissions (Cai *et al.*, 2019; Leme *et al.*, 2018). This hybrid philosophy combines components from Lean, directed towards process improvement and Green, focused on performance measures to reduce environmental impact (Amrina & Zagloel, 2019).

With South Africa joining other counties in a united front against unwanted environmental effects and Lean and Green emerging as a means of resolve, a need exists to develop a Lean and Green framework that can guide South African manufacturing organisations towards reducing their GHG emissions.

1.4 Research aim

Emerging from the research opportunity, the aim of this study is to design a framework that will conceptualise and guide GHG emission reduction in the South African manufacturing industry by means of Lean and Green.

1.5 Research objectives

In order to achieve the aforementioned aim, the following set of research objectives have been formulated:

1. Conceptualise Lean and Green principles, tools, methodologies, and SLR methods
2. Extract and categorise design elements for Lean and Green GHG reduction
3. Design literature-based conceptual framework
4. Verify that the SLR process is completed with research integrity
5. Verify that the framework satisfies all the design requirements
6. Confirm the validity of the research problem, research design and research output (framework)

7. Confirm the construct validity and internal consistency of the survey

A framework is an approach to prescribe a set of elements and constructs that constitute a situation, process or philosophy (Soni & Kodali, 2013). These objectives are used to inspire the appropriate research design.

1.6 Research design

Considering that this qualitative study is orientated towards new concepts and theories, a design science research (DSR) paradigm was followed, specifically using action design research (ADR). DSR is also deemed applicable for field problems, as it aims to develop generic actionable knowledge (Van Aken, 2005). Therefore, DSR will serve as the paradigm in which this research study is encased.

Hofstee (2006:107-117) differentiates between the research design and research method. The research design serves as the approach used to design the manner in which the study would unfold, whereas the research method concerns the general techniques used to complete the study. In order to adhere to the objectives that are aligned to the aim of this study, a research design has been formulated and is presented in Figure 2. This figure also provides an outline of all the distinct chapters (Ch) in this dissertation and the corresponding aim and research objectives.

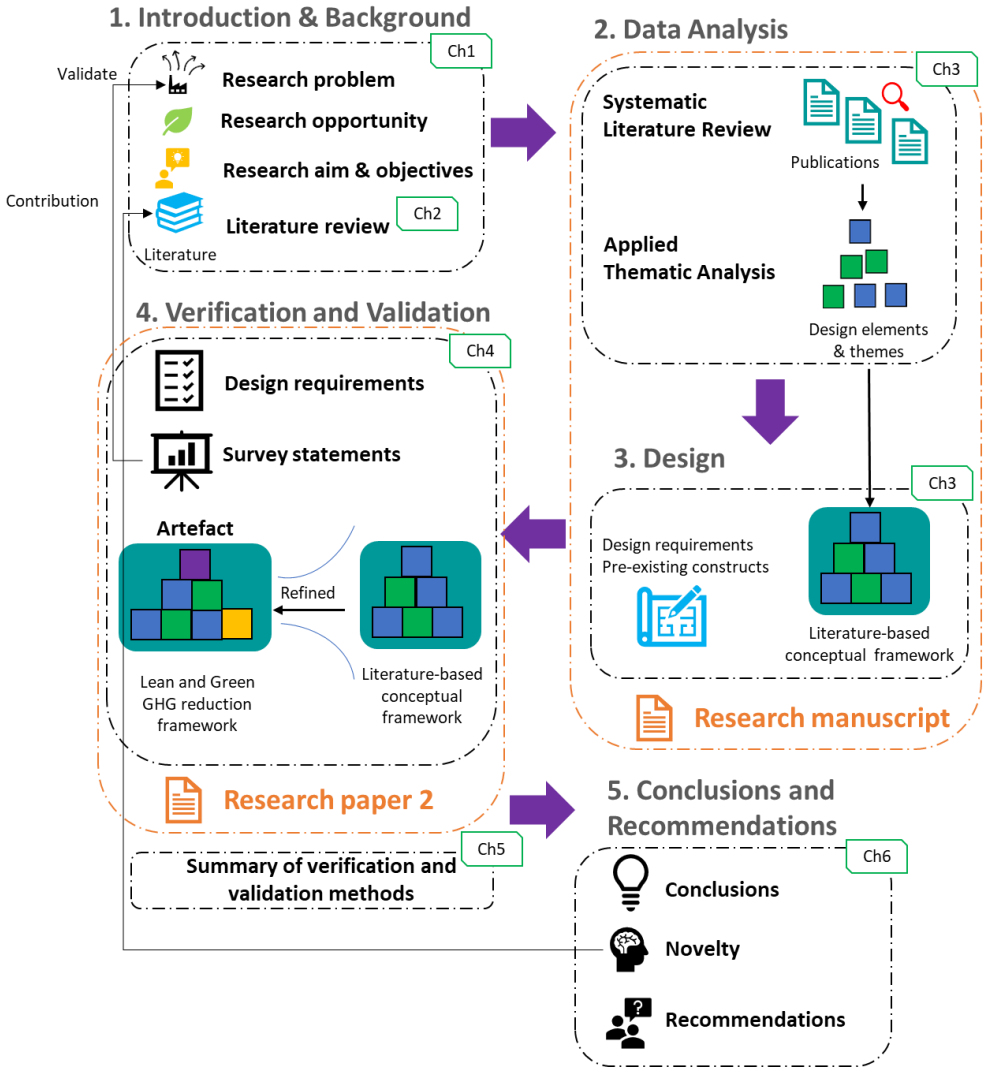


Figure 2 Research design

This research design is cast within the DSR paradigm using ADR. Firstly, a background to the nature of this study and the problem is observed when scouring literature. Furthermore, the literature study (Chapter 2) ensures knowledge enrichment and delineates the study.

The next phase of this research encompasses the data analysis and design by means of a two-stage method involving a qualitative systematic literature review (SLR) and applied thematic analysis (ATA). This body of literature was used to extract and conceptualise GHG emission reduction using Lean and Green. Using the emergent themes from the ATA, various design elements and themes are formulated and presented in a literature-based conceptual framework (Chapter 3).

Once the literature-based conceptual framework was designed, surveys were used to refine the framework as the final artefact belonging to this study, namely the Lean and Green GHG reduction

framework (Chapter 4). This framework was verified and validated using methods summarised in Chapter 5, some of which originate from the research manuscripts and research publications from Chapter 3 and 4. Before this research study can be executed, ethical considerations need to be taken.

1.7 Ethical considerations

Ethical approval was obtained from the North-West University Engineering Research Ethics Committee (NWU-ENG-REC). A letter of informed consent was used to obtain consent from the relevant environmental engineers and managers within various private manufacturing organisations in South Africa.

Furthermore, the identity of all organisations and participants will remain confidential throughout the dissertation. The data will be handled with the utmost security and safeguarded from external parties. The researcher has undertaken to follow the researchers code of conduct by the North-West University. The signed agreement has been provided in **Appendix A**. In conjunction, the ethics approval letter (ethics number NWU-01771-19-A1) can be found in **Appendix B**.

1.8 Chapter summary

This chapter serves to delineate this research. In addition, we were introduced to the aim of designing a framework to conceptualise and guide GHG emission reduction in the South African manufacturing industry by means of Lean and Green.

To fulfil this aim, the following research objectives, method and chapter reference are summarised in Table 1.

Table 1 Research objectives, method and associated chapter

Research objectives	Research method	Chapter/ research paper
1. **Conceptualise Lean and Green principles, tools, methodologies, and SLR methods**	Literature Review	Chapter 2
2. **Extract and categorise design elements for Lean and Green GHG reduction**	Qualitative Systematic Literature Review (SLR) and Applied Thematic Analysis (ATA)	Chapter 3 (Research manuscript)

Research objectives	Research method	Chapter/ research paper
3. Design literature-based conceptual framework	Consolidation of emergent themes and application of design requirements within ADR using CIMO-logic	
4. Verify that the SLR process is completed with research integrity	Independent researcher verifies the search results and filtered publications	Chapter 5 & Appendix C (checklist)
5. Verify that the framework satisfies all the design requirements	Surveys	Chapter 4 (SAIIE Research paper 2)
6. Confirm the validity of the research problem, research design and research output (framework)		
7. Confirm the construct validity and internal consistency of the survey	Application of Cronbach alpha	Chapter 5, section 5.2.4

The aforementioned objectives are embedded into the overarching research design presented in section 1.6. Ethical considerations are also formulated according to procedures governed and enforced by the North-West University. In order to further contextualise the study, the literature pertinent to the nature of this study is reviewed in Chapter 2.

Chapter 2

Literature study

This chapter explores the literature concerning Lean, Green, Lean and Green, the state of GHG emissions in South Africa and aspects pertaining to the research design.

2 Literature Study

State of the art literature was used to provide an overview of all theoretical concepts and principles pertaining to this research. In order to scour and reflect on existing literature, key terms were investigated under reputable academic databases. This exercise facilitates knowledge enrichment and introduces some of the fundamental terms and concepts applicable to this study. All relevant topics are addressed in this chapter are compartmentalised using the theme analysis encapsulated in Figure 3.

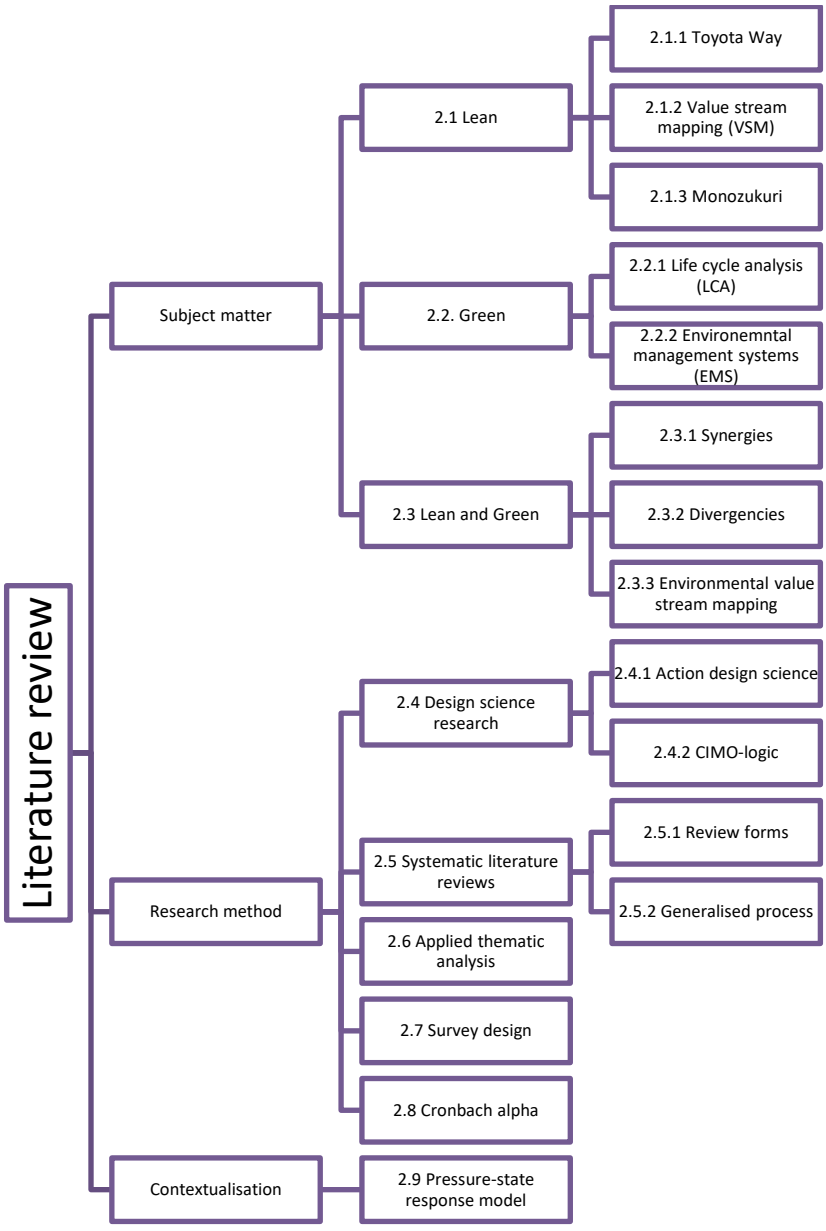


Figure 3 Theme analysis

In order to discuss each concept in light of the study, the sequencing and referencing are listed in Figure 3. Initially, the relevant subject matter is introduced. Lean and Green are explained in

their original and distinct forms. By discussing the antecedents of Lean and Green, we are able to understand the merged paradigm. In this way, the hybrid paradigm (Lean and Green) is then further investigated. The next subsections provide additional literature which pertain to the nature of this research, albeit in content or specific to objectives discussed in Chapter 1. This includes design science research, qualitative systematic literature review, applied thematic analysis and survey design. A pressure-state response model (section 2.9) is used to contextualise the study. Finally, a chapter summary is also provided in section 2.10. The numbering system listed in the figure refers to the subject matter discussed in the various subsections to follow.

2.1 Lean philosophy and tools

Lean philosophy has become a noteworthy process improvement philosophy within numerous sectors. Lean focuses on eliminating waste (inefficiencies) and reducing non-value adding activities to deliver improved customer value (Womack *et al.*, 2008). The seven forms of waste were classified by Taichi Ohno (1912-1990), one of the pioneers of Lean production (Womack & Jones, 2010:16). A summary of each Lean waste is provided in Table 2, accompanied by a respective example.

Table 2 Seven Lean wastes as detailed by (Bicheno & Holweg, 2017)

Lean Waste	Explanation	Example
Overproduction	Producing too much, too early or just-in-case	High levels of work in progress or producing in erratic bursts
Waiting	Directly associated with the flow, any time that is wasted in production or service delivery	During production, any time a part is not moving. In service environments, any time a person is waiting for a machine
Unnecessary motions	Micro and macro wastes in movement owed to human and layout	Workstation configurations and ineffective ergonomic considerations
Transporting	Movement of materials which is non-value adding to the customer	Doubling handling which affects productivity and quality

Lean Waste	Explanation	Example
Overprocessing	Inappropriate processing of products which can refer to machines and processes.	Product or service components which do not align with functionalities customers required
Inventory	Ideally, Lean strives for zero inventory due to lead- time increases and adverse effects on quality and productivity.	High product volumes, push systems and susceptibility to product obsolescence
Defects	A nonconforming product or service delivery which introduces costs and/or hampers quality	Scrap, rework or delays

Building on these 7 proclaimed wastes, Bicheno and Holweg (2017:21-22) have proposed new wastes. These are also said to be appropriate in service and manufacturing environments. These new wastes are described as follows:

- **Untapped human potential** – a more prominent addition to the seven lean wastes. This is often referred to as the formal term being the 8th Lean waste. This refers to the inability to obtain insight from people.
- **Making the wrong product efficiently** – Womack and Jones' 8th waste. This is closely associated with the waste of overproduction.
- **Excessive information and communication** – submerging people in an abundance of unnecessary information.
- **Waste of time** – Failing to prioritise information with regards to urgency and importance, resulting in ineffective sequencing and uneven balance of allocated or available time.
- **Inappropriate systems** – not confined to computers or automation, systems which steal valuable time in the processes. Systems or processes which can be simplified to receive the same desired goal in a shorter time or with greater ease.
- **Energy and water** – Wasted sources of power and water despite management systems implemented in existing factories or service centres.
- **Natural resources** – stressed as the most crucial waste, aiming to conserve materials. This argues that "*Lean is Green*" (Bicheno & Holweg, 2017:22).

Lean principles were originally developed in a manufacturing context used to impact organisations across operational and strategic levels for the purposes of process improvement (Womack *et al.*,

2008). However, several adaptations of Lean have proven successful in other areas as well. Literature documents the successful application of Lean in industries such as banking, healthcare, information systems, supply chain and management practices (Aherne & Whelton, 2010; Chen *et al.*, 2013; dos Santos & do Rosário Cabrita, 2016; Hicks, 2007; Nicholas, 2015).

In order to elaborate on Lean, the Toyota Way and Toyota Production System must be discussed.

2.1.1 The Toyota Way

The original version of Lean was first developed at Toyota (Bicheno & Holweg, 2017). Lean serves as a means of explaining the thought processes and guiding forms of interaction between people (Coetzee *et al.*, 2016). The Toyota House (Figure 4), also known as the Lean Enterprise House encapsulate all of the principles that constitute Lean.

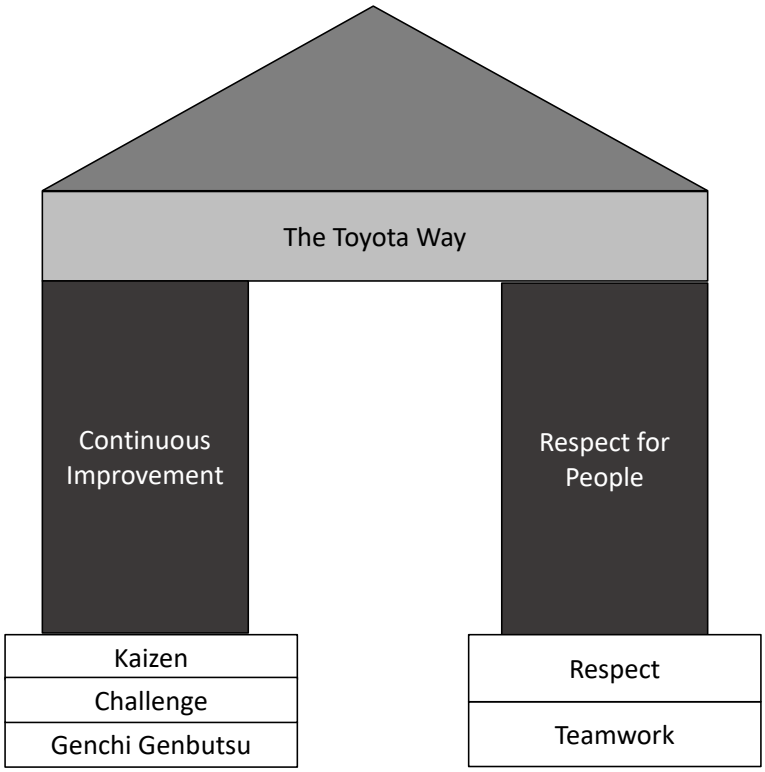


Figure 4 The Toyota Way House adapted from Liker and Hoseus (2008) and Bicheno and Holweg (2017:5)

The Toyota Way is built on two core pillars, namely respect for people (RFP) and continuous improvement (Kaizen). Kaizen is the Japanese term for continuous improvement for change (kai) for the better (zen) . Within the Lean paradigm, Kaizen calls on organisations, regardless of industry, to reflect, learn and adapt their processes on an ongoing basis. Kaizen has been successful in a multitude of sectors, such as education, inventory management, logistics,

automotive and service industries (Barraza *et al.*, 2009; Emiliani, 2005; Monden & Hamada, 1991; Palmer, 2001). While the practical implications of Kaizen are at times a complex process (Styhre, 2001), as it can be a challenge to successfully implement due to lack of understanding.

However, Kaizen speaks to environmental performance, In the same manner that it strives to continuously improve, Kaizen can serve as a means of continuously trying to reduce GHG emissions, energy consumption, water usage or other negative environmental aspects (Cherrafi *et al.*, 2019).

Two more aspects related to continuous improvement is challenge and Genchi-genbutso. Challenge calls on teams to creatively realise their dreams and form a long-term vision, while Genchi-genbutsu refers to the process of going to the source and making correct decisions through consensus (Coetzee *et al.*, 2016).

RFP is supported by Respect, taking responsibility and respect for each other, as well as Teamwork focused on ensuring professional and personal growth (Liker & Hoseus, 2008). From a sustainability driven perspective, it becomes crucial to ensure people are engaged and encouraged to adopt a more environmentally considerate approach. This ensures that the notion of Lean waste also considers the implications it can have on the environment.

Liker (2003) referred to Lean as the Toyota Way but since 1991, Womack *et al.* (2008) began describing Lean management as the Toyota Production System (Ito, 2016). The Toyota Production System (TPS) serves as a mechanism, and is not a Toolkit used for process improvement (Coetzee *et al.*, 2016). An illustration of the TPS house has been provided in Figure 5.

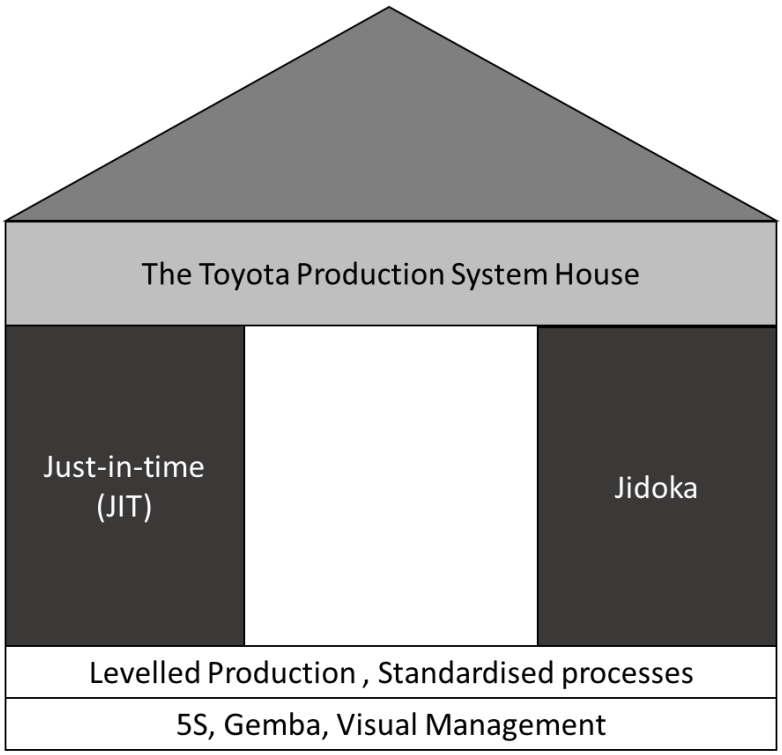


Figure 5 The TPS house adapted from Liker (2003) and Bicheno and Holweg (2017:4)

While Toyota and TPS continue to evolve (Bicheno & Holweg, 2017), the core purpose remains the same, increasing efficiency by reducing waste and keeping people and processes close to heart. TPS relies on Just-in-time (JIT) and Jidoka (automation with human touch). Just-in-time production integrates activities in order to yield minimal inventory levels and high-volume production (Chase *et al.*, 2018). The concept of levelled production (Heijunka) and standardised processes conform to the conceptual attributes of Lean that speak to production scheduling, reduced process strain, communicating, following and improving standards (ElMaraghy & Deif, 2014; Pereira *et al.*, 2016). In accompaniment to the TPS house, 5S serves as a housekeeping practice that can not only identify forms of environmental waste (Randhawa Jugraj & Ahuja Inderpreet, 2017), but allows and facilitates increased process visibility with a place for everything, and everything in it's place (Fabrizio & Tapping, 2006). The notion of Gemba, requires one to walk to floor and observe the inefficiencies at its core, while visual management serve as mechanisms which are intended to guide, manage and control flow and processes at hand (Bicheno & Holweg, 2017). Collectively, these embody the process improvement techniques which drive efficiency with a people-centred approach to continuously adapt and enhance processes and increase profit for an organisation.

Lean makes use of various tools essential for process improvement initiatives. One of the most commonly used tools is value stream mapping (VSM).

2.1.2 Value stream mapping

Value stream mapping is an illustrative approach that allows one to understand the flow of material and information as a product transitioning through the value stream (Rother *et al.*, 2003). Hines and Rich (1997) discuss various tools used to identify and understand the value stream. The objective of this study conducted was to guide future research towards a new decision-making process when mapping the value stream or supply chain. Table 3 defines each tool in terms of its origins with a rating across each of the seven lean wastes. Each rating evaluates the level of correlation and practicality. The notations low (L), medium (M) and high (H) denote the level of correlation and practicality of each lean waste, subject to each form of the mapping tool identified in the research.

Table 3 Origins of seven value stream mapping tools from Hines and Rich (1997)

Mapping tool	Origin	Lean Wastes						
		Over-production	Waiting	Transport	Over-processing	Inventory	Motion	Defects
Process activity mapping	Industrial engineering	L	H	H	H	M	H	L
Supply chain response matrix	Time compression/ logistics	M	H	-	-	H	L	-
Production variety funnel	Operations management	-	L	-	M	M	-	-
Quality Filter Mapping	Unspecified	L	-	-	L	-	-	H
Demand amplification mapping	Systems dynamics	M	M	-	-	H	-	-
Decision point analysis	Efficient consumer response/logistics	M	M	-	L	M	-	-

Mapping tool	Origin	Lean Wastes						
		Over-production	Waiting	Transport	Over-processing	Inventory	Motion	Defects
Physical structure mapping	Unspecified	-	-	L	-	-	-	-

Recommendations allude to industry and research-based approach when selecting a tool that assesses a particular waste. More so, Hines and Rich (1997:63) suggest that an extended value stream setting should address the wasteful activities between organisations and their internal processes for an effective internal waste reduction. These elements are often incorporated in lean diagnostic toolkits, which elaborate on certain value stream mapping techniques.

The following higher levelled sub-section (Section 2.2) will elaborate on Green principles for the purposes of defining Lean and Green in Section 2.3.

2.1.3 Monozukuri

According to Zokaei *et al.* (2017a), Monozukuri embodies the true being of Toyota in accordance with sustainability. This Japanese term directly translates to production, but is "*the older sister of sustainable manufacturing*"(Zokaei *et al.*, 2017a:95). It also stems beyond this, encouraging the respect of individuals and harmonious manufacturing with nature. It can also be tied to sustainable design logic. In a study by Ranky (2007), Monozukuri is voiced as an eco-friendly sustainable design and manufacturing approach which proved to reduce waste within a manufacturing facility in Japan once applying a rule-based approach.

The inherent features that link to sustainable practices within the Lean paradigm have been showcased in the preceding subsections. We now define the Green philosophy in order to further contextualise the Lean and Green paradigm discussed in this research.

2.2 Green philosophy and tools

Simultaneously, consumers, shareholders and regulators are all fixated on obtaining more sustainable products and services (Cherrafi *et al.*, 2017). Green philosophy aims to promote sustainable practices and environmental preservation. More recently than Lean development, green manufacturing has become an emergent initiative which promotes sustainable practices

that reduce the environmental impact of organisations (Dornfeld, 2012). This principle ensures that resources are not depleted but rather consumed in a sustainable manner.

Several green principles strive towards eliminating emissions and negating the harmful implications imposed onto societies. Examples of environmental practices include eco-efficiency analysis and life cycle management (Leme et al., 2018:518). The manufacturing and competitive strategies drive cost, flexibility, quality and time. Similar to the Lean philosophy, green wastes have been established (Zokaei et al., 2017a). The eight forms of green waste are depicted in Figure 6.

Figure 6 Green wastes adapted from Zokaei et al. (2017b:46)

The Green wastes seek to ensure environmental prosperity and sustainable consumption of natural resources. Examples of land contamination and air emissions may originate from volatile organic compounds (VOCs) or other forms of physical waste detrimental to the environment.

2.2.1 Life Cycle Assessment (LCA)

An organisation or country's carbon footprint measures the total carbon emissions directly and indirectly caused by a series of activities accumulated over the life stages of a product (Wiedmann *et al.*, 2016). Caro (2019) defines a carbon footprint as an environmental indicator measuring the overall amount of GHG emissions.

While (CO_2) is one example of a GHG, numerous others, as mentioned in Chapter 1. include gases such as ozone (O_3), methane (CH_4) and nitrous oxide (N_2O) (Gohar & Shine, 2007:1). Standardised GWP units are utilised for measuring the carbon footprint of an organisation. During an LCA, the carbon footprint of all activities is calculated and estimated across the design, implementation, operation and disposal attributed to production or service offerings of an organisation. A LCA can serve as a reputable means to computing GHG emissions, by identifying the stages at which more stringent environmental considerations must be made (Cellura *et al.*, 2018).

The balance between IPCC codes for GHG emissions from energy consumption is also an alternative approach for computing GHG emissions (Cellura *et al.*, 2018). The preferred outcome from any LCA strides beyond product marketability analysis, but rather a means to assess the environment impact of a specific product or service (Ciambrone, 1997). The fundamental goals of a LCA is illustrated in Figure 7.

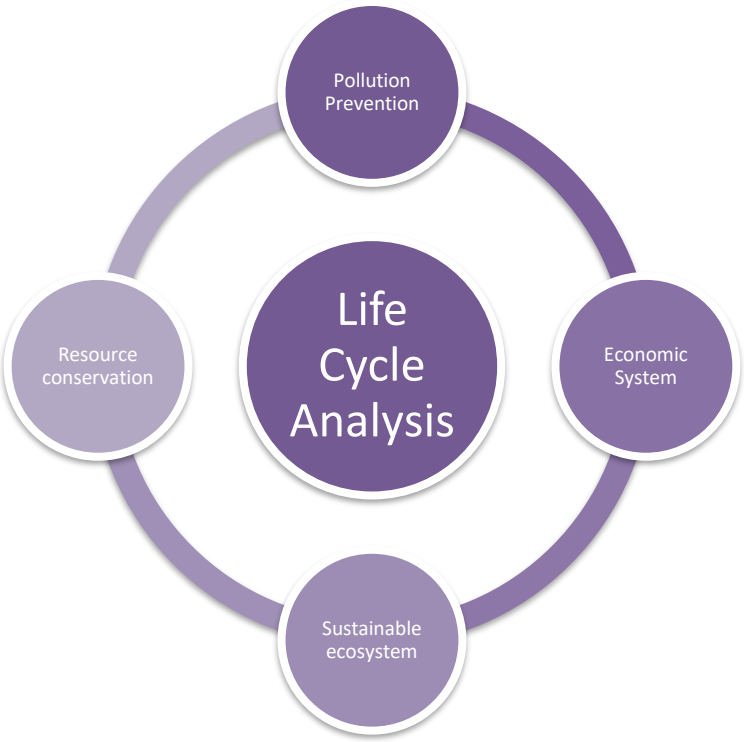


Figure 7 Life Cycle Analysis Goals from Ciambrone (1997:4)

A successful LCA should impose a positive impact on the human health, natural resources, economic system, ecosystem and prevent pollution in a cost-effective manner. Another tool used to promote improved levels of environmental performance is an environmental management system.

2.2.2 Environmental management systems

Due to the increasing environmental awareness, pressures, constitutional government policies, and regulations, organisations are led to embrace green manufacturing or adopt an environmental management system (EMS) policy (Chen, 1997).

According to Fu *et al.* (2017), the World Commission on Environment and Development (WCED) defines environmental management as an all-inclusive activity to reach environmental objectives by planning, organising, coordinating, controlling, and supervision. The selection or adoption of an EMS is determined by the culture, background or customer requirements of an organisation (Hui *et al.*, 2001).

EMS have proven successful in improving environmental performance and certifying achievements when implemented on a large scale (Disterheft *et al.*, 2012). In order to achieve this, EMS serves as a systematic means to apply business management to environmental concerns by developing processes and products that improve competitiveness and environmental performance concurrently (Stead & Stead, 1992).

The application of EMS is not exclusive to improving environmental performance by measuring and assisting organisations to control natural resources during production. It can also be used to assess financial performance based on resource cost and utilisation (Watson *et al.*, 2004). The implementation of EMS has now moved beyond the private sector, but also educational institutions and public sectors. Adopting EMS can be a sound means to address environmental, social and economic issues (Ikram *et al.*, 2019). By incorporating EMS, key performance indicates such as GHG emissions, energy consumption and waste management can be identified and tied to strategic goals in an organisation (Lo-Iacono-Ferreira *et al.*, 2018).

Manufacturing organisations have now been confronted with the goals and aspirations of carbon neutrality and low carbon manufacturing.

2.2.3 Low carbon manufacturing

The manufacturing industries accounts for 36% of carbon emissions and almost 33% of energy consumption (IEA, 2011). Among many environmental and economic pressures imposed, low carbon manufacturing has become essential, provided in does not compromise on productivity and costs (Tian *et al.*, 2019).

Low carbon manufacturing (LCM) is concerned with reducing CO_2 emissions by modifying systems and processes accordingly (Tridech & Cheng, 2011). The following figure represents the main terms which concern LCM.

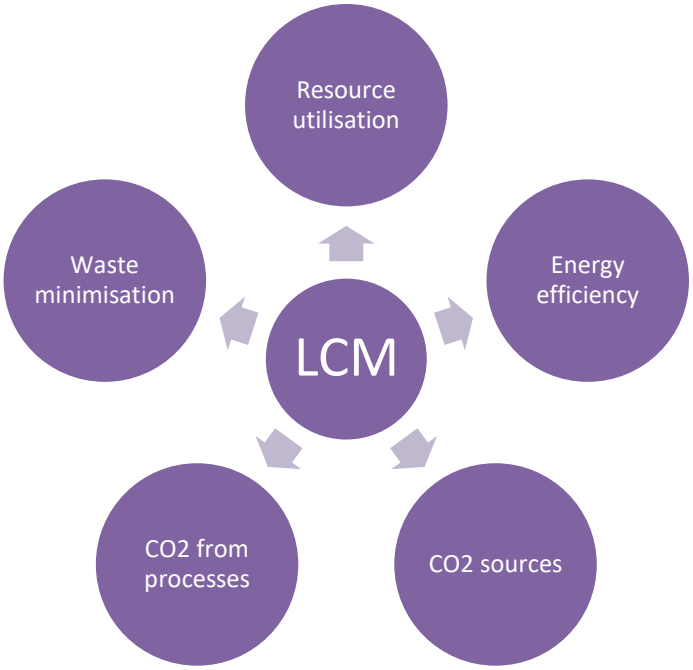


Figure 8 LCM Characterisation redrawn from Tridech and Cheng (2011:4)

The concept of LCM has also been used for supplier development purposes by means of an analytical model (Jharkharia & Das, 2019).

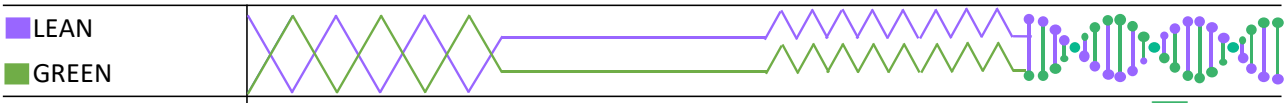
Recently, the European Union have urged their respective industries to strive towards carbon neutrality by the year 2050 (EU, 2020) . Even more so, some seek to achieve zero emissions by specific years. While this is indeed a noble cause, many scholars believe in carbon neutral renewable technologies, or increased technology innovations as a means to achieve this (Giampieri *et al.*, 2019; Zhao & You, 2020).

This method serves as one means to reduce GHG emissions. The principles of VSM, LCA, EMS and LCM have become fundamental concepts within Lean and Green philosophy.

2.3 Lean and Green philosophy and methodologies

Within the Lean paradigm, the combination of Lean and Green principles have emerged in modern literature (Abreu *et al.*, 2017; Leme *et al.*, 2018; Wiese *et al.*, 2015). Research communities have underlined the similarities between Lean and Green principles. Where green initiatives measure environmental performance measures to limit resource consumption levels

and emissions, Lean principles strive for zero waste, higher levels of productivity and customer value satisfaction. Lean and green principles comprise of both Lean and Green manufacturing characteristics to sustain natural ecosystems and society without compromising productivity (Brecht, 2012:47). Figure 9 illustrates the learning maturity stages experienced when adopting the Lean and Green paradigm.



Relationship	**Conflicting**: Polarity between Lean and Green	**Benign**: Both may co-exist, but are non-complementary	**Synergetic**: Positive relationship perpetuated	**Symbiotic**: Lean and green form part of the same strategy
Example	Frequent deliveries rising emissions, whereas lowering emissions reduces productivity	Lean team pursues economic goals whereas green teams pursue environmental goals independently	Reducing product waste reduces green impact simultaneously	L&G strategy for reducing loss imparted to society during entire production life cycle
Stage of learning maturity	**Unconscious incompetence:** Not knowing what you don't know	**Conscious incompetence:** Knowing what you don't know	**Conscious competence** Not knowing what you do know	**Unconscious competence** Knowing what you do know (2nd nature)

Figure 9 Lean and Green maturity stages adapted from Zokaei *et al.* (2017b:56)

As illustrated in Figure 9, various companies may function at different stages of Lean and Green maturity. In the primal stage, companies pursue independent lean and green initiatives which counteract one another. Organisations which fall victim to this stage are those who pursue lean improvement projects under environmental regulations unaware of the relationship between the two paradigms. During the next stage, an organisation may become aware of the association between these two facets and begin separate initiatives that are non-complementary in nature.

However, it is possible for certain organisations to realise this relationship and internalise lean and green practises across operational and managerial levels. In such an instance, organisations reap the reduction of lean and/or green wastes with a relationship that is defined as either synergetic or symbiotic.

The fundamentals of Lean and Green can be further explained using the Lean and Green house from Verrier *et al.* (2016). By building on the learning maturity stages from Zokaei *et al.* (2017a), Verrier *et al.* (2016) guide organisations with the best practices from Toyota in light of recent synergies that have been established between Lean and Green principles and philosophy on a

strategic level. The Lean and Green house (inspired by the Lean Enterprise House) is encapsulated in Figure 10Figure 10.

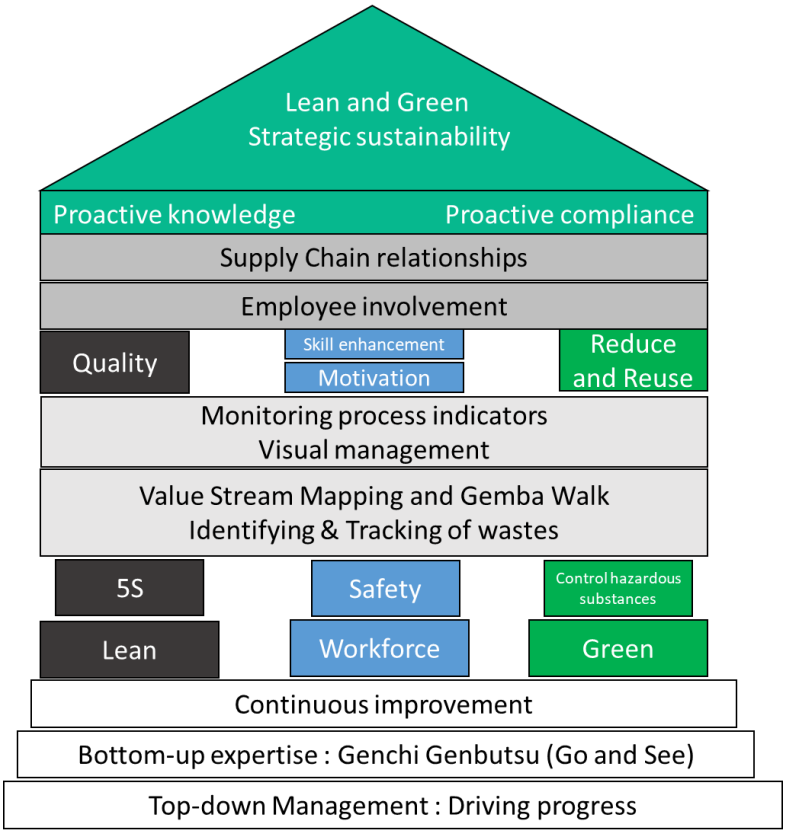


Figure 10 The Lean and Green house adapted from Verrier *et al.* (2016:154)

Continuous improvement, Go & See and Top-Down Management serve as the foundation and have been documented in literature. To construct a lean and green strategic sustainability model (holistic approach), the three fundamentals pillars are Lean (with a focus on 5S), the workforce and their safety (people), and green with efforts made to control hazardous substances (the environment). The first two all-encompassing layers reflect on VSM, Gembas and the identification and tracking of wastes within a process, monitoring process indicators in an environment executing by incorporating visual management.

Wiese *et al.* (2015:4) stated that "*because environmental wastes and pollution are not the primary focus points of lean implementation, the gains may not be maximised in the normal course of a lean initiative*". This argument contests the range of benefits Lean has an organisation; more specifically, those directed towards environmental performance. This innate similarity and shared similarities are further investigated.

2.3.1 Lean and Green paradigm synergies

Lean and Green paradigms share an innate connection that cannot be disregarded. A connotation is made between each lean waste (muda) and environmental impact. This association is demonstrated in Table 4.

Table 4 Lean mudas and their associated waste adapted from Verrier *et al.* (2016:4)

Lean waste (muda)	Related Green impacts
Overproduction	Unnecessary use of energy and raw materials
	Direct output emissions owed to hazardous substances
Unnecessary inventory	Excessive power usage for heating, cooling & lighting
	Potential extra material used (WIP) and rubbish produced from excess inventory violating stock against policies
Transport	Energy use
	Emissions generated
Motion	Potential for more space (energy) and packaging (materials) required
Defects	Waste of raw material and energy
	Management of re-treatment (energy, disposals)
Over-processing	Unnecessary energy and raw materials required
	Additional rubbish & emissions created
Waiting	Spoiled energy and resources
	Potential material damages
Lost human potential	Lost potential for improvement

As showcased by Table 4, the effects of Lean wastes can be correlated with one or environmental waste or form of degradation. This further supports the collective efforts and shared visions that Lean and Green has in achieving productivity and environmental performance. To extend on this notion, Figure 11Figure 11 offers a visual representation thereof.

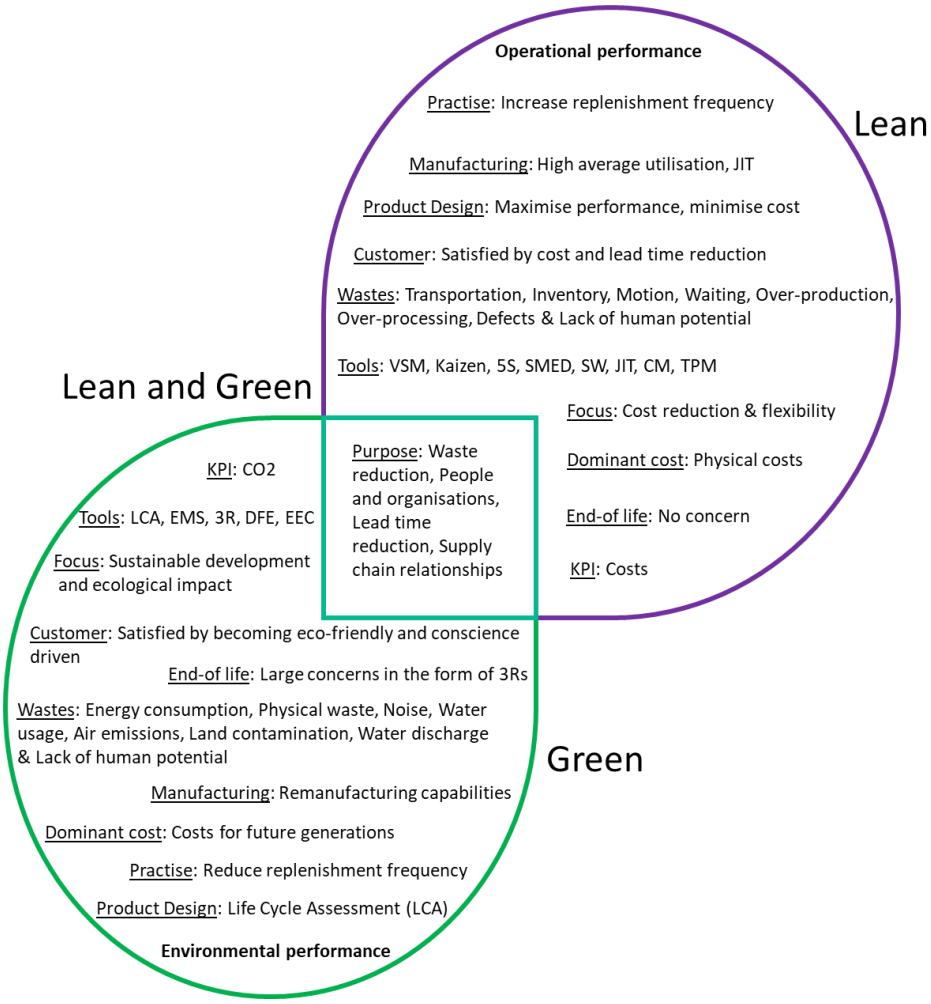


Figure 11 Lean and Green paradigm overlap adapted from Dües *et al.* (2013:5) and Zokaei *et al.* (2017b:45)

This overlap is highlighted in Figure 11, Lean and Green paradigms comprise of respective product design, focus, wastes and tools used to facilitate operational performance (Lean) and environmental performance (Green). However, this hybrid paradigm (Lean and Green) shares the common purpose in reducing waste, recognizing the value of people and organisations

2.3.2 Lean and Green Divergencies

Wiese *et al.* (2015:4) stated that "because environmental wastes and pollution are not the primary focus points of lean implementation, the gains may not be maximised in the normal course of a lean initiative". Despite the convergence between Lean and Green principles, they are still polarized by certain characteristics (Brecht, 2012). One of the most conflicting tradeoffs is the feasibility regions of Lean and Green solutions in relation to zero waste and zero emissions, as illustrated in Figure 12.

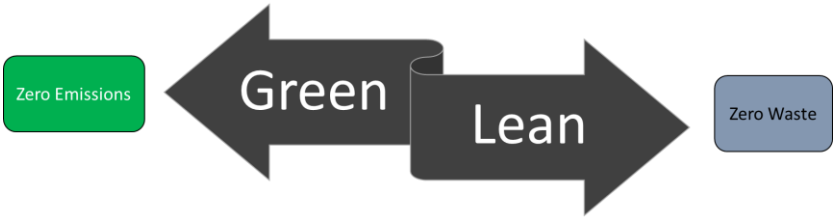


Figure 12 Lean and green polarity

Lean solutions drive cost savings, where concepts such as one-piece flow and JIT are introduced. The effect of these concepts increases the energy usage of certain resources which ultimately increases carbon emissions. Green solutions would aim for minimal emissions, which would result in increased costs incurred due to new procedures, technologies, initiatives, or incentives pursued.

Researchers have contemplated the exact sequence lean and green initiatives should be introduced into organisations. An extensive study by David and Found (2016) explored the common sequence of lean and green initiatives across countries around the world. In summary, the results of the implementation sequences of lean and green individually and collectively are illustrated in Figure 13.

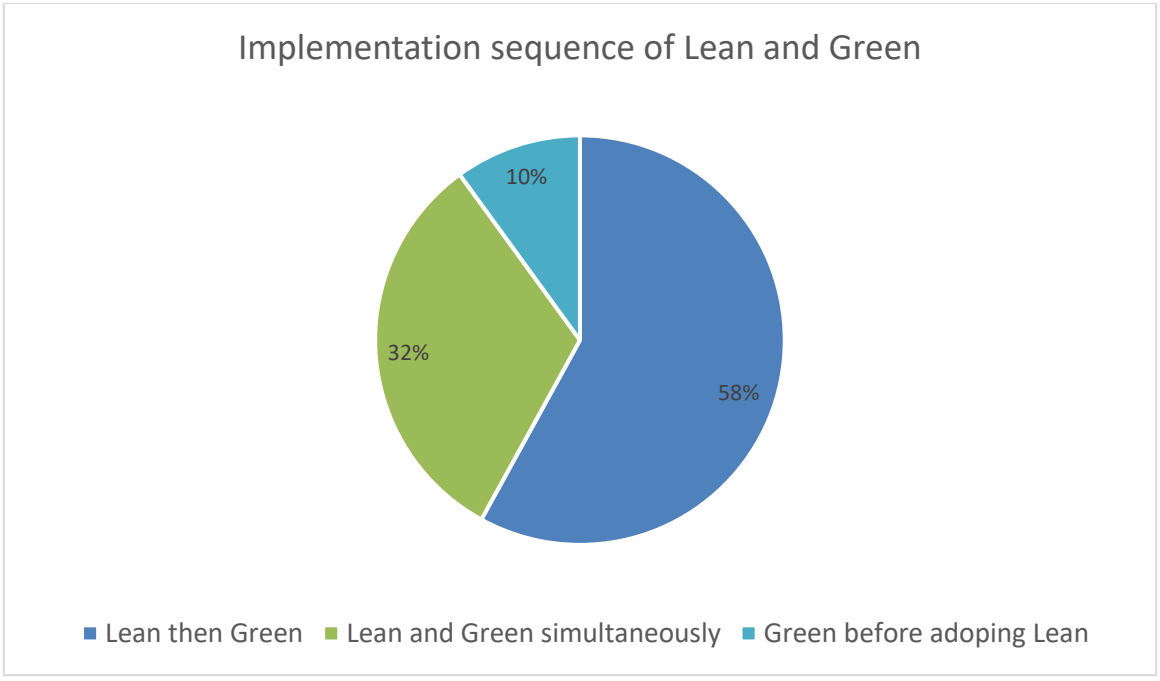


Figure 13 Sequence of Lean and Green initiatives adapted from David and Found (2016:19)

Figure 13 illustrates the most common sequence for implementations composed of lean, followed by green initiatives being introduced. However, Galeazzo *et al.* (2014) conducted an analysis of three pollution-prevention projections undertaken by two manufacturing plants.

It is suggested that future research establishes the characteristics that dictate a preferred initiative sequence between these two paradigms. One of the most commonly used Lean and Green tools is an adaption of value stream mapping (VSM) with the intent of increasing environmental performance (Dieste *et al.*, 2019; EPA, 2007a; Wills, 2020).

2.3.3 Value stream mapping measuring environmental performance

In a similar way in which Lean strives to eliminate waste, Zokaei *et al.* (2017b:67-68) developed a lean and green diagnostic toolkit to eliminate green wastes. The toolkit outlines the scope and usefulness of each technique according to business needs. The Lean and Green diagnostic toolkit is presented in Table 5. An "X" marks a respective technique appropriate to a specific business need to be identified.

Table 5 Lean and green diagnostic toolkit adapted from Zokaei *et al.* (2017b:68)

Business need	System boundary mapping	Green impact matrix	Green big picture map	Eco-maps			Value impact ratio	Lifecyle analysis	Footprint analysis
				Water	Energy	Waste			
Overview	X	X	X				X	X	
Establish focus	X	X	X				X	X	
Scope process	X	X	X						
Walking the flows				X	X	X			X
Detail analysis				X	X	X		X	X
Organisational cross-functioning							X	X	X

Business need	System boundary mapping	Green impact matrix	Green big picture map	Eco-maps			Value impact ratio	Lifecyle analysis	Footprint analysis
				Water	Energy	Waste			
Significant opportunity for innovation		X		X	X	X			

However, adaptations for value stream mapping (VSM) presents opportunities to serve as an effective tool for monitoring flow and factoring in green performance measures. VSM also serves as an overview of a process that has been scoped.

Faulkner and Badurdeen (2014) conceptualised a sustainable value stream map (Sus-VSM) to visualise the process water, raw material, and energy consumption from a satellite dish production line. One of the unique characteristics of this VSM is its ability to capture the amount of water required, consumed and lost during the process stages.

During the development of the (Sus-VSM), variations of VSM were investigated. The following adaptations were identified:

- EPA Lean and environmental toolkit (EPA, 2007a)
- EPA Lean and energy toolkit (EPA, 2007b)
- Environmental VSM (EVSM) (Torres Jr & Gati, 2009)
- Sustainable value chain map (SVCM) (Norton & Fearne, 2009)
- Sustainable manufacturing mapping (SMM) (Paju *et al.*, 2010)
- Energy & environment VSM (EEVSM) (Kuriger & Chen, 2010)
- Lean sustainable production assessment tool (Kuriger *et al.*, 2011)
- Green VSM (Dadashzadeh & Wharton, 2012)

While traditional VSM approaches evaluate total value-adding, and non-value adding time, modern literature has argued that the need for including energy is vital (Prather, 2011:8). An analogy can be made with carbon tax procedures and incentives used to reduce CO2 emissions in South Africa by factoring in energy.

Various other value stream models include the extended energy value stream model (Fischer *et al.*, 2015). This method was applied in a discrete production environment, where the energy

consumption of factories is measured cause-dependently to individual processes (Posselt *et al.*, 2014). A multi-criteria and multi-step selection process are used to determine the most appropriate improvement measures, often referred to as solution elements.

A Lean industrial energy efficiency analysis framework proposed by Cavallaro (2013:381) elaborates on a means of obtaining a future state E-VSM using a Bayesian network. This approach can determine improvement areas in the event of insufficient quantitative data available.

Similar to Faulkner and Badurdeen (2014), Davies (2016:132) listed the guidelines and frameworks used in the development of the WESM framework as follows:

- International performance measurement and verification protocol (DOE, 2012:17,18)
- Energy audit guideline from the Government of Hong Kong Special Administrative Region
- Energy audit manual and tool from the Canadian Office of Energy Efficiency and Natural Resources (CIPEC, 2011:6)

Davies (2016) has also considered energy value stream mapping frameworks created by the Fraunhofer Institute (Erlach, 2013), Institute for Machine Tools and Industrial Management (Reinhart *et al.*, 2010), and the California Manufacturing Technology Consulting agency (Prather, 2011). The applicability and relevance of VSM to assess environmental performance are also made evident in literature that is further elaborated on in Chapter 3.

While it is believed that VSM produces limited detail with an inability to account for high process variation (Gurumurthy & Kodali, 2011), it creates a solution space that supports improvements within a process (Lugert *et al.*, 2018). Value stream mapping has become a popular tool used to spur environmental performance.

2.4 Design science research (DSR)

Design science research is a paradigm in which one seeks to enhance human knowledge by creating innovative artefacts (Coetzee *et al.*, 2019; Hevner *et al.*, 2004). The well designed and developed artefacts generated in this paradigm are believed to contribute new knowledge to literature and real-world applications (Hevner & Chatterjee, 2010). This has become prominent within the information systems community and field of business and management studies (Costa *et al.*, 2020).

According to Van de Ven (2007), this is an appropriate means to engage scholarship with various stakeholders to understand and solve complex problems or opportunities. Examples of innovative

artefacts created by using this paradigm include those that are conceptual (models, frameworks), formal logical instructions, systems design, social innovations, design theories and design propositions (Aken, 2004; Denyer *et al.*, 2008; Hevner *et al.*, 2004; Offermann *et al.*, 2010; Peffers *et al.*, 2012; Vaishnavi & Kuechler, 2015).

However, there are four distinguishable artefacts within DSR. As discussed by Mwilu *et al.* (2016), these are:

- **Constructs**: Means to define and communicate problems and solutions
- **Models**: Representations of real-world situations for enhanced understanding
- **Methods**: Defining processes in order to provide guidance on solving problems
- **Instantiations**: Demonstrate the implementation of artefacts as a functioning system

This framework illustrates three research cycles, namely (Hevner, 2007):

- **Relevance cycle**: Connects the contextual environment with the design science activities
- **Rigour cycle**: Links the knowledge base of scientific foundations with design science activities
- **Design cycle**: Iterates between core activities of developing, building and evaluating the artefact

By incorporating these cycles, a research framework for executing and evaluating DSR is visualised in Figure 14.

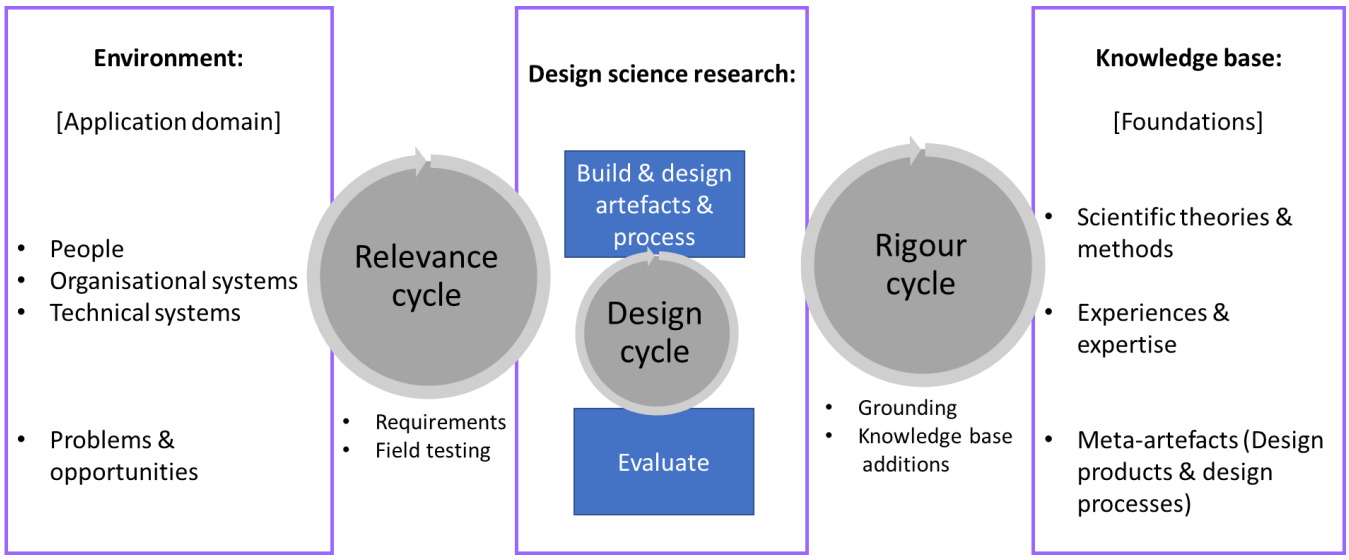


Figure 14 Design Science research framework (Hevner, 2007)

2.4.1 Action Design research (ADR)

Action design research (ADR) is a research method that builds and evaluates artefacts that yield design knowledge (Sein *et al.*, 2011). ADR has the ability to resolve two challenges, namely (1) addressing a problem situation within an organisation by intervening and evaluating, but also (2) constructing and evaluating the capabilities of the artefact being able to address the problem (Sein *et al.*, 2011). Moreover, this perpetuates the building, intervention and evaluation of artefacts which academic scholars and practitioners can apply in an intended context (Coetzee, 2019; Sein *et al.*, 2011). ADR can be executed in four distinct phases, namely (Coetzee, 2019; Sein *et al.*, 2011):

- **Stage 1**: Problem formulation (perceived problem by researchers where artefacts must be informed by theories)
- **Stage 2:** Building, intervention and evaluation (creating a solution space to design an artefact using the platform created in stage 1)
- **Stage 3**: Reflection and learning (learnings during the development of the artefact is applied to a broader class of problems)
- **Stage 4**: Formalisation of learning (outlining accomplishments and outcomes)

The purpose of DSR and ADR strives solve problematic situations (field problems) by designing innovative artefacts (Denyer *et al.*, 2008), an approach which is adopted in this study and discussed further in Chapters 3 and 4. In order to design a GHG reduction framework, the CIMO-logic will be followed.

2.4.2 CIMO-logic

In support of this paradigm, Denyer *et al.* (2008) present the CIMO-logic which serves as a design proposition. This uses prescriptive knowledge, a major component within DSR. This relies on the logic of Bunge (2012), and is fixated on organisational adoption within a managerial level. The following table presents the component and explanation belonging to the CIMO-logic. In order to provide further perspective in line with the nature of this study, the rightmost column discusses the specific degree to which each CIMO component will be used to build the Lean and Green GHG reduction framework.

Table 6 CIMO Logic with relevance to study

Component	Explanation	Relevance to study
Context (C)	External and internal factors, human condition that impacts behaviour	Understanding the core concepts that influence and help quantify GHG reduction (Chapter 1 and Chapter 3)
Interventions (I)	The forms of remedial actions at hand	GHG reduction design elements (Chapter 3)
Mechanisms (M)	An aspect tied a particular, or set of interventions	GHG reduction themes (Chapter 3) and Lean and Green GHG reduction framework (Chapter 4).
Outcome (O)	The overall goal or objective behind the intervention	Seeking to reduce GHG emissions using the Lean and Green paradigm (Testing the framework in Chapter 5)

This method serves as a means of achieving research synthesis, by designing according to an organisation. In order to extend the approach, a qualitative systematic literature review and applied thematic analysis will be used to formalise GHG reduction elements and themes embedded into a conceptual-literature based framework.

2.5 Systematic literature review (SLR)

A systematic literature review is an explicit and reproducible technique for identifying, evaluating and synthesising existing sources of literature developed by academic scholars and practitioners (Fink, 2019). According to Xiao and Watson (2019), the two forms of literature reviews (1) serve as background for empirical studies and (2) constitute a stand-alone work (Templier & Paré, 2015). The former is used to provide context or identify a gap in literature a study intends to fill, whereas the latter is categorised by the purpose of the review in order to provide interpretation on an existing body of literature.

Section 2.5.1 discusses the various forms of SLRs and Section 2.5.2 provides an overview of a generalised process of conducting an SLR, which has been selected for the study and featured in Chapter 3.

2.5.1 Forms of reviews

According to Xiao and Watson (2019:4-5), the purpose of an SLR is to describe, test, extend or critique a body of literature to extract more profound meaning. A summary of these types is embodied in Table 7.

Table 7 Summary of SLR types adapted from Booth et al. (2012:26-27)

Review type	Description
Critical	Demonstrate thorough research with a critical evaluation of the quality. Typical results include a hypothesis or model derived from in-depth analysis and conceptual innovation.
Integrative	Experimental and non-experimental research methods to understand a phenomenon based on findings from theoretical and empirical literature.
Literature review	Current literature studied across a range of academic interest, which may include research findings.
Mapping review / systemic map	Categorises and maps literature for the purposes of identifying areas for future research.
Meta-analysis	Statistical approach to quantify the effect of results documented in quantitative studies.
Mixed studies review/ mixed methods review	Customised review approaches or methods all of which possess review components for the purposes of a study.
Overview	Survey and characterise a body of literature.
Qualitative systematic review/ qualitative evidence synthesis	Themes or constructs identified across various qualitative studies and presented in an integrative or comparative nature.

Review type	Description
Scoping review	Identifying the nature and extent of nature by means of a preliminary assessment of the size and scope of literature.
State-of-the-art review	A review addressing current issues and offers a new perspective on an issue. An area for future research is often identified.
Systematic search and review	Combines the benefits of critical reviews and a comprehensive search process for best evidence synthesis.

Xiao and Watson (2019) conducted a study on the various methodologies for literature reviews by means of a systematic search. The findings were categorised by the literature review typology. For literature reviews intended to extend knowledge, a qualitative or mixed approach may be followed. By focusing on a mixed approach, two review types are presented, namely a (1) critical interpretative and (2) framework synthesis. For the purposes of the research, a mixed methods review will be followed in order to formalise a literature-based framework with design requirements orientated around the aim and objects stipulated in Chapter 1. An additional feature of this particular SLR qualifies the type of review as state-of-the art, given the current framework developed.

2.5.2 General SLR process

The three major phases fulfilled during a systematic literature review are (1) planning, (2) conducting and (3) reporting of the review (Alexander *et al.*, 2019:5). Boland *et al.* (2017:9) provide a 10-step systematic literature review process for an SLR based master's dissertation detailed as follows:

1. **Planning the review** – Considering time and resources to plan the SLR in its entirety critically.
2. **Defining search protocol** – Perform scoping searches to identify background literature to formulate a research question and set inclusion and exclusion criteria summarised by a search protocol.
3. **Literature searching** – Identify academic evidence from bibliographic databases aligned to the research question.
4. **Screening titles and abstracts** – Identify relevant sources of literature by evaluating the title and abstract with the research question and discard irrelevant literature.
5. **Obtaining papers** – Acquire the academic sources of literature that have been screened.

6. **Selecting full-text papers** – Subject literature to the inclusion criteria defined in Step 2.
7. **Data extraction** – Summarise relevant information in tables and figures.
8. **Quality assessment** – Evaluate the methodological quality via a quality assessment tool.
9. **Analysis and synthesis** – Critique and synthesise the data using a narrative or meta-analysis approach.
10. **Writing, editing and disseminating –** Detailing the background, method, results and findings before drawing conclusions from the review and disseminating the findings.

There exist many other methods to scour and analyse existing literature. One of which, is an applied thematic analysis (ATA).

2.6 Applied thematic analysis (ATA)

Applied thematic analysis (ATA) is a qualitative research approach used to investigate and identify themes during the process of data analysis (Auerbach & Silverstein, 2003; Guest *et al.*, 2012a). This method identifies, analyses and reports patterns (themes) within qualitative data (Nikitas *et al.*, 2019).

Applied thematic analysis moves beyond explicitly evaluating texts and focuses on identifying and describing both tangible and intangible phenomena, products, services or systems within the data, which are become the emergent themes (Guest *et al.*, 2012b; Liu *et al.*, 2020). These themes are typically represented by codes used in software programs used for textual analysis. Forms of analysing this data can involve identifying code co-occurrence and graphically representing the relationships between codes (themes) within the set of data (Guest *et al.*, 2012b).

Applied thematic analysis has proven successful in analysis perceptions, words and phrases regarding emergent technologies, governing structures and industries (Cooper *et al.*, 2020; Iyamu *et al.*, 2020; Liu *et al.*, 2020).

2.7 Survey design

A survey helps describe the trends and opinions by studying a sample thereof (Creswell & Creswell, 2017). It allows researchers to obtain information by engaging with a sample of respondents from a defined population (Blair *et al.*, 2013).

As discussed by Mangaroo-Pillay (2020:24), several authors stress the pertinence of reducing measurement errors, emphasising ethical considerations (Bryman & Bell, 2016; De Vos *et al.*,

2011; Fanning & Evaluation, 2005; Sinkowitz-Cochran, 2013). A solution to this is to ensure that surveys conform to the following:

- Survey format should be uncluttered
- Instructions should feature in the survey
- A thank you message should be included at the end of the survey
- A pre-existing scale should be used for responses
- Statements should not be vague or ambiguous
- Statements should not be leading or persuasive
- Statements should not contain unexplained terms, jargon or acronyms
- Statements should be as few as possible, testing for the core aspects of a research study
- Statements should as short as possible
- Statements should not double-barrelled
- Grouping should be utilised for categorising statements
- Surveys should maintain anonymity and confidentiality of the participants
- Statements should be composed in simple and basic English, and presented at the appropriate level
- Each statement should be relevant to the validation and verification process of a research study

Some of these survey design requirements are incorporated into the verification of the survey, discussed in Chapter 4.

2.8 Cronbach alpha

The Cronbach alpha statistic serves to test that a survey or questionnaire have been designed accordingly, and that they are fit for purpose (Taber, 2018). It is deemed the most common measure for internal consistency and reliability (Shamsuddin *et al.*, 2015). The calculation of the Cronbach alpha statistic is as follows:

$$\propto = \frac{k}{k-1}\left(1 - \frac{\sum {s^2}_i}{{s^2}_T}\right)$$

Equation 1 Cronbach alpha calculation according to Vale *et al.* (1997)

With k the number of terms, ${s^2}_i$ the variance belonging to the ith term and ${s^2}_T$ the total score variance across the results obtained. The value of this statistic ranges between 0 and 1, where the variance of the group sum is the sum of the variance of each independent variable . Should

variable share a positive correlation, the sum of variance increases. In this way, we are able to evaluate the internal consistency according to benchmarked values in literature. Table 8 serves as an outline of the internal consistency ratings based on the Cronbach alpha level obtained.

Table 8 Cronbach's Alpha Rule of Thumb (Habidin et al., 2015; Shamsuddin et al., 2015)

Cronbach alpha level	Internal Consistency
$\boldsymbol{\alpha \geq 0.9}$	Excellent
$\boldsymbol{0.8 \leq \alpha < 0.9}$	Good
$\boldsymbol{0.7 \leq \alpha < 0.8}$	Acceptable
$\boldsymbol{0.6 \leq \alpha < 0.7}$	Questionable
$\boldsymbol{0.5 \leq \alpha < 0.6}$	Poor
$\boldsymbol{\alpha < 0.5}$	Unacceptable

The power of this will be used to confirm the construct validity and internal consistency belonging to the survey results obtained in Chapter 3 and further discussed in Chapter 5, section 5.2.4.

2.9 Pressure-state response models

Pressure state response model (PSR) frameworks use indicators that can be used to represent the pressures, transitional state and response within a particular setting (Levrel *et al.*, 2008). Ultimately, pressure-state response models and their indicators can be used to evaluate the intuitive structures regarding pressures of human activities on environmental states, report on political responses and decisions, manage interactions within economical spheres and formalise environmental problems (Gómez *et al.*, 2019; Levrel *et al.*, 2008). For the purposes of further contextualising the study using the supported literature from this chapter, Figure 15 serves as a pressure-state model delineating the scope of this research further.

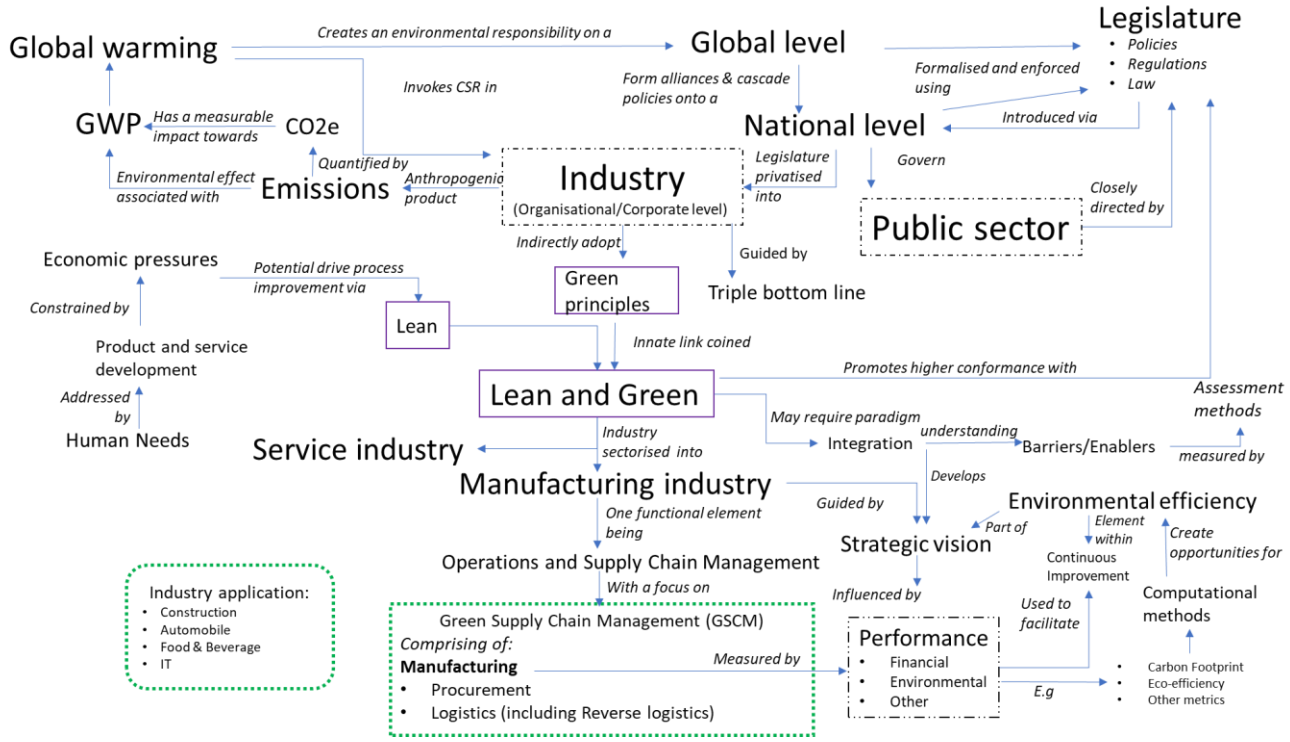


Figure 15 Pressure-state response model framework contextualising study

The issue of GHG emissions is quantified in terms of CO_2e, which has a global warming potential associated with global warming. The rise in anthropogenic activities is dictated by growing human needs and economic pressures related to the respective nature of Lean and Green paradigms.

The innate relationship between these two paradigms led to the new knowledge domain known as Lean and Green. This is applied in various industries with various descriptors (performance measures, computation methods, governance). Other industries aim to address this within multiple sectors, at different levels using legislature and policies to enforce decisions made by numerous stakeholders.

2.10 Chapter summary

As can be witnessed, this study is related to the human needs and anthropogenic activities across various levels and recognises the principles which formed the Lean and Green paradigm. The intricacies of this study tie to various attributes within this paradigm, which are to be explored in the South African manufacturing industry. For the purposes of identifying the fundamental elements for GHG reduction within the Lean and Green paradigm, a qualitative systematic literature review and applied thematic analysis will be used. This approach is used to identify themes and constructs which are pertinent to the establish of a framework. These attributes are

to be further explored during the design, verification and validation of the Lean and Green GHG emission reduction framework for the South African manufacturing industry.

This chapter provided the relevant literature with regards to Lean, Green and the Lean and Green paradigm. In conjunction, the systematic literature review, applied thematic analysis and survey design literature encapsulated within the research methodology were also investigated and studied.

Chapter 3

Systematic literature review and applied thematic analysis

3 Data analysis: systematic literature review and applied thematic analysis

This dissertation uses an article-based approach, and this chapter presents the first article. The title, purpose and findings of this manuscript are summarised as follows:

Title: A Literature-based conceptual Lean and Green framework for GHG emission reduction in the manufacturing industry.

Abstract: Lean and Green is an emerging topic promoting higher levels of productivity while simultaneously reducing the environmental impact of an organisation. Greenhouse gas (GHG) emissions are an evident threat to environmental sustainability, and manufacturing companies are tasked with adhering to best sustainable practices. In South Africa, the need to reduce our environmental impact is of a greater concern than ever before with growing environmental concerns stressed globally. However, no Lean and Green framework exists for guiding the reduction of GHG emissions. Moreover, no initial starting point for such a framework are available in literature.

This study therefore aims to formalise the design elements and themes of a Lean and Green framework for GHG emission reduction within the South African manufacturing industry. A two-stage hybrid methodology was followed, encompassing a systematic literature review (SLR) and an applied thematic analysis (ATA) of 56 publications.

The design of this framework highlights pre-existing Lean and Green models, strategies, tools, metrics and computational methods. The research findings present design elements for a framework guiding the reduction of GHG emissions.

Submission: The content of this chapter was submitted to the **Journal of Cleaner Production August 2020**. The manuscript was returned with feedback. At the time of concluding this dissertation, the feedback was incorporated into a revised manuscript planned for future submission. The sample of the codes generated in ATLAS.ti can be found in Appendix E.

A Literature-based Conceptual Lean and Green framework for GHG emission reduction in the manufacturing industry

Abstract

Lean and Green is an emerging topic promoting higher levels of productivity, while simultaneously reducing the environmental impact of an organisation. Greenhouse gas emissions are an evident threat to environmental sustainability, and manufacturing companies are tasked with adhering to best sustainable practices. In South Africa, the need to reduce our environmental impact is of a greater concern than ever. However, no Lean and Green framework exists for guiding the reduction of GHG emissions in the country. Moreover, no design elements for such a framework are available in literature.

Therefore, the aim of this study is to formalise the design elements and themes of a Lean and Green framework for GHG emission reduction within the South African manufacturing industry. A two-stage hybrid methodology was followed, encompassing a systematic literature review (SLR) and an applied thematic analysis (ATA) of the 56 publications.

The research findings present design elements for a framework guiding the reducing GHG emissions. The design of this framework highlights pre-existing Lean and Green models, strategies, tools, metrics and computational methods.

Keywords: Lean and Green, GHG emissions, design elements, Systematic Literature Review, Applied Thematic Analysis, South Africa

1. Introduction

Greenhouse gas (GHG) emissions are ever-increasing (Yaman, 2019),and this is believed to pose a detrimental effect on the environment (Zheng et al., 2019). Countries around the world have responded to this dilemma. According to Bekun et al. (2019), South Africa is responsible for 42% of GHG emissions in Africa in relation to its economic growth and energy usage. In an effort to reduce the carbon footprint, South Africa (among several other countries) has become a signatory to the Kyoto Protocol in a conscious environmental effort pledging to control GHG emissions (Gohar & Shine, 2007). Policy makers also formed the Paris Agreement, seeking to hold the global average temperature increase below 2°C. Countries all around the world have been confronted with this challenge of reducing the adverse impact on the environment caused by anthropogenic activities (Sharma & Gandhi, 2016).

One of the measures taken by South Africa for this purpose is by legislation. The South African Carbon Tax Act (No. 42483 of 2019) was promulgated in June 2019 (RSA, 2019). The purpose of the act is to provide an imposition of tax on the carbon dioxide equivalent on industries that emit GHGs above a specified threshold per activity. Beyond this effort to introduce carbon tax, however, a larger commitment is needed for sustainable practises.

The principles of Lean and Green offers a new perspective on sustainable production, using its Lean traits to instil continuous improvement from an environmentally responsible standpoint (Dües *et al.*, 2013). Research efforts have explored core enablers and barriers for the successful integration of these two paradigms (Cherrafi *et al.*, 2017; Farias *et al.*, 2019a). Farias *et al.* (2019a) evaluated criteria and practices for lean and green performance assessments by composing a literature-based framework, consequently, deducing performance criteria and practises of Lean and Green.

A future research stream suggests researchers investigate sustainable practices which would lead to increased performance with regards to specific operational and environmental criteria (Farias *et al.*, 2019a). The research provided in this paper extends on this idea, with a specific focus on GHG emissions by investigating methods for quantifying and reducing emissions using Lean and Green. In South Africa, Davies (2016) developed a framework to reduce water and energy consumption using a water and energy value stream mapping approach. However, energy consumption is one approach used to quantify GHG emissions. Until now, no research has focused on reducing GHG emissions by means of Lean and Green in the South African context.

Therefore, the aim of this study is to formalise design elements and themes which guide GHG reduction by means of Lean and Green.

This paper is divided into five sections. Section 2 explains the Lean and Green paradigm, while section 3 outlines the research methodology used to extract the 5 design elements codified through applied thematic analysis. The findings and discussions of each element is detailed in section 4 together with the proposed framework. Finally, conclusions and future recommendations are presented in section 5.

2 Lean and Green overview

Lean is a process improvement philosophy which defines 8 types of "waste" (inefficiencies) that one aspires to reduce or eliminate in its pursuit for efficiency. The term "lean production" first appeared in 1988, and has proven its ability to improve efficiencies in numerous industries (Modig & Åhlström, 2012:76-78). Lean has been applied in supply chain, management, company culture, healthcare and other service industries (Aherne & Whelton, 2010; Chen *et al.*, 2013; Gupta *et al.*, 2016; Mangaroo-Pillay *et al.*, 2019). Its success in manufacturing and service industries is unparalleled. Green is concerned with the societal needs and values in a manner that minimises the environmental wastes of the entire system (Zokaei et al., 2017a). The application of its principles are witnessed in business models, construction, transportation, IT and manufacturing industries around the world (Deng et al., 2017; Duarte & Cruz-Machado, 2013; Orji & Wei, 2016; Seth et al., 2016).

Within the lean paradigm, the combination of lean and green principles have emerged in modern literature (Abreu *et al.*, 2017; Leme *et al.*, 2018; Wiese *et al.*, 2015). Research communities have underlined the similarities between lean and green principles. Where green initiatives measure environmental performance measures to limit resource consumption levels and GHG emissions, lean principles strive for zero waste, higher levels of productivity and customer value satisfaction. Lean-and-green principles comprise of both lean and green manufacturing characteristics in order to sustain natural ecosystems and society without compromising productivity (Brecht, 2012:47).

As previously discussed in section 2.1, the manufacturing industry will be used to conceptualise the design elements and themes required for GHG reduction. In order to achieve this, the research method (outlined in section 3) was followed.

3 Research method

For this study, a hybrid research method was executed, integrating a systematic literature review (SLR) and an applied thematic analysis (ATA) in two sequential stages. The transition between the search results and coded themes are depicted in **Figure 1**. During the ATA, the quotations coded from the various literature sources are distilled into 5 themes.

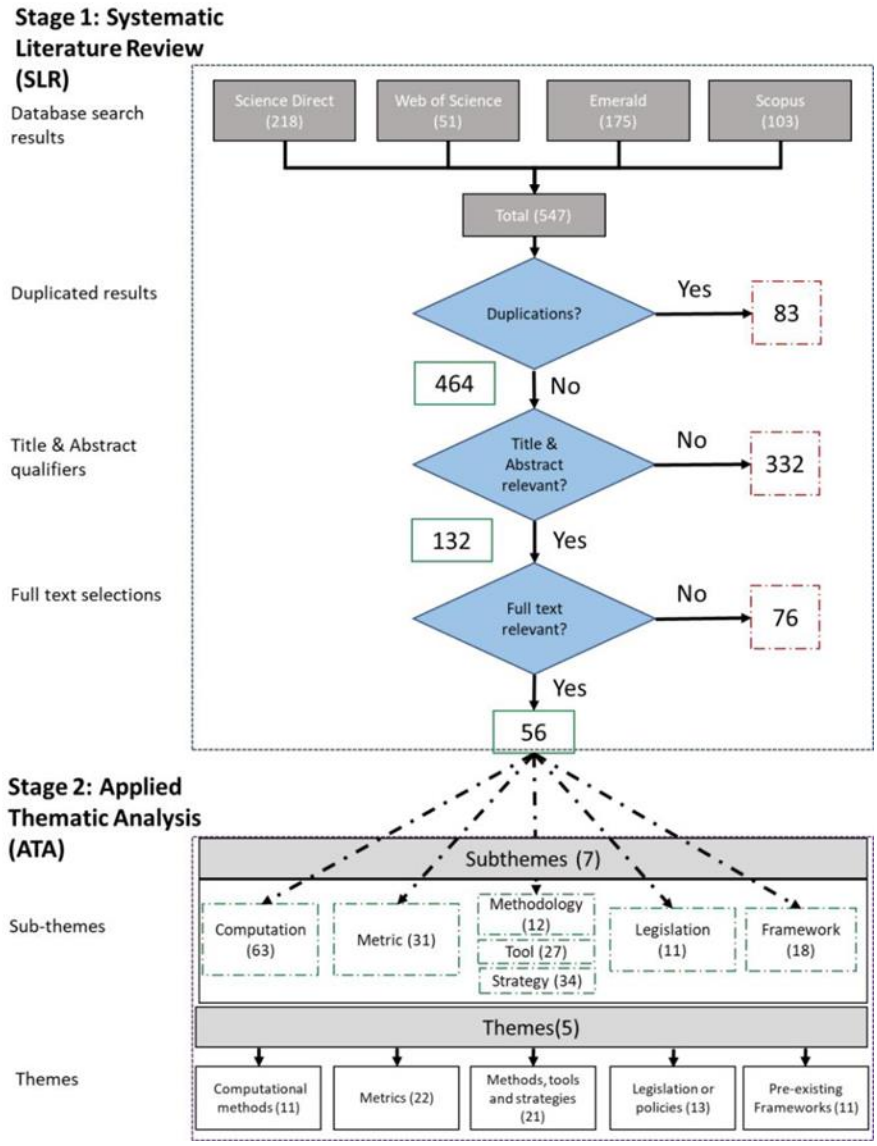


Figure 1 – Publication selection & data extraction process

As illustrated in **Figure 1**, the research method encompasses two distinct stages. Section 3.1 discusses the Systematic Literature Review, while the ATA is explained in section 3.2.

3.1 Stage 1: Systematic literature review

An SLR is an explicit and reproducible technique for identifying, evaluating and synthesising existing sources of literature developed by academic scholars and practitioners (Fink, 2019). It was used to obtain full-text publications relevant to the aim of this study. The SLR process by Boland *et al.* (2017:9) is

comprised of the following steps: (1) Planning the review, (2) Defining search protocol, (3) Literature searching, (4) Screening titles and abstracts, (5) Obtaining papers, (6) Selecting full-text papers, (7) Data extraction, (8) Quality assessment, (9) Analysis and synthesis and (10) Writing, editing and disseminating the findings. However, due to the nature of this study, the last 4 steps were combined and substituted by an applied thematic analysis (discussed in section 4). This modification was made in order to formalise design elements for the Lean and Green GHG reduction framework presented in section 4.6.

During the planning step of the SLR, literature was scoured to enrich knowledge and understanding of the subject matter. The search protocol was formalised in **Table 1**, indicating the different components, selection and rationale followed.

Table 1 - Research search protocol

Component	Selection	Rationale
Keywords	Lean, Green, Framework, Model, Tax, South Africa, emissions	Key terms relevant to the purpose of the study
Platforms	Science Direct, Web of Science, Emerald Insight and Scopus	Reputable platforms for high-quality journals accessible to researchers
Search strategy	“Lean and Green” AND ("Framework" OR "Model" OR "Tax" OR "South Africa" OR "* emission*")	Boolean expressions used for search results more relevant to the purpose of this study
Time-frame	2015-2019*	Deemed the most appropriate time-frame for state-of-the-art literature and literature most relevant
Inclusion criteria	• Review/Research articles or papers in English • Focus on GHG emissions • Within Lean and Green research field • Must conform to time-frame	Ensure the academic integrity and quality of literature is withheld
Exclusion criteria	Publications focused solely on: logistics, supply chain performance assessment, risk analysis, product-service design systems, renewable sources, urban planning, construction, six sigma, transportation, IT or green computing	Refine academic search results for publications most relevant to the nature of this study

**Includes articles that have been accepted for publication before September 2019, but are only available online*

The search protocol was used to screen literature and obtain the papers which adhered to the inclusion criteria. The list of the selected publications is detailed in **Table 2.**

Table 2 – Full text publications selected in study

No.	Author	Title
1	Ramos *et al.* (2018)	A lean and cleaner production benchmarking method for sustainability assessment: A study of manufacturing companies in Brazil
2	Garza-Reyes *et al.* (2018b)	A PDCA-based approach to Environmental Value Stream Mapping (E-VSM)
3	Pang and Zhang (2019)	Achieving environmental sustainability in manufacture: A 28-year bibliometric cartography of green manufacturing research
4	Leong *et al.* (2019)	Adaptive analytical approach to lean and green operations

No.	Author	Title
5	Farias *et al.* (2019b)	An ANP-based approach for lean and green performance assessment
6	Edtmayr *et al.* (2016)	An Approach to Integrate Parameters and Indicators of Sustainability Management into Value Stream Mapping
7	Choudhary *et al.* (2019)	An integrated lean and green approach for improving sustainability performance: a case study of a packaging manufacturing SME in the U.K.
8	Zhu *et al.* (2019)	Application of green-modified value stream mapping to integrate and implement lean and green practices: A case study
9	Fu *et al.* (2017)	Applying the green Embedded lean production model in developing countries: A case study of china
10	Sartal *et al.* (2018)	Are all lean principles equally eco-friendly? A panel data study
11	Belhadi *et al.* (2018)	Benefits of adopting lean production on green performance of SMEs: a case study
12	Leme *et al.* (2018)	Creating value with less impact: Lean, green and eco-efficiency in a metalworking industry towards a cleaner production
13	Farias *et al.* (2019a)	Criteria and practices for lean and green performance assessment: Systematic review and conceptual framework
14	Das and Jharkharia (2019)	Effects of low carbon supply chain practices on environmental sustainability
15	Zokaei *et al.* (2017)	Environment is free; but it's not a gift
16	Caldera *et al.* (2018)	Exploring the characteristics of sustainable business practice in small and medium-sized enterprises: Experiences from the Australian manufacturing industry
17	Caldera *et al.* (2017)	Exploring the role of lean thinking in sustainable business practice: A systematic literature review
18	Cherrafi *et al.* (2019)	Green and lean: a Gemba-Kaizen model for sustainability enhancement
19	Muñoz-Villamizar *et al.* (2019)	Green value stream mapping approach to improving productivity and environmental performance
20	Szymańska-Brałkowska and Malinowska (2018)	Improving company's environmental performance through Green Lean approach
21	Ng *et al.* (2015)	Integrating and implementing Lean and Green practices based on proposition of Carbon-Value Efficiency metric
22	Yun *et al.* (2019)	Interactions in sustainable supply chain management: a framework review
23	Jakhar *et al.* (2018)	Is lean synergistic with sustainable supply chain? An empirical investigation from emerging economy
24	Marco-Ferreira *et al.* (2019)	Lean and Green: practices, paradigms and future prospects

No.	Author	Title
25	BR *et al.* (2016)	Lean management – a step towards sustainable green supply chain
26	Henao *et al.* (2019)	Lean manufacturing and sustainable performance: Trends and future challenges
27	Fercoq *et al.* (2016)	Lean/Green integration focused on waste reduction techniques
28	Bhattacharya *et al.* (2019)	Lean-green integration and its impact on sustainability performance: A critical review
29	Ball (2015)	Low energy production impact on lean flow
30	Fischer *et al.* (2015)	Method for Selecting Improvement Measures for Discrete Production Environments Using an Extended Energy Value Stream Model
31	Carvalho *et al.* (2017)	Modelling green and lean supply chains: An eco-efficiency perspective
32	Barbosa-Póvoa *et al.* (2018)	Opportunities and challenges in sustainable supply chain: An operations research perspective
33	Yeo *et al.* (2016)	Planning for Environmental Sustainability Improvements – A Concept based on Eco-Efficiency Improvement
34	Bhupendra and Sangle (2016)	Pollution prevention strategy: a study of Indian firms
35	Teng *et al.* (2019)	Principal component analysis-aided statistical process optimisation (PASPO) for process improvement in industrial refineries
36	Cai *et al.* (2019)	Promoting sustainability of manufacturing industry through the lean energy-saving and emission-reduction strategy
37	Kumar *et al.* (2015)	Review of Green Supply Chain Processes
38	Moussa *et al.* (2017)	Reviewing the use of the theory of inventive problem solving (TRIZ) in green supply chain problems
39	Ambekar *et al.* (2019)	Role of culture in low carbon supply chain capabilities
40	Greinacher *et al.* (2015)	Simulation Based Assessment of Lean and Green Strategies in Manufacturing Systems
41	Gong *et al.* (2019)	Sustainability investments and production planning decisions based on environmental management
42	Zackrisson *et al.* (2017)	Sustainability Performance Indicators at Shop Floor Level in Large Manufacturing Companies
43	Kumar and Rodrigues (2018)	Synergetic effect of lean and green on innovation: A resource-based perspective
44	Jawahir and Bradley (2016)	Technological Elements of Circular Economy and the Principles of 6R-Based Closed-loop Material Flow in Sustainable Manufacturing
45	Piyathanavong *et al.* (2019)	The adoption of operational environmental sustainability approaches in the Thai manufacturing sector
46	Garza-Reyes *et al.* (2018a)	The effect of lean methods and tools on the environmental performance of manufacturing organisations

No.	Author	Title
47	Amrina and Zagloel (2019)	The Harmonious Strategy of Lean and Green Production: Future Opportunities to Achieve Sustainable Productivity and Quality
48	Dieste *et al.* (2019)	The relationship between lean and environmental performance: Practices and measures
49	Hartini and Ciptomulyono (2015)	The Relationship between Lean and Sustainable Manufacturing on Performance: Literature Review
50	Piercy and Rich (2015)	The relationship between lean operations and sustainable operations
51	Garza-Reyes *et al.* (2018c)	Total quality environmental management: adoption status in the Chinese manufacturing sector
52	Martínez León and Calvo-Amodio (2017)	Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective
53	Singh *et al.* (2017)	Towards zero waste manufacturing: A multidisciplinary review
54	Angelis-Dimakis *et al.* (2016)	Value chain upgrading in a textile dyeing industry
55	Thanki and Thakkar (2016)	Value–value load diagram: a graphical tool for lean–green performance assessment
56	Kurdve *et al.* (2015)	Waste flow mapping to improve sustainability of waste management: a case study approach

Using the search protocol (Table 1), 56 Publications were selected after full text screening. An independent researcher served as a primary reviewer in verifying the search results obtained during the SLR. During the verification process, all the keywords and titles from the 547 publications were screened and filtered, reproducing the same corresponding set of 56 publications used in this study. **Figure 2** illustrates the distribution of these selected publications between 2015 and 2019.

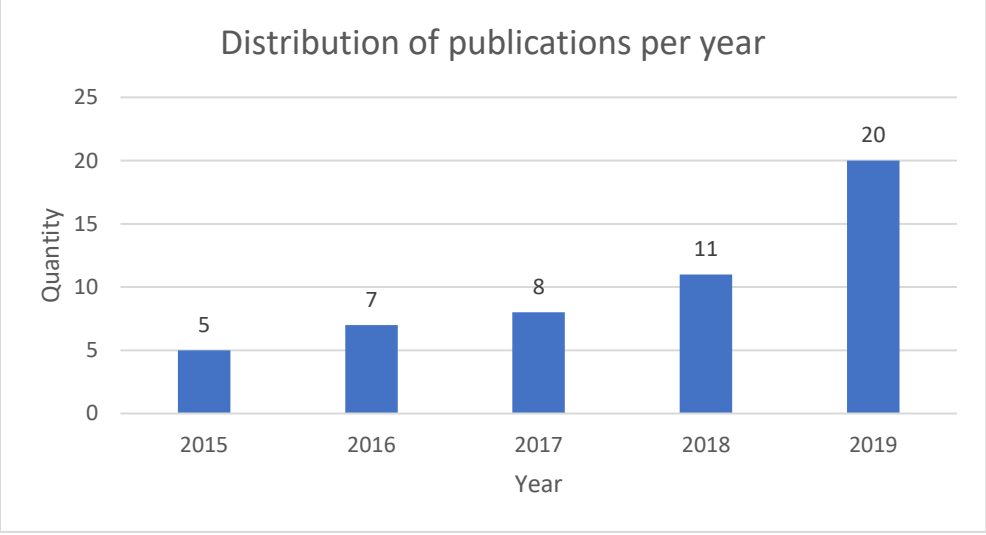


Figure 2 – Distribution of publications per year

The academic interest in Lean and Green is made evident by the increasing distribution of publications under the conditions of the search strategy deployed in this study. In broader contexts, the following table demonstrates the increased publications when searching the term “Lean and Green” from 2012 to 2019 across the same databases.

Table 2 – Increasing trend in Lean and Green research

Year	Scopus	Emerald Insight	Web of Science	Science Direct	Total
2012	10	17	3	11	41
2013	21	7	3	15	46
2014	31	18	9	33	91
2015	14	20	8	34	76
2016	35	30	12	37	114
2017	21	25	10	48	104
2018	31	55	21	58	165
2019	42	74	25	44	185

As voiced in **Table 2,** 2013 saw a sudden decrease in Lean and Green research published in Emerald Insight, which could be subject to fluctuating embargo periods across certain journals which fall under the publishing house. Despite the abnormality in the year 2015 and 2017 across all databases, one can see an increasing cumulative increase in Lean and Green research. This increase may suggest that the advantages of this new paradigm are becoming popular with more research publications reaching scholars and practitioners.

The second stage of the hybrid methodology, the applied thematic analysis (ATA), was used for analysing the selected publications. An overview of this stage is discussed in the following section.

3.2 Stage 2: Applied thematic analysis

ATA is a form of qualitative research performing data analysis in order to identify and investigate identified themes (Auerbach & Silverstein, 2003; Guest et al., 2012). The ATA facilitated the data extraction, analysis and synthesis of the literature. The full-text papers were subjected to coding within ATLAS.ti software for textual analysis.

During the data extraction process, seven sub-themes were identified and further distilled into five themes (Castleberry & Nolen, 2018:6-7; Coetzee et al., 2019; Stafford et al., 2009). During this process, relevant key words, equations, figures and sentences were translated as design elements within each of the themes. These themes each contain design elements for the Lean and Green GHG reduction framework discussed in section 4.5.

During the analysis, the relationship between each of the 5 themes and their design elements were critiqued. Here, the trends and discussions from academic scholars were used to map the relationships illustrated in the framework.

For the synthesis of the literature, the conceptual Lean and green framework for GHG reduction consolidates all of the relevant literature for the purposes of this study.

4 Findings and discussions

The aim of the study was to formalise design elements and themes for GHG reduction by means of Lean and Green. A SLR and an ATA was used to scour state of the art literature, extract, analyse and synthesize the findings. This section presents the details from each of the five themes formalised during the ATA, which will be used to develop the conceptual GHG reduction framework:

- Theme 1: Computational methods (Section 4.1)
- Theme 2: Metrics (Section 4.2)
- Theme 3: Methods, tools and strategies (Section 4.3)
- Theme 4: Legislation or policies (Section 4.4)
- Theme 5: Pre-existing frameworks (Section 4.5)

The following subsections discusses these themes with their respective design elements. These findings were used to further conceptualise the Lean and Green framework for GHG reduction introduced in section 4.6.

The following subsections discusses these themes with their respective design elements. These findings were used to further conceptualise the Lean and Green framework for GHG reduction introduced in section 4.6.

4.1 Computational methods

Computational methods are used to calculate and study complex systems. The array of computational methods found during the SLR have been documented in **Table 4** with the generalised approach and computation method observed. The parenthetical numerals correspond with the full-text paper numbers outlined in **Table 2**.

Table 4 - Summary of Theme 1: Computational methods

Approach	Computational methods	Paper
Analytical	Optimisation	(3;4;29;32;35;37)
	Fuzzy logic	(3)
	Structural equation modelling (SEM)	(8)
	State space modelling	(36)
Statistical	Design of Experiments	(27;33)
	Simulation	(2;3;68;32;40;48)
Standardised guidelines	GHG guidelines	(6;14;42)
	Carbon footprinting	(4;6;7;14;21;28;33;40)
	Input - output analysis	(3;38)
Financial	Cost profiling	(40)
	Data Envelopment Analysis	(3)

According to the results from **Table 4**, the most popular computational methods include optimisation, simulation and carbon footprinting. Optimisation methods included genetic algorithms, metaheuristics and multi-objective optimization (Taddeo *et al.*, 2019). Optimisation and simulation methods require

large datasets, whereas carbon footprinting serves as an efficient alternative for calculating carbon emissions in the absence of adequate data (Angelis-Dimakis *et al.*, 2016). Several advanced carbon footprinting and eco-efficiency methods evaluate process activity chains or activities for an in-depth analysis across each production stage (Ng *et al.*, 2015). Many of these models evaluate an assortment of performance measures – each with their own desired outcome. Based on the circumstances of pre-existing data, the urgency and complexity of the problem pertaining to GHG emissions, an appropriate computational approach must be selected.

Many optimisation models incorporate models which are driven to solve for optimum solutions with regards to financial, productivity or environmental performance measures. Several models factor emissions as a constraint or use financial costs, energy, industrial discharge to quantify emissions. Examples of computational methods include standard optimisation models (Harris *et al.*, 2014; Kumar *et al.*, 2015), structured equational modelling (SEM) for environmental performance or state space modelling (Cai *et al.*, 2019).

A simulation imitates the operation and behaviour of real-world processes or systems using models developed to run over time (Banks *et al.*, 1996). Some of these methods can be used to amplify the accuracy of certain environmental performance measures. Greinacher *et al.* (2015) developed a simulation factoring energy consumption and eco-efficiency values with an I/T/O model for cost time profiling. The output measures the cost-time profiles and CO_2-cost profiles per machine process. The simulation provided detailed analysis of times, costs, energy and material efficiency of a manufacturing system. With reasoning from this, time, costs, energy and material consumption are critical parameters for computing GHG emissions.

Design of experiments (DoE) was another statistical approach witnessed in the literature. Design of experiments is an empirical approach for the purposes of screening, understanding, improving and optimising a system (Montgomery, 2013). DoE can be used to understand variable effects, their interactions and their influence on a specific performance measure. In a study conducted by Teng et al. (2019), DoE was used to determine and reduce the effects of emission related variables in order to ensure environmental performance. However, Design of experiments is not exclusive to variable significance testing. Following a methods based analysis, Fercoq et al. (2016) used design of experiments to measure solid waste management performance using the influence of different Lean and Green.

Emissions can be quantified using the process and module (Greinacher *et al.*, 2015:4). A standard carbon footprint is calculated using the product of the average consumption of a resource from an activity and its standard emission factor (Choudhary *et al.*, 2019:5). GHG guidelines include ISO 14 067, Defra 2010, PAS 2050 and the Greenhouse Protocol. The Department for Environment, Food and Rural Affairs (DEFRA) of the UK have urged people to live more sustainable since 2005 (Eppel *et al.*, 2013). DEFREA also provides businesses with guidelines for reporting energy usage and GHG emissions according to energy and carbon reporting standards. Such protocols have enabled organisations and environmental agencies to create and adhere to sustainability initiatives. It is therefore pivotal that any environmental regulatory body, country or organisation must be guided by GHG protocols or standards.

While various approaches are used to calculate, monitor or improve productivity in an environmentally conscious manner, no preferred method was observed. Certain analytical approaches adopt a complex computational method to address environmental performance, whereas other methods rely purely on guidelines. Several authors combine numerous metrics, but most of the computational methods factor an

efficiency or environmental measure quantified according to time, CO2 or its financial cost. In contrast, a new or previously acclaimed metric is often consulted - as discussed in the following section.

4.2 Environmental Metrics

Metrics are used to link the strategy and form of execution of an organisation in order to create ultimate value (Melnyk et al., 2004). This subsection considers the environmental metrics pertaining to GHG emissions (**Table 5**). This table coincides with the textual data coded in ATLAS.ti. Each of the environmental metrics are associated with the text that appeared in the paper numbered referenced in the rightmost column. Furthermore, categories were created in order to class each metric under their collective purpose or idea.

Table 5 – Summary of Theme 2: Environmental metrics

Category	Environmental Metric	Paper no.
CO_2	Carbon efficiency	(4;8)
	Carbon footprint (CO_2e/ton)	(3;4;6;13;14;22;25;26;41)
	Carbon value efficiency	(13;19;21)
	Low carbon capabilities	(39)
	Carbon intensity	(10;39)
	Carbon dependency	(39)
	Carbon exposure	(39)
	Carbon risk	(39)
	Cost assessment	(32)
Emissions	VOC emissions	(26;27)
Energy	Energy consumption (Kwh/h)	(2;3;5;11;14;16;17;19;22;26;36;39;52)
	Energy efficiency	(40)
	Energy performance score (EPS)	(22)
Efficiency	Eco-efficiency	(12;22;23;31;54)
	Productivity	(21;26)
	Operational efficiency	(22)
	VSM value adding/non-value adding time	(13;19)
Financial	Product labelling cost	(22)
	Operational cost	(26;32)
	Net economic output (NEOi)	(53)
Indices	Lean-green indices	(4;5;21)

Based on the findings obtained from the publications selected in this research, **Table 5** suggests that academic scholars considerCO_2e/ton as a potential metric. This is owed to its CO_2 policy reporting functionality, but also for its opportunity to create new performance measures that can be monitored to improve environmental efficiency.

Ultimately, the carbon footprint can be used to assess the performance of a green supply chain (BR *et al.*, 2016:5). According to Leong *et al.* (2019:3), the carbon footprint is a key component when measuring environmental effects. Das and Jharkharia (2019:6) suggest that a carbon footprint analysis calls for systematic tools and methodologies. Examples of such tools include SCEnAt and SimaPro, which can be used for life cycle analysis across the entire supply chain. In this way, organisations can also rely on existing software programs to facilitate or enable them to achieve GHG reduction in their industry.

A CO_2 footprint indicator is a consumption-based indicator describing GHG emissions from human activities. The CO_2 emission can be calculated using the operational hours, the energy or resource usage by a machine and the GWP of the component (Leong *et al.*, 2019:9). The CO_2 footprint indicator can still be used for other GHG's by reverting to the CO_2 equivalent. Mitigation strategies driven by this indicator has proven to be efficient with regards to cost reduction (Alvarez *et al.*, 2016). A CO_2 metric can thus serve as a guide for organisations to conceptualise and deploy environmental strategies which improve their operations.

Energy consumption presents itself as a sound means to measuring sustainability. Das and Jharkharia (2019:5) argue that the audit and analysis of energy consumption during production has an indirect benefit on GHG emission reduction. The energy intensity also provides an alternative perspective on energy efficiency using its ratio between energy consumption and GDP of a country (Zha *et al.*, 2019). The energy intensity and cost per unit manufactured share an inverse relation (Davies, 2016:28). Therefore, an attempt to save on the cost per unit can be reached by increasing the energy intensity, thereby improving the energy efficiency and reducing GHG emissions.

A low carbon supply chain aims to reduce the total carbon footprint by analysing the procurement, manufacturing, storage, logistics and recycling stages within the supply chain (Das & Jharkharia, 2019). The focus of a low carbon supply chain is to reduce energy consumption, pollution, and emissions by improving the efficiency of direct or indirect activities. In order to categorise carbon capability, the corporate carbon performance is studied. This can be segmented into the carbon intensity, carbon dependency, carbon exposure and carbon risk. The Supply Chain interactions and management become vital contenders for a GHG reduction framework.

The carbon intensity measures the quantity of CO_2 expressed as the amount of carbon per US dollar (Bank, 2019). According to Ambekar *et al.* (2019), the carbon intensity is dependent on the low carbon practises used within a supply chain as its' targets govern the degree of carbon dependency. Ultimately, carbon emission reduction leads to a reduced level of carbon emission which improves the carbon intensity of an organisation.

The carbon risk approximates the changes in an organisation's degree of carbon exposure (Hoffmann & Busch, 2008). A low carbon supply chain is reliant on members aware of their carbon risk by limiting their carbon exposure. Furthermore, carbon performance targets must be met by understanding carbon dependencies, increasing the carbon intensity and introducing low carbon practises. Within a manufacturing environment, this can be met by using environmental performance measures that members within an organisation are all familiar with.

Once the desired metric(s) and computational method is selected, the next step is to deploy an appropriate method or tool using a strategic approach. The next section will discuss various Lean and Green methods, tools and strategies discovered during the ATA.

4.3 Lean and Green methods, tools and strategies

In order to facilitate GHG reduction, various Lean and Green tools and methods could be considered. For the effective implementation thereof, a clear strategy needs to be conceptualised (Bhupendra & Sangle, 2016). **Table 6** summarises strategies associated with respective tools and methods used to reduce GHG emissions, as revealed during the ATA. Some of these aspects also pertain to knowledge domains which share similar objectives to the Lean and Green paradigm.

The principles of waste management via 3R (Reduce, Reuse, Recycle) has established a reputation for strong lean waste reduction, so much so that it is considered a main practise within Lean and Green (Fercoq *et al.*, 2016; Piyathanavong *et al.*, 2019). Developing a recycling policy within organisations reduces the carbon footprint per product. Another strategic approach which indirectly reduces GHG emissions, is through energy efficiency, reduced VOC usage, evaporative based cooling systems and low power lighting systems (BR *et al.*, 2016).

For pollution prevention, the environmental driving force is to reduce emissions, effluents and waste. Whereas continuous improvement (CI) is stipulated as the key resource with the competitive advantage being reduced costs. The suggestion of CI alludes to kaizen being a contributing factor in the pursuit of GHG reduction.

The understanding of pollution prevention policies and their results affect the success rate of projects within a company (Bhupendra & Sangle, 2016:5). Management levels of organisations must provide sufficient training and understanding across the entire organisation for an effective strategy to realise. The three lean methods closely associated with emissions management are value stream mapping, TPM and the flow principle (Caldera *et al.*, 2017:9). The use of traditional VSM and environmental VSM was ever-present during this research. VSM can be used in its traditional sense, combined with new performance metrics and environmental measures, or be supported by software for thorough insight. However, it is believed that the traditional indicators of the VSM tool do not correctly associate productivity with environmental factors (Muñoz-Villamizar *et al.*, 2019:5). Dieste *et al.* (2019) advises that applying or adapting VSM unveils environmental opportunities which harmonise with kaizen, 5S and supply chain management.

In spite of lean facilitating 5S and TPM, it is thwarted by regulations which hamper environmental practices (Martínez León & Calvo-Amodio, 2017). Therefore, to overcome this challenge, regulations need to be recognised as part of any organisations vision and more importantly, part of any improvement initiative.

Examples of adapted Value Stream Mapping tools include the Environmental Value Stream Map (E-VSM) (Garza-Reyes *et al.*, 2018b), green-modified value stream map (Zhu *et al.*, 2019), sustainable value stream mapping (SVSM) (Sartal *et al.*, 2018), material-value stream mapping (MVSM) (Fu *et al.*, 2017) and waste management using VSM (Edtmayr *et al.*, 2016). Other VSM adaptations shift their focus on emissions more extensively. A carbon-value efficiency VSM (CVE-VSM) by Ng *et al.* (2015) demonstrated a 29.9% carbon footprint reduction using time and carbon efficiency. In order to follow Lean and Green practises, a form of performance mapping is required to create meaningful value.

Within the Lean and Green paradigm, much research is invested in understanding conflicting practises in accordance to Lean and Green (Zokaei *et al.*, 2017). The lean tool with the most significant environmental effect is just in time (JIT) with regards to replenishment frequencies. JIT enforces low inventory levels with more frequent transportation, ultimately creating pollution and reduced environmental performance due to CO_2 emissions and additional packaging (Dieste *et al.*, 2019; Martínez León & Calvo-Amodio, 2017; Sartal *et al.*, 2018).

Table 6 – Summary of Theme 3: Tools and methods strategy for GHG reduction

Strategy	***Method or Tool***				
Maximise resource efficiency (3,26,34)	Increased resource consumption (26;37)	Resource based view (43)	Reduce material consumption during production (14;37)	Maintenance (46): TPM (8;11;13;16;28;46;48;49;52)	
Policy analysis (3,23)	Implement ISO 14 000 (14)	Environmental compliance (23)	Energy auditing (13;23)	Environmental audit (34)	
Supply chain management	Supplier training and assessment (14)	Minimising inventory (13;27)	Replenishment frequency (27;52)	Reduce lead time (13)	
Low carbon practises (14)	Environmentally friendly purchasing (14;25)	Low carbon purchasing (14)	Emissions trading, carbon credit investment (17)		
Technology evolution (9)	End-of-pipe control technology (14)	Technology transfer (14)	New technology (20;32)	Cleaner technology strategy (CTS) (34)	Group technology (13)
Environmental management practices (9,13,14,17,25, 45)	EMS (14; 31) certifications (11)	Waste flow mapping (17;21;56), Green Performance Mapping (42)	Sustainable/Environmental Value Stream mapping (2;4;8;9;10;17;19;21;28;30;35; 55)	Housekeeping practises (13;34): 5S (1;11;13;16;19;43;46;47;48;49;50;52)	
People management (17)	Top management support (14)	Management helix (Smith et al., 2010) (17)	Respect for people (RFP) (10) and lean management (28)	Leadership and people involvement (13;18;34), employee engagement (17)	Human Resource Management (48)
Harmonious manufacturing (Monozukuri) (15)	Cleaner production (1;3;17;38;45)	6R-based Closed-loop Manufacturing (44)	Cellular manufacturing (1;13;17;47;49)		
CSR (22, 48)	Managing Triple Bottom Line (14;27;28;39)	Performance across each TBL pillar (26)			
Carbon footprinting (CF) analysis (25)	Categorise CF per unit (25)	Life Cycle Analysis (45;53)	CF accounting (14)		

Strategy	***Method or Tool***					
Energy efficiency (29,36)	Reduced energy consumption (16;17;32)	(EPA) Lean and environmental toolkit (2;28)	Energy analysis (14)			
Sustainable business practices (45)	Circular economy (45;46)	Natural- Resource-Based View (16)	Green marketing (39) & Knowledge sharing (14)	Regenerative development (16)	Benchmarking (1)	SWOT (35)
Environmental emissions	Emissions management (17)	LESER (36)	EEC (5;13;36)	Emission reduction strategies (2;14)	Emission identification (2)	
Traditional Lean	Kaizen event (1;16;18; 21;28;43;46;47;48;51)	VSM (1;7;13;17;46;47;48)	JIT (7;9;10;12;45;47;51)	Jidoka (10), Gemba (18) & Kanban (11;52)	SMED (12;13;48;49;52)	Pull approach (17)
Traditional Green	Input-output analysis (3;40)	Re-cycling of wastes (16;22;25;36;43;44;51)	Waste hierarchy (13;27;45;53) & Waste Management (39)	Eco-efficiency improvement (33)		
Quality measures	TQM (13;48)	TQEM (51)				
Other strategies, tools and methods	LESER (36)	Carbon- value efficiency methodology (17)	5 Why (16)	Standardised work (1;50)	Impact ease matrix (18)	Competing values framework (CVS) (39)
	Ishikawa (21)	TRIZ (38)	A3 report (15;16)	Strategic planning, affinity diagram (18)	PDCA (16)	

Martínez León and Calvo-Amodio (2017:8) found that one-piece flow, JIT, SMED, Andon, Kanban and mass customisation create negative environmental effects due to no reduction in CO_2 emissions or its increase in waste or energy consumption. In contrast to this opinion, the effect of JIT can facilitate reduced CO_2 emissions. This is owed to the lower levels of energy consumption due to less storage space reliant on support facilities. Lower inventory levels reduce obsolete products which could have posed a threat the environment. This includes industrial discharge and Volatile Organic Compounds (VOCs).

A survey questionnaire by Garza-Reyes et al. (2018a) captured 250 responses noting the effects of lean tools on environmental performance within manufacturing industries globally. The lean tools studied were JIT, automation, kaizen, TPM and value stream mapping. Using structured equational modelling (SEM), it was found that TPM and JIT share a strong correlation to environmental performance in terms of pollutant releases. The findings by Garza-Reyes et al. (2018a) advise manufacturing organisations to use TPM as a first resort and suggest that automation and VSM will not improve environmental performance. This strengthens the reasoning behind researchers adapting VSM within an environmental context, stressing its high potential in improving environmental and operational efficiency.

Maintenance and housekeeping are closely linked with reducing direct and indirect emissions during production. TQEM strives to eliminate waste and pollution by assimilating TQM principles and environmental strategies (Garza-Reyes et al., 2018c). General housekeeping practises such as 5S allow for easy waste identification. Many scholars have expanded on this concept by introducing 7S, a housekeeping practise which encompasses 5S with safety and sustainability. The combined use of VSM and 7S in a study by Vinodh *et al.* (2011) revealed that the principles are complementary, and its collective effort leads to environmental preservation. Therefore, housekeeping and maintenance are considerable elements for the GHG reduction framework.

In an extensive bibliometric analysis of 220 papers by (Pang & Zhang, 2019), research was categorised according to aspects assessing decision levels within the environmental pillar. From this pillar, CO_2 served as the most recursive aspect assessed with 28% of all the papers using CO_2 to drive strategic decisions, 7% on a tactical level and 1% on an operational level. This suggests that CO_2 studies provide the greatest aid to organisations on a strategic decision level more than any other.

Cleaner production (CP) serves as an opportunity to reduce environmental impacts (Ramos *et al.*, 2018). CP integrates economic, environmental and technological strategies to products and processes in order to increase resource efficiency. According to Ramos *et al.* (2018), CP reduces raw material consumption and creates ease of compliance with environmental legislation. Some organisations also redirect decisions according to a cleaner technology strategy (CTS). CTS focuses purely on production and consumption to reduce negative effects onto society and the environment (Bhupendra & Sangle, 2016). Investing in new technologies has proven to reduce air emissions, provide cost savings and create a better working environment (Szymańska-Brałkowska & Malinowska, 2018).

A benchmarking method suggested by Ramos *et al.* (2018:4) provides a deeper understanding of a company's activities in relation to cleaner production. Questionnaire results revealed that companies with only ISO 9001 displayed less adherence to cleaner production processes, as opposed to those were both ISO 9001 and ISO 14 001 certification. These findings suggest that the combination of the two international standards are more beneficial and aid organisations in achieving cleaner production status.

Circular economy (CE) theory focused on restorative or regenerative industrial systems which use a value retention process in order to maintain materials, resources and minimise waste (Haupt & Hellweg,

2019). According to Kristensen and Mosgaard (2020), the association between CE and sustainability are one of the following three forms, that CE is (1) a condition for sustainability, (2) share a beneficial or (3) compensatory relationship. Countries such as South Africa, the UK, Thailand and India have made use of circular economy for its cost reduction properties (Garza-Reyes *et al.*, 2018a; Mativenga *et al.*, 2017; Piyathanavong *et al.*, 2019). Thus, Circular Economy principles can be considered as a design element for GHG reduction in the South African manufacturing industry.

Another novel approach to GHG reduction is the carbon culture of an organisation. The use of this philosophy allows organisations to obtain low carbon capabilities by understanding and basing strategic decisions according to their carbon culture and determinants.

The vast array of strategies shows the numerous strategic directions organisations could follow to reduce GHG emissions. Each strategy relies on a financial component, a degree of regulatory compliance, elements from an established set of principles, a methodology or highly specific subject matter. In order to identify forms of regulatory compliance, various legislation and policies were retrieved during the ATA and discussed in the following section.

4.4 Legislation or policies

Product quality and regulations guide manufacturing organisations in making responsible decisions. ISO 14 000 serves as an international standard used to stipulate the requirements for an environmental management system (Das & Jharkharia, 2019; ISO, 2015). **Table 7** demonstrates the findings from the ATA with regards to legislation and polices.

Table 7 – Summary of Theme 4: Legislation or policies

Form of legislation	Paper no.	Objective
Policies	(3)	Guidelines proposed by an institution or agency
Carbon trading & Carbon tax	(39)	Trading credits for CO_2emissions or incurring tax obligations
ISO 9000	(28;46;49;50;51)	International standards on quality management
ISO 9001	(1;28;43)	Quality management systems based on customer satisfaction (Souza & Alves, 2018:5)
ISO 14 000	(1;9;14;22;28;45;50)	Environmental management systems for environmental performance which includes greenhouse gases, carbon footprint of products, requirements and guidelines for quantification, communication and auditing
ISO 14 001	(1;5;13;14;22;23;24;31;34;49)	
ISO 14 064	(41)	
ISO 14 067	(14;33)	
ISO 14 004	(25)	Guidelines for environmental auditing
ISO 14 010	(25)	
ISO 14 011	(25)	
ISO 14 012	(25)	
ISO 50 001	(10;43)	Energy management system standards

A form of carbon governance is perpetuated by environmental management systems (EMS). Another means to reducing carbon emissions is achieved using a carbon trading strategy. This involves carbon exchanges certified by emission reduction authorities (Gong *et al.*, 2019). Carbon trading schemes allow organisations to offset their reported carbon footprint using this method. Due to its controversy misaligned with Lean and Green principles, carbon trading was not considered as a potential design element for the GHG reduction framework.

The product category rules of ISO 14 067 provide creditable GHG reporting methods for auditing purposes. A study focused on a sustainability investment decision model based their carbon footprint calculations on ISO 14 067 (Yeo *et al.*, 2016). The findings from this case study demonstrate the involvement of government cap and trade policies on GHG emission reduction investments and production planning decisions.

During the ATA, an innate trend between ISO standards, lean and green performance was discovered. ISO standards can be amalgamated with lean principles. While ISO is primarily used to ensure international quality standards (Kalpakjian & Schmid, 2013:1038), it can also be used to ensure the highest quality with regards to energy management and environmental management systems. Lean management principles is a suggested means to spur the development of environmental management principles (Bhattacharya *et al.*, 2019:9). In spite of TQEM considered a variation of ISO 14 001 (Curkovic *et al.*, 2005), it ensures environmental compliance for eco-efficiency by considering pollution, controlling waste and emissions (Jakhar *et al.*, 2018).

Despite the idea that ISO 9 000 focuses on lean performance, companies with this certification tend to naturally move on to adopt ISO 14 000 (Bhattacharya *et al.*, 2019). ISO 14 001 constitutes a framework which can be used with a PDCA approach for continuous improvement (ASQ, 2015). However, a review paper by Hartini and Ciptomulyono (2015) found that an integrated system comprising of lean production and ISO 9 000 have lower emissions than ISO 14 000. This could be owed to ISO 9 001 combining quality management systems (QMS) with environmental management systems (Da Fonseca, 2015), as opposed to the more specific approach ISO 14 000 has on QMS.

One of the most commonly used Energy management system standards is ISO 50 001 (Davies, 2016:44). This ISO standard also assists with estimating the effect of GHGs and provides reduction strategies (BSR, 2012). This was used in a case study by Kumar and Rodrigues (2018) to understand best practises for GHG reduction and energy usage.

Lean performance is able to promote environmental performance using life cycle analysis and certifications (Bhattacharya *et al.*, 2019:8). During a waste management case study, Kurdve *et al.* (2015) found that a method which integrates environmental management into an improvement system should be founded on the lean principles of root cause analysis and visualisation. Therefore, an effective GHG reduction strategy can be rooted in the ISO 9 000 series (owed to its strong association to lean). However, the quality standards of ISO 14 001 and carbon footprint reporting guidelines are also recommended for environmental efficiency. Organisations could also consider the combination of the ISO 14 000 and 9 000 series which facilitate a PDCA cycle approach. Many academics have conceptualised frameworks which seek to promote operational and environmental performance or improve sustainable practises according to certain criteria. We now evaluate pre-existing Lean and Green frameworks in section 4.5.

4.5 Pre-existing Frameworks

During the ATA, various Lean and Green frameworks were studied to identify potential traits or elements that can be factored into the conceptual GHG reduction framework for the South African context. Each framework possessed a novel approach towards sustainability across managerial, organisational and operational levels by means of

strategic or tactical decisions. Some of these models evaluate single or various metrics and propose solutions for their respective areas of application using certain tools or methods. However, no pre-existing frameworks were evident in the South African context. Therefore, the available frameworks were used to extract relevant constructs that could be utilised in designing a conceptual framework for the South African context (**Table 8)**.

Table 8 - Pre-existing Lean and Green frameworks

Framework	Purpose	Relevant construct considered
Green manufacturing system inter-relations with an economic-social-eco system (Taddeo et al., 2019)	Green manufacturing is essential for sustainable manufacturing and societal development. Sustainability assessment form the basis for policy decisions. A cycle is formed between the external economic-society-ecosystem and internal manufacturing systems	The interaction between the application, organisational and system hierarchy levels of a green manufacturing system is illustrated. A decision support system is a suggested interface between environmental, social and economic effects. Policies require modelling when introduced into a green manufacturing system
Conceptual relationships between economic, social and environmental performance (Yun et al., 2019)	Analysis on interactions within supply chain management, outlining the model proposed by Carter and Rogers (2008)	For environmental performance, an integrated strategy is vital. Organisational culture provides social performance, whereas risk management ensures economic-environmental performance.
Operational efficiency and environmental performance improvement framework (Choudhary et al., 2019)	Green Integrated Value Stream Mapping (GIVSM) method used to reduce the carbon footprint of a packaging manufacturing SME in the U.K.	Stage 1 involves process mapping, translated into a GIVSM. Two parallel streams follow, identifying green waste in CO_2e/kg and lean wastes (8 wastes). Two RCA's are conducted for the two parallel streams, before its consolidation into a future state GIVSM as part of a continuous improvement framework
Low carbon culture adoption model (LCC) (Ambekar et al., 2019)	Low Carbon Culture (LCC) model for obtaining low carbon capabilities	Segmented into three stages. Stage 1 lists low carbon determinants (carbon tax and carbon trading). Within the low carbon culture (stage 2), the three dimensions (organisational orientation, governing structures and the level of carbon emissions) create a low carbon supply chain capability in the final stage
Assessment framework linking best practises to performance (Farias *et al.*, 2019)	Operational and environmental performance measures are associated with lean and green best practises	For best environmental practises, lean and green are considered as one integrated system. Best practises include VSM, Kaizen, 5S, Environmental Management Systems, EEC, JIT, TPM, SMED, 3R and Design for Environment (DFE)
Lean-Green model for SMED application (Júnior *et al.*, 2018:3)	Three phase model focusing on (1) the application of SMED (Lean form of identification), (2) carbon footprint calculation and (3) estimation of eco-efficiency	Identification of activities stem from Lean thinking. Analysis is quantified by means of Green manufacturing. The effects of solutions are quantified by its eco-efficiency

Framework	Purpose	Relevant construct considered
Conceptual model of eco-socio-lean production (Amrina & Zagloel, 2019:4)	A computation model involving the input, process and output of ESLP parameters with an objective to reduce production costs.	Suggested improvement strategies include Green Value Stream Mapping, Material and Process Re-engineering, an environmental management system and a periodic Top Management (Genchi Genbutsu)
PDCA E-VSM implementation approach (Garza-Reyes *et al.*, 2018)	Environmental-VSM used to improve environmental performance through continuous according to Deming's PDCA cycle	For an E-VSM implementation, strategic goals must be defined from the onset. The intent of the study, data collection & team formation is crucial. Green wastes are identified, and the future state VSM foresees the elimination thereof. An implementation or action plan must to be formalised afterwards
LESER strategy (Cai et al., 2019:3)	Lean-energy saving and emission-reduction strategy conceptualised within 5 stages.	For emission reduction, a framework should consider re-evaluation, sustenance and standardisation in order to promote continuous improvement
Sustainable Supply Chain (Barbosa-Póvoa et al., 2018:20)	Operations Research methods are outlined in order to facilitate the development of generic tools to manage a sustainable supply chain	A decision level focus is required to address sustainability challenges across a strategic, tactical and operational level. An efficient solution needs to be used in a comprehensive model
Method for selecting solution elements (Fischer et al., 2015)	Energy efficiency model deployed in a discrete manufacturing environment. A factory model initiation hierarchy model is used, and an extended Energy Value Stream Map is created.	Extended Value stream analysis is proposed, where cost drivers are weighted against certain user preferences, or organisational requirements. A weighted factor is set on each energy/cost driver by means of a driver weighting matrix and cross impact analysis to select the final solution elements

Several frameworks elaborate on conceptual relationships between organisation levels for environmental performance while others apply a range of tools within a specific context. Many of these frameworks follow no more than 4 or 5 cyclical stages. During the conceptualisation of a Carbon Footprint framework by BR *et al.* (2016), three principals were adopted, namely (1) understanding the carbon footprint, (2) distinguishing between emissions that can be reduced or eliminated and (3) focusing on measures which derive the largest cost benefit. Various constructs from pre-existing frameworks were used to set design requirements, consolidate and conceptualise a Lean and Green literature-based framework (discussed in section 4.6).

4.6 Conceptual Lean and Green GHG reduction framework

Under the specific search protocol followed in this study, no pre-existing South African Lean and Green frameworks were obtained. This collection of literature suggests that the South African context of Lean and Green has hardly begun. In order to conceptualise a framework for GHG emission reduction, numerous design elements were formalised using the five themes that were identified during the SLR and ATA.

Together with the design elements and themes that should be included, the following design requirements were also set (Coetzee, 2019:68-69; Mangaroo-Pillay, 2020:41-42): (1) the framework must co-ordinate the elements within each theme, (2) be simple in structure, (3) legible, (4) simple to understand, (5) provide a

visual distinction between various design elements and themes and (6) holistically their association to Lean and Green. By simple in structure, this refers to a clear and intuitive design.

By combining the findings from the ATA and the set design requirements, a Lean and Green GHG reduction framework has been conceptualised in **Figure 3**. This has been designed using the CIMO-logic by Denyer *et al.* (2008), which serves to solve field problems by considering the context, interventions, mechanisms and outcome. This framework is developed for the manufacturing industry through the publication selection process and textual data coded in ATLAS.ti Within the manufacturing sector, the design elements and themes present the intervention and mechanisms for the purposes of achieving GHG reduction.

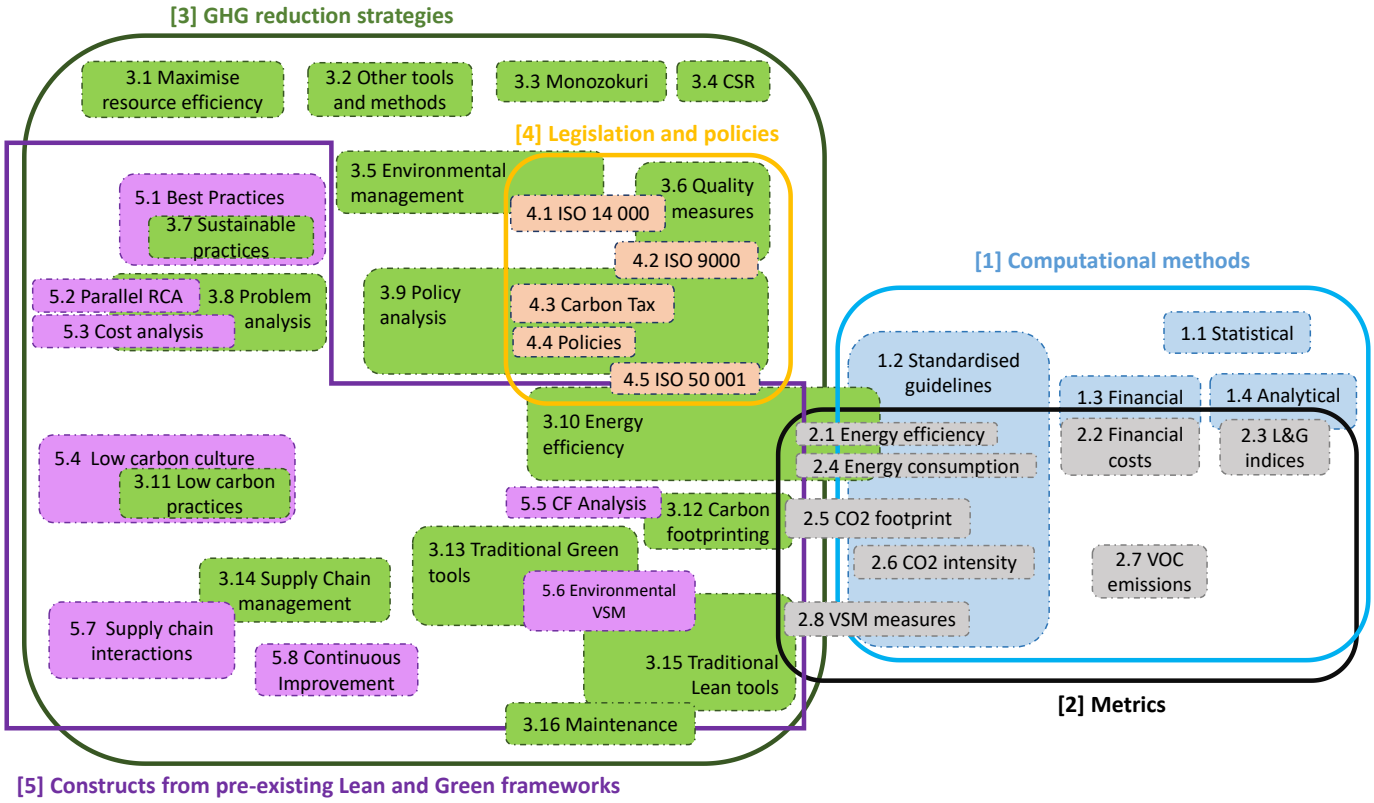


Figure 3 – Conceptual literature-based Lean and Green framework for GHG reduction in the manufacturing industry

The framework co-ordinates the various elements within each of the five themes. Each theme has been colour-coded and numbered according to the themes during the ATA. These numbers correspond with the theme discussions in this paper, but also follow the numerical order needed to further develop a custom GHG reduction strategy for a specific company. This framework uses the overlap between each theme or element to represent the indirect and direct relationships they share in achieving GHG reduction in terms of the theory and nature they possess. The GHG reduction strategies (3rd element in the framework) is a consolidation of the tools and methods which compute GHG emissions are facilitate the reduction thereof. Furthermore, the framework is representative of Lean and Green principles having been obtained from the various research publications under the conditions of the research protocol.

From a conceptual standpoint, the framework needs to cater for legislation. Possible adverse effects between Lean and Green solutions should be avoided. In conjunction, the proposed actions should align with the organisational culture of a company and its corporate strategy. Moreover, a form of process mapping must be performed to evaluate GHG emissions. CO_2 emissions need to be studied and continuous improvement should be a core requirement for achieving GHG reduction.

A core feature for any conceptual framework is to provide understanding and demonstrate the integrated roles of particular concepts (Jabareen, 2009). The conceptual Lean and Green framework considers operational inefficiencies within an organisation with the intention of reducing GHGs. The orientation of its components follows a generalised format from Baba *et al.* (2006:24), where a conceptual benchmarking framework was proposed. This suggested format guided the typical interface between the various themes belonging to the Lean and Green conceptual framework. Using the relationship between the various design elements and themes, overlaps were used to represent mutual inclusion or exclusion of specific subject matter. These relationships were motivated by the findings presented in each of the themes discussed in section 4.1-4.5.

To develop an effective means to reduce GHG emissions, a manufacturing organisation will need to understand their existing data infrastructures, adopt a computational method (theme 1) and metric (theme 2) to quantify GHG emissions. The interaction between the design elements for the basis for any initiative or project an organisation may undertake.

Next, the company conceptualises a strategy (theme 3) which aligns with their company goals and visions. Note the vast levels of interaction between legislation and polices (theme 4), but also pre-existing constructs from other GHG frameworks (theme 5). The range of design elements extracted pre-existing constructs have been configured with relevant GHG reduction strategies identified in the literature. This framework recognises a strategy as the driven force for any GHG emission reduction initiative. When considering certain strategies, ISO standards and legislation of great concern shares an overlap, thus alluding to the effect it may have with regards to environmental management, quality measures, policy analysis and energy efficiency. We now welcome the practical implications of the conceptual literature-based framework proposed in this study.

4.7 Implications for practice and research

Within this framework, a form of environmental value stream mapping methodology is recommended. Furthermore, this methodology should inherently be based on CI using a Kaizen approach. Kaizen refers to change for the better, a principle which must continuously feature within an organisation in order to prevent complacency (Liker & Franz, 2011). Dieste *et al.* (2019) Based on the victories of research noted in this study, VSM can become the core function to not only map, but conceptualise GHG reduction. There exists an innate connection between VSM and environmental performance (Edtmayr *et al.*, 2016). The framework identifies key concepts and denotes the direct and indirect associations within respective themes. This framework demonstrates the fundaments to achieve GHG reduction conceptually, but inspires methodological perspectives that can be set. In for researches to develop a method for GHG emission reduction, the formalised GHG reduction design elements offer the building blocks that can be tailored to a specific manufacturing context. Using each theme, a sequential method can be established, one that recognises aspects for consideration when seeking to reduce GHG emissions by means of Lean and Green.

The next section presents the conclusions and recommendations based on this study.

5 Conclusions and recommendations for future research

In order to develop an effective GHG reduction strategy across organisational levels, the amalgamation of various tools, methods and techniques are required to facilitate sustainable practices. In this study, design elements from literature are used to propose a GHG reduction framework in an attempt to provide structure to the different aspects belonging to Lean and Green. In this way, the various design elements and themes for GHG reduction are formalised.

With the limited literature available specific to the South African manufacturing industry, the framework reveals design elements which appeal to manufacturing industries in many countries. This framework will be able to assist manufacturing organisations develop GHG emission reduction frameworks in their local context using Lean and Green.

When producing research, there are of course limitations. While this framework is indeed conceptual, it was verified by ensuring a rigorous method was followed before verifying that it complies to all set design requirement discussed in section 4.6. However, the framework needs to be validated in the South African manufacturing industry. For example, a validation method may take the form of surveys distributed to academics and practitioners learned in this subject matter. Furthermore, a Lean and Green implementation framework could be developed specifically for South Africa.

Environmental value stream mapping was a highly recursive design element obtained during the ATA. Furthermore, a form of environmental value stream mapping is the prescribed method for achieving GHG reduction. More extensive work can reconsider which form of environmental value stream mapping and metrics would be best suited. On the other hand, researchers can contest the appropriate Lean and Green tool or methodology by drawing comparatives using their GHG reduction potential.

Carbon footprint (CF) accounting has emerged from carbon footprinting practises as a method for auditing and reporting emissions. Carbon accounting is an assessment method associating CO_2e to industries or organisations (Stechemesser & Guenther, 2012). The CF accounting system supports the financial implication any emission may have, resulting in organisations having interest in environmental preservation Prior to the implementation of the South African Carbon Tax Act, an evaluation of the South African carbon tax was conducted by Alton *et al.* (2014), where a dynamic economy-wide model was developed in order to calculate a tax-phased pricing strategy. According to Alton *et al.* (2014), a phased-in tax of R403 ($30) per ton (Nedbank, 2019) was recommended in order to meet 2025 environmental targets. After the end of the first carbon tax period (January 2020), research could conduct a comparative study between the tax-phased pricing proposed by Alton *et al.* (2014) vs. the pricing strategy detailed in the South African Carbon Tax Act (No. 42483 of 2019). This comparative may reveal the effects of tax pricing strategies in order to meet 2025 environmental targets. Therefore, a topic for future research can be to re-evaluate principles of carbon pricing. According to Finon (2019):

"A carbon pricing instrument cannot be the main pillar of a three-pronged carbon policy in emerging economies' climate package, and even less so in less developed economies whose carbon policy is in the first stages of implementation"

It is therefore recommended that additional methods to support carbon pricing are conceptualised, specifically in developing countries. New opportunities for research are reflected through each theme. The following research propositions in **Table 8** are provided within each theme addressed in the study.

Table 8 – Research propositions for future research

Element	Research proposition(s)
Computational methods	• How would various computational methods compare in terms of the time, accuracy and data volumes required?
Metrics	• What are the perceptions of these metrics used to reduce GHG emissions? • Can socio-economic, eco-environmental and socio-environmental metrics be used to reduce GHG emissions?
Tools, methods and strategies	• Which green manufacturing tools, methods or techniques are yet to be translated into a lean context and vice versa? • What are strategic factors to consider under carbon tax policies?
Legislation and policies	• Which carbon tax policies or regulations can be adopted between developing countries?
Pre-existing frameworks	• Can several pre-existing frameworks be integrated into cyclical stages for continuous improvement?
Conceptual Lean and Green GHG framework	• Are elements outstanding or irrelevant to the framework's purpose? • Are there themes which are absent, or require further research? • Can other industries inherit the design elements or themes proposed in this framework?

This research only considered design elements for GHG reduction the manufacturing industry. This could be extended to other sectors, exploring applications of Lean and Green GHG reduction in service sectors may reveal new design elements. Alternatively, new environmental criteria and sustainable practises can be evaluated in different contexts or extend to other industries.

This research offers a theoretical contribution through this holistic GHG reduction framework. The use of Lean and Green can present opportunities to reduce GHG emissions and aid organisations in making clear, sustainable decisions for the well-being of the environment, society and the foreseeable future.

6 Resources

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Chapter 4

Refined Lean and Green Framework for GHG reduction in the South African manufacturing Industry

4 Refined Lean and Green Framework for GHG reduction in the South African manufacturing Industry

Title: Designing a Lean and Green framework for GHG reduction in the South African manufacturing industry.

Abstract: Lean and Green is an emergent field of research focused on promoting operational efficiency and environmental performance. One of the environmental measures within this paradigm, is greenhouse gas emissions (GHGs) – an ever-present threat to society. The aim of this study is to design and evaluate a literature-based Lean and Green framework for GHG reduction in the South African manufacturing industry. Surveys were distributed to Subject Matter Experts to test and design a refined Lean and Green framework for GHG reduction.

By incorporating Design Science Research, various design elements and themes belonging to the framework were evaluated. Participants voiced the relevance and potential for GHG reduction, but also provided additional elements from the literature-based framework obtained from a Systematic Literature Analysis and Applied Thematic Analysis. The refined framework from this study allows future researchers to develop GHG methodologies by means of Lean and Green.

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DESIGNING A LEAN AND GREEN FRAMEWORK FOR GHG REDUCTION IN THE SOUTH AFRICAN MANFUCATURING INDUSTRY

ABSTRACT

Lean and Green is an emergent field of research focused on promoting operational efficiency and environmental performance. One of the environmental measures within this paradigm, is greenhouse gas emissions (GHGs) – an ever-present threat to society. The aim of this study is to design and evaluate a literature-based Lean and Green framework for GHG reduction in the South African manufacturing industry. Surveys were distributed to Subject Matter Experts to test and design a refined Lean and Green framework for GHG reduction. By incorporating Design Science Research, various design elements and themes belonging to the framework were evaluated. Participants voiced the relevance and potential for GHG reduction, but also provided additional elements from the literature-based framework obtained from a Systematic Literature Analysis and Applied Thematic Analysis. The refined framework from this study allows future researchers to develop GHG methodologies by means of Lean and Green.

1 INTRODUCTION

The South African manufacturing industry contributed an average of R325 Billion to its Domestic Product (GDP) between 1993 and 2019 [1]. This nourishes our domestic economy, sustains employment and ensures societal relief. Unfortunately, this industry embraces numerous challenges. One of which is the high demand, productivity requirements, competitors, and environmental obligations they must abide to.

South Africa has one of the highest CO2 emissions per capita and is the largest energy consumer on the continent [2]. It is a well-known fact that GHG emissions are an overwhelming threat contributing to global warming [3]. As with other countries, South Africa is forced to abide to various environmental regulations and policies. In 2019, the South African Carbon Tax Act (No. 42483 of 2019) was introduced, pricing emissions at R120 per CO2 equivalent above a prescribed threshold [4]. The manufacturing industry is confronted with reducing its Greenhouse Gas (GHG) emissions and a need exists to develop a method to assist with this task. Lean and Green presents itself as a resolve.

Lean is a process improvement philosophy aimed at reducing inefficiencies (waste) in order to promote higher levels of productivity [5]. Lean categorises 8 forms of waste (Inventory, Motion, Waiting, Over-production, Over-processing, Defects, Transportation and Un-used employee intellect) [6, 7].

Lean was initially developed for the manufacturing environment, first appearing in a 1988 article by Krafcik [8]. However, Lean has been implemented in a wide variety of industries which include healthcare, construction, systems design, IT and other service sectors [9, 10, 11, 12]. In addition, Lean can be used to simultaneously reduce environmental effects [13].

The Green philosophy is concerned with the reduction of the environmental affects posed by anthropogenic activities [14]. According to Zokaei et al [15], the 8 forms of Green waste are air emissions, energy consumption, land contamination, water discharges, water usage, noise, physical waste and lost human potential. This has been used to assess supply chain management among other applications [16, 17].

Lean and Green strives to simultaneously increase productivity (by means of lean principles) and reduce the environmental effect (by incorporating green principles). Farias et al [18] suggests best sustainable practices and criteria from a framework which identifies the relationships and concepts of Lean and Green performance. The suggested practices are VSM (Value Stream Mapping), Kaizen, 5S, SMED (Single Minute Exchange of Die), JIT (Just in Time), Cellular manufacturing, TPM (Total Productive Maintenance), EMS (Environmental Management System), 3R (Reduce, Reuse, Recycle), DFE (Design for Environment) and EEC (Environmental Emission Control). In order to show the overlap between these two paradigms, **Figure 1** compares these respective traits.

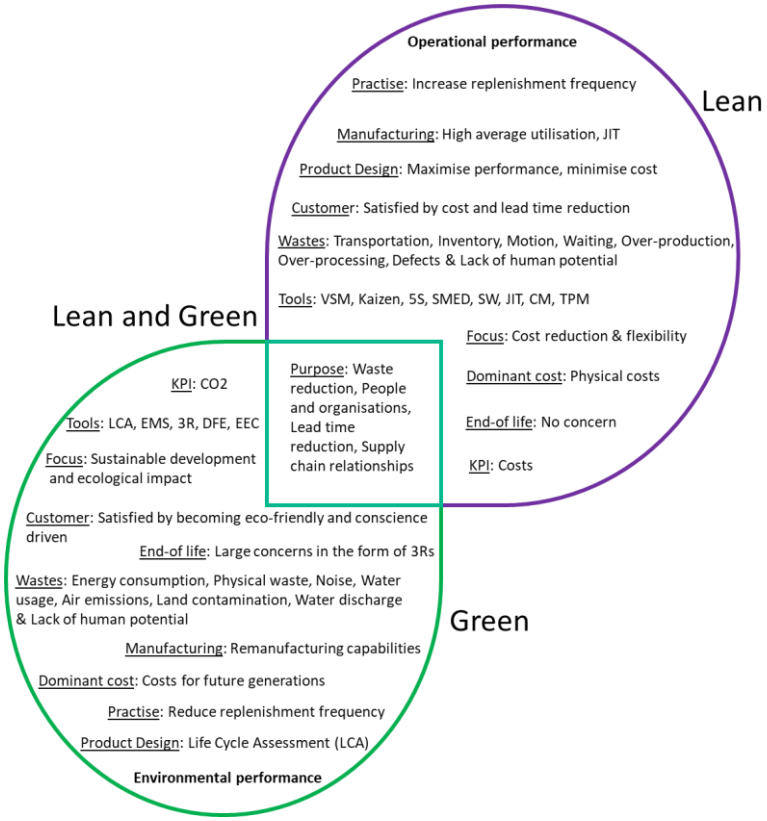
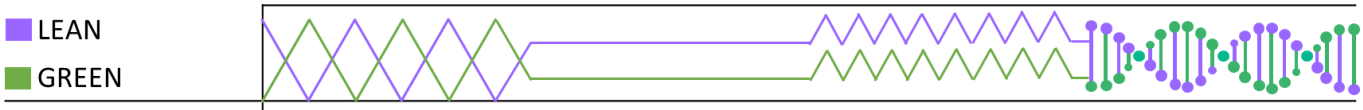


Figure 1 Lean and Green overlap adapted from Dües et al [19] and Zokaei et al [15]

Despite the trait differences listed in Figure 1, Lean and Green holds a shared purpose to achieve waste and lead time reduction, recognise people and organisations, but maintain supply chain relationships [19, 15]. For any institution to fully harness the potential of Lean and Green, the relationship between the two philosophies must be recognised. One way of doing so, is by outlining the two paradigm relationships intertwined across different levels of learning maturity.

The levels of Lean and Green maturity have been depicted in **Figure 2**, as adapted from Zokaei et al [15]**.** The initial representation of the Lean and Green relationships was categorised according to innocence and degree of knowledge realised. This approach substantiates this relationship, but can be further enhanced using the learning maturity stages discussed by Bradley [20]. These levels include unconscious incompetence, conscious incompetence, conscious competence & unconscious competence. Using these learning maturity levels; the variated representation of the relationship more accurately depicts the expected stages levels of learning when embracing Lean and Green.



Stage of learning maturity	**Unconscious incompetence:** Not knowing what you don't know	**Conscious incompetence:** Knowing what you don't know	**Conscious competence** Not knowing what you do know	**Unconscious competence** Knowing what you do know (2nd nature)
Relationship	**Conflicting**: Polarity between Lean and Green	**Benign**: Both may co-exist, but are non-complementary	**Synergetic**: Positive relationship perpetuated	**Symbiotic**: Lean and green form part of the same strategy
Example	Frequent deliveries rising emissions, whereas lowering emissions reduces productivity	Lean team pursues economic goals whereas green teams pursue environmental goals independently	Reducing product waste reduces green impact simultaneously	L&G strategy for reducing loss imparted to society during entire production life cycle

Figure 2 Lean and Green maturity stages adapted from Zokaei et al [14]

As illustrated in **Figure 2**, various companies may function within different stages of lean and green maturity. In the primal stage, companies pursue independent lean and green initiatives which counteract one another. Organisations which fall victim to this stage are those who pursue lean improvement projects under environmental regulations, unaware of this relationship. During the next stage, an organisation may become aware of the association between these two facets and begin separate initiatives non-complementary in nature. The next two stages recognise the relationships and aims to improve productivity and environmental performance. One can argue that green is dictated by legislature, which can ultimately be resolved by continuous improvement in accordance with Lean principles. In summary, this figure represents the innate relationship shared between Lean and Green respectively.

However, little guidance is provided in literature on how to apply or implement this approach within organisations. Moreover, no methodology exists for reducing GHG emissions with Lean and Green. As a steppingstone towards such a methodology, a framework must first be developed.

Therefore, the aim of this paper was to design and evaluate a literature-based Lean and Green framework for GHG reduction in the South African manufacturing industry.

2 RESEARCH METHODOLOGY

In a qualitative research study, new concepts and theory are created [21, 22]. For this reason, a design science research (DSR) paradigm was followed. This involves multiple stakeholders during the development of a state-of-the-art artefact [23, 24]. The research methodology has been encapsulated in **Figure 3**.

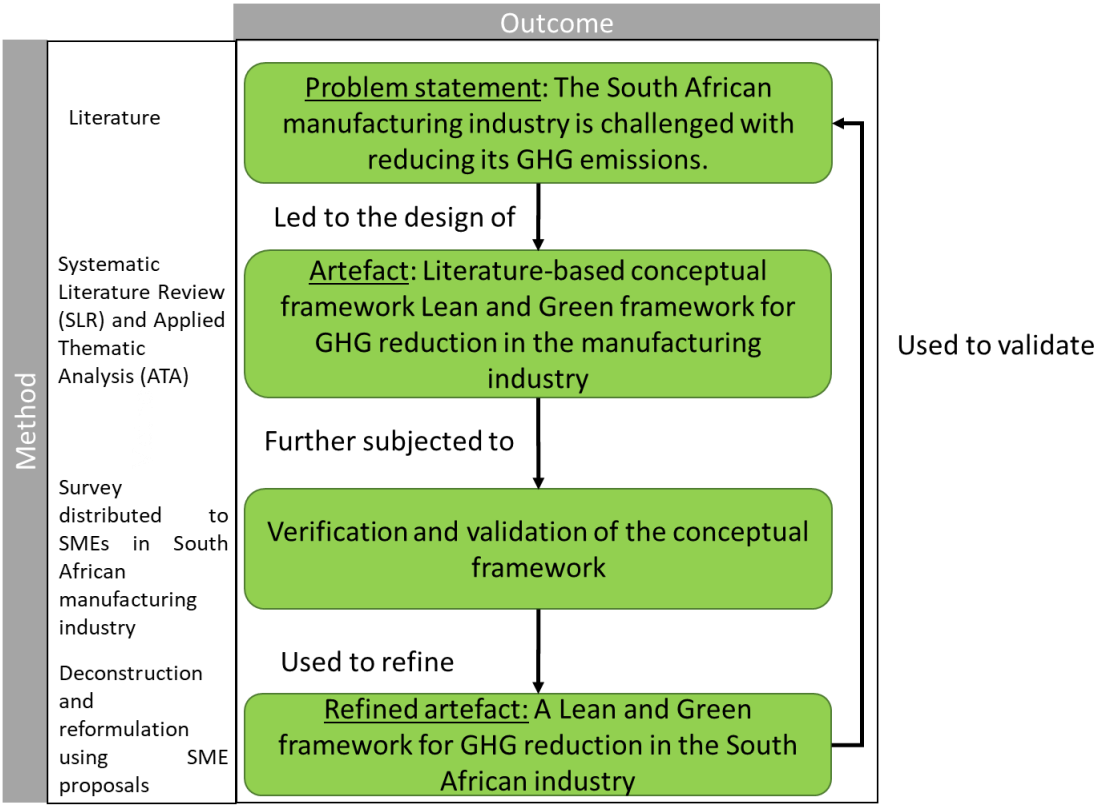


Figure 3 Research methodology

2.1 Systematic Literature Review and Applied Thematic Analysis

By following a systematic literature review (SLR) and an applied thematic analysis (ATA), a conceptual literature-based Lean and Green framework for GHG reduction was developed.

A SLR was used to screen and identify 56 publications from an initial set of 464 publications from scientific databases. The keywords Lean, Green, framework, model, tax, South Africa and emissions were used to search between 2015-2019. An ATA was used to formalise the essential design elements and themes recommended by academic scholars. This data was consolidated by coding in ATLAS.ti.

2.2 Survey

A survey was used to evaluate the literature-based conceptual Lean and Green framework.

2.2.1 Survey design

The survey had the following objectives:

1. Validate that the South African manufacturing industry is challenged with reducing its GHG emissions
2. Verify the established design requirements for the framework
3. Verify that all design elements and themes of the literature-based framework are appropriate for GHG reduction
4. Verify that all potential design elements and themes are identified
5. Verify the associations between the design elements
6. Verify the associations between themes
7. Validate that the framework addresses the research problem

According to Al-Ghamdi [25], an average more than 3 on a 5 point Likert scale indicates a higher level of success (agreement). In this study, a consensus rate of 60% (3 on a 5-point Likert scale) was used. By factoring the results for each of the survey statements (Table 1 Summary of survey design requirements, statements and questionsTable 1 in Annexure A) and suggestive commentary, a refined Lean and Green framework is proposed (section 3.2.6).

Demographic information was also incorporated in the survey, outlining the participant's industry and years of experience. This survey was designed as a Google Form, accompanied by an explanatory 5-minute video on the conceptual framework.

The survey design relied on the objectives of this study and specifications outlined in the table located in Annexure A. This table provides a summary of the objectives, survey design requirements, specifications, survey statements and questions. The right-most column of this table provides the survey results. A Likert scale was used to evaluate the degree by which participants agree or disagree with the survey statements, and a dichotomous scale (yes or no response) for questions posed. Questions which prompted participants to elaborate further (Q2 & Q4) are discussed in section 3.2.2-3.2.5.

2.2.2 Participants

The survey was disturbed to Subject Matter Experts (SMEs) within the South African manufacturing industry using a purposive sampling technique: snowballing. SME's included environmental engineers, managers or practitioners learned in operational and environmental efficiency.

3 FINDINGS

3.1 Systematic Literature Review and Applied Thematic Analysis

During the SLR and ATA, five themes categorise 41 design elements extracted from 56 research publications. The results of the SLR and the ATA lead to the formulation of a conceptual literature-based Lean and Green framework for GHG reduction, as depicted in **Figure 4.**

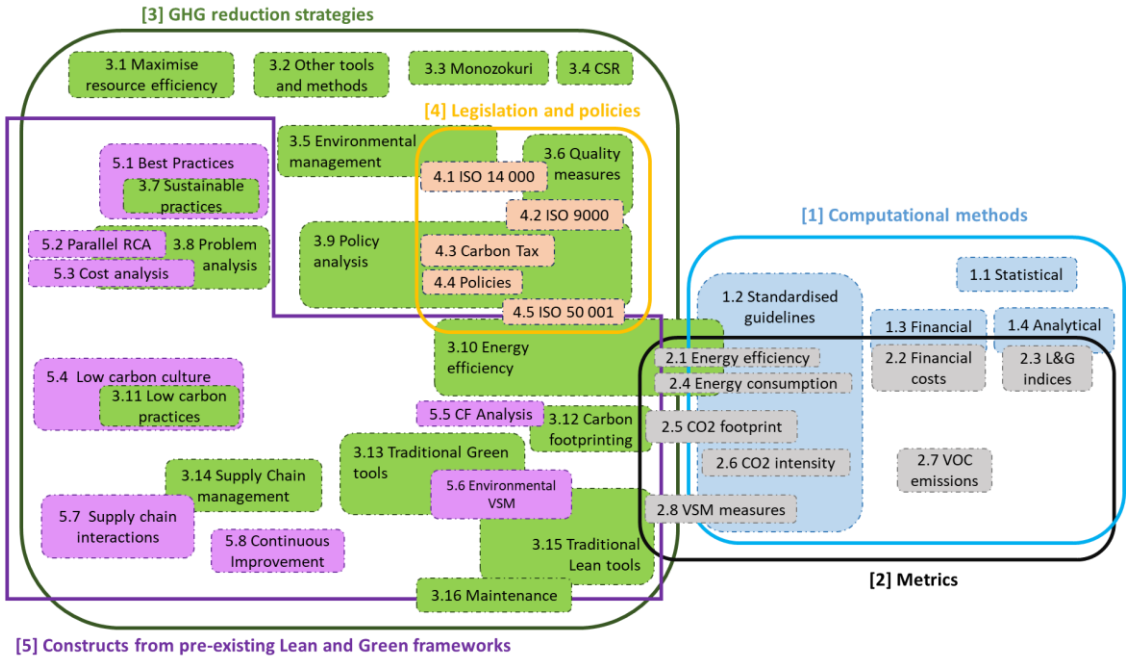


Figure 4 Literature-based Conceptual Lean and Green framework for GHG reduction in the manufacturing industry

Each element is colour coded and numbered, incrementing left to right from the top and bottom of each bordered line (theme). The overlaps of each bordered line depict their relationship amongst each other. Similarly, the overlap of various design elements illustrates mutual inclusion or exclusion between respective traits.

On the right-hand side, the framework stipulates GHG computation methods (in blue) which can be used for further analysis. One approach may be a statistical approach by means of simulation modelling or experimental design studies [26], [27]. A more popular approach is through standardised guidelines for energy, CO2 and value stream mapping performance measures using Greenhouse gas guidelines, carbon foot printing or environmental value stream mapping [28] [29]. Other methods include a financial approach by means of cost-profiling [26], envelopment analysis [30] or the use of an analytical method involving optimisation models, structural equation modelling (SEM) and state space modelling [31, 32].

From a strategic standpoint (top left-hand corner in green), organisations can maximise their resource efficiency using a resource-based view, reduce material consumption or increase resource consumption. Monzokuri is a Japanese term symbolising creative and balanced manufacturing of products, in harmony with nature and society [33]. Other Lean and Green tools and methods include 5 Why, Ishikawa diagrams, TRIZ (Theory of Inventive problem solving), Affinity Diagrams and PDCA [34, 35, 36]. Some of these strategies are associated with certain forms of legislature, policies, or international standards (middle centre in orange). These prompt higher compliance with tax regulations and environmental reporting ranging from energy audits to GHG reporting. These resources guide strategies concerning environmental management, quality, policy analysis and energy efficiency.

The last theme in the bottom left-hand corner (constructs from pre-existing Lean and Green frameworks in purple) was used to conceptualise the nature of the proposed framework in Figure 4. Best practices are associated with those which are sustainable. An in-depth analysis on the operational efficiency and environmental performance can be achieved through parallel root cause-analysis, cost and carbon footprint analysis. Additional elements include managing supply chain interactions, invoking continuous improvement, maintenance or instilling a low carbon culture. This framework identifies environmental value stream mapping as the preferred tool for GHG reduction [18, 29, 37]. Therefore, any such methodology aimed at GHG reduction must incorporate this tool to map out, identify and improve on environmental performance.

Collectively, this framework provides the elements needed for GHG reduction in a manufacturing industry. While the design elements and themes included in the conceptual literature-based framework represented manufacturing industries across the world, a further need existed to verify the elements of the framework for the South African manufacturing industry. This verification process was fulfilled by means of a survey.

3.2 Survey findings

3.2.1 Participants demographics

Survey participants stemmed from the South African manufacturing industry. The representation of this industry is embodied in **Figure 5**.

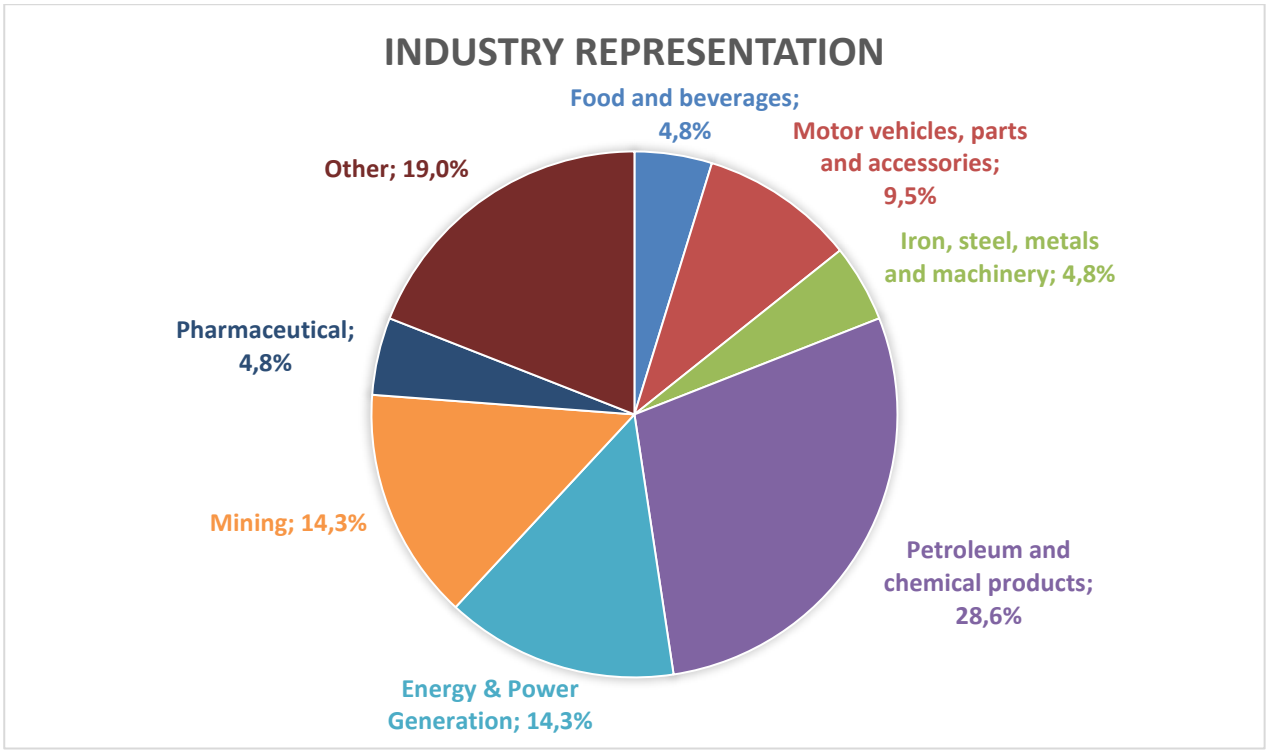


Figure 5 Industry representation of survey participants

Based on the industry representation, the majority of participants work in the petroleum and chemical production industry. This spread of various manufacturing industries shows the unbiased nature and shared experience of this research problem. The degree of industry experience is a vital statistic to include in a qualitative study [22]. A distribution of the years of experience belonging to survey participants is illustrated in **Figure 6**.

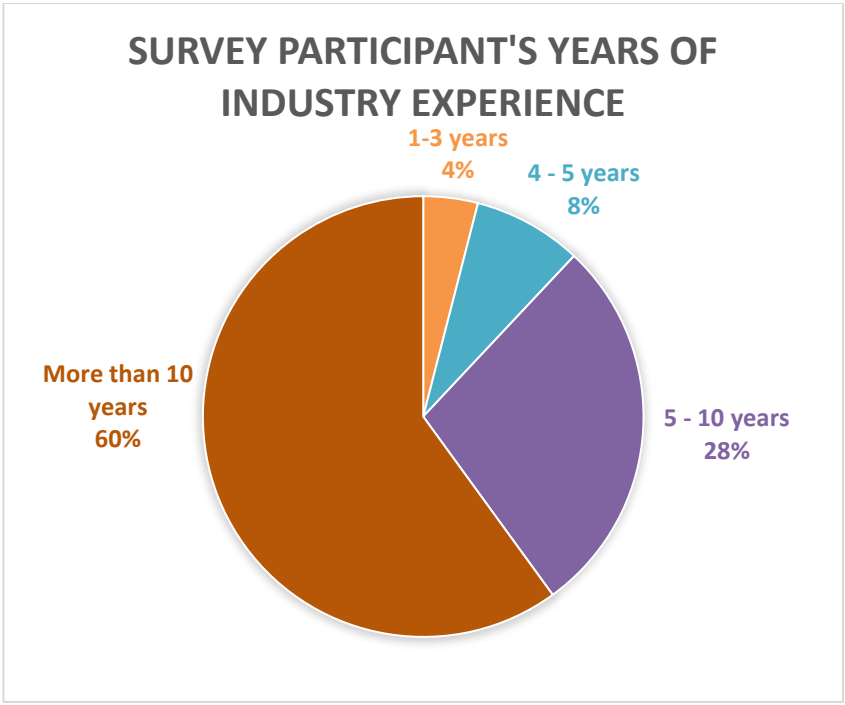


Figure 6 Survey participant years of experience

As illustrated in Figure 6, the level of participant's experience predominately exceeds 10 years. It is probable that these SME's have a higher job position, suggesting that they fulfil a supervision or managerial role in their place of work.

The survey statements and results from the study are provided in Annexure A. An elaboration on the results and suggestions from participants is further discussed in sections 3.2.2-3.2.5.

3.2.2 Objective 1 - Research problem

The identities of each participant are anonymised, denotated P1 to P25 for the 25 survey respondents. Survey participants felt strongly that the research problem is indeed an issue this industry faces (4.32 average).

There is often a mismatch and uncertainty within manufacturing organisations (P8). Companies require incentives or local government legislature to enforce environmental practices (P19). Interestingly, enforcement is a critical factor from regulatory bodies (P11). This is crucial since environmental specialists experience low buy-in from operational functions in an organisation. This could be improved by ensuring such institutions correctly enforce environmental policies, procedures and legislation.

Several organisations perceive GHG reduction as an additional cost to company (P8, P19). It has a large capital investment with what is believed to be a low return when efficiency improvements are overlooked. Manufacturing companies are pressured to become carbon neutral, which P15 believes is inherently impossible. This argument is also made in literature [38, 39].

South Africa is faced with socio-economic difficulties (P9), cleaner technologies could result in job loss. Due to shareholder pressure, profit margins are at risk when GHG emissions are reduced (P21). Although renewable energy sources and leaner technologies mitigate CO2 emissions (P14), they threaten job employment and may require extreme modifications to existing energy infrastructures (P8, P9). Existing infrastructures do meet air quality emission standards (P11) and legacy-infrastructures will be difficult to upgrade accordingly (P8).

P19 argues that organisations unmotivated to adopt Lean production may lag in their competitive environment. Methods to encourage or adopt Lean manufacturing must be further investigated in South Africa [40].

P25 believes that South Africa is on its way to a greener society already reliant on non-renewable energy sources. The awareness of GHG emissions is still low (P8, P12), and a larger effort should be made to enlighten organisations.

3.2.3 Objective 2 - Design-requirements

The framework design requirements yielded an average score of 3.57. Participants found that the conceptual framework should be further simplified (P10, P16, P3). To achieve this, the pre-existing constructs from Lean and Green frameworks from the conceptual model are modified into strategic elements. Since frameworks are used to guide strategic decisions, the elements from pre-existing frameworks embody the Lean and Green GHG reduction strategies. These modified strategic design elements will thus feature in the refined Lean and Green framework for GHG reduction.

Additional changes included an overlap simplification (P16, P20), footnote (P12, P14, P21) and rotation about the y-axis (P3, P15).

3.2.4 Objective 3 to 6 - Survey questions, design element and theme associations

Majority of participants believe the design elements are appropriate with an average score of 3.9 and 3.88 for design element, theme appropriateness and associations. P19 argues that all

are essential. However, 84% of participants believed that certain elements or themes can be omitted from the framework.

P7 and P8 feel that the framework is logically assembled but could be further simplified. Forms of simplification include costs and regulations (P5) and cost analysis (5.3) vs financial costs (2.2) by P8. The analysis of financials must begin with a prescribed method. For this reason, these two elements now share an association. Carbon footprinting strategy (3.12) and carbon footprint analysis (5.5) was consolidated into a new design element "Carbon footprinting & CO2 intensity" with analysis (P8).

32% of participants identified additional design elements or themes which could be incorporated. P17 suggests frame monitoring and control strategies to measure the effectiveness of an organisation's adaption to Lean and Green. For this reason, "Control measures" become an additional strategic design element. Similarly, change management (P7), GHG procedures, and incentives (12B,12L & 12l) for legislation and policies (P10) were also included as a new design element. Since renewable energy sources are a means to mitigate emissions (P14), renewable energy sources became a new strategic element.

P17 advises that ISO 18 001 is also included as it increases full stakeholder participation and an essential element to deploy this framework. ISO 18 001 is an international standard for health and safety systems [41]. Since occupational health and safety is crucial for any organisation, it can be used for active decision-making [42].

3.2.5 Objective 7 – Capability of literature-based framework

In summary, the participants believe that the conceptual Lean and Green framework could reduce GHG emissions in the South African manufacturing industry. This is made evident by the 3.96 average obtained in the table provided in Annexure A. An average score of 4.12 stresses that the five themes could address the problem, while an average of 3.8 suggests that the conceptual framework in itself will do so.

3.2.6 Refined Lean and Green framework for GHG reduction

By incorporating the feedback from the various subject matter specialists, a newly refined framework was designed (**Figure 7**).

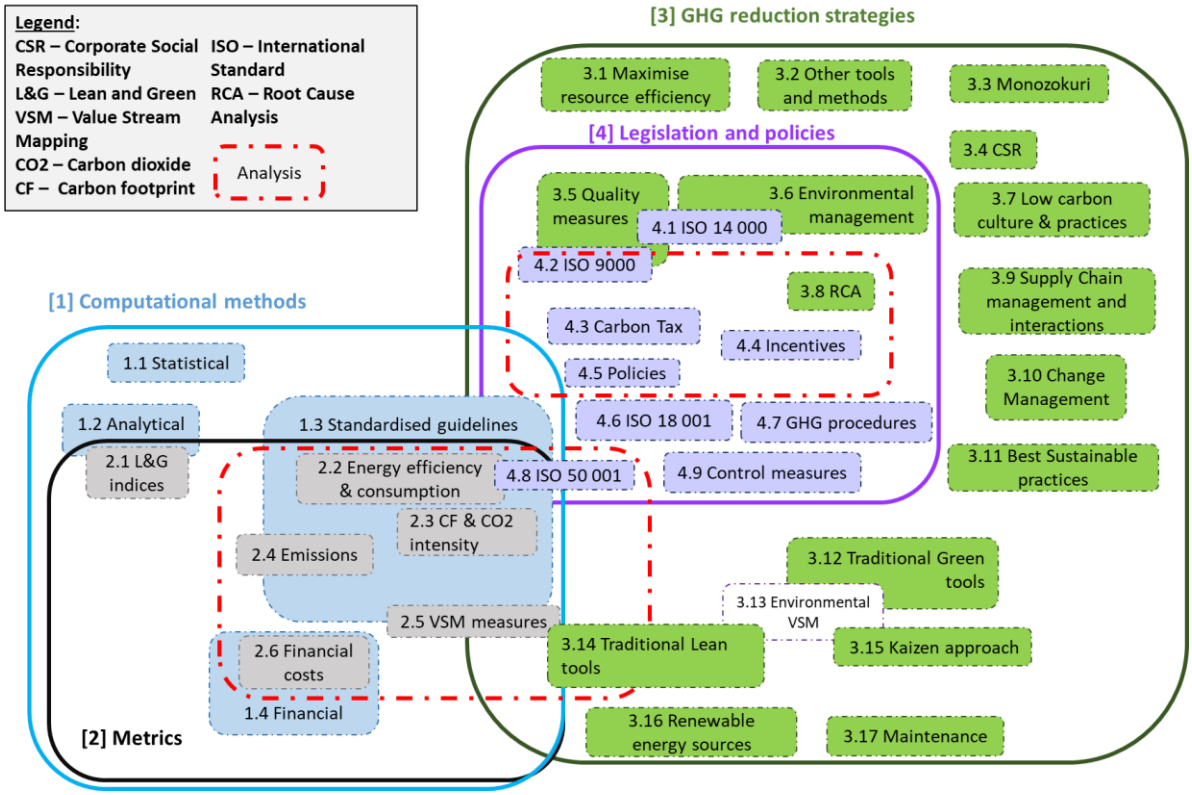


Figure 7 Lean and Green framework for GHG reduction in the South African manufacturing industry

The modifications made to the initial framework has a more intuitive appeal, higher degree of legibility and visual distinction between the various design elements and themes. With the conceptual framework designed, the next research steps must be undertaken. Conclusions and future recommendations are discussed in section 4.

4 CONCULSIONS AND FUTURE RECOMMENDATIONS

Based on the survey results and refined framework, a means to GHG reduction in the South African manufacturing industry can be achieved using the framework proposed in this study. By deploying Design Science Research in this study, the refined framework was thus designed.

Several survey findings were not included in the refined framework. P7 argues whether Monzokuri should be incorporated in the model. However, Monozkuri is a core principle pertaining to Lean and Green [43]. It is also referred to as "the older sister of sustainable manufacturing" [15]. P8 recommends optional or essential design elements which can be used for objective analysis in industry. With the combination of Lean and Green part of a new field of research, and GHG emission reduction by means of this principle sailing uncharted waters, more research is required. For now, all design elements in the framework are considered essential until it is physically implemented in industry, or by means of a methodology developed.

"It is very difficult to predict the usefulness of a framework without testing it on real world case studies to get actual results" (P14). In correlation with this comment, Authors [44, 45] advise that the iterative use of the framework and expert opinion in industry will further validate that the theory in the framework provides the best available explanation (solution) for the problem using literature. This coincides with principles of construct validation. Thus, the practicality of the designed framework will be realised and validated in industry when used in case studies.

Based on the survey results, the framework has been validated. The same can be said for the framework design requirements, relationship and relevance of each design element and theme. This framework outlines the essential design elements and themes applicable to the manufacturing industry of South Africa. Furthermore, these are considered to holistically represent the principles of Lean and Green.

Considering that Lean and Green is still in its infancy stages, it is yet to be fully realised and implemented in South Africa. Despite the use of lean for sustainable practices, the application of this newly coined paradigm has yet to take form. Therefore, a deep understanding of Lean and Green implementation strategies is needed. For this reason, future research could analyse the implementation factors for Lean and Green in South Africa, followed by an implementation model for Lean and Green similar to David SM [46]. In addition, a methodology could be developed to assess the levels and degree of paradigm integration.

A noteworthy research cause can further contextualise Lean and Green in the South African context. Moreover, Lean and Green can be defined within other sectors in South Africa. One could also consider the effects of future carbon trading and pricing strategies. The strategies recommended by Alton et al [47] suggest that modifications to carbon taxes that include carbon adjustments and appropriate carbon tax revenue recycling can ensure that environmental regress is compensated with a fair economic benefit.

With the current COVID-19 pandemic, new ways of configuring processes, procedures and systems become essential. According to Cohen [48], the need for sustainable practices may be of greater need than ever. This pandemic may serve as an experimentation for downsizing the consumer economy and promote sustainable consumption transitions. Lean and Green may assist in shaping the new society and strategies organisations can turn to.

Higher levels of economic development have proven to decrease energy consumption intensities [49]. Furthermore, energy consumption and CO2 emissions share a unidirectional causality. Hence, strategies, business models or innovations which spur economic development can indirectly reduce CO2 emissions in South Africa. The relationship and environmental gain from these activities can be further investigated.

Despite the need for greening processes, industries must constantly re-evaluate aspects for the most beneficial outcome. These decisions ultimately shape our society and must therefore be taken in the right direction, in the most careful and calculated manner possible. Lean and Green may become a new field of research that can deliver an environmentally conscious, productive, innovative and strategically driven society benefiting oneself and our environment.

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ANNEXURE A

Table 1 Summary of survey design requirements, statements and questions

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
1. Verify the research problem	Convert research problem into survey statement	ST1: The South African manufacturing industry is challenged with reducing their GHG emissions.	4.32
2. Verify the established design requirements for the framework	The framework must co-ordinate elements within each theme using a standard approach	ST2: A standard approach (in the form numbering and colours) is used to formalise, categorise and compartmentalise each element in a theme.	3.84
	The framework must be simple in structure	ST3: The framework is simple in structure.	3.28
	The framework must be legible	ST4: The framework is legible.	3.68
	The framework must be intuitive	ST5: The framework is intuitive to follow.	3.16
	The framework must provide a visual distinction between various elements	ST6: The framework separates and merges different elements	3.68
	The framework must holistically detail elements	ST7: The framework formalises, categorises & compartmentalises elements relevant to Lean and Green	3.8

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
	associated with Lean and Green		
	The relationship amongst the five themes must be defined using visual distinctions or overlaps between the design elements	ST8: By viewing the overlaps between the elements, the relationships between the 5 themes can be understood.	3.56
3. Verify that all design elements and themes are appropriate for GHG reduction	Ensure all design elements are relevant	Q1: Are there any elements or themes within the framework which should be omitted? Q2: If yes, please elaborate	84% Yes 16% No
4. Verify that any potential design elements and themes are identified	Accept suggestions on outstanding elements or themes which were not identified in the literature	Q3: Are there any outstanding elements or themes which you can identify? Q4: If yes, please elaborate	32% Yes 68% No
5. Verify the associations between the design elements	Ensure that the appropriate direct and indirect relationships between each design element are made	**(ST9-22) State the level by which you agree or disagree with the association and layout design for the following elements:**	
		9. Standardised guidelines with energy efficiency, energy consumption, CO2 footprint, CO2 intensity and VSM measures	4.08

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
		10. Financial costs and financial computational methods	3.88
		11. Lean and Green indices and analytical methods	3.75
		12. Carbonfootprinting strategy, Carbon footprint analysis and CO2 footprint metric	4.08
		13. Environmental VSM with Traditional Green tools and Traditional Lean tools	3.96
		14. Traditional Lean tools and Maintenance	3.71
		15. Supply chain management and interactions	3.79
		16. Low carbon practices and a low carbon culture	3.88
		17. Problem analysis strategy with parallel root cause analysis and cost analysis	3.92
		18. Best practices and sustainable practices	3.92
		19. ISO 14 000 with environmental management and Quality measures	3.75

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
		20. ISO 9 000 with quality measures and policy analysis	3.75
		21. ISO 50 001 with policy analysis and energy efficiency	3.88
		22. Policy analysis with carbon tax and policies	4.04
6. Verify the associations between the themes	Ensure that the appropriate direct and indirect relationships between each theme are made	**(ST23-25) State the level by which you agree or disagree that the following themes share an association:**	
		23. GHG reduction strategies with legislation and policies, constructs from pre-existing Lean and Green frameworks, metrics and computational methods	3.88
		24. Metrics with computational methods and constructs from pre-exiting Lean and Green frameworks	3.88
		25. Legislation and policies with GHG reduction strategies and constructs from pre-existing frameworks	3.88
7. Validate that the framework	Validate the themes and framework against the research problem	**(ST26-27) State the level by which you agree or disagree that:**	
		26. The five themes could address the research problem.	4.12

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
addresses the research problem		27. The framework could address the research problem.	3.8

Chapter 5

Verification and validation summary

This chapter provides a review of the verification and validation methods and results performed in this research study.

5 Verification and validation summary

This chapter provides a summary of the specific methods used to perform the verification and validation of the Lean and Green GHG reduction framework, as presented in Chapter 3 (research manuscript) and Chapter 4 (SAIIE Green publication). These also align with the objectives introduced in Chapter 1. By deploying the design science research paradigm, these methods promoted the refinement of the conceptual framework to a standalone framework tailored for the South African manufacturing industry.

5.1 Verification approach

Verification is associated with the substantiation of a model or framework designed according to design requirements, specifications or an intended form (Balci, 1998; Coetzee, 2019). The process of verifying any framework, the significance and applicability is established within a given domain, which facilitates wider acceptance (Soni & Kodali, 2013:12-14).

The purpose of the following subsections is to provide clarity on the method of verification with regards to:

1. The SLR search results selection process,
2. The framework design requirements; and
3. The relationships between design elements and themes belonging to the Lean and Green GHG emission reduction framework in this study.
4. The survey design requirements

5.1.1 SLR results selection process

During the qualitative systematic literature review, numerous publications were obtained from the selection process discussed in Chapter 3. The publications included in the study, were verified by means of an independent researcher. All search results from various databases were exported into comma-separated values (CSV) files. These were consolidated into a master Microsoft Excel spreadsheet. This file contained the title, keywords, journal, abstract and year of publication obtained from the search strategy outlined in the search protocol of the SLR. The filtering procedure was applied by conditional formatting the rows and columns belonging to each search result, with the keywords belonging to the search strategy, inclusion and exclusion criteria. Negative conditional formatting was used to flag publications that featured wording tied to the exclusion criteria. For each of the search results, an independent researcher viewed the justification provided for including or excluding a publication given the title, keywords, abstract,

conditional formatting and downloaded full-text publications provided. A checklist was used to verify the SLR results, as provided in **Appendix D**.

5.1.2 Framework design requirements

During the ATA discussed in Chapter 3, five themes were used to code the publication results obtained from the SLR using Atlas.ti. One of the five themes, constructs from pre-existing Lean and Green frameworks served as a baseline for several design requirements which governed as a core design requirement for the framework. Several design requirements for a framework were also sourced from literature (Coetzee, 2019:68-69; Mangaroo-Pillay, 2020:41-42). The following design requirements were formulated within the context of the framework's design:

- The framework must co-ordinate elements within each theme using a standard approach
- The framework must be simple in structure
- The framework must be legible
- The framework must be simple to understand
- The framework must provide a visual distinction between various elements
- The framework must holistically detail elements associated with Lean and Green
- The relationship amongst the five themes must be defined using visual distinctions or overlaps between the design elements

The conceptual Lean and Green GHG reduction framework was formulated using these design requirements. The compliance with these design requirements was verified using survey statements discussed earlier in Chapter 4. Consensus is declared with an average above three on a 5-point Likert scale, similar to Al-Ghamdi (2014). These results were obtained from a total number of 25 participants. For the analysis of Likert scale data, parametric statics yield unbiased tests, which can be applied to ordinal data and are more robust that nonparametric tests (Norman, 2010; Sullivan & Artino Jr, 2013). An extraction of these specific survey statements (as provided in Appendix A of the SAIIE Green paper) and the corresponding results are shown in Table 9. This table also been modified to include the sample standard deviation, assessing the deviation from mean of each statement. The standard deviation measures the spread of data around the mean (Devore *et al.*, 2013:72-74). A high standard deviation infers a low centrality and lower levels of consensus.

Table 9 Framework design requirement survey results

Framework Design Requirement	Survey statements (ST)	Average (5)	Standard deviation
The framework must co-ordinate elements within each theme using a standard approach	**ST2**: A standard approach (in the form of numbering and colours) is used to formalise, categorise and compartmentalise each element in a theme.	3.84	0.54
The framework must be simple in structure	**ST3**: The framework is simple in structure.	3.28	0.96
The framework must be legible	**ST4**: The framework is legible.	3.68	0.79
The framework must be intuitive	**ST5**: The framework is intuitive to follow.	3.16	0.88
The framework must provide a visual distinction between various elements	**ST6**: The framework separates and merges different elements	3.68	0.88
The framework must holistically detail elements associated with Lean and Green	**ST7**: The framework formalises, categorises & compartmentalises elements relevant to Lean and Green	3.8	0.63
The relationship amongst the five themes must be defined using visual distinctions or overlaps between the design elements	**ST8**: By viewing the overlaps between the elements, the relationships between the five themes can be understood.	3.56	0.75
	Grand mean	**3.57**	

As indicated in Table 9, the standard deviation shows a moderately high dispersion around each mean. All survey statements scored above 3.5, declaring consensus pertaining to survey statements 2,4,6,7 and 8. However, survey statements 3 and 5 obtained an average of 3.28 and 3.16, respectively. This argues that the literature-based conceptual framework is not simple in structure, nor intuitive to follow. Using the ADR approach, these suggestions were used to refine the framework from a literature-based conceptual framework, to a validated framework.

5.1.3 Framework design elements and themes

The design elements and themes proposed in the literature-based framework were subjected to verification by means of survey statements, tied to the following objectives as presented in the SAIIE Green paper:

- Verify appropriateness (GHG emission capabilities) of design elements and themes belonging to the framework
- Verify that all potential design elements and themes are identified (those evident in industry, but absent in the literature sourced in Chapter 3)
- Verify the association (relationships) between design elements within the framework
- Verify the association between themes within the framework

These objectives were translated into seventeen survey statements and four questions which have been extracted in Table 10. Questions were incorporated into the survey in order to identify irrelevant and relevant design elements and themes belonging to the literature-based conceptual framework. For each component that has been verified, the specification and average survey result/percentage agreement are also outlined accordingly.

Table 10 Framework design element and theme survey results

Verification component	Specification	Survey statements (ST) or question (Q)	Average (5) or percentage Yes/No	Standard Deviation
Verify that all design elements and themes are appropriate for GHG reduction	Ensure all design elements are relevant	Q1: Are there any elements or themes within the framework which should be omitted? Q2: If yes, please elaborate	84% Yes 16% No	N/A

Verification component	Specification	Survey statements (ST) or question (Q)	Average (5) or percentage Yes/No	Standard Deviation
Verify that any potential design elements and themes are identified	Consider suggestions on outstanding elements or themes which were not identified in the literature	Q3: Are there any outstanding elements or themes which you can identify? Q4: If yes, please elaborate	32% Yes 68% No	N/A
Verify associations between the design elements	Ensure that the appropriate direct and indirect relationships between each design element are made	**(ST9-22) State the level by which you agree or disagree with the association and layout design for the following elements:**		
		9. Standardised guidelines with energy efficiency, energy consumption, CO2 footprint, CO2 intensity and VSM measures	4.08	0.63
		10. Financial costs and financial computational methods	3.88	0.93
		11. Lean and Green indices and analytical methods	3.75	0.76
		12. Carbon footprinting strategy, Carbon footprint analysis and CO2 footprint metric	4.08	0.56
		13. Environmental VSM with Traditional Green tools and Traditional Lean tools	3.96	0.6
		14. Traditional Lean tools and Maintenance	3.71	0.91

Verification component	Specification	Survey statements (ST) or question (Q)	Average (5) or percentage Yes/No	Standard Deviation
		15. Supply chain management and interactions	3.79	0.88
		16. Low carbon practices and a low carbon culture	3.88	0.77
		17. Problem analysis strategy with parallel root cause analysis and cost analysis	3.92	0.69
		18. Best practices and sustainable practices	3.92	0.63
		19. ISO 14 000 with environmental management and Quality measures	3.75	0.94
		20. ISO 9 000 with quality measures and policy analysis	3.75	0.94
		21. ISO 50 001 with policy analysis and energy efficiency	3.88	0.85
		22. Policy analysis with carbon tax and policies	4.04	0.69
Verify the associations between the themes	Ensure that the appropriate direct and indirect relationships between each theme are made	23. GHG reduction strategies with legislation and policies, constructs from pre-existing Lean and Green frameworks, metrics and computational methods	3.88	0.71

Verification component	Specification	Survey statements (ST) or question (Q)	Average (5) or percentage Yes/No	Standard Deviation
		24. Metrics with computational methods and constructs from pre-existing Lean and Green frameworks	3.88	0.71
		25. Legislation and policies with GHG reduction strategies and constructs from pre-existing frameworks	3.88	0.81
		Grand mean	3.88	

As detailed in Table 10, there is a moderately high standard deviation, pertaining to ISO 900,1400 with computational methods relating to financial costs. Excluding this result, a high level of consensus has been obtained when evaluating the various design element and theme appropriateness. The same outcome was found with regards to the direct and indirect relationships illustrated in the framework.

5.1.4 Survey design requirements

A set of survey design requirements can be extracted from literature (as discussed in Chapter 2) and shaped into a checklist for the purposes of verification. For the purposes of formulating the survey, the insight of academic scholars was sought in order to obtain appropriate survey design requirements. Table 11 stipulates the survey design requirements used in this research.

Table 11 Survey design requirements

Survey Design requirement	Check
Uncluttered survey format	✓
Survey instructions are included	✓

Survey Design requirement	Check
A thank you message features in the survey (survey video)	✓
A pre-existing scale (5-point Likert scale) is used for responses	✓
Statements should not be vague or ambiguous	✓
Statements are not leading or persuasive	✓
Statements do not contain unexplained terms, jargon or acronyms (that were not explained in survey video)	✓
Statements should not double-barrelled	✓
Survey statements are as short and few as possible	✓
Survey statements have been grouped accordingly	✓
Survey maintains the anonymity and confidentiality of participants	✓
Each statement is composed of simple English	✓
Each statement is relevant to the validation and verification process of a research study	✓

These requirements were included in the survey that was shared with subject matter experts as defined in Chapter 1.

5.2 Validation approach

The essential quality criterion in creating knowledge is validity, that which is deemed valid by the scientific community based on the evidence provided (Van Aken, 2005). More specifically, it is a means of fulfilling specified intend using confirmed examination and provision (López *et al.*, 2015). In context of fulfilling the aim of this research and ensuring rigour of the research by deploying ADR within the DSR paradigm (using DSR guidelines), the following needs to be validated:

1. The research problem
2. The research method followed
3. The research output: Lean and Green GHG emission reduction framework

4. Internal consistency of survey

5.2.1 Research problem

This study identified that the South African manufacturing industry is challenged with reducing their GHG emissions. The following survey statement was used to validate the research problem, with its average survey result, shown in Table 12.

Table 12 Research problem survey result

Objective	Survey statement (ST)	Average (5)	Standard deviation
Validate the research problem	**ST1**: The South African manufacturing industry is challenged with reducing their GHG emissions.	4.32	0.54

As can be seen in Table 12, the high average of 4.32 and standard deviation of 0.54 alludes to a high degree of consensus regarding the problem statement formulated in this study. From this, we can concur that the South African manufacturing industry is indeed challenged with reducing their GHG emissions.

5.2.2 Research Design

The DSR guidelines allowed for built-in validation with regards to the research design. This is further explained using the guidelines, description, execution and chapter references embodied in Table 13.

Table 13 DSR guidelines (Hevner *et al.*, 2004)

Guidelines	Description	Execution	Chapter reference
1.Design as an artefact	DSR must produce an identifiable and viable artefact (construct, model, method or instantiation)	A Lean and Green framework was the designed artefact	Chapter 3

Guidelines	Description	Execution	Chapter reference
2.Problem relevance	The objective of DSR is to develop technology-based solutions pertinent and relevant business problems	This framework conceptualises and enables GHG emission reduction in the South African manufacturing industry	Chapter 3 and 5
3.Design evaluation	The utility, quality and efficacy of a design artefact must be rigorously demonstrated by means of well-executed evaluation methods	Surveys subjected to subject matter experts were used to verify the usability, effectiveness and applicability of the Lean and Green GHG emission reduction framework	Chapter 4
4.Research contributions	Effective DSR must produce clear and verifiable contributions in the areas of the design artefact, design foundations, and/pr design methodologies	This framework is the first to formulate the essential themes and elements for GHG emission reduction	Chapter 5
5.Research rigour	DSR relies upon the application of rigorous methods in both the construction and evaluation of the design artefact	A two-stage hybrid methodology encompassing a systematic literature review and applied thematic analysis.	Chapter 3
6.Design as a search process	The search for an effective artefact must utilise available means to reach the desired end while satisfying laws in the problem environment	When introducing the background of the study (Chapter 1) and the state of GHG emissions in South Africa. The problem is also validated during the survey	Chapter 1, Chapter 2 & Chapter 5

Guidelines	Description	Execution	Chapter reference
7.Commiunication of research	DSR must be effectively presented to management-orientated and technology-orientated audiences	The results of this research (Lean and Green GHG emission reduction framework) were communicated to the audience via a 5-minute asynchronous electronic presentation which explained the framework. Similarly, the research is communicated in this dissertation, documentation and research publication.	Thesis document (Chapter 5 more specifically)

5.2.3 Research Output: Lean and Green GHG emission reduction framework

The Lean and Green GHG reduction framework was validated by means of two survey statements. These statements were used to evaluate the ability of the Lean and Green GHG emission reduction framework to conceptualise and guide GHG emission reduction for the South African manufacturing industry.

This evaluation is directly correlated with survey statements 26 and 27 and their results, as detailed in Table 14. These statements evaluate the ability of the five themes (within the framework) and the framework in being able to address the research problem identified in this study.

Table 14 Framework validation survey results

Validation	Survey statements (ST)	Average (5)	Standard deviation
Validate the themes and	**(ST26-27) State the level by which you agree or disagree that:**		

framework against the research problem	9. The five themes could address the research problem.	4.12	0.63
	10. The framework could address the research problem.	3.8	0.73
	Grand mean	**3.96**	

Based on these survey results revealing a low dispersion around the mean of 4,12 and 3.8 respectively, the Lean and Green framework does address the research problem identified in this study. Despite consensus being reached between participants, the framework design was in need of improvement as a requirement of ADR. This was a consequence of low levels of agreement regarding a simple structure and intuitive nature of the framework. Overall, the Lean and Green GHG emission reduction framework was verified and validated using the methods discussed in this chapter.

5.2.4 Survey internal consistency

As configured in Chapter 1, Objective 7 serves to evaluate the internal consistency with regards to the survey results, but also its construct validity. While the literature review serves to convey the core aspects which the Cronbach alpha coefficient aims to achieve, this was used to evaluate the survey more stringently.

In order to perform this analysis, the scores from the 25 survey participants (as discussed in Chapter 3) and 27 survey statements were used to compute the Cronbach alpha. The details of these calculations can be accessed in Appendix F. A summary of this calculations is provided in Table 15.

Table 15 Cronbach alpha parameters and calculation

Parameter	Value
Total Items (n)	27
Sum of variance	15,7376
Variance of total scare	159,8464
Cronbach Alpha	0,93622

From this we are able to confirm the construct validity and internal consistency of the survey has been substantiated in accordance with the high Cronbach alpha value of 0.94, deemed excellent (Habidin *et al.*, 2015; Shamsuddin *et al.*, 2015). This value was computed by studying and calculating the variance for each participant, across all survey statements as well as the total variance of the score obtained. This showcases a high correlation between each statement and scoring consistency belonging to each independent survey participant. We can confirm that the consistency of each evaluation is indeed acceptable.

5.3 Chapter summary

The Lean and Green GHG reduction framework, research problem and research design have been verified and validated using the methods discussed in this chapter. The following chapter serves to conclude the research study and pave the way for future research opportunities.

Chapter 6

Conclusions and recommendations

This chapter concludes the research study and explains the novelty thereof. Moreover, limitations and future recommendations are accompanied by concluding remarks.

6 Conclusions and recommendations

This final chapter will reflect on the findings throughout this study and identify the research limitations. The shortfalls will serve as building blocks for future recommendations. To conclude, the novelty and contribution of this research will be discussed.

6.1 Research study

As GHG emissions are increasing with more anthropogenic activities across all parts of the world, a sound solution becomes more urgent. Various industries have turned to remedies in the form of legislation, protocols, guidelines, and methodologies to improve their environmental performance. This study identified the challenge plaguing the South African manufacturing industry regarding reducing their GHG emissions.

Consequently, this study aimed to design a Lean and Green framework that could conceptualise and guide GHG emission reduction in the South African manufacturing industry.

The study explored the fundamentals of the Lean and Green paradigm and GHG emission reduction in the South African manufacturing industry.

In order to contextualise and lay the knowledge foundations pertaining to the nature of this study, an initial literature study explored the Lean and Green paradigm, along with the components belonging to methods used in this research (objective 1).

A two-stage hybrid methodology was able to extract the essential design elements and themes for a GHG emission reduction framework using Lean and Green. Firstly, the qualitative SLR assisted in scouring the literature using stringent research search protocol across academic databases outlined in Chapter 3. Thereafter, the design elements for GHG reduction were extracted and classed within five emergent themes during the ATA, asexplained in Chapter 3 (Objective 2). For more detail, a sample of the textual data coded has been provided in Appendix E.

The literature-based conceptual framework (obtained from the aforementioned hybrid methodology) required refinement. During this process, design elements were included, removed or amalgamated with similar elements as advised by the survey participants. In addition, the fifth theme (constructs from pre-existing Lean and Green frameworks) was forged within the final framework to encompass the true nature of Lean and Green (objective 3).

During the qualitative SLR, the research publications were verified by an independent researcher, with a sample provided in **Appendix C**, and verification checklist in **Appendix D (objective 4).** Here, specific reference is made to the technical manner in which the publications were screened before being subjected to the ATA.

The final framework obtained validity after subject matter experts reached consensus through the survey. The survey was used to verify that the framework satisfies all design requirements (Objective 5). These refer to the design requirements suggested by academic scholars, and the constructs from pre-existing Lean and Green frameworks (Theme 5 discussed in Chapter 3). The survey was also used to confirm the validity of the research problem, research design and research output (framework) (Objective 6).

The use of Cronbach was also found to confirm the construct validity and internal consistency of the survey after obtaining a score of

6.2 Research contribution

Lean and Green is an emergent research field which has gained academic interest amongst scholars. This ever-advancing field of research is yet to take form in developing countries such as South Africa. Furthermore, no Lean and Green research has focused on formalising the elements (mechanisms) for GHG emission reduction, as most work has only been used to formalise the identity of the Lean and Green paradigm in the academic field. The DSR knowledge contribution framework (Figure 16) can represent the context of a research project and potential DSR research contribution.

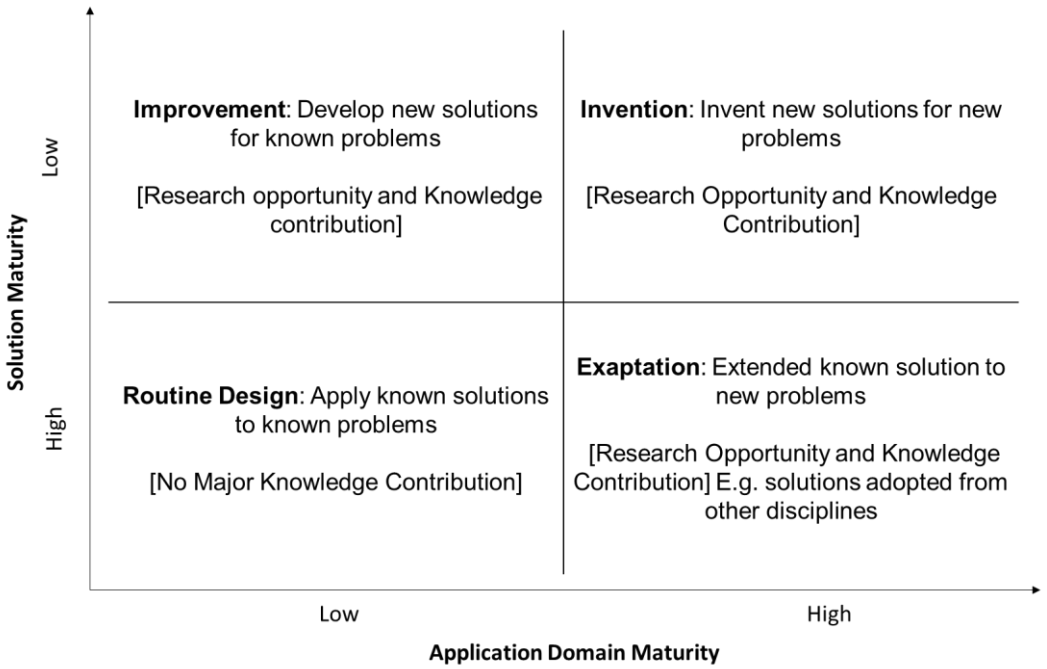

Figure 16 DSR Knowledge Contribution Framework adapted from Gregor and Hevner (2013)

As shown in Figure 16, four classes are defined according to the degree of maturity belonging to the solution and application domain. The contribution of the framework from this study can be deemed as an improvement and exaptation. According to the research problem identified, the solution maturity regarding GHG emission reduction is known to society. However, the research opportunity in formalising design elements for GHG reduction within the Lean and Green paradigm. For this reason, the DSR knowledge contribution from this research can serve as an improvement by building on existing literature, thereby falling into the top left-hand quadrant.

From an equal but opposite perspective, GHG emissions can be perceived as a new problem, for which Lean and Green offered a resolve. In this way, the contribution can also be interpreted as an exaptation, located in the bottom right-hand quadrant of Figure 16. According to Gregor and Hevner (2013), the goal of this quadrant is to create better solutions by means of efficient products, processes, services, technologies and in the case of this research, ideas.

The findings from this research offer researchers and practitioners the essential elements and themes needed for GHG reduction by means of Lean and Green. In addition, this research introduced the principles of Lean and Green in the South African environment. GHG emissions have been a growing concern in society for several years. Lean and Green offer an opportunity to address this challenge encountered in various industries. This study showcases the potential and capabilities built into the Lean and Green paradigm.

6.3 Limitations and future recommendations

Despite the advances made in this research, there were limitations that can be further explored.

A verified and validated Lean and Green GHG reduction framework was designed in this study. The elements for GHG emission within the Lean and Green paradigm were formalised in this way for the first time. However, an extension on this could entail the development of a Lean and Green GHG reduction methodology that explicitly defines the steps, metrics and environmental value stream mapping (EVSM) tool that needs to be followed to achieve GHG emission reduction within a specific organisation or industry.

Also, since this framework has been designed theoretically and validated in principle by participants, its effectiveness when applied in industry still needs to be determined. Case studies can be created within the South African manufacturing industry that can take form using the framework proposed in this research. Researchers can seek inspiration from other Lean and Green implementation models similar to David and Found (2016). By incorporating this research, a Lean and Green implementation model can be tailored and redefined for South Africa. An attempt to define such a model, may begin with outlining a South African learning maturity advancement model. This is highly recommended, due to the term **Lean and Green** seldomly used or coined domestically. This may allude to organisations requiring further guidance when adopting this paradigm in order to best negate polarities and misguided visions within an organisation.

The design intent for the Lean and Green GHG reduction framework is to target the South African manufacturing industry. Beyond this, further research could explore the Lean and Green identity for the South African environment as a means to improve productivity and environmental performance. Similarly, this can be generalised to other developing countries. Despite the growing research and case studies reported in literature, the opportunity to spur and develop this paradigm in other contexts is most valid.

This framework can also be extended to other industries within South Africa or address more environmental concerns within the manufacturing industry using Lean and Green. Lean and Green socio-environmental factors and environmental performance metrics can be defined for the South African environment. This would be highly beneficial considering the poor energy mix and environmental state of the country. When adopting this paradigm, integration and assessment become crucial. To facilitate the paradigm integration, assessment criteria and methods have already been designed within the Lean and Green arena (Bhattacharya *et al.*,

2019; Fercoq *et al.*, 2016). Research efforts could pursue creating these forms of integration within more local contexts.

Lean and Green is also used to help drive strategic goals and define business models. With the growing popularity and implementation of Industry 4.0 technologies from the Fourth Industrial Revolution, numerous advantages and advancements have been made. However, numerous challenges have been experienced during this adoption. To date, research has already explored improving the strategy and vision towards the Fourth Industrial Revolution (4IR) (Leong *et al.*, 2020). This can be furthered by considering other dynamics with the Lean and Green paradigm that can align with 4IR. Academics now use the term Industry 5.0, a new term used to stress the human aspects and sustainability concerns that Industry 4.0 fails to provide (Demir & Cicibas, 2017). Despite this debate between Industry 4.0 and Industry 5.0 terms, the need exists to define sustainable guidelines and methods when working with these technologies. Lean and Green can also be designed in the new Society 5.0 vision Japan seeks to follow. Society 1.0 to 5.0 journey has been propagated by each industrial revolution. This approach can be studied and tested in societal settings in countries where the Fourth Industrial Revolution is set to take form.

6.4 Concluding remarks

The Lean and Green paradigm is becoming a field of research with increasing interest and opportunities to resolve the environmental issues society dwells upon. The multidisciplinary nature of the Industrial Engineering discipline encourages further investigation with regards to Lean and Green. Beyond the environmental gains yielded by adopting this paradigm, this may serve as a fundamental stepping-stone to harness new potential in various knowledge domains, seek new solutions to existing problems or even help shape and redefine societal constructs, systems, technologies and interaction with our environment.

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Appendix A

Signed Researcher Code of Conduct

Appendix A

Signed Researcher Code of Conduct

CODE OF CONDUCT FOR RESEARCHERS

This code of conduct is applicable to all NWU researchers.

As a researcher of the North-West University (NWU), I subscribe to the rules of the NWU Institutional Research Ethics Regulatory Committee (IRERC), all applicable policies of the NWU as well as all national and international laws and regulations applicable to my field of study. Furthermore, I commit myself to abide by the ethical principles and responsibilities as set out in the Singapore statement on Research Integrity (22 September 2010), in any and all research endeavours that I undertake as a researcher of the NWU.

The four major principles of research integrity to which I will adhere and that will guide my research are:

- Honesty in all aspects of research
- Accountability in the conduct of research
- Professional courtesy and fairness in working with others
- Good stewardship of research on behalf of others

Consequently I will also adhere to the following ethical responsibilities:

1. I will take responsibility for the originality and trustworthiness of my research.

2. I will stay abreast of and adhere to all institutional, national, and international laws, regulations, and policies applicable and related to my research.

3. I will at all times employ appropriate research methods, base my conclusions on critical analysis of the evidence and report my findings and interpretations fully and objectively.

4. I will keep clear and accurate records of all research that I have conducted in a manner that will allow verification and replication of my work by others, if applicable.

5. I will, where applicable, share my data and findings openly and promptly, in line with external funding rules. This will be done as soon as possible after I have had an opportunity to establish priority and ownership claims.

6. I will take responsibility for my own contributions to publications, funding applications, reports and other representations of my research. I will also and only include authors who meet valid authorship criteria.

7. I will acknowledge the names and roles of those who made significant contributions to my research in publications, including writers, funders, sponsors, and others, but do not meet authorship criteria.

8. In my peer reviews, I will provide fair, prompt and rigorous evaluations and I will respect confidentiality when I review others' work.

9. I will disclose all conflicts of interest (financial and other) that could compromise the trustworthiness of my work in research proposals, publications, public communications, and in review activities.

10. When I publically address a community in the spirit of academic freedom, I will in all stages base my professional comments on research findings (if applicable) and my expertise. I will distinguish between professional comments and opinions based on personal views.

11. Should any irresponsible research practices and/or research misconduct become known to me or brought under my attention, I will report such irresponsible research activities to the appropriate authorities.

12. I will respond to irresponsible research practices or conduct, by taking prompt actions as set out in the procedures of the university. I will also protect those who report misconduct in good faith, to the best of my abilities.

13. I will endeavour to create and sustain an environment that encourage research integrity through education of students, research teams and peers, as well as abide by policies, and reasonable standards for advancement.

14. I will at all times weigh societal benefits against the risks inherent in my work.

Name: Meelan Roopa

Signature:

Date: 4/9/19

Appendix B

Ethics approval letter for study

Private Bag X1290, Potchefstroom
South Africa 2520

North-West University Engineering Research Ethics Committee (NWU-ENG-REC)

Tel: 018 299-2645
Email: ENG-REC@nwu.ac.za

11/13/2020

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the North-West University Engineering Research Ethics Committee (NWU-ENG-REC) on 11/13/2020, the NWU-ENG-REC hereby approves your study as indicated below. This implies that the NWU-ENG-REC grants its permission that, provided the general and specific conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: Designing a Lean and Green framework for the reduction of GHG emissions in the South African manufacturing industry

Principal Investigator/Study Supervisor/Researcher: R Coetzee
Student: Meelan Roopa (26275988) meelanroopa@gmail.com
Ethics number: **NWU-01771-19-A1**
Institution Study Number Year Status
Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application Type: Single
Approval date: 10/18/2019
Expiry date: 8/23/2020

Risk: **Low Risk**

Approval of the study is provided for a year, after which continuation of the study is dependent on receipt and review of annual monitoring report and the concomitant issuing of a letter of continuation.

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:

- *The principal investigator/study supervisor/researcher must report in the prescribed format to the NWU-ENG-REC:*
  - *Annually on the monitoring of the study, whereby a letter of continuation will be provided annually, and upon completion of the study; and*
  - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*
- *The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the principal investigator/study supervisor/researcher must apply for approval of these amendments at the NWU-ENG-REC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*
- *Annually a number of studies may be randomly selected for active monitoring.*
- *The date of approval indicates the first date that the study may be started.*
- *In the interest of ethical responsibility, the NWU-ENG-REC reserves the right to:*

- *request access to any information or data at any time during the course or after completion of the study;*
- *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;*
- *withdraw or postpone approval if:*
  - *any unethical principles or practices of the study are revealed or suspected;*
  - *it becomes apparent that any relevant information was withheld from the NWU-ENG-REC or that information has been false or misrepresented;*
  - *submission of the annual monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and/or*
  - *new institutional rules, national legislation or international conventions deem it necessary.*
- *NWU-ENG-REC can be contacted for further information via ENG-REC@nwu.ac.za or 018 299 2645*

Special conditions of the research approval (if applicable): NA

Special in process conditions of the research for approval (if applicable): NA

The NWU-ENG-REC would like to remain at your service and wishes you well with your study. Please do not hesitate to contact the NWU-ENG-REC for any further enquiries or requests for assistance.

Yours sincerely,

Dr. Rojanette Coetzee
Chair NWU-ENG-REC

Current details:(25767984) \NWUNextCloud\ENG-REC\Letters sent\[Date]\9.1.5.4.3_NWU-ENG-REC_REC_EAL_[student surname_name]

File Reference: 9.1.5.4.2

Appendix C

SLR publication search result sample

The following table serves as sample of the research publications filtered during the SLR. Across all academic databases used in the SLR (Web of Science, Emerald Insight, Science Direct & Scopus), the research title, author, journal, year, abstract and keywords were exported in csv format, with the exception being Emerald Insight. Conditional formatting was used to colour code each result using red and green. The green fill represents cells which contain the inclusion criteria under the conditions provided in the Research protocol (Table 1 in Chapter 3). The green cells represent the exact terms which feature as exclusion criteria in the aforementioned table. Where a red cell and green cell match a specific row (publication), a note for inclusion was used to substantiate it qualifying for full text reading. Clear cells were excluded from full text reading. The following sample only represents a segment of the research publications obtained from Science direct. The full dataset, comprising of 547 rows was reviewed by an independent researcher in this format. A verification checklist was completed, which can be found in **Appendix D**.

Table 1 – Sample set of SLR publications obtained from research protocol.

No	Author	Title	Journal	Year	Abstract	Keywords	Database	Note for inclusion
34	H.T.S. Caldera, C. Desha, L. Dawes	Evaluating the enablers and barriers for successful implementation of sustainable business practice in 'lean' SMEs	Journal of Cleaner Production	2019	'Sustainable business practice' is an aspiration for an increasing proportion of small and medium-sized enterprises (SMEs) around the world, promising profitability, resilience and positive social and environmental impacts. 'Lean thinking' has evolved as a popular business strategy for SMEs to achieve sustainable business practice, addressing the need for efficiency in production and waste reduction. In this study we explore the co-evolution of 'lean and green thinking' and the potential for lean and green practices to enable successful transitions to sustainable business practice. Focusing on investigations into manufacturing SMEs in Queensland, Australia, we first establish four key enablers and six key barriers to sustainable business practice, derived from a series of in-depth interviews with Chief Executive Officers and senior managers involved in sustainability and lean manufacturing. We offer an institutional theory perspective on these findings, concluding the potential for normative, coercive and mimetic drivers to influence SMEs to shape environmental, social and economic decision making and legitimize the transition to sustainable business practice. We then present a novel 'Model of strategic enablers of sustainable business practice' to guide SMEs to intentionally use their lean and green strategies to successfully adopt sustainable business outcomes. We propose that through adopting lean and green thinking to transition to sustainable business practice, SMEs can more	Lean and green; Enablers; Barriers; Small and medium-sized enterprises; Institutional theory	Science Direct	

No	Author	Title	Journal	Year	Abstract	Keywords	Database	Note for inclusion
					rapidly contribute to the circular economy at the level of firm. Agencies and professional bodies can support SMEs in this transition through targeted interventions that address the enablers and barriers presented.			
35	Suresh Kumar Jakhar, Himanshu Rathore, Sachin Kumar Mangla	Is lean synergistic with sustainable supply chain? An empirical investigation from emerging economy	Resources, Conservation and Recycling	2018	In the extant literature some researchers have agreed upon the nature of inter-relationship between lean and green as synergistic whereas other have termed it as coincidental or even dichotomous. We submit that the inconclusiveness in the relationship between lean and green arises from not investigating it from a holistic standpoint. In this study, we address this gap by adjudging the relationship of lean systems with holistic supply chain context which includes sourcing, production and logistics. The proposed hypotheses are grounded in the resource-based view of the firm. We examine the relationship in the context of emerging economy such as India. Results obtained using structural equation modelling method indicates that lean implementation positively influences the implementation of sustainability practices for supplier selection and production but negatively impacts sustainability practices for delivery and logistic services. We conclude that the relationship between lean management and sustainable supply chain management is not straightforward. Gain at some place may cause loss at other places. Therefore, the net impact must be seen in totality and segmented analysis is the cause of inconclusive findings.	Lean; Green; Sustainable supply chain; Emerging economy	Science Direct	
36	Cristina López, Rocío Ruiz-Benítez	Multilayer analysis of supply chain strategies' impact on sustainability	Journal of Purchasing and Supply Management	2019	Integrating lean, green and resilient strategies into Supply Chain (SC) decisions is a key success factor for transformation toward sustainability. These strategies are increasingly common in the SC, although their implementation and results are not the same across different SC levels (Tier 1, 2 and 3 suppliers and the focal company). In spite of this, earlier studies have not explored in detail their effects on environmental, economic and social sustainability dimensions nor differentiated between SC levels and therefore implementation strategies overlook the difference between these levels. Accordingly, a novel multilevel analysis of the aerospace manufacturing SC based on Interpretive Structural Modeling (ISM) is carried out. This approach allows exploring the effects of combining lean, green and resilient strategies on	Multi-tier supply chain; Sustainability; Lean SCM; Resilient SCM; Green SCM; Aerospace manufacturing sector	Science Direct	

No	Author	Title	Journal	Year	Abstract	Keywords	Database	Note for inclusion
					specific sustainability performance measures in the aerospace manufacturing SC. The findings reveal differences between SC levels on the effects of lean, green and resilient strategies on the different sustainability dimensions. Additionally, Tiers 2 and 3 show a higher resistance or lower implication in the development of lean, green and resilient strategies than the focal company and Tier 1 companies. Final ISM models become a useful tool for managers to specifically establish coordinated long-term SC sustainability programs for each SC level.			
39	W. Muchaendepi, C. Mbowa, J. Kanyepe, M. Mutingi	Challenges faced by the mining sector in implementing sustainable supply chain management in Zimbabwe	Procedia Manufacturing	2019	Sustainable supply chain management (SSCM) is the incorporation of ecological concerns into the inter-organisational exercises of supply chain management. The implementation of SSCM in the mining sector has been a slow process. The study was conducted to determine the challenges facing effective implementation of sustainable supply chain management within mining sector in Zimbabwe. The researchers employed a case study of mining sector, where descriptive data research method was utilized with a target population comprising 1000 companies and a sample of 91 organizations was obtained, using Slovin's equation. The researchers adopted the convenience sampling technique which involved the choice of subjects who were well equipped with relevant information to the researchers focus. A convenient sample size of 40 mining companies in Zimbabwe was selected based on of researchers' easy accessibility to them. The findings revealed that, presently there is absence of structural and organisational change to support implementation of sustainable supply chain management. The study recommends that the organisations and different stakeholders should ensure that there is structural and organisational change to support, improvement of legal and regulatory framework on environment, reduction of cost connected with green products and distribution of resources vital for effective implementation of sustainable supply chain management.	Green Supply Chain Management; Reverse Logistics; Supply Chain Managemnet; Sustainability	Science Direct	
42	Anass Cherrafi, Jose Arturo Garza-Reyes, Vikas Kumar, Nishikant	Lean, green practices and process innovation: A model for green	International Journal of	2018	This paper investigates the relationship between lean, green and process innovation practices and green supply chain (GSC) performance. Data were collected	Lean; Green; Process innovation; Green supply chain	Science Direct	

No	Author	Title	Journal	Year	Abstract	Keywords	Database	Note for inclusion
	Mishra, Abby Ghobadian, Said Elfezazi	supply chain performance	Production Economics		from 374 manufacturing firms and results analyzed using Structural Equation Modeling (SEM). The findings revealed a synergetic effect between process innovations, green and lean practices, which play a crucial role towards the improvement of GSC performance. In particular, the results suggested that: (1) lean practices such as JIT, set-up time reduction, cellular manufacturing, and waste elimination can significantly contribute to improve GSC performance; (2) green practices including eco-design, life cycle assessment, green manufacturing, reverse logistics, and waste management significantly and positively affect GSC performance; (3) process innovation practices such as fast response to new processes introduced by other companies within the same sector, pioneering disposition to introduced new processes, and number of changes in the process introduced in one year, do not have a direct contribution to improving GSC performance; finally that (4) process innovation amplifies the effect which contributes for lean and green practices to offer a higher payoff rate in terms of GSC performance when these are coupled with process innovation activities. This paper presents an innovative approach since it studies simultaneously the three dimensions of sustainability (environmental, social and economic), the lean, the innovation process and green paradigms, which are considered strategic for supply chain competitiveness. Investigating the relationships between the four strategies is a contribution that the authors hope will become a forward step for promoting sustainability in manufacturing supply chains.	performance; SEM; Survey		
43	Kanchan Das,	Integrating lean systems in the design of a sustainable supply chain model	International Journal of Production Economics,	2018	Lean based systems include several practices and tools that have the potential to facilitate an organization to be economically, environmentally, and socially sustainable. The objective of this research is to integrate applications of lean systems in the design and planning model of a supply chain to improve sustainability performances of the overall business. The study defines and identifies antecedents, enablers, and ingredients of sustainable supply chain based on the literature. It also identifies practices and outcomes of Lean based systems that may be applied to supply chain functions in the perspectives of established	Lean systems; Sustainability performance; Supply chains; Enabler for sustainability; Ingredients of sustainability; Design model	Science Direct	

No	Author	Title	Journal	Year	Abstract	Keywords	Database	Note for inclusion
					sustainability criteria. Such practices and outcomes of lean based systems are then incorporated in the design of a sustainable supply chain to become enabler, antecedents or ingredients of sustainability to improve overall business performances. A numerical example illustrates the applicability of the approach.			
44	Ron Van Duin, Bart Wiegmans, Lori Tavasszy, Birgit Hendriks, Yunzhu He,	Evaluating new participative city logistics concepts: The case of cargo hitching	Transportation Research Procedia,	2019	Five years ago the project Cargo Hitching started with the goal to use the unused capacity of public transport passenger vehicles for freight and parcel transport. Like many new city logistics initiatives it is a difficult challenge to setup a profitable private business model. A rural pilot project was developed in the East of the Netherlands, building on Dutch government funding (Dinalog), with several Dutch universities, the province of Gelderland, public transport service provider Connexxion and city logistics service provider Binnenstadservice. The paper describes how viability for the cargo hitching project was organized, providing important social and environmental benefits as well as a sustainable business model for the system.	Integration; passenger transport; parcel delivery; business model; social value; city logistics	Science Direct	
51	Dah-Chuan Gong, Chi-Wei Kao, Brett A. Peters,	Sustainability investments and production planning decisions based on environmental management	Journal of Cleaner Production,	2019	Abstract: Europe 2020 strategy highlighted that sustainable consumption and production requires resource and energy efficiency. In terms of sustainability in energy, carbon footprint, conservation, efficient energy use, and emissions trading are some major concerns. Under the Kyoto Protocol, a trading market mechanism is developed as a policy of reducing the emissions of greenhouse gases in each country. Firms are always considering whether the investment cost on emission reduction matches the benefit. One possible practice is to look for energy savings that are able to offset additional costs from the sustainability investment. This paper aims to establish such a sustainability investment decision model, which uses dynamic programming for solutions to minimize cost. The purpose is to effectively reduce emissions produced during production through investment in energy-saving, high productivity equipment and allocation of production capacity considering emissions (or so-called carbon) trading market price, greenhouse gas emission credits or caps given by the government, inventory cost, and production cost. Management-oriented implications are proposed following analysis of the results of detailed numerical examples.	Sustainability investment; Emissions (or carbon) trading; Production planning; Dynamic programming	Science Direct	

Appendix D

SLR filtering process verification checklist

By completing this search result verification, I hereby acknowledge that I have tested the search strategy on the databases listed below, and that this was completed with research integrity.

Criteria	Checked	Comment
Search strategy		
Using the search strategy ("Lean and Green") AND ("Framework" OR "Model" OR "Tax" OR "South Africa" OR "*emission*") from 2015 to September 2019. The following search results are obtained:		
• Science Direct: 218	✓	
• Web of Science: 51	✓	
• Emerald Insight: 175	✓	
• Scopus: 103	✓	
Total: 547 publications	✓	
Duplications		
83 Duplicated publications were obtained	✓	
All duplications were removed		
New total: 464 Unduplicated publications	✓	
Inclusion criteria		
All non-english publications were removed	✓	
Only research and review papers were included	✓	
Exclusion criteria		
By excluding publications focused on logistics, supply chain performance assessment, risk analysis, product-service design systems, renewable sources, urban planning, construction, mining, six sigma, transportation, IT or green computing, the following publications remain:	✓	
Science Direct: 37	✓	
Web of Science: S	✓	
Emerald Insight: 6	✓	
Scopus: 8	✓	
Total: 56 publications selected	✓	
No publications were falsely included in the final selection	✓	
No publications were incorrectly excluded from the final selection	✓	

Appendix E

ATA Atlas.ti code sample

The following table serves as a sample of the codes and output table from ATLAS.ti. The quotation content refers to the textual data coded, whereas the document refers to the relevant publication from which the quotation content was found. Furthermore, the Computation code, refers to one of the themes which feature in the literature-based conceptual framework presented in Chapter 3. The raw data from this table is associated with Table 3 from Section 4.1 belonging to Chapter 3. In a similar fashion, other themes and quotation content was processed and presented in Section 4 of Chapter 3.

ID	Quotation Name	Document	Quotation Content	Codes	Reference
4:1	Genetic Algorithm, Multi Objective Optimization	Achieving environmental sustainability in manufacture A 28-year	Genetic Algorithm, Multi Objective Optimization	Computation	9:2994 - 9:3041
4:5	Simulation	Achieving environmental sustainability in manufacture A 28-year	Simulation	Computation	9:3761 - 9:3770
4:6	Achieving environmental sustainability in manufacture A 28-year	Achieving environmental sustainability in manufacture A 28-year	(Equations)	Computation	12:405:212 - 12:435:213
4:8	Achieving environmental sustainability in manufacture A 28-year	Achieving environmental sustainability in manufacture A 28-year	(Equations)	Computation	12:101:241 - 12:142:243
4:10	Algorithm	Achieving environmental sustainability in manufacture A 28-year	Algorithm	Computation	9:3786 - 9:3794

4:17	algorithms	Achieving environmental sustainability in manufacture A 28-year	algorithms	Computation	14:691 - 14:700
4:18	simulations	Achieving environmental sustainability in manufacture A 28-year	simulations	Computation	14:703 - 14:713
4:19	Data Envelopment Analysis	Achieving environmental sustainability in manufacture A 28-year	Data Envelopment Analysis	Computation	9:3830 - 9:3854
4:21	input- output analysis	Achieving environmental sustainability in manufacture A 28-year	input- output analysis	Computation Tool	15:666 - 15:689
11:23	ISO 14067, Defra 2010, PAS 2050 and Greenhouse Protocol	Effects of low carbon	ISO 14067, Defra 2010, PAS 2050 and Greenhouse Protocol	Computation	5:847 - 5:901
20:4	Analytical	Interactions in sustainable	Analytical	Computation	9:1777 - 9:1785
29:8	Optimization	Role of culture in low carbon	ptimization	Computation	5:2850 - 5:2860
29:9	structural equation modeling (SEM	Role of culture in low carbon	structural equation modeling (SEM	Computation	5:2574 - 5:2607
29:10	multi-objective linear programming	Role of culture in low carbon	multi-objective linear programming	Computation	5:2620 - 5:2653

46:13	carbon footprint	Lean-green integration and its impact on sustainability performance	carbon footprint	Computation	8:3854 - 8:3869
47:2	carbon dioxide (CO2) emissions, namely: directly assessing the carbon…	Opportunities and challenges in sustainable supply chain An operations research perspective	carbon dioxide (CO2) emissions, namely: directly assessing the carbon footprint; measuring Green House Gases (GHG); assessing CO2 emissions through the environmen- tal impact category “Global Warming Potential”; and assessing CO2 through the environmental impact category “Climate Change” (CC)	Computation Metric	14:1432 - 14:1729
47:5	Simulation 10 23 – – Optimization 60 110 5 3 Queuing Theory 1 – – –…	Opportunities and challenges in sustainable supply chain An operations research perspective	Simulation 10 23 – – Optimization 60 110 5 3 Queuing Theory 1 – – – Data analysis – 9 1 1 Neural networks 1 1 – – Expert systems – – 1 – Decision analysis 4 10 – 1 Metaheuristics 4 5 – – Statistics	Computation	10:954 - 10:1159
48:1	TRIZ	Reviewing the use of the theory of inventive problem solving (TRIZ) in	TRIZ	Computation	8:5836 - 8:5839
55:4	Carbon Footprint ¼ Total Amount Used in Selected Activity Standard E…	An integrated lean and green approach for improving sustainability performance a case study of a packaging manufacturing SME in the U K	Carbon Footprint ¼ Total Amount Used in Selected Activity Standard Emission Factor	Computation	6:683 - 6:768

68:2	Emissions are calculated according to process and indirect modules	Simulation based assessment of lean and green strategies in manufacturing systems	Emissions are calculated according to process and indirect modules	Computation	4:1411 - 4:1477
68:3	Simulation based assessment of lean and green strategies in manufacturing systems	Simulation based assessment of lean and green strategies in manufacturing systems	(Equations)	Computation	5:44:162 - 5:294:308
68:6	Simulation	Simulation based assessment of lean and green strategies in manufacturing systems	Simulation	Computation	3:4782 - 3:4791
68:8	shows the resulting cost-time and CO2-cost profiles. 75% of generated…	Simulation based assessment of lean and green strategies in manufacturing systems	shows the resulting cost-time and CO2-cost profiles. 75% of generated CO2-emissions are caused by 2 processes, which are responsible for 21% of value addin	Computation	5:4007 - 5:4163
78:2	Ctotal ¼ Cva þ Cnva	Application of green modified value stream mapping to integrate and implement lean and green practices A case study	Ctotal ¼ Cva þ Cnva	Computation	8:2503 - 8:2522
78:3	C efficiency ¼ Value added products or value added services carbon e…	Application of green modified value stream mapping to integrate and implement lean and green practices A case study	C efficiency ¼ Value added products or value added services carbon emission	Computation	8:3645 - 8:3723

78:4	Cva ¼ X N i¼1 Cva i ¼ X N i¼1 Cm i þ CiE ¼ P P i¼1 NPj¼1…	Application of green modified value stream mapping to integrate and implement lean and green practices A case study	Cva ¼ X N i¼1 Cva i ¼ X N i¼1 Cm i þ CiE ¼ P P i¼1 NPj¼1 Qm i;j EFim;j Mi;j þ XP i¼1 SXl¼1 Eidle þ Pi;l tiva ;l EFelec	Computation	8:2734 - 8:2887
78:5	process; Pi;l: rated power of lth equipment of the single piece produ…	Application of green modified value stream mapping to integrate and implement lean and green practices A case study	process; Pi;l: rated power of lth equipment of the single piece product of the ith process; tiva ;l : efective working time of the lth equipment of the single piece product of the ith process (value-added time); and EFelec: discharge coefcient of electric energy. Cnva ¼ X N i¼1 Cnva i ¼ X N i¼1 Cnm i þ CinE þ X R w¼1 CT w þ Cl ¼ X P i¼1 NXj¼1 h i Qm i;j EFim;j 1 Mi;j þ X P i¼1 SXl¼1 Eidle i;l þ Pi;l tinva ;l EFelec þ X R w¼1 ET w EFelec þ El EFelec (5) Where: Cnva i : non-value-added c	Computation	9:1 - 9:552

78:9	In the GMVSM model (Figure 1), the following attri- butes are include…	Application of green modified value stream mapping to integrate and implement lean and green practices A case study	In the GMVSM model (Figure 1), the following attri- butes are included. Pi: ith process; Xi: required number of operators of the ith process; Ni: required number of equipment of the ith process; Mi;j: jth material consump- tion of the ith process; Ei;j: jth energy consumption of the ith process; Ti0: non-value-added time of the preceding ith process; Ti: non-value-added time of the ith process; ti : value-added time of the ith process; Ei0: energy con- sumption of the non-incremental value of the preceding ith process; ei: energy consumption of the incremental Figure 1. Green-modifed value stream mapping. 6 X.-Y. ZHU ET AL. value of the ith process; Ei: energy consumption of the non-incremental value of the ith process; Di0: non-value- added transportation distance of the preceding ith pro- cess; di: value-added transportation distance of the ith process; Di: non-value-added transportation distance of the ith process; Ci0: non-value-added carbon emission of the preceding ith process; ci: value-added carbon emis- sion of the ith process; and Ci: non-value-added carbon emission of the ith process.	Computation	7:1520 - 8:490
78:10	Yv ¼ ΔCv m Ymvk þ ΔCEv YEvk þ ΔCTv YTvk þ ΔCIv YIvk ηv ¼ ΔQv…	Application of green modified value stream mapping to integrate and implement lean and green practices A case study	Yv ¼ ΔCv m Ymvk þ ΔCEv YEvk þ ΔCTv YTvk þ ΔCIv YIvk ηv ¼ ΔQv m EFm Ymvk þ ð Þ Eidle þ P Δtv YEvk þ ΔETv EFelec YTvk þ ΔEIv EFelec YIvk ηv ¼ P P i¼1 NPj¼1 ΔQv mi;j EFim;j Ymvk þ PP i¼1 SPl¼1 Eidle i;l þ Pi;l Δtiv;l	Computation	9:3068 - 9:3432

			EFelec YEvk þ PR w¼1 ΔEv Tw EFelec Yvk " T þ ΔEIv EFelec YIvk# ηv		
78:12	simulation	Application of green modified value stream mapping to integrate and implement lean and green practices A case study	simulation	Computation	5:805 - 5:814
79:7	MFCA	Applying the green Embedded lean production model in	MFCA	Computation	6:1006 - 6:1009
82:3	CFðkgCO2Þ ¼ ECðGJÞ CES kgCO GJ 2 (1) CES ¼ h DCO2H x%H þ DCO2B x%…	Creating value with less impact Lean, green and eco-efficiency in a	CFðkgCO2Þ ¼ ECðGJÞ CES kgCO GJ 2 (1) CES ¼ h DCO2H x%H þ DCO2B x%B þ DCO2P x%P þ DCO2G x%G þ DCO2C x%C þ DCO2N x%N þ DCO2W x%W þ DCO2O x%O (	Computation	4:3087 - 4:3271
82:5	EE ¼ Product value Environmental impact	Creating value with less impact Lean, green and eco-efficiency in a	EE ¼ Product value Environmental impact	Computation	4:4108 - 4:4148
82:6	EE ¼ Total setup hours in one semester Carbon emission during setup H…	Creating value with less impact Lean, green and eco-efficiency in a	EE ¼ Total setup hours in one semester Carbon emission during setup Hours gCO2	Computation	4:5028 - 4:5109
82:7	EE ¼ Total production hours in one trimesterðfor each type of machineÞ…	Creating value with less impact Lean, green and eco-efficiency in a	EE ¼ Total production hours in one trimesterðfor each type of machineÞ Carbon Emission during productionðfor each type of machineÞ Hours gCO2	Computation	5:1634 - 5:1778

82:8	EE ¼ Total production hours in one trimesterðsetup þ productionÞ Carb…	Creating value with less impact Lean, green and eco-efficiency in a	EE ¼ Total production hours in one trimesterðsetup þ productionÞ Carbon Emissionðsetup þ productionÞ Hours gCO2	Computation	5:1787 - 5:1900
89:2	CFPVAT ¼ X N i ADVAT;i EFi (3) where: CFPVAT is the carbon footpr…	Integrating and implementing Lean and Green practices based on	CFPVAT ¼ X N i ADVAT;i EFi (3) where: CFPVAT is the carbon footprint generated during value added time. ADVAT,i is the activity data during value added time for activity i. EFi is the emission factor for activity i. N is the total number of activity during value added time. Similar to assessing the carbon footprint generated during value added time, Eq. (4) computes the carbon footprint generated during non-value added time. CFPNVAT ¼ X N i ADNVAT;i EFi (4) where: CFPNVAT is the Carbon Footprint generated during non-value added time. ADNVAT,i is Activity Data during non-value added time for ac- tivity i. EFi is Emission Factor for activity i. N is the total number of activity during n	Computation	5:522 - 5:1243
89:3	The CVE proposed above and the other information are then presented i…	Integrating and implementing Lean and Green practices based on	The CVE proposed above and the other information are then presented in a Carbon-Value Effciency VSM (CVE-VSM). This en- ables users to visualise and analyse the value adding activities based on the amount of carbon footprint generated. The CVE-VSM will be presented in the case study in the subsequent sections.	Computation	5:1266 - 5:1582

89:9	CFPVAT is the carbon footprint generated during value added time. CFP…	Integrating and implementing Lean and Green practices based on	CFPVAT is the carbon footprint generated during value added time. CFPNVAT is the carbon footprint generated during non-value added time. There are a number of methodologies to quantify carbon foot- print (International Organisation for Standardisation, 2013, 2006a, 2006b; The British Standards Institution, 2011). To streamline the carbon footprint quantifcation, a generic formula is adopted from (Ng et al., 2014b, 2014c, 2012, 2011). Eq. (3) computes the carbon footprint generated during value added time. CFPVAT ¼ X N i ADVAT;i EFi (3) where: CFPVAT is the carbon footprint generated during value added time. ADVAT,i is the activity data during value added time for activity i. EFi is the emission factor for activity i. N is the total number of activity during value added time. Similar to assessing the carbon footprint generated during value added time, Eq. (4) computes the carbon footprint generated during non-value added time. CFPNVAT ¼ X N i ADNVAT;i EFi (4) where: CFPNVAT is the Carbon Footprint generated	Computation	5:1 - 5:1058
99:4	Design of Experiments	LeanGreen integration focused on waste reduction techniques	Design of Experiments	Computation	1:1271 - 1:1291

100:3	programming model" since it makes possible to opti- mize different ob…	Modelling green and lean supply chains An eco-efficiency perspective	programming model" since it makes possible to opti- mize different objective functions	Computation	4:1974 - 4:2060
103:2	Design of experiment	Principal component analysis-aided statistical process optimisation	Design of experiment	Computation	1:924 - 1:943
103:3	Principal Component Analysis (PCA)	Principal component analysis-aided statistical process optimisation	Principal Component Analysis (PCA)	Computation	2:3305 - 2:3338
106:2	CO2 footprint indicator; EVCO2 ¼ minimum monthly CO2 emission=total i…	Adaptive analytical approach to lean and green operations	CO2 footprint indicator; EVCO2 ¼ minimum monthly CO2 emission=total i monthly production average monthly CO2 emission =total i monthly production	Computation	9:3962 - 9:4108
106:3	Carbon emission of i ¼ Total operation hours exhaust gas mass flowra…	Adaptive analytical approach to lean and green operations	Carbon emission of i ¼ Total operation hours exhaust gas mass flowrateof i gas GWP of component i (28)	Computation	9:3369 - 9:3476
110:4	simulation	A PDCA-based approach to Environmental Value Stream Mapping (E-VSM)	simulation	Computation	2:4138 - 2:4147
115:2	¼ CO2 emissions (kg/year)/materials	Are all lean principles equally eco-friendly - A panel data study	¼ CO2 emissions (kg/year)/materials	Computation	5:6103 - 5:6137

136:2	carbon footprint (CFP)	Planning for Environmental Sustainability Improvements – A Concept based on Eco-Efficiency Improvement	carbon footprint (CFP)	Computation	2:2861 - 2:2884
136:3	Planning for Environmental Sustainability Improvements – A Concept based on Eco-Efficiency Improvement	Planning for Environmental Sustainability Improvements – A Concept based on Eco-Efficiency Improvement	(Equations)	Computation Framework	3:56:182 - 3:288:513
138:1	multi objective optimization	Review of Green Supply Chain Processes	multi objective optimization	Computation	2:4775 - 2:4803
138:3	Harris et al. (2014) have proposed a model that optimises the CO2 emi…	Review of Green Supply Chain Processes	Harris et al. (2014) have proposed a model that optimises the CO2 emission and financial cos	Computation	3:5379 - 3:5472
138:4	simulation	Review of Green Supply Chain Processes	simulation	Computation	7:124 - 7:133
148:3	The second step assigns the elementary flows to impact categories acc…	Value chain upgrading in a textile dyeing industry	The second step assigns the elementary flows to impact categories according to the contribution of the resource/emission to different environmental problems, using standard characterisation factors, and evaluates the significance of potential environmental impact	Computation	6:937 - 6:1202

150:4	State space model	Promoting sustainability of manufacturing industry through the lean	State space model	Computation	6:2169 - 6:2185
150:5	Promoting sustainability of manufacturing industry through the lean	Promoting sustainability of manufacturing industry through the lean	(Equations)	Computation	6:296:173 - 6:572:474
155:6	Equivalent per kilowatt hour of generation [gCO2eq/kWh] from a specifi…	An Approach to Integrate Parameters and Indicators of Sustainability Management into Value Stream Mapping	Equivalent per kilowatt hour of generation [gCO2eq/kWh] from a specific product	Computation	3:1972 - 3:2051
155:8	In the method “carbon footprint analysis” the total greenhouse gas (…	An Approach to Integrate Parameters and Indicators of Sustainability Management into Value Stream Mapping	In the method “carbon footprint analysis” the total greenhouse gas (GHG) emissions are estimated in terms of carbon equivalence (i.e. as tons of carbon dioxide equivalent [tCO2e] or grams of CO2 equivalent per kilowatt hour of generation [gCO2eq/kWh] from a specific product [40].	Computation	3:1771 - 3:2058
155:9	Simulation	An Approach to Integrate Parameters and Indicators of Sustainability Management into Value Stream Mapping	Simulation	Computation	2:4862 - 2:4871

155:11	(GRI)	An Approach to Integrate Parameters and Indicators of Sustainability Management into Value Stream Mapping	(GRI)	Computation	1:5069 - 1:5073
160:10	mathematical mode	Sustainability investments and production planning decisions based on environmental management	mathematical mode	Computation	4:5685 - 4:5701
163:9	simulation	The relationship between lean and environmental performance Practices and measures	simulation	Computation	4:3442 - 4:3451

Appendix F

Survey results & Cronbach alpha calculations

The following table represents the survey results from the 25 participants. These results are associated with the survey statements provided in Annexure A of Chapter 4. The total score has also been provided in the rightmost column. Furthermore, the Cronbach alpha and parameters feature at the bottom of this Appendix.

Table 1 – Sample set of survey results with Cronbach alpha parameters and calculation

Participant	ST 1	ST 2	ST 3	ST 4	ST 5	ST 6	ST 7	ST 8	ST 9	ST 10	ST 11	ST 12	ST 13	ST 14	ST 15	ST 16	ST 17	ST 18	ST 19	ST 20	ST 21	ST 22	ST 23	ST 24	ST 25	ST 26	ST 27	Total
P1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	4	5	4	4	4	5	5	5	113
P2	5	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	107
P3	5	4	2	4	2	2	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	4	2	96
P4	4	4	3	3	3	4	4	3	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	103
P5	5	3	1	2	1	2	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	75
P6	5	4	4	4	2	4	4	3	4	4	4	4	4	3	4	4	4	4	4	4	4	4	3	3	4	4	4	103
P7	4	4	5	4	3	4	4	4	4	4	3	4	4	3	4	4	4	4	4	4	4	4	4	4	4	5	4	107
P8	5	4	3	4	4	4	4	4	4	3	3	4	4	5	3	5	3	4	3	3	3	4	3	4	5	4	4	103
P9	5	4	4	4	3	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	91
P10	4	4	2	2	2	3	2	3	4	4	3	4	3	3	4	4	5	3	2	2	4	4	3	3	3	4	3	87
P11	4	4	4	4	4	4	4	4	4	4	4	4	3	4	3	4	4	4	3	3	3	4	4	4	4	4	4	103
P12	4	5	4	4	4	5	5	4	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5	129
P13	3	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	4	4	123
P14	4	4	4	2	4	5	4	5	5	5	3	5	4	5	5	3	4	5	3	5	5	5	5	4	4	4	3	114
P15	5	4	3	5	2	4	4	4	5	4	3	4	4	2	3	4	3	4	2	2	2	4	4	3	4	4	4	96
P16	5	5	3	4	3	1	2	2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	120
P17	3	3	4	5	3	4	4	3	4	4	5	5	5	4	5	5	5	5	5	5	4	5	5	5	5	3	2	115
P18	3	3	2	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3	3	4	4	79
P19	4	4	4	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	107
P20	5	4	2	3	3	4	4	3	4	4	4	4	4	4	2	3	3	3	3	3	3	3	4	4	4	4	2	93
P21	4	4	3	4	2	4	4	4	3	2	2	4	4	4	3	4	3	4	3	3	3	3	3	4	3	4	5	93
P22	4	4	4	4	4	4	4	4	5	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	3	4	4	107
P23	5	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	4	5	4	5	5	115
P24	5	4	3	4	4	3	4	4	4	3	4	4	4	2	4	3	4	4	4	4	4	4	4	4	3	4	4	102
P25	4	3	2	3	4	4	4	4	4	3	4	4	4	5	5	4	4	4	5	5	5	3	4	3	4	4	3	105
Variance	0,46	0,29	0,92	0,62	0,77	0,78	0,40	0,57	0,39	0,53	0,58	0,31	0,36	0,82	0,77	0,59	0,47	0,39	0,88	0,88	0,71	0,48	0,51	0,51	0,67	0,27	0,8	

Total Items	27	Variance of total scare	159,8464
Sum of variance	15,7376	Cronbach	0,93622031