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

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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.

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

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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.

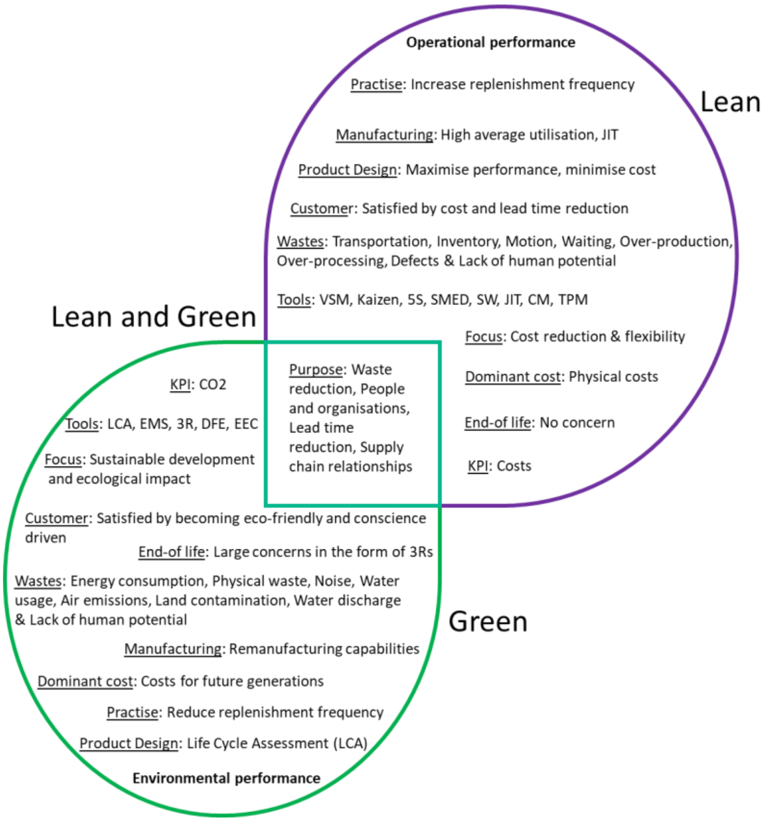

Figure 1: Lean and Green overlap adapted from Dües et al [19] and Zokaei et al [15]

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 [15, 19]. 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**.

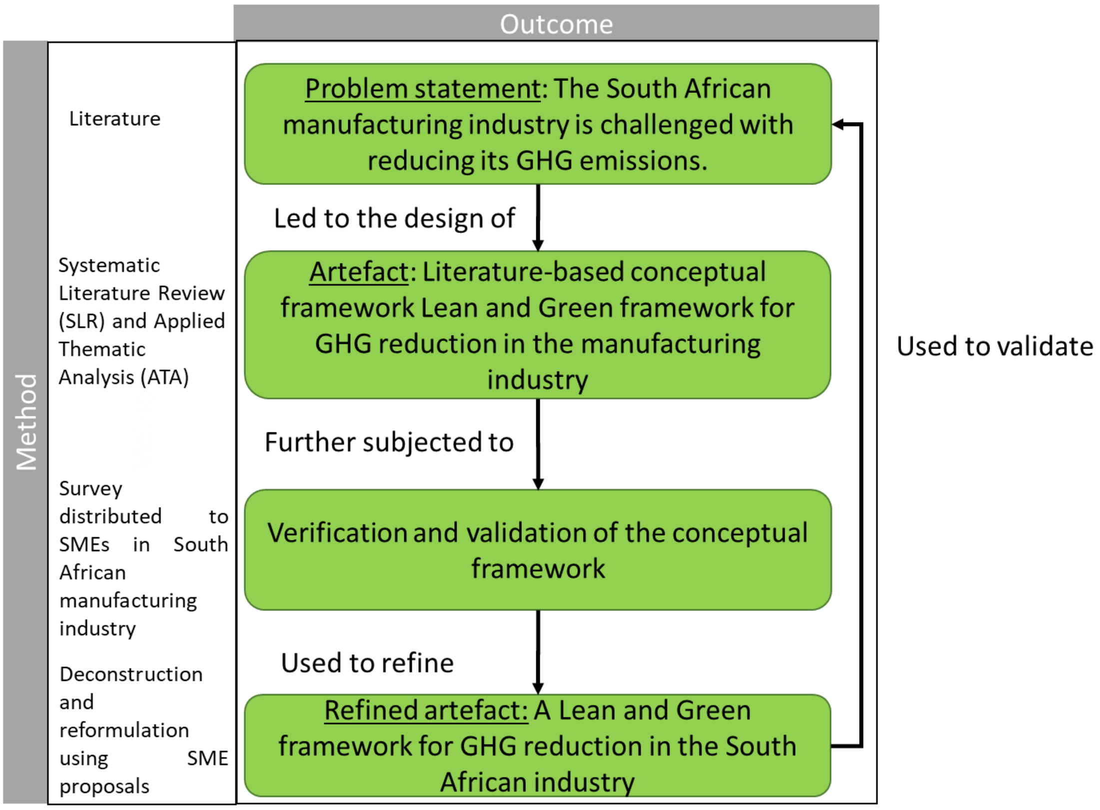

Figure 3: Research methodology

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.**

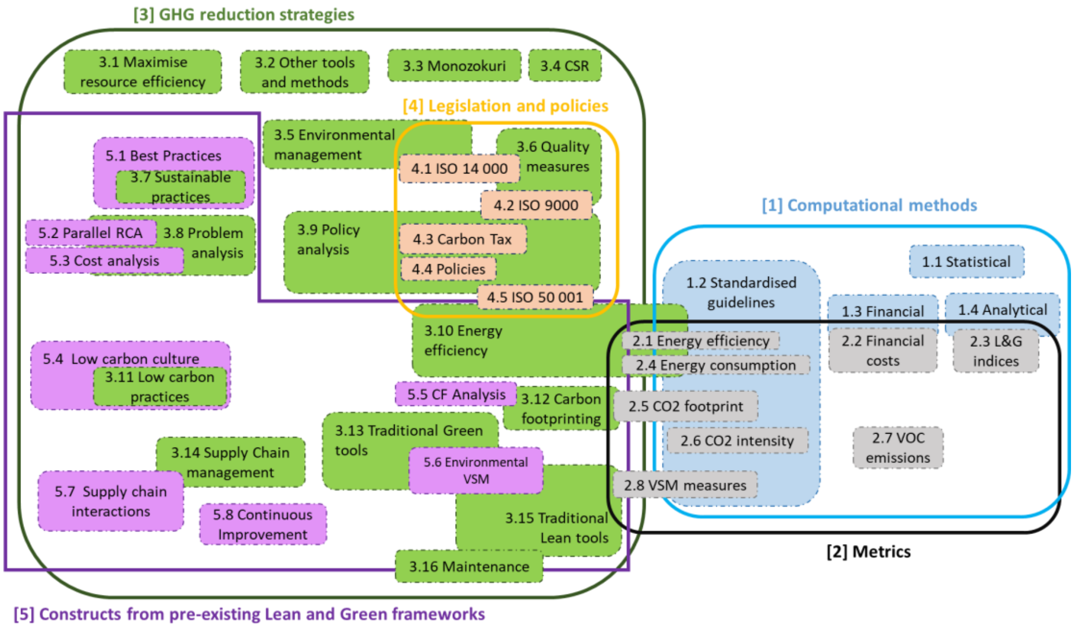

Figure 4: Literature-based Conceptual Lean and Green framework for GHG reduction in the manufacturing industry

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**.

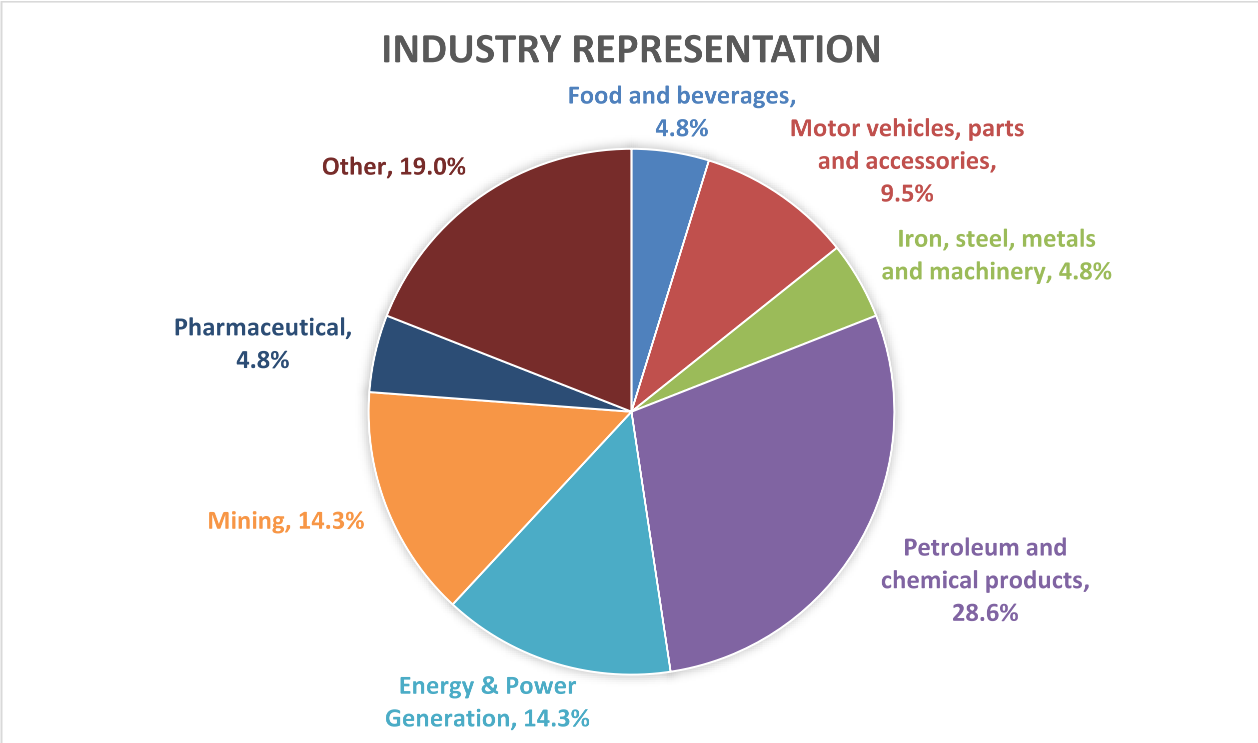

Figure 5: Industry representation of survey participants

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**.

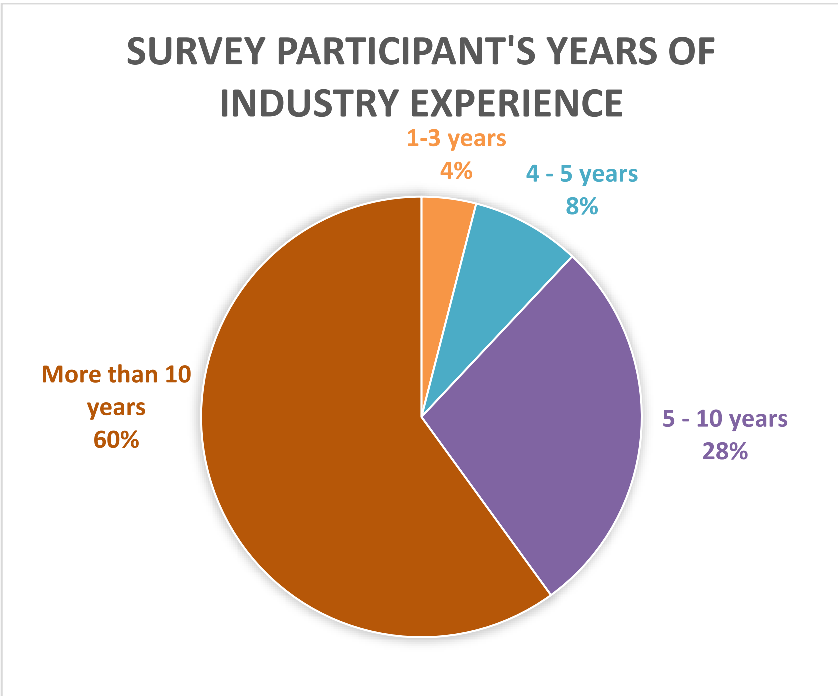

Figure 6: Survey participant years of experience

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**).

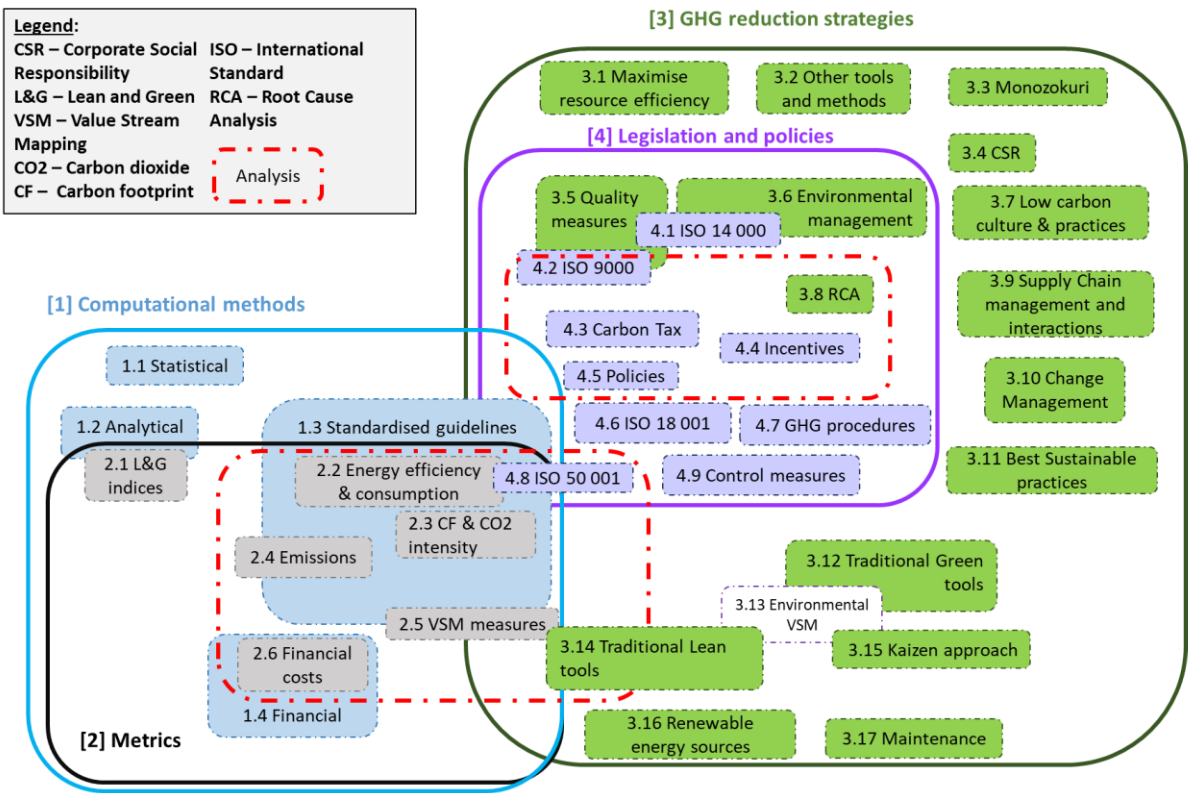

Figure 7: Lean and Green framework for GHG reduction in the South African manufacturing industry

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.

5 REFERENCES

[1] **Stats SA.** 2020. Trading Economics: South Africa GDP From Manufacturing [Online]. Available from: https://tradingeconomics.com/south-africa/gdp-from-manufacturing [Accessed 10 May 2020].

[2] **Oxford. 2017.** "CO2 emissions per Capita," Our World in Data.

[3] **Gore, A.** 2006. An inconvenient Truth, Rodale.

[4] **WWF.** 2019. The Carbon Tax 2019 explained,World Wide Fund for Nature [Online]. Available from: https://www.wwf.org.za/?28421/The-Carbon-Tax-2019-explained. [Accessed 10 June 2020].

[5] **Tsutsui, W. 1999.** Manufacturing ideology: Scientific management in twentieth-century Japan, *American Historical Review,* vol. 4, no. 104, pp. 1278-1279.

[6] **Liker, J.K. 2003.** The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer, McGraw Hill Professional.

[7] **Womack, J.P. and Jones, D.T. 2010.** Lean Thinking: Banish Waste and Create Wealth in Your Corporation, Simon and Schuster.

[8] **Krafcik, J.F. 1988.** Triumph of the Lean Production System. *Sloan Management Review*, vol. 30, no. 1.

[9] **Burgess, N. and Radnor, Z. 2013.** Evaluating Lean in healthcare. *International journal of health care quality assurance*.

[10] **Maradzano, I., Dondofema, R. and Matope, S. 2019.** Application of lean principles in the South African construction industry. *South African Journal of Industrial Engineering*, vol. 30, no. 3, pp. 210-23.

[11] **Sassanelli, C., Terzi, S., Perzzotta, G. and Rossie, M. 2015.** How lean thinking affects product service systems development process, Ciarapica Filippo Emanuele.

[12] **Vignesh, V., Suresh, M. and Aramvalarthan, S. 2016**. Lean in service industries: A literature review. *IOP Conference Series: Materials Science and Engineering*.

[13] **Davies, E. & Van der Merwe, K. 2016.** Methodology to produce a water and energy stream map (WESM) in the South African manufacturing industry. *South African Journal of Industrial Engineering*, vol. 27, no. 3, pp. 219-29.

[14] **Scuton, R. 2014**. Green Philosophy: How to think seriously about the planet, Atlantic Books.

[15] **Zokaei, K., Lovins, H., Wood,A. & Hines, P. 2017.** Creating a Lean and Green Business System: Techniques for improving profits and sustainability, CRC press.

[16] **Jan-Adrian, C. 2012**. Maturity assessment of green supply chain management in the South African FMCG Industry. University of Pretoria.

[17] **Sharifa K. and Othman M. 2020**. The impact of green human resource management practices on sustainable performance in healthcare organisations: A conceptual framework. *Journal of Cleaner Production*, vol. 243.

[18] **Farias, L., Santos, L., Gohr, C., Oliveira, L. and Amorim, M. 2019**. Criteria and practices for lean and green performance assessment: Systematic review and conceptual framework. *Journal of Cleaner Production*, vol. 218, pp. 746-762.

[19] **Dües, C., Tan, K. and Lim M. 2013**. Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain. *Journal of Cleaner production*, pp. 93-100.

[20] **Bradley, F. 1997**. Unconscious Incompetence to Unconscious Competence. *Adults Learning (England)*, vol. 9(0).

[21] **Kreuger L. and Neuman, W. 2006**. Social work research methods: qualitative and quantitative applications., Boston: Pearson Education6.

[22] **de Vos, A., Strydom, H., Fouche C., and C. Delport. 2010**. Research at grass roots. Pretoria, Van Schaik, pp. 397-401.

[23] **Coetzee, R. 2019**. Towards designing an artefact evaluation strategy for human factors engineering: A lean implementation model case study. *South African Journal of Industrial Engineering*, vol. 30, no. 3, pp. 289-303.

[24] **Henver, A. 2007**. A three cycle view of design science research. *Scandinavian Journal of Information Systems*, vol. 28, no. 1, pp. 87-92.

[25] **Al-Ghamdi, K. 2014.** A survey of the practices of the approaches taught in an industrial engineering undergraduate programme. *South African Journal of Industrial Engineering*, vol. 25, no. 2, pp. 121-134.

[26] **Greinacher, S., Moser, E., Hermann, H. and G. Lanza. 2015**. Simulation Based Assessment of Lean and Green Strategies in Manufacturing Systems. *Prcedia CIRP,* vol. 29, no. 2015 Jan, pp. 86-91.

[27] **Fercoq, A., Lamouri, S. and Carbone, V. 2016**. Lean/Green integration focused on waste reduction techniques. *Journal of Cleaner production,* vol. 137, no. Nov 20, pp. 567-78.

[28] **Ambekar, S. 2019.** Role of culture in low carbon supply chain capabilities. *Journal of Manufacturing Technology Management,* vol. 21.

[29] **Choudhary, S., Nayak, R., Dora, M., Mishra, N. and Ghadge, A. 2019**. An integrated lean and green approach for improving sustainability performance: a case study of a packaging manufacturing SME in the U.K. *Production planning & Control,* no. 30, pp. 353-68.

[30] **Pang, R. and Zhang, X. 2019**. Achieving environmental sustainability in manufacture: A 28-year bibliometric cartography of green manufacturing research. *Journal of Cleaner production*.

[31] **Cai, W., Lai, K., Liu, C., Wei, F., Ma, M., Jia, S., Jiang, Z. and Lv, L. 2019.** Promoting sustainability of manufacturing industry through the lean energy-saving and emission-reduction strategy. *Science of the Total Environment,* vol. 665, pp. 23-32.

[32] **Zhu, X., Zhang, H. and Jian, Z. 2019**. Application of green-modified value stream mapping to integrate and implement lean and green practices: A case study. *International Journal of Computer Integrated Manufacturing,* pp. 1-16.

[33] **Saito, K., Salazar, A., Kreafte K. and E. Gruike**. **2017**. Hitozukuri and Monozukuri Centries Old Eastern Philosophy to seek harmony within nature. *Interdisciplinary Information Science,* vol. 17, no. 1, pp. 1-9.

[34] **Cherrafi, A., Elfezazi, S., Hurley, B., Garza-Reyes., Kumar. V, Anosike, A. and Batista, L. 2019**. Green and Lean: a Gemba–Kaizen model for sustainability enhancement. *Production Planning & Control,* vol. 30, no. 5-6, pp. 385-399.

[35] **Carvalho, H., Govindan, K., Azevedo, S. and Cruz-Machado, V. 2017.** Modelling green and lean supply chains: An eco-efficiency perspective. *Resources, Conservation and Recycling,* vol. 120, pp. 75-87.

[36] **Moussa, F., Rasovska, I., Dubois, S., Du Guio,R. and Benmoussa, R. 2017**., "Reviewing the use of the theory of inventive problem solving (TRIZ) in green supply chain problems. *Journal of cleaner production,* vol. 142, pp. 2677-2692.

[37] **Ramos, A.R., Ferreira, J.C.E., Kumar, V., Garza-Reyes, J.A. and Cherrafi, A. 2018**. A lean and cleaner production benchmarking method for sustainability assessment: A study of manufacturing companies in Brazil. *Journal of Cleaner Production,* vol. 177, pp. 218-231.

[38] **Vandenbergh, M. and Steinemann, A.** 2007. The carbon-neutral individual. *NYUL*.

[39] **Gössling, S. 2009**. Carbon neutral destinations: A conceptual analysis. *Journal of Sustainable Tourism,* vol. 17, no. 1, pp. 17-37, 2009.

[40] **Mangaroo-Pillay, M. 2019**. Investigating the root causes of long lead times in the automotive aftersales industry by means of the lean philosophy: A South African Case study. *SAIIE neXXXt,* Port Elizabeth.

[41] **NPT**. 2020. NPT ISO certification & consultancy [Online]. Available from: http://www.nptmanagementsystems.co.uk/management-systems/what-is-iso18001. [Accessed 27 May 2020].

[42] **Rodrigues, M., Sá, A., Masi, D., Oliveira, A., Boustras, G. and Leka, S. 2020**. Occupational Health & Safety (OHS) management practices in micro-and small-

sized enterprises: The case of the Portuguese waste management sector. *Safety Science,* vol. 129, 2020.

[43] **Aoki, A. and Staeblein, T. 2017**. Monozkuri capability and dynamic product variety: an analysis of the design-manufacturing interface at Japanese and German automakers. *Technovation,* vol. 70, pp. 33-45.

[44] **Marczyk, G. and DeMatteo, D**. 2005. Essentials of research design and methodology, John Wiley & Sons.

[45] **Hurtmann, D. 2020**. Demand management in health care: the case for failure demand. Doctoral Thesis under Examination: Univeristy of the Witwatersrand.

[46] **David, S. and Found, P. 2016**. An implementation model for lean and green. *Understanding the Lean Enterprise*, Springer,Cham, pp. 1-29.

[47] **Alton, T., Arndt, C., Davies, R., Hartley, F., Makrelov,** K.**, Thurlow, J. and Ubogu, D. 2014**. Introducing carbon taxes in South Africa. *Applied Energy,* vol. 116, pp. 344-54.

[48] **Cohen, M.J. 2020**. Does the COVID-19 outbreak mark the onset of asustainable consumption transition?. *Sustainability: Science, Practice and Policy*.

[49] **Bekun, F., Emir, F. and Sarkodie, S. 2019.** Another look at the relationship between energy consumption, carbon dioxide emissions, and economic growth in South Africa. *Science of The Total Environment,* vol. 655, no. 10 March 2019, pp. 759-765.

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

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
	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
	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	Ensure that the appropriate direct and	**(ST9-22) State the level by which you agree or disagree with the association and layout design for the following elements:**	

Objective	**Design Requirement or Subject matter specifications**	**Survey statement (ST) or Question (Q)**	**Avg. result (5)**
between the design elements	indirect relationships between each design element are made		
		9. Standardised guidelines with energy efficiency, energy consumption, CO2 footprint, CO2 intensity and VSM measures	4.08
		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

Objective	Design Requirement or Subject matter specifications	Survey statement (ST) or Question (Q)	Avg. result (5)
		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
		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

Objective	**Design Requirement or Subject matter specifications**	**Survey statement (ST) or Question (Q)**	**Avg. result (5)**
		25. Legislation and policies with GHG reduction strategies and constructs from pre-existing frameworks	3.88
7. Validate that the framework addresses the research problem	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
		27. The framework could address the research problem.	3.8