
Impact of Lean Six Sigma on Sustainability: Relationships and framework for their integration

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Preface

This master thesis was conducted during the autumn of 2018 as the completion of my Master of Science in Mechanical Engineering, at the Faculty of Engineering, Lund University; and the completion of my Master of Industrial Engineering at the Polytechnic University of Valencia. It has been a challenging time where I have been able to apply a great part of the knowledge that I learned during my years at university.

This has been a very interesting period of my Master, which has allowed me to deepen my knowledge about concepts which I have always been curious.

I am grateful to many people who made this thesis possible. First, I would like to thank the interviewed and their companies, who let me know about their procedures and their opinions. They gave me valuable insights for the completion of this project. Thanks to Julian Fox and Tetrapack, Anders Bergman and Höganäs, Johan Valett and Haldex, Marlies Kock and Sandvik.

I want to thank my family and friends as well for their support and motivation.

Finally, I want to thank Bertil I Nilsson, my supervisor at the Faculty of Engineering at Lund University, for his support through the project, always giving me the right feedback and guidance. I am grateful to him as well for providing this thesis with helpful company contacts to perform the interviews.

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Abstract

Title	Impact of Lean Six Sigma on Sustainability: Relationships and framework for their integration.
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Problem definition	Nowadays society is very concerned with sustainability. Companies try their best to meet sustainability customers' expectations and regulations. The adoption of Lean and Six Sigma could bring sustainability improvements, but it is not clear how these three areas are combined and how they are currently addressed by companies.
Purpose	Explore the relationship between Lean, Six Sigma and Sustainability, and how the deployment of the first two support the overall sustainability of an organization. Moreover, to develop a framework for Lean Six Sigma and Sustainability integration, providing a general guide for a wide scope of companies of different industries.
Methodology	The research approach of this thesis is both exploratory and descriptive. It is based in a qualitative mean, done by 4 interviews to relevant companies and a literature study. A further explanatory study to understand the relationships between the concepts is used. This is used for making a framework for LSS and Sustainability integration.
Results and conclusion	Nowadays, more than ever, companies have an interest and intent in sustainability, with a focus on the environment and on social aspects such as health and safety. Lean Six Sigma can support that with a structure, which is a solid foundation and a good start for a sustainable business. LSS improves use of resources, reduces waste and improves safety, ethics and leadership. But that alone is not enough for sustainability excellence. LSS doesn't affect material extraction, product use, product disposal or recycling. Therefore, sustainability initiatives are needed to move a company to an excellence spot. Those can be obtained by benchmark and is possible to combine them with Lean Six Sigma through the integrated framework presented in this Master thesis.
Key words	Lean, Six Sigma, Sustainability, Green manufacturing, Sustainable manufacturing, Integrated framework.

Glossary and acronyms

DMAIC	The five steps of a Six Sigma process: Define, Measure, Analyze, Improve and Control.
Green Manufacturing	A manufacturing system that has a minimal environmental impact.
ISO	International Organization for Standardization, a non-governmental organization that develops standards for industry and international trade.
KPI	Key Performance Indicator, a measure of the performance level of a process that is strategic for the business.
LCA	Life Cycle Assessment, a technique for studying the environmental potential impacts of a product through its life cycle.
Lean	Lean is a quality management program to promote higher levels of quality and make the processes more flexible and responsive, reducing their waste, through the use of a set of tools and a process methodology.
LSS	Lean Six Sigma, the integration of both Lean and Six Sigma, to reduce waste and variation on processes.
PDCA	A management method for continuous improvement with the steps of Plan, Do, Check and Act.
Six sigma	Is a quality management program to improve process quality through reduction of defects and variability of a process. It achieves that through the use of several statistical techniques and tools.
Sustainability	The concept of having a balance between the human development and the protection of the environment, being able to meet the needs of the present without compromising the needs of future generations. It englobes three dimensions: economic, environment and social.
Sustainable Manufacturing	A manufacturing system that minimizes environment impact, take into consideration the social dimension and do not harm the economic viability.
Triple Bottom Line	A framework to evaluate the performance of a company through the economic, environment and social dimensions of sustainability.

VSM

Value Stream Mapping, a Lean tool for analyzing the addition of value through a process perceived from the customer point of view. Used to redesign processes, finding the non-value adding activities that are considered a waste and should be removed.

3 pillars of sustainability

Same as three dimensions of sustainability, which are the economic, environmental and social.

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1 Introduction

This first chapter gives a background for the master thesis and briefly explains the concepts of Lean, Six Sigma, Sustainability and their relationship. Then, the purpose of the thesis is presented among the problem definition, the research questions and delimitations of this study. Finally, there is a brief description of the chapters and structure of the thesis.

1.1 Introduction to Lean, Six Sigma and Sustainability

Advanced international competition does not only focus on price or cost but also on the full range of quality. Quality is per definition to offer and specify goods and/or service in accordance with customer's needs and requirements.

Secondly, a supplier needs to fabricate goods and produce services in accordance with the agree specification – at first time and at every time a delivery will take part.

Thirdly the supplier needs to stay with international standards and other regulatory requirements, including environmental and socio-political values.

There are three areas of interest to support all type of process within a supplier's jurisdiction and in the whole value chain – from raw material via fabrication and distribution to recycling and reuse. These knowledge areas are Lean, Six Sigma and Sustainability.

Companies are aware of the increasing attention of environmental concerns. They need to integrate those concerns into their strategic plans and activities, such as environmental protection, waste management, product life cycle, worker health and safety and community relations. At the same time, there is a trend to enhance the connection between quality and sustainability. Sustainability focuses on environmental performance improvements and reductions of waste, and those are addressed by quality management practices of continuous improvement such as Lean or Six Sigma. ISO 14000 also links both areas by applying ISO 9000 (Foster, 2013).

Although a lot of research has been done on Lean, Six Sigma and lately on its integration as a unified methodology, there is not too much information about how these policies can impact the sustainability philosophy of a company. Or how well the companies that use Lean or/and Six Sigma are well in accordance with requirements of sustainability. Many SME think that even one of these areas are heavy to introduce - high costs, plenty of training, high level of documentation/bureaucracy. But maybe, if an SME starts with one of these (Lean or Six Sigma), it will be rather easy to cover all three. The introduction of Lean could help make the first steps of the sustainability road while reducing costs, improving quality and improving the overall profit of the organization at the same time.

Currently, Lean and Six Sigma bring quality benefits that potentially could improve the sustainable performance of a company. Also, many firms have integrated sustainability in their strategic planning, and proactively improve towards more sustainable operations. Therefore, it is key to know the relationships between Lean, Six Sigma and Sustainability.

Lean and Six Sigma could be the initiators to a complete sustainable business, with economic, environmental and social goals to achieve. And from that, with the addition of sustainable initiatives and KPIs, a transition to a complete sustainable manufacturing business is feasible. An integrated framework that could coordinate all these concepts and could guide towards sustainability is very desirable.

1.2 Purpose

The main purpose of this research is to explore the relationship between the three areas of Lean, Six Sigma and Sustainability, how companies combine these different systems and how the deployment of the first two helps the overall sustainability of an organization. Furthermore, their synergies and deviations will be analyzed, so it is a purpose of the thesis to explore these relations and find how companies overcome them. Also, it's important to investigate the tools that companies use, the frameworks, and how they prioritize their improvements and make their decisions. Furthermore, from the knowledge and experience acquired from the literature and from producing the cases study, the purpose is to develop a framework for Lean Six Sigma (LSS) and Sustainability integration, providing a general guide for a wide scope of companies of different industries. There have been other frameworks developed in the literature, but usually are industry specific or don't cover all the matters that companies are concerned.

1.2.1 Problem definition

Society is more concerned than ever with sustainability. Companies try their best to meet customers' expectations and regulations. During the last decades more and more companies have started adopting Lean and Six Sigma into their production processes and organization. Their subsequent improvements, mainly translated in an optimization of processes, could bring sustainability improvements as well. But, as it is extended in the introduction, it is not clear how these three areas are combined and how they are currently addressed by companies. This research aims to explore what Lean and Six Sigma can offer to companies for their sustainability improvement. Furthermore, the integration of these two systems with a sustainable/green initiative could be very beneficial and is discussed as well.

1.2.2 Research questions

The questions that drive the research of this paper are presented in this section. They are divided on 4 different ideas:

- RQ1.** How and why do Lean and Six Sigma improve the sustainability of a company?
- RQ2.** What are the limitations of Lean and Six Sigma on the improvement of Sustainability and how to overcome them?
- RQ3.** Is it necessary to add new tools to Lean and Six Sigma to address sustainability problems or opportunities?
- RQ4.** Which pillar of sustainability is affected the most by Lean and Six Sigma?

1.2.3 Delimitations

The thesis focuses on a literature review and on a multicase empirical study of 4 companies with experience on the utilization of Lean, Six Sigma and with a sustainability interest. These companies do not represent the whole industry but their insights can support the ideas and conclusions that are discussed in the literature.

1.3 Structure of the report

The thesis is structured in the following way:

Chapter 1: Introduction

The first chapter gives a context for the thesis, its purpose, the research and its limitations.

Chapter 2: Methodology

The second chapter explains the research methodology and the data collection methods used.

Chapter 3: Theoretical references

The third chapter develops a background for the topics behind the thesis. Gives a basic knowledge about Lean, Six Sigma, Sustainability, the impact of the firsts two on the last and the models that tried to mix two or all of these concepts.

Chapter 4: Empirics

The fourth chapter shows the insights from the 4 cases, made from interviews with four companies. The cases show the effects of Lean and Six Sigma on the triple bottom line of sustainability and the frameworks and ideas that these companies use for combining these systems. Furthermore, the fifth case consist on a research of some methodologies for measuring sustainability.

Chapter 5: Analysis

The fifth chapter investigates the similarities and deviations of literature and the empirical findings of the previous cases, to come to a conclusion for each research question.

Chapter 6: Proposition

The sixth chapter introduces some new concepts and proposes a framework for Lean Six Sigma Sustainability integration, with its focus, roadmaps and recommendations.

Chapter 7: Reflections

The seventh chapter starts with the recommendations for the implementation of the integrated framework. Then, the academic contribution of this master thesis is explained. Finally, reflections regarding future research directions for these topics are discussed.

2 Methodology

The second chapter explains the research methodology including the data collection methods used. Firstly, the approach used to perform the research is explained. Secondly, the research design used for the thesis is presented. Then, there is an explanation of how the data has been collected. Finally, there is an explanation of the general criteria for assuring the quality of this thesis.

2.1 Research strategy

There are different research methods that can be used to perform a study. An exploratory research seeks to find what is happening, helping to clarify the understanding of the problem. Usually ends narrowing the focus of the study as it continues. Another method is the descriptive research, which intends to make a clear picture of the subject studied. Another one is the explanatory study, which studies the concepts and then try to make relations between them. (Saunders, Lewis, & Thornhill, 2009)

The research approach of this thesis is both exploratory and descriptive. It is necessary to explore the subjects that this research covers and have a general overview of them, to make it possible to understand how Lean and Six Sigma can impact the triple bottom line of sustainability and which are their limitations. Furthermore, is necessary to understand how companies use LSS and how they combine it with their sustainability ambitions and initiatives. A clear description of the subjects discussed in this research is also needed, for that matter some descriptive approach is beneficial. This is used for example when describing Lean/Six Sigma tools or frameworks that the companies use. Finally, in some parts, a further explanatory study for explaining the relationships between the concepts is used. This is used for making a framework for LSS and Sustainability integration.

2.1.1 Qualitative and quantitative research

The research methods are usually divided into qualitative or quantitative. However, this distinction doesn't have to be seen as a boundary since there are research that moves between the spectrum of these two terms, using characteristics of one of them while using the other method. Anyway, this distinction can be helpful to understand the issues that a research has to face.

A quantitative research is an objective research method that focuses on the collection of data in order to prove a theory, with a deductive approach. It's a way of understanding social reality as something objective that can be studied as an external entity.

A qualitative research is a subjective research method that focuses on the meaning of things since quantitative data is not generated. It generates theories, with an inductive approach, from the research. It understands social reality as something continuously changing created by the people. (Bryman & Bell, 2011)

2.1.2 Research approach

It is necessary to go deep into the existing knowledge of Lean, Six Sigma, Sustainability and the relations that these areas might have. For this matter, several books and articles about these topics were reviewed. Some other more tangential articles for specific gaps on the knowledge of some areas were reviewed as well, this is the case to understand sustainability metrics for example. Furthermore, it is important to have empirical knowledge from companies with experience in these topics. Therefore, case study can be of utmost value for obtaining empirical data. Interviews are the appropriate method for doing those case studies.

Therefore, this thesis research is qualitative, and uses literature reviews and interviews for collecting information through which theories can be generated and analyzed.

2.2 Research design

The research design followed in this thesis, based on the main steps of a qualitative research by (Bryman & Bell, 2011) and customized by the author for this project is the following:

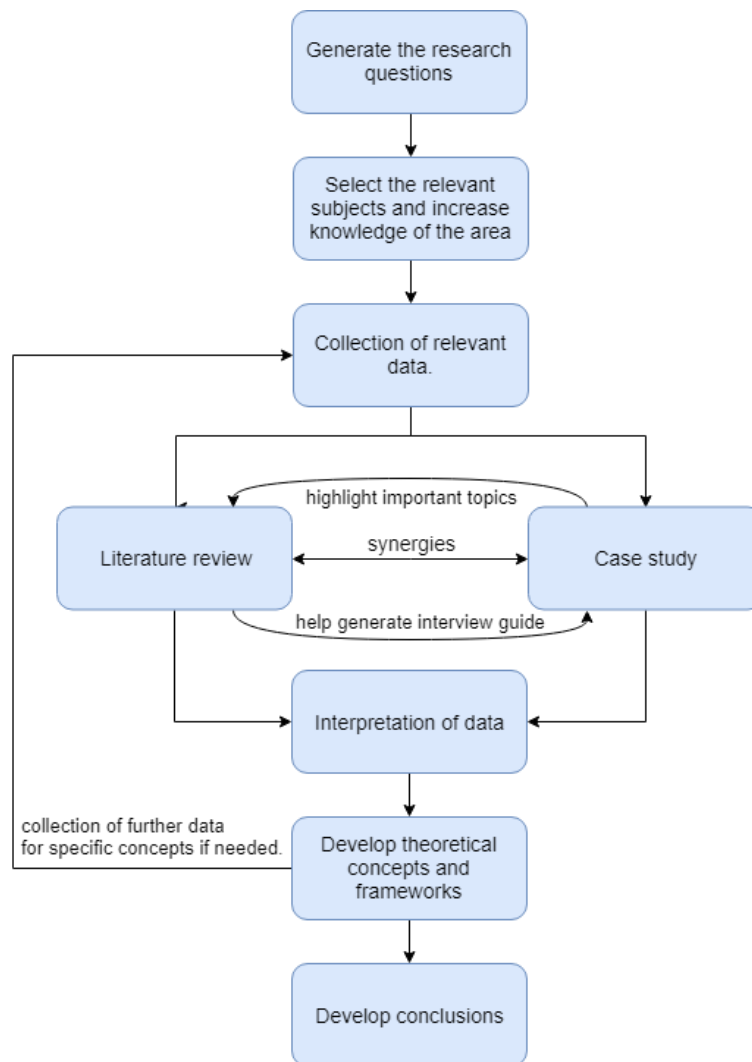


Figure 2.1. Research design for the master thesis. Made by the author based on (Bryman & Bell, 2011)

2.3 Data collection methods

2.3.1 Literature review

The books studied for this research were related to different topics including Quality management, Lean, Six Sigma, Sustainability. They gave a general understanding of the concepts.

For getting information about an integration of Lean, Six Sigma and Sustainability scientific articles were the main source, since this is a new subject of knowledge and there are no books that cover completely the topic. The search for articles was mainly done using LUBsearch. The key words used to find the right articles were Lean, Six Sigma, sustainability, green manufacturing, integration. Furthermore, other articles were searched for understanding sustainability metrics.

The main article reviewed for this research is (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016), that makes a review of the existent literature about Lean Six Sigma Sustainability integration. From that article, other sources referenced by it were reviewed as well. One of the most important is (Garza-Reyes, 2015). Both of them are the main sources for the theoretical framework of this master thesis.

Furthermore, literature for case research has been studied.

2.3.2 Case study

A case study research is an observational analysis that focuses on a contemporary phenomenon within its particular context, (in contrast with an experiment, that purposely separates it from the context). It uses various sources of evidence, and is helped by prior theoretical frameworks to guide the analysis. (Yin, 2014)

A case research is the adequate method when the research fulfills three conditions: the research questions are “how” and “why” based, the researcher has no control over the phenomenon and it is a contemporary event. Then the case study is an adequate way to perform the study. (Yin, 2014)

The basic idea is to use a case study to build theory inductively. The theories emerge from the relationships and patterns from one or multiple cases. Those are built along a repetitive process of reviewing the case data, the new possible theories and the related literature. (Eisenhardt & Graebner, 2007)

The starting point begins with a good review of related literature, identifying a gap that can be studied and proposing the research question to address that. It is also important to explain why the theory building instead of the theory testing approach has been used for the research. (Eisenhardt & Graebner, 2007)

Not necessarily it has to be a research of a single case, there are also multi case studies, that can be more robust since the evidences are larger. For a single case study, the qualitative data may be presented as a story in the text. This narrative with quotations from the key people involved (obtained usually by interviews) and other evidences are connected with the theory to show the relationship between the phenomenon and the theories. (Eisenhardt & Graebner, 2007)

There has been literature that supports a positive effect on sustainability for companies that are using Lean and Six Sigma, for example in (Sri Hartini, 2015). Therefore, in this thesis, starting from that point, the main goal is to understand how these methodologies can improve the sustainability and why this phenomenon happens. Case study research fits this need perfectly.

2.3.3 Case research design

A research design is the plan followed to get from the research questions to its answers, by using empirical data, to build a conclusion of the study. The design should help to identify which data and from which sources are the appropriate to address the research questions. For a proper design, 5 factors are important (Yin, 2014):

1. The research questions: defined in the first chapter. Basically, in this case is how companies that use Lean and Six Sigma improve their sustainability and why it works.
2. The propositions, if any: to know what should be examined, in this case the proposition is that organizations use Lean and Six Sigma for improving their operations and that also help to develop their sustainability.
3. Its units of analysis: in this case, the analysis of possible unintentional sustainability improvements thank to the adoption of LSS, intentional improvements using the LSS methodology, the sustainability initiatives and tools.
4. The relationship between the data and the propositions.
5. The criteria to interpreting the findings.

A preexisting theory can help a lot in the design of the case. In this thesis, the previous theory is taken from (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) with “The integration of Lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model”.

So the cases presented in this master thesis aim to give empirical validation to the ideas presented on that paper and summarized on the section 3.7 of this text. Those theories that formed the base for this work will be corroborated with the findings of these cases, so generalizations may be done. (Yin, 2014).

2.3.4 Interviews

One of the most important ways to get case study evidences is through interviews. Interviews are guided conversations in a fluid way with an informant of the case company with knowledge on the matter. Questions are usually open ended and try to maintain a conversation about the topic rather than an enquiry with specific questions. Nevertheless, some kind of structure to conduct the communication is likely as well. For this research, the interviews were around 1 hours long, following a number of premade questions about the topic. However, the mentality was to have an open ended conversation, where further questions were asked if the explanations were not enough or other interesting topics appeared, trying to maintain a fluid conversation rather than a rigid one. (Yin, 2014)

An interview question guide was made before the first interview and maintained during the other interviews. However, slightly changes were made after the first interview, deleting few questions, due to interview time constraints and the repetition of already considered topics. This question guide can be seen in the appendix (A4).

This question guide follows the following structure:

The firsts questions (1-3) are sustainability related, to know better the sustainability situation of the company and their ambitions. They work also as general questions to help to start the interview in a fluent way. The next questions (4-6) ask about the use of Lean and Six Sigma in the company and about their possible improvements on the sustainability of the company. Then, questions (8-13) go further in how LSS might help sustainability. Asking about the reasons, the sustainability tools that could add value there, the impact on each sustainability pillar and limitations. Finally, the last questions (14-16) ask about what's the opinion of the informant of the integration of the three systems and the frameworks they use for that matter if any.

The interviews were held preferably in person and at the company location. The idea was that that would help with building trust and making a more fluent conversation. Moreover, the non-verbal communication could be observed making easier to recognize when the informants were emphasizing parts of their answers or were uncomfortable. However, that face to face interview was not possible with two companies, where a call/skype was the method used.

The interviews were selected so that the interviewed were familiar with the topic of discussion and could give insights related to the research questions. Aiming this, to find the appropriate companies, they needed to fulfill some requirements:

- To be experienced in Lean and Six Sigma.
- To be interested in sustainable development.
- To be working within Sweden.
- To be interested in this research and willing to participate on an interview.

And for getting the right information by an interview, the persons selected had to:

- Know the general information about the company and their situation.
- Know how Lean and Six Sigma is applied at their company.
- Know their sustainability goals and how they assure sustainability.
- Know how Lean, Six Sigma and Sustainability affects the company and the metrics that they use for measuring that.

The supervisor of this Master Thesis recommended a number of companies that could fulfill the requirements. The supervisor also recommended some key persons of those companies that could participate in the interview. An email was sent to those companies explaining the purpose of the research and wanting to know their interest in the matter. Some proposed a different person for the interview, leading to establishing contact with the informant. Finally, the terms of the interview were established, and a location and date decided or a time for a call set.

The interviews were all recorded and a transcript was made after so the information could be analyzed in an easier way.

The list of interviews made for this research is the following:

Company	Informer	Date	Location
Tetrapack	Julian Fox	18 of October	At Tetrapack, Lund
Höganäs	Anders Bergman	24 of October	Phone interview
Haldex	Johan Valett	26 of October	At Haldex, Landskrona
Sandvik	Marlies Kock	30 of October	Phone interview

Table 2.1 List of interviews done for this master thesis

Two of them were done as a meeting at the company location while the other two were done by a phone call.

2.4 Criteria for the quality of this research

In order to assess the quality of this research there are three concepts that are very important:

2.4.1 Reliability

For a study to be consistent needs to have consistent data, in other words, that if the study is repeated using the same methods, the input data will be the same. From this data a conclusion can be elaborated, that must be the same in both cases. This way the results of the study are repeatable. If that is the case then the measures are consistent. (Bryman & Bell, 2011)

2.4.2 Replication

For a study being able to be replicated by another researcher, its procedures to perform the research need to be very well detailed. Otherwise repeating the same study in the future won't be possible. (Bryman & Bell, 2011)

2.4.3 Validity

The most important concept to measure the quality of a study is validity. It is implicated with the integrity of the conclusions of the research (Bryman & Bell, 2011). There are different types of tests of validity, with different tactics to assure the quality of a research (Yin, 2014):

Construct validity: It concerns the issue of whether a measurement really measures a concept or not. It can be assured through the use of multiple sources of evidence, or triangulation. For that matter, in this thesis, different literature sources that assess the same issues were reviewed. Also, 4 different case studies through interviews were made, to assess the same questions from different informants and collect different data that could lead to the same conclusion. This way it could help to strengthen the validity of this research.

Internal validity: is relevant when doing explanatory research, when trying to explain what causes led to an event, in order to explain the causal relationship. It is concerned with the integrity of an explanation for an event. For that matter all the other plausible explanations and possibilities should be considered and the evidence should converge into the cause chosen.

External validity: it is concerned with the matter that if a research can be generalizable beyond the walls of the particular study, no matter the research method used. So the same conclusions will be obtained using different methods.

3 Theoretical references

This chapter develops a references background for the topics behind the thesis, covering the key concepts from the literature that will be empirically analyzed in further chapters. From the analysis of books and other publications, this section gives a basic knowledge about Lean, Six Sigma, Sustainability, the impact of the firsts two on the last and the models that tried to mix two or all of these concepts.

3.1 Lean

In the 50s there was a crisis in Japan and Toyota Motor Company was struggling as well. Its director, Eiji Toyoda, visited the Ford's plant in Detroit looking for ideas to try to save his company. But after returning to Japan, Eiji and Taiichi Ohno, his production executive, determined that Ford's mass production wouldn't work in Japan since the context was not the same. On the contrary than Ford, Toyota had to face a long range of different products with low demands and big investments were impossible at that moment.

They made a new system, a system where workers were his main asset. During 30 years they perfected the system solving Toyota's problems. They couldn't produce big batches because of its machinery limitations, but made this a virtue. Surprisingly, lower batches increased the quality of their products and the work in progress was reduced resulting both in cost savings. Then, they also used this system to help and improve their suppliers' activities. They called this system Lean. (Dennis, 2015)

What is Lean manufacturing? Lean is a set of tools and a process methodology that attempts to deliver the higher quality and make the processes more flexible and more responsive, all this at the lowest cost and in the least time possible. The key to achieving this is to determine and eliminate waste in the process. (Dennis, 2015)

Lean focuses its philosophy in reducing waste, that is defined as everything that doesn't add value for the customers. Specifically, (Dennis, 2015) defines 8 types of waste:

Motion: The excessive movement of the personal or machines for completing a task.

Waiting time: Wasted time waiting for workers, machines to finish, rework of defective parts, equipment breakdowns.

Overproduction: To make products when there is no demand for them.

Inventory: Keeping more materials, parts and work in progress than necessary.

Transportation: Transportation of materials through the factory.

Over processing: To do more than what the customer actually demands.

Defects: The waste of making and having to repair or replace a defective product.

Knowledge: not using the full potential of the staff. Or being disconnected from the customers and suppliers.

However, Lean is not only about waste reduction. Some of its key principles (Arthur, 2007) are:

- Determine the value from the customer voice. Focus on what the customer wants.
- To use pull production systems, where the demand is the factor that determines the units produced, minimizing the inventory.
- Reduce the work flow to ideally one, so there are no inventories or waiting times in between machines.
- Make quality products at the first time, stop and fix the problem if it occurs.
- Use visual sign techniques so issues are easily visible.

3.2 Six Sigma

Six sigma is a quality management program started at Motorola in 1982 in a pursuit to reduce costs improving the products designs. Is believed that Six Sigma had a big role improving their quality and as a consequence help them win the 1988 Baldrige National Quality Award (Snee, 2010). But with time, Six Sigma has evolved into a program for the whole organization. It includes planning, training of personal, pay for learning... And it demands an involvement of the individuals into the program (Foster, 2013).

Statistically speaking, sigma is the Greek letter (σ) that represents the standard deviation from the mean. If we divide the sigma with the mean of the process, we can get an idea of its variability. The higher the variability of a process the more difficult to control its outcomes.

A one sigma range from the mean includes 66% of the total values, 95% for 2sigma, 99% for 3sigma, and 99.99966% for 6 sigma.

A six sigma process means that all those values are inside the specifications (what is demanded by the internal or external customer), with only 3.4 values out of specification every million, so a very low rate of defects. In contrast, a 3 sigma process produces 66 defects (out of range) per million opportunities. Therefore, Six Sigma's goal is to improve process quality through reduction of defects and variability of a process. It achieves that through the use of several statistical techniques and tools. (Basu, 2011)

Six Sigma uses the DMAIC process to address the improvement projects. The tools used in Six Sigma are not new, and had been used in quality management, but they are sorted and used in a specific way. Each one it's useful in a certain step of the DMAIC process. (Foster, 2013). These steps are:

Define: Where some possible improvements projects are defined, evaluated, and then one is selected according to its potential benefits. Finally, further definition of the selected project is done consisting of its goals, metrics, members involved... (Foster, 2013). The define step tries to answer the question: "Is this the right project now?" (Wedgwood, 2016)

Measure: Where the state of the process as it is now is understood. The key is to find how its performance before the improvements are made. The use of mapping tools helps during this phase. (Wedgwood, 2016)

The measure step tries to answer the question: “How well is the process performed?” (Wedgwood, 2016)

Analyze: Where data is analyzed to know which inputs need to be changed to improve the performance of the process. The inputs that are the main source of variation of the process are identified and statistical tools are used to understand how these variables interact with the outcome result (Foster, 2013).

The analyze step tries to answer the question: “Why is the process performing the way it is?” (Wedgwood, 2016).

Improve: Where a solution for the problem that the process is having is elaborated and implemented (Wedgwood, 2016).

The improve step tries to answer the question: “What should the new process be to perform the right way?” (Wedgwood, 2016).

Control: Where the improved process is managed and the necessary tools implemented to ensure that it keeps working in this new better state. These tools usually include control plans and control charts. (Wedgwood, 2016).

The control step tries to maintain “The performance at the level it needs to be” (Wedgwood, 2016).

3.3 Sustainability

Sustainability is a concept that has been getting more relevance during the last decades. As an example, now 93% of the largest world companies report on sustainability (UN, 2018).

Improving sustainability is not a supplement for companies, it is a necessity, a new competitive criterion. Traditionally, the improvement of social and environmental sustainability has been viewed as obstacles for the economic development of the companies, but nowadays, is proved that those efforts result in less operating cost and more employee satisfaction. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

The United Nations define sustainable development as:

“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. (UN, 2018)

A sustainable development can be seen from three perspectives: environmental, economic and socio-political. These three pillars of Sustainability need to be satisfied simultaneously to be ahead of competition, if not, the system will be unsustainable (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016).

The Sustainability Dynamic Model (Figure 3.1.) can be used to describe the direct and indirect effects that new solutions have into these perspectives. (Stark, Seliger, & Bonvoisin, 2017)

The changes on one perspective can affect the other dimensions with a proportional magnitude and duration. This way, a value solution created to improve one of the dimensions, indirectly impact the others as well. (Stark, Seliger, & Bonvoisin, 2017)

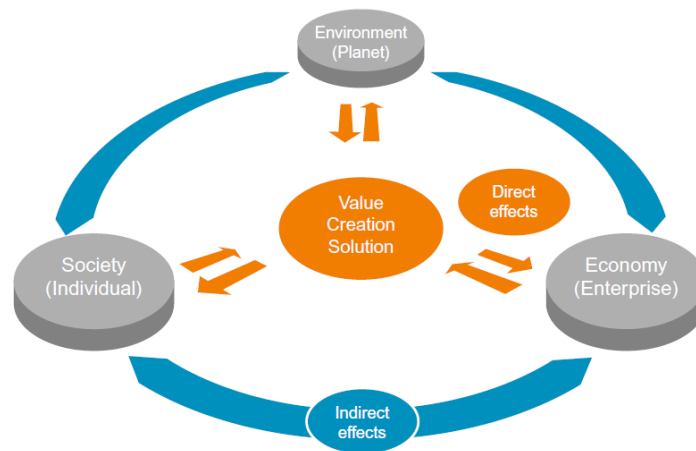


Figure 3.1. The Sustainability Dynamic Model (Stark, Seliger, & Bonvoisin, 2017)

Value creation solutions can be seen from the inside, or as a demand from the outside (society, environment, economy). As an example of an inside value creation solution, a new clean technology that has a direct effect on the gas emissions and benefits the environment, indirectly affecting the society and the economy. As an example of the model seen from the outside, the demand from the society for clean energy solutions as a consequence of global warming awareness. This create value solutions that could manage the problem, affecting the environment, and indirectly the other dimensions. (Stark, Seliger, & Bonvoisin, 2017)

The United Nations proposed 17 Goals to achieve by the year 2030 for a sustainable future. The goals face the basic challenges humanity faces nowadays, (Figure 3.2) (UN, 2018). Companies can use those goals to direct their strategies and use their indications to progress towards a sustainable business.



Figure 3.2. The 17 Goals for a Sustainable development (UN, 2018)

Apart from that, there are many initiatives and principles proposed for a sustainable development.

Generally speaking, Timothy C. Lindsey established 3 principles that society could follow in order to become more sustainable (Lindsey, 2010):

- *Principle 1: "improved sustainability is achieved through reducing wastefulness".*
- *Principle 2: "improving quality improves sustainability".*
- *Principle 3 "sustainability is best achieved through implementing better systems" (Lindsey, 2010)*

Another example more centered with the industry are the 9 principles of Green Engineering determined during the Sadestin conference (American Chemical Society, 2018):

1. *"Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools".*
2. *"Conserve and improve natural ecosystems while protecting human health and well-being".*
3. *"Use life-cycle thinking in all engineering activities".*
4. *"Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible".*
5. *"Minimize depletion of natural resources".*
6. *"Strive to prevent waste".*
7. *"Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures".*
8. *"Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability".*
9. *"Actively engage communities and stakeholders in development of engineering solutions". (American Chemical Society, 2018)*

3.4 Impact of sustainability on Market value

The profit impact on the market of promoting sustainable initiatives on an organization is discussed by (Jacobs, Subramanian, Hora, & Singhal, 2017), where studies if the environmental initiatives have an impact (positive or negative) on the market value of the company.

Environmental initiatives could affect financial performance through revenue gains or cost reductions. Increased revenue can be obtained through increasing gains in current markets or entering new markets. Showing intent for sustainability could lead to better corporate reputation, which could increase sales (Jacobs, Subramanian, Hora, & Singhal, 2017). Cost reductions benefits are discussed along this master thesis.

The results from the study discussed by (Jacobs, Subramanian, Hora, & Singhal, 2017) generally speaking, show no significant positive correlation between environmental initiatives and market performance. However, there is no significant negative impact either, so those initiatives do not harm market profit.

More specifically, the market reaction was insignificant to environmental business strategies, ecofriendly products, renewable energy and recycling. Environmental altruism (such as gifts for sustainability causes) likely could improve market profit through gains from increased reputation. Voluntary emission reductions (not forced by new regulations) could impact negatively the market (worried about the reductions possible cost), so the reasons for that initiative should be justified properly. Finally, the ISO 14001 certification is related to a positive market impact. In sum, aggregating all the environmental initiatives, the market does not react to them altogether, but reacts slightly to some specific initiatives (Jacobs, Subramanian, Hora, & Singhal, 2017).

3.5 Lean Six Sigma Integration

Lean and Six Sigma are methodologies that focus on the processes, but they focus on different things. While Lean is centered in simplifying processes by eliminating non-value-adding activities (waste), Six Sigma focuses on the metrics that drive a process in order to improve them and maintain them. So in short, the first focuses on eliminating what shouldn't be there and the second focuses on doing what it is right in the first time. (Wedgwood, 2016)

This Lean Six Sigma integration took place in the late 1990s and early 2000s (Snee, 2010). Lean Six Sigma is a:

“Business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom line results... it is also an effective leadership development tool” (Snee, 2010)

There have been many frameworks for Lean Six Sigma integration. The main point to use both methodologies is to use them as an integrated system to address projects instead of using Lean or Six Sigma in isolation depending on the kind of issue. Nevertheless, depending on the needs of the project, Lean tools or Six Sigma tools could dominate. (Snee, 2010)

The root cause of problems, not the symptom, can help to decide which tools are the more adequate inside an integrated methodology. For example, if the goal is to reduce variation Six Sigma tools will prevail, and if reducing waste and increase flow is the goal Lean tools will help the most. (Snee, 2010)

Most of this document is considering these systems (Lean and Six Sigma) and their implications separately. The literature evaluates them in a separate way, either talking about the benefits of Lean or Six Sigma on Sustainability, but not the combination of both (LSS). However, there is no reason to think that a well done integration or simply using both systems will not have the same benefits or limitations than the sum of the parts. This is shown in the company cases, which use both Lean and Six Sigma, reaching similar results as the theory predicts.

3.6 Sustainability improvements through Lean and Six Sigma

In the last years, sustainable initiatives have been on the rise as a requisite to fulfill regulations and social and market demands. The organizations that combine the efforts of Lean manufacturing and a green thinking (an environment friendly mentality) achieve both higher economic competitiveness and green results. (Garza-Reyes, 2015)

The evidences brought by the literature review “The relationship between lean and sustainable manufacturing on performance” (Sri Hartini, 2015) suggest that Lean benefits the triple bottom line of Sustainability, mainly on the environment and economic aspect. However, not all the practices are related to better sustainable results and Lean alone is not enough to fix all sustainable issues.

Still, the benefits that the main Lean and Six Sigma tools have on sustainability are discussed in the literature review made by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016). An adapted table obtained from that article showing the environmental and social benefits of those tools can be seen in the appendix (A3).

Companies that are Lean, are more likely to welcome environmental ambitions. The promotion of waste reductions provides incentives to deploy green philosophies and tools. Both Lean and Green thinking aim for waste reduction, but Green also is concerned with material consumption and recycling. There are several synergies between Lean and Green thinking, which suggest that Lean can be a catalyst for Green ambitions, being easier to fulfill them. As an example, the seven Lean wastes can be related to Green thinking: optimize transportation to reduce costs (Lean) and reduce the use of energy and CO2 emissions (Green), reduce inventory since it can reduce lead time (Lean) and it needs less storage space which will consume less energy for heating or cooling (Green). (Garza-Reyes, 2015)

Companies that also add Green components (*product and process redesign, disassembly, substitution, reduce, recycling, remanufacturing, consume internally, prolong use, returnable packaging, spread risks, new markets creation, waste segregation and alliances*) to the Lean classic components (quality, cost, profit, customer focus and delivery) will achieve better results (Sri Hartini, 2015). Green can't be seen as a toolbox but as a series of initiatives and principles with the use of a single tool: Life Cycle Assessment (Jose Garza-Reyes, 2016).

However, there are also some limitations to the integrated use of Lean and Green thinking, since neither of them aims for reducing the process variation. Lean lacks a systematic structure to find root causes of complex problems and Green does not fix this issue. Green is mainly a series of practices and methods “(environmental operations management, green supply chains, reverse logistics, design for environment, green building, green manufacturing)” (Garza-Reyes, 2015). Lean doesn't have a prioritization approach or a project approach for improvement. Those characteristics do not allow to align Green and Lean initiatives to profitability and business requirements. Six Sigma and its systematic and statistical driven approach could be the answer to overcome these limitations. So the DMAIC methodology could be used as the frame where Lean and Green initiatives are implemented and sustained. (Garza-Reyes, 2015)

3.7 Lean Six Sigma Sustainability Integration

A possible integration between Lean, Six Sigma and Sustainability has been discussed in the literature, and (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) made a review of these publications adding the drivers, barriers, benefits, synergies, conflicts, and critical success factors for an integrated approach plus suggesting how a framework of this would look like.

What makes companies adopt some kind of integrated model is their strategic goal to improve economically, environmentally and socially with the help of Lean and Six Sigma. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

The integrated model proposed by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) seek to generate an efficient and organized framework for continuous improvement. Joining these three systems the deficiencies of the others can be reduced (Figure3.3).

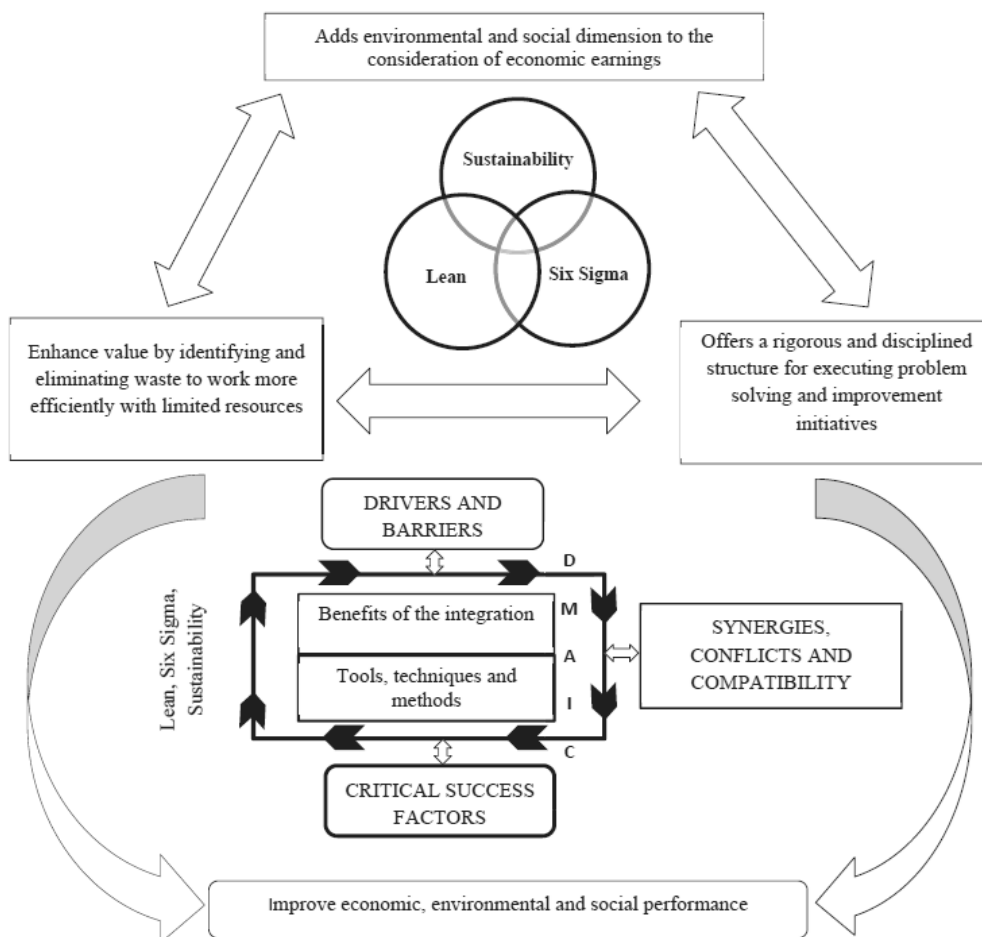


Figure 3.3. Integrated model for Lean, Six Sigma and Sustainability proposed by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

The DMAIC steps of Six Sigma could be the roadmap for all the methods and tools of these 3 systems, creating compatibility and synergies among them. It is a rigorous and structured way for problem solving. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

This framework could perform as a base to provide a project form to the sustainability initiatives, being the umbrella through that those initiatives could be deployed and addressing their limitations as it is represented in the Figure 3.4. (Jose Garza-Reyes, 2016)

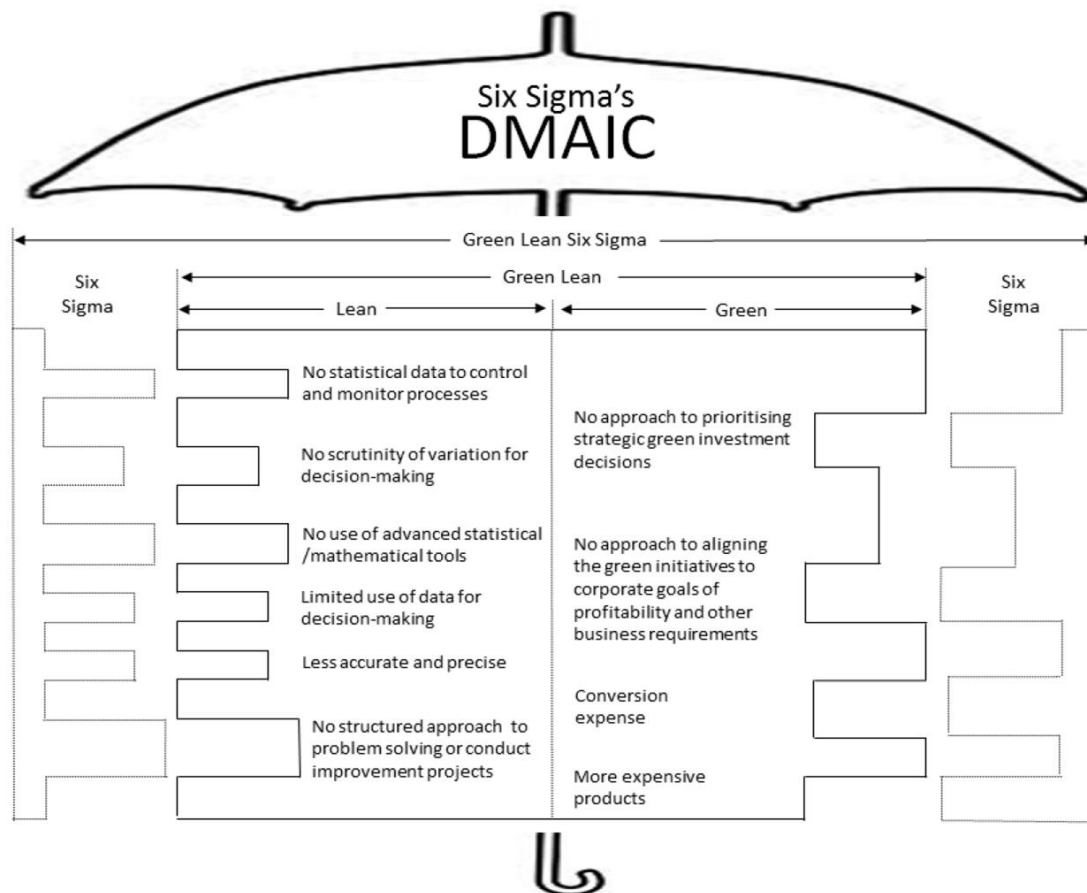


Figure 3.4. Addressing the limitations of Lean and Green through Six Sigma, by (Jose Garza-Reyes, 2016)

The DMAIC steps could sequence and link Green, Lean and Six Sigma tools when doing a project (Garza-Reyes, 2015):

Define: to prioritize the initiatives and investments in an objective way to know where to deploy them. To know which parameters to target. And finally which projects to select with its objectives, scope and resources.

Measure: to establish metrics to monitor the key process characteristics. This step will make an organization to determine metrics for wastes in the organization and other sustainable related measures.

Analyze: to evaluate the processes and find the root causes of the parameters monitored. To show the causes of the unnecessary use of materials, energy...

Improve: to propose and test new solutions to eliminate the root causes of problems.

Control: to set mechanisms to monitor and sustain improvements.

Another framework reviewed for the integration uses Value Stream Mapping to identify areas of waste before the DMAIC phases could apply the relevant Lean and Six Sigma tools to fix the wastes, see Figure 3.5. (Powel, Lundebly, Chabada, & Dreyer, 2017)

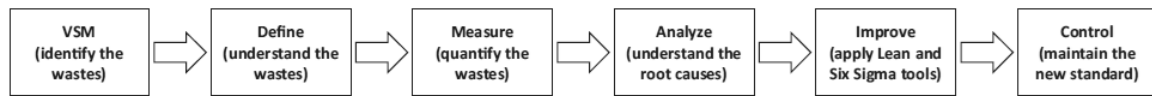


Figure 3.5. Use of VSM as a way to identify wastes, by (Powel, Lundebly, Chabada, & Dreyer, 2017)

Drivers and barriers for the integration:

(Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) describes the internal and external drivers that can encourage companies to implement Lean, Six Sigma and Sustainability. Among the internal are the cost reductions, profitability, risk management, and the improvement of the corporate and resources management. While among the external are the consumers, regulations, and shareholders.

It also shows the main barriers to encounter: the lack of environmental awareness, the perception that it will increase costs, organizational structures that separate the environmental and continuous improvement decisions, a lack of metrics and a lack of involvement into Lean Six Sigma projects. There's still the old belief that environmental and social development is an obstacle for economic growth, so companies need to be convinced that actually, it will boost their profits.

It is noticeable that organizations that are already using Lean or Six Sigma are more likely to welcome environmental innovations. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

Benefits of the integration:

Implementing these systems may improve an organization performance, but there is a lack of performance measurement systems for this integration, they exist exclusively for each management system separately. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

The integration can benefit a company in many ways. It can enhance employee morale and commitment, the working environment, reduce costs, improve profits, meet customer expectations, can make processes and equipment more reliable, improve the efficiency of resources, reducing environmental impact; among many others. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

Tools

The Lean and Six Sigma tools seem to have also an effect reducing environmental and social impacts apart from reducing wastes. Its use is very encouraged, since they are well tested and well known by the employees. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

In the Appendix (A3) there is an adapted table acquired from (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) with a description of the environmental and social benefits of the main Lean and Six Sigma tools.

Compatibility of the three systems

The research made shows that this integration can possibly have positive and negative impacts on the three sustainability pillars.

There is a synergy between Lean, Six Sigma and Sustainability, in the way that companies that are familiar with the firsts can achieve the last one easier. Sustainability can be seen as an extension of Lean and Six Sigma. At the end, publications show that there is a correlation between the performance of a company and the integration of Lean, Six Sigma and Sustainability, and that an integration of the three systems could give a better outcome than the implementation of just one. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

There are many similarities between Lean, Six Sigma and Sustainability. They focus on reducing waste, the philosophy of continual improvements, supply chain relationships, management and employee engagement, customer needs fulfillment, and they have a similarity between the tools and methods. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

However, the three strategies cannot be completely combined since there exist some conflicts. Sometimes fulfilling customer needs can mean the use of extra material as extra packaging or the use of environmentally not friendly products. Still, if Lean and Six sigma focus on sustainability, they can impact the transformation processes, but basically will have no effect on material extraction, product use and its disposal. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

As an example, Lean and Six Sigma can improve the processes and achieve minimum waste at the production plant, but still at the end of the product life there will be waste with its disposal. This could be even worse for single-use products such as razors. The two strategies also don't take into account the impact that the product could have on the environment with its use. The same can be said about products with an intensive material use or with an unsustainable material selection. Lean and Six Sigma basically will have no effect on these issues. Other policies made by organizations need to be in place to address the complete lifecycle of products, such as recycling, an ethic and sustainable extraction of materials and so one.

Furthermore, some Lean and Six Sigma tools could have a negative impact on sustainability. The Lean just in time choice can reduce lot sizes and increase number of deliveries, which can translate into more traffic congestion and gas emissions. Kaizen events for improvement can impact sustainability as well, since rapid improvements not well analyzed could need more resources, therefore increasing emissions. A continuous improvement may not be a sustainable improvement. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

It is significant the difference between the Lean and sustainability definition of waste. For the first, waste is anything that doesn't add value to the product. For sustainability, waste is associated with the misuse of any natural resources such as materials, water or energy. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

To summarize, there are conflicts between the three systems when are tried to be integrated, but they don't block their integration. The benefits they can bring together give a reason for their integration and that can overcome their limitations. (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016)

Gaps for future research:

The direction for the development of this topic was stated by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016), determining the gaps for future research in the area:

- There is a lack of performance measurement systems to measure Lean, Six Sigma and sustainability from economic, environmental and social aspects. There is a need of metrics, performance indicators and methods. They should be valid as well for specific industries.
- There are many frameworks for this integration (based PDCA, DMAIC or Kaizen events) but usually are industry specific. Therefore, a generic framework is needed, valid for different industries and different types of organizations.
- For the SMEs to achieve economic, social, and environmental goals they need to optimize at maximum their use of resources, knowing that they can't make huge investments or changes. Therefore, they need help for successfully implement Lean, Six Sigma and sustainability with limited resources.
- There is a lack of research of this integration in the service industry.
- There is a need to englobe more of the social dimension in the integration. Health and safety, morale, stress, etc. need to be examined.
- There is a need to apply Lean, Six Sigma and sustainability for industries in developing countries.
- There is a need for more information of the pre-implementation phase of these systems as an integrated one. Questions as if they need to be implemented sequentially or simultaneously need to be addressed.

Finally, (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) highlight the lack of a specific integrated model. They have proposed the framework shown in figure 3.3 based in the DMAIC method.

4 Empirics

This chapter supports the previous literature insights with empirical data from four companies analyzed through the following 4 cases, made from interviews. The cases show the effects of Lean and Six Sigma on the economic, environmental and social concerns of sustainability. Furthermore, it explains the frameworks and ideas that these companies use for combining these systems. Finally, the fifth section consist on a research of some methodologies for measuring sustainability.

4.1 Case I: Tetrapack

Tetrapack is the world's leading company with food packaging and processing solutions. They have the head offices in Lund, Sweden and Lausanne, Switzerland. It was founded in 1943 by Dr. Ruben Rausing, beginning with creating a package for milk. (Tetrapack, 2018)

They are experts in solutions for food products processing, packaging and distribution. Their motto "Protects what's good" manifest their vision for making food safe and available everywhere. They are able to achieve that while keeping a low consumption of raw materials and energy. Some of the products that they work with are dairy products, beverages and cheese among many others. (Tetrapack, 2018)

With their more than 24,000 total employees, Tetrapack works closely with their customers and suppliers to fulfill the needs of hundreds of millions of people in more than 160 countries. (Tetrapack, 2018)

Their products are divided with several categories: packaging, processing and services. With packaging, they offer a range of different carton packaging solutions for fresh products, protecting the nutritional value and the taste of the food, but also offering to the consumer comfort, with easy opening and shelf life and a visually appealing package. With processing, they offer solutions for processing equipment for food. And finally a range of services as maintenance, upgrades, automation and training installation. (Tetrapack, 2018)

Tetrapack view on sustainability:

For the informant of Tetrapack, Julian Fox, sustainability is making sure that they do sustainable things for the long term, focusing on economics, environment and social aspects and making sure that those are balanced. Tetrapack express their sustainability goals as protecting food, people and future. (Fox, 2018).

Food is their core business, its security and availability are key things that they work on. Preventing food waste is very important for them, so with the use of their packaging products it can be transported across continents without perishing, thus reducing wasted food. This contributes directly to the UN Sustainable Development Goals 2 (Zero hunger) and 12 (Responsible production and consumption). (Fox, 2018) (Tetrapack, 2018)

Protecting people is another sustainability goal for them, the protection of their customers and their employees. They pursue diversity and inclusivity, contributing directly to the UN

Sustainable Development Goal 8 (Decent work and economic growth) and 17 (Partnership for the goals). (Fox, 2018) (Tetrapack, 2018)

Protecting future relates to making sure that the environment is still fit while they do business. The informant explained that they should do no harm and ideally improve the environment as a consequence of their activities. This contributes to the UN Sustainable Development Goals 6 (Clean water and sanitation), 7 (Affordable and clean energy), 9 (Industry, innovation and infrastructure), 12 (Responsible production and consumption), 13 (Climate action), 15 (Life on land) and 17 (Partnership for the goals). (Fox, 2018) (Tetrapack, 2018)

Each of these pillars has several topics for improvement as it is showed in the following figure:

Our pillars	Our 14 top material topics
Food	<ul style="list-style-type: none"> <li data-bbox="389 757 1305 837">1 Food availability How we work across the value chain to ensure food is available, accessible and affordable, by consumers everywhere. <li data-bbox="389 842 1305 922">2 Customer health and safety How we ensure that our products and services are assessed for any potential health and safety impacts during their lifecycle. <li data-bbox="389 927 1305 1003">3 Food waste How our food processing and packaging solutions and programmes help decrease food loss and wastage across the value chain.
People	<ul style="list-style-type: none"> <li data-bbox="389 1025 1155 1093">4 Occupational health and safety How we ensure our people are free from harm in every project and activity.
Futures	<ul style="list-style-type: none"> <li data-bbox="389 1115 1337 1196">5 Supplier environmental assessment How we conduct our due diligence process and work with our suppliers to ensure that negative environmental impacts are prevented and mitigated across our supply chain. <li data-bbox="389 1200 1337 1281">6 Supplier water use How we conduct our due diligence process and work with our suppliers to ensure negative impacts associated with water use are prevented and mitigated across our supply chain. <li data-bbox="389 1285 1337 1366">7 Packaging design and resource use How we integrate environmental risks and opportunities into our product design and innovation, including renewable content, recyclability of packaging, and weight optimisation. <li data-bbox="389 1370 1337 1424">8 Packaging renewability How we incorporate materials from renewable sources into our packaging products. <li data-bbox="389 1429 1337 1482">9 Energy use and GHG emissions How we reduce the impact of our own operations on climate change. <li data-bbox="389 1487 1337 1563">10 Machines and equipment: waste generation How our food processing, packaging and service solutions help our customers minimise wastage and spoilage. <li data-bbox="389 1568 1337 1644">11 Machines and equipment: energy use and GHG emissions How our food processing, packaging and service solutions help our customers reduce their impact on climate change. <li data-bbox="389 1648 1337 1724">12 Machines and equipment: water use How our food processing, packaging and service solutions help our customers keep water consumption down. <li data-bbox="389 1729 1337 1832">13 Packaging recycling How we promote and increase recycling through supporting infrastructure development, raising consumer awareness about used beverage carton (UBC) recycling, and working with partners to boost business opportunities for recyclers. <li data-bbox="389 1836 1337 1892">14 Packaging climate impact How we measure and manage the CO₂ footprint of our packaging products.

Figure 4.1. Tetrapack top topics related to their three pillars (Tetrapack Sustainability Report 2018, 2018)

According to the informer, they use an extensive array of metrics for measuring their sustainability from social, economic and environmental aspects. From having a membership of Sedex (for ethical supply chains) to being member of RE100 (so by 2030 they will be using 100% renewable electricity). (Fox, 2018)

Balance of the three sustainability pillars.

To balance the economic and environmental aspects of sustainability, the informant explains the concept of waste hierarchy. In its bottom there is the landfill, then energy recovery (where the materials are burned to recover their energy), then there are different types of recycle and reuse of the materials, at the top there is the reuse of the resources for their original use and finally the reduction and prevention of the waste in the first place. Typically, you have to explore which is more economically beneficial. They try to have 0% landfill utilization. They also work with the authorities to stimulate the recycling and recollection of the materials at their end of use. They can make investments in waste management and infrastructure, create markets for waste, search innovative uses of waste; but consumer waste behavior is something where they have no control, where only is possible to influence them. (Fox, 2018)

The economic benefit of that must be balanced with the ethical environment aspect, where the ethical aspect is never in question. They have a code of conduct, and a supplier code as well. So for working together, suppliers must adopt those values too, never being in question. But of course then the return of the investment and those things are a constant in business. (Fox, 2018)

Tetrapack use of Lean, Six Sigma and its effect on sustainability:

Tetrapack is using Lean, with an ambition of 0 waste and 100% involvement. They also use Six Sigma and Statistical process control for critical quality parameters in all of their production processes, with a number of different belts in the organization. They have the ambition to use these systems in their knowledge factories as well, for producing their technology. They try to remove waste there during that knowledge process, but its form is a bit different. (Fox, 2018)

The informant considers that Lean and Six Sigma can be critical for improving how they operate their processes. Lean looks for the non-value activities and takes them out from the process and Six Sigma gets the process in control so the yield can be maximized. A process transforms inputs into outputs, and if it is a physical process it can involve materials, energy, water and as an output give products and waste (in different forms, from air emissions, water emissions to wasted energy). Considering that, anything you can do for reducing that waste will make a big difference, being Lean and Six Sigma instrumental to improve their sustainability. (Fox, 2018)

However, Lean and Six Sigma won't make you walk all the road of sustainability. For example, they won't force a transformation from non-renewable to renewable inputs, or promote circular economies such as reusing or recycling products at the end of its life. (Fox, 2018)

Applying these systems for solving sustainability issues sometimes can be seen as breaking a nut with a sledgehammer. When there are lots of data, complicated interactions between

the factors and the root cause is not clear then something like Six Sigma can be very useful. Projects such as energy efficiency, where there is a lot of data to pick (measurements in all of their sites, the weather, the operations at those sites...) are great candidates for Lean and Six Sigma. Otherwise, Lean and Six Sigma would be the wrong approach, they would be just a big hammer for breaking a nut, in the way that they can complicate things more than necessary. Sometimes, more simple solving methodologies like PDCA would do the job well. It's more important that the people know the basics and apply the right tools when needed. (Fox, 2018)

A Lean mindset and the use of Lean tools can make an organization work on a structured and systematic way, and at the beginning, coming from an ad hoc way of working, it will have huge impact. But the informant believe is that the classic Lean will take an organization to a certain point where the returns will diminish. Then, other more modern tools are needed such as discrete events simulation. (Fox, 2018)

The informant say that Lean and Six Sigma will have an effect on the environmental and economic pillar of sustainability, since removing waste it has an impact in those aspects. But if health and safety are included in the social pillar it can benefit the last one as well. (Fox, 2018)

Nevertheless, this needs to be balanced since taking a production plant from a 50% utilization to an 85% utilization without thinking on the sustainability impacts can make the access routes clog with lorries coming at a higher rate, having an impact on the area (air emissions, resources...) For the economical factor it can be beneficial, but not for the environment. That doesn't mean that those improvements shouldn't be made, but sustainable choices are needed at the same time. There is always a dialog between the three sustainability pillars, and in any business decision some sort of balance needs to be done. (Fox, 2018)

Being sustainable means that at the end you are having a zero impact on the natural and social environment. But it is better to seek to make a positive impact, going further than the net zero approach. (Fox, 2018)

Informant view on Lean Six Sigma sustainability integration:

The informant says that he is not sure that a Lean Six Sigma Sustainability integration would be entirely possible. Most of the companies with focus on Lean use it for the manufacturing operations. Sustainability in Tetrapack is more about the direction of the business, embodied into their strategy, not only for the short and medium term, but for the long term as well. (Fox, 2018)

4.2 Case II: Höganäs

Founded in 1797, Höganäs is the world company leader in iron and metal powders with a capacity of 500,000 tons per year. They develop solutions for automotive components, brazing, electrical motors, additive manufacturing and water treatment. In general, they work with very customer specific products with 2500 customers around 75 countries. (Höganäs, 2018)

Their vision is to inspire the industry to make more with less, improving resource efficiency. Their metal powders are used for making thousands of different products in a wide range of applications. They offer more effective and lighter products with reduced environmental impact. (Höganäs, 2018)

Their vision is that metal powders can contribute to a sustainable development, contemporary problems such as resource scarcity, clean water and renewable energy. (Höganäs, 2018)

Höganäs view on sustainability:

The informant uses the definition of the World Commission on Environmental and Development in 1987 for sustainability, “development that meets the needs of *the present without compromising the ability of future generations to meet their own needs*” (UN, 2018). Höganäs have sustainability as a focal point and they use a term called Mount Sustainability with the 5 areas they want to position themselves in the future (Figure 4.2). (Bergman, 2018)

Their 5 areas are:

- “*A great and meaningful workplace*”: where the focus is the wellbeing of the coworkers, balancing their life, competence issues, the use of the right tools, fulfillment and enjoyment of the work. They believe that a personal in balance will do better job and will tend to be loyal.
- “*Building communities and responsible partnerships*”: to assure high ethical standards.
- “*Sustainable offerings and long-term profitability*”: to meet the needs of a sustainable transition of society.
- “*Future-proof business*”: For a safe, clean, efficient and long term sustainable business.
- “*Climate neutral operations*”: to minimize their climate footprint. (Bergman, 2018) (Höganäs, 2018)

Mount Sustainability is used as a focal point that marks transition.

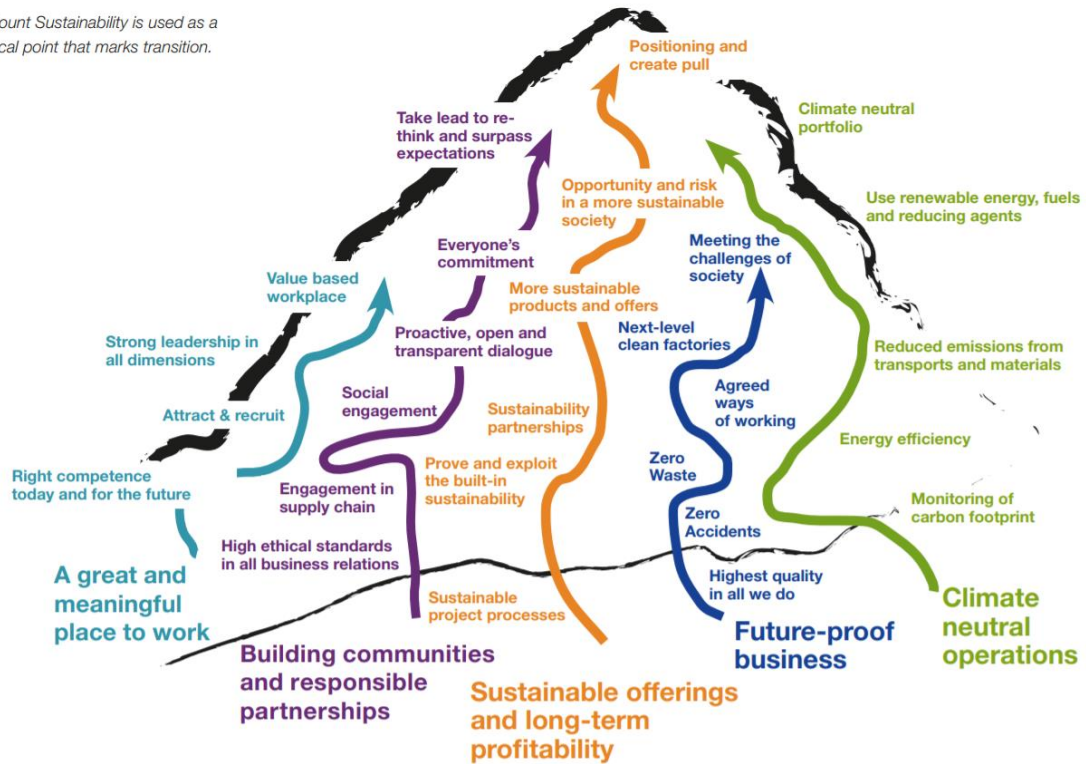


Figure 4.2. The 5 areas of Mount Sustainability (Höganäs Sustainability Report 2017, 2018)

Balancing the three pillars of sustainability:

The informant point of view is that the three sustainability pillars are interlinked, and all are improved with Lean and Six Sigma. It is not possible to have a successful business with a crew that is not focused, engaged, with knowledge. Those are social aspects. It's key to succeed to provide a good social environment for their coworkers, that will improve all pillars since they are interlinked. (Bergman, 2018)

Höganäs use of Lean, Six Sigma and its effect on sustainability:

The informant explains that for internal efficiency Lean is the way. They use Six Sigma as well in pockets of the organization, but not everywhere. Their philosophy is called More Höganäs, founded on Lean principles. Their view is very linked to continuous improvements, doing every day better than yesterday. But sometimes they need to make big investment that can affect their work conditions, energy consumption, raw materials, etc; in those cases, for incremental changes with big steps, they use a project form. So they differ between the everyday steps and the big steps. (Bergman, 2018)

His believe is that Lean improves the sustainability of an organization. Lean is key to succeed, it gives the insights and almost an expectation to improve the work, the team work, and the processes. It will connect people. It will create ambition targets for improvement. It erases idling, quality errors, it improves the use of resources, the efficiency, and energy consumption; and all these things will improve the environmental footprint. And moreover,

you will have the things more classically linked to business and performance: delivery time, quality... (Bergman, 2018)

“Lean is a system that seek continuous improvement, and continuous improvement are applauded by sustainability” (Bergman, 2018). For Höganäs, Lean is a structured way of involvement with KPI to follow up, of engagement of all coworkers. And at the end, sustainability targets and business targets are all the same. (Bergman, 2018)

For sustainability matters, they are familiar with many tools such as Life Cycle Assessment, Life Cycle Inventory and a tool they call Sustainability Life Cycle Analysis to put in mind all the ideas, for helping in the most important decisions. The tools can help to create comparisons, and to find opportunities to improve. That way they can help to see if they are sustainability leaders in the area or need to improve. With the Sustainability Life Cycle Analysis, they can include social, economic, and environmental aspects, to analyze them together and help decision making. But not everything is put into numbers since it is hard to find a unit for combining social risks and an air emission for example. (Bergman, 2018)

Informant view on Lean Six Sigma sustainability integration:

There is a difference between the Lean definition of waste and the environmental waste. For Lean, waste is the measure of the failure of having internal efficiencies. It can be resources, time, lack of competence. However, environmental waste is something that comes out from operations. That may be emissions, wasted materials, poor quality products... It's more related to the organization footprint while the Lean definition is related to continuously improve the internal efficiencies. Nevertheless, they both are connected, if the internal efficiencies are improved, the environmental emissions will be reduced as well, achieving less waste from poor quality, energy use... They both are connected but not defined in the same way. (Bergman, 2018)

Höganäs includes the sustainability goals in their long term strategy, realized through the business plan. They anchor sustainability progress in their normal way of making decisions. Sustainability it's not on the side. (Bergman, 2018)

For an integrated model of Lean Six Sigma and Sustainability, the informant say that Lean and Six Sigma gives internal efficiency, engagement, prioritization, the possibility to follow up on new approaches. With an integration that will not change. But is important to build sustainability ambition into the business planning and work, and make that fall down into the organization where Lean is already existing. That will bring new KPIs, new areas to focus on, more ambitions... The two things are meant to be married (Bergman, 2018), because *“if you have your systems in place and ways of working in place, then you can drop almost any ambition”* (Bergman, 2018).

4.3 Case III: Haldex

Haldex is a Swedish company that operates worldwide with a history dating back to more than 100 years ago. They develop and manufacture solutions for the global commercial vehicle industry. They are experts with brakes and air suspension systems for heavy vehicles, being the world leader of brake adjusters for drum brakes. Their products are reliable, innovative and improve safety, vehicle dynamics and environmental sustainability. (Corporate Haldex, 2018)

Haldex view on sustainability:

Haldex believes that sustainability is about being an ethical organization and having an ethical business regarding how they treat their employees, how they do their business, how they treat their suppliers, how they manage the utilization of natural resources... With this in mind, they identified three key areas to make a huge impact and build global objectives: Safe Haldex, Ethical Haldex and Green Haldex. (Corporate Haldex, 2018) (Valett, 2018)

Safe Haldex is the Haldex program for safety, where safety is the number one priority. Their motto since 2014 is "If you can't do it safely, don't do it". It works in two aspects: safety in terms of work place so they don't have any accident or injuries in their operations, but also safety in the utilization of their products so their customers can use them without getting hurt. Many of their products are used for safety purposes: brakes, ABS systems, etc. So for them this aspect is very important, as it is noticeable in their tagline of a world of safer vehicles. (Corporate Haldex, 2018) (Valett, 2018)

Their target during the next year is to reduce and have no accidents at all the Haldex facilities. They have many process indicators and metrics to lead to that. For Haldex, an accident is a worker's absence of the normal task for more than 2 hours, instead of the one-day line of most companies. They also use "near misses", where the risk of an accident was there but nothing happened by luck. They measure the number of accidents, number of accidents per million work hours, number of near misses and a number of underlying process indicators to show how effective they are to achieve those no-accidents results. Things like the number of risks observations from the workers, number of preventive actions taken. (Valett, 2018)

Ethical Haldex is the Haldex program for ethical behaviors. They have no tolerance for bribery, corruption, child labor and discrimination. For that matter they elaborated a code of conduct that all their employees need to know and follow. It is impossible to document and give roadmaps for all situations so they follow three values to provide a guidance: "Customer first", "Respect for the individual" and "Passion for excellence". Their short term goal here is to have no deviations from the code of conduct. (Corporate Haldex, 2018) (Valett, 2018)

Green Haldex is the environmental program for Haldex, so that they have a sustainable utilization of natural resources and materials. This is done in terms of their production and in terms of the utilization of their products by customers. Both should produce a positive environmental impact. (Valett, 2018)

Their first key goal is to improve material efficiency to convert the raw material into products with minimum or no waste generated. They measure the ratio in-out of materials to know how much material is wasted and in which form, and also which of that is recycled. (Valett, 2018)

Their second key goal in the matter is the reduction of the carbon footprint and all the causes of its generation. The metrics here are just tones of CO2 since their point of view is that what's important for the earth is the total amount and not the amount per products made. Those air emissions are also segmented into the source from which they come from, is it heating, transportation, production processes, etc and what source it comes from, is it oil, electricity, LPG... (Valett, 2018)

In terms of the use of their products, they also measure the CO2 generated by their products. There is a carbon footprint associated with the design of their products. Heavier brakes will increase the weight of a truck or a bus and it will consume more diesel because is heavier. Light brakes can reduce diesel consumption, or it can increase the truck load capacity. And having in mind that a truck and trailer has multiple brakes and also need an air compressor for operate them, an air cleaner, an air dryer, valves... The weight of the whole system and thus its design have a big impact on the carbon footprint. (Valett, 2018)

Haldex use of Lean, Six Sigma and its effect on sustainability:

Haldex uses their own “framework for strategy development and result driven improvement”, the Haldex Way. This framework originates from a Lean production system, and has been improved with a business excellence logic for strategy deployment and result driven improvements. Nowadays deployable in all functions and processes at Haldex. It works as a philosophy in terms of core values, establishing priorities, behaviors and principles. It works as well by providing methods to guide how they manage their processes, procedures and in general to guide how they do what they do. (Valett, 2018)

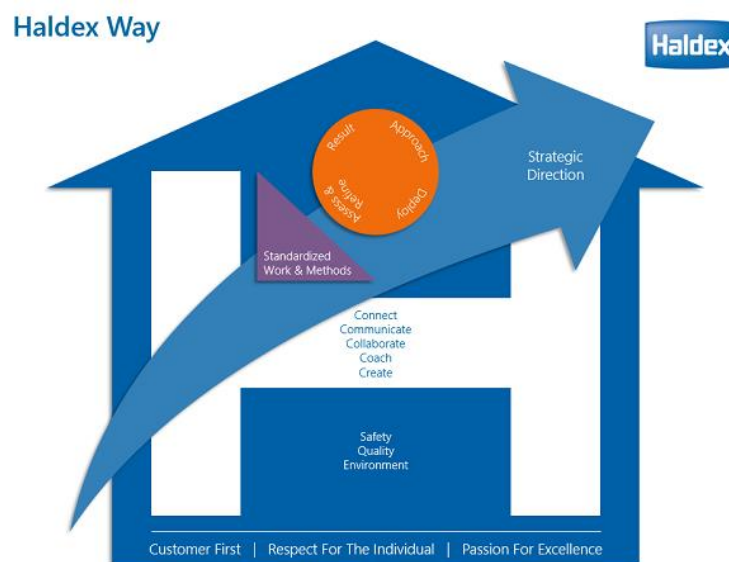


Figure 4.3. Haldex Way framework (Haldex Way Introduction, 2018)

At Haldex Six Sigma is a subset of Lean, together with other problem solving methods. They have it as a component of their Haldex Way to use it when is needed, same as other tools such as 5S, TPM... (Valett, 2018)

They prioritize their projects to work based on their top priorities, which are safety, quality and environment. But other priorities are needed as well for having a successful business, things like cost, delivery, profit, etc. Those are equally important but are not allowed to intercede with the top 3. Sometimes that can be seen as a conflict, as a paradox, but is a “healthy paradox”. Both environment and profit are needed. Looking it that way synergies can be made. (Valett, 2018)

The informant says that Lean definitely improves the sustainability of a company. They both are very integrated and have many synergies. Lean is a good approach for environmental sustainability, safety, ethics, leaderships, behaviors... Lean, and their way of using it, the Haldex Way, not only supports, but enhances the sustainability of a company. It needs to be point it out, because it is obvious. A basic example of this is that by using a subset of Lean, Total Productive Maintenance, the machines’ quality, productivity and availability will be increased. Those are good environmental KPI too, since the more efficient the machines are the more environmental the process will be. That way, it is possible to run the machines without scrap, with no rejections, with a high availability that permits to plan better the production, improving the logistics, reducing transport and in general optimizing the flow. The better productivity the better the resources are used, either materials, human resources or energy consumption. (Valett, 2018)

Nevertheless, Six Sigma and DMAIC are not always the answer to be applied for sustainability projects. It totally depends on the project to be done, its nature. For some projects with a sustainability purpose, Six Sigma can be the perfect method. Typically, those projects are complex, with unknown root causes and with many data needed. DMAIC can help a lot in those cases. On the other hand, if the root cause is known, with no real problem aspect, and those are short projects; then Six Sigma is not the right method, and other methods typically fit better. The right method for those projects depends on the project itself, with a whole toolbox of methods and tools to choose from. (Valett, 2018)

They don’t rely on Kaizen events too much either. Those discontinuous events can make changes in focused areas, but the informant affirms that is important to make the organization learn to implement and follow up to improve continuously as part of every employee’s role and responsibility. If all the employees are capable to implement, follow up and improve, they can generate more improvements and results than relying only on separate Kaizen events. (Valett, 2018)

Explanation of the tools they use for sustainability purposes:

The informant affirm that is necessary to sometimes add new tools to address more specific sustainable problems. All the methods in Haldex Way support sustainability, and can be applied to improve it. But there are some sustainable specific tools that add value and are the drivers for picking other tools. The most important tools they use for each area are described below (Valett, 2018).

For Safe Haldex, the key tools used are (Valett, 2018):

- The standardized work, to standardize the process. They describe what, how and why in their process standards. They specify and make clear why is important to follow the standard, either for safety aspects, quality aspects or environmental aspects. They make clear what needs to be done, for avoiding safety, quality or environmental risks. Then there are structures to measure deviations to the standard and to improve it, and how to effectively train employees in a standard.
- The safety cross, a method for improve safety behavior and awareness. Every day the team reflects if there has been any accident or near miss or anyone observed a safety risk. They consider a failure to not observe any risk and success to do so, marking it with green. They want to make people aware of risk asking that question every day, expecting people to see the risks and address them. Sometimes further investigation and planned actions are needed to fix the risks.
- The global accident communication, to inform all the other Haldex sites of an accident in one plant. For example, if an accident occurs at Landskrona plant all the other sites will be communicated. They will see if they have the same risks and take proactive action to avoid accidents.
- The take 5, a quick safety risk assessment tool to do before an unstandardized work. It takes 5 minutes to identify possible risks before doing the operation.
- Safety risks observations, to learn to see risks. A small team (2-4 persons) gathering, observes an area or process for 5 minutes and share with them what safety risks they have seen, behavior or technical risks, and discusses them. Then they address them if possible or report them for more investigation and action. The purpose of this tool is to make people learn from each other to observe risks, since everybody have different eyes. Everybody in operations shall do this a few times per year.
- Safety audits, also part of the laws and regulations of the countries.
- Risks assessments before process changes, such as layout modification, moving a production line...

For Green Haldex (Valett, 2018):

- The green performance map, an umbrella methodology. Basically is a map of energy and material utilization of any kind. It makes easier to visualize what generates the carbon footprint and the material deficiencies. They use this tool in order to prioritize their projects and initiatives. There is a cost and effort associated for all projects. This tool can help decide where to invest that cost and effort. For example, they could change all the lights to LED, but with that cost and effort they could also optimize slightly their transportation activities, which as a result the impact would be better.
- The green product assessment, a similar tool, but for the development of products. To develop them in an environmental way, so that they become an environmental product.
- There are also many KPI, environmental audits, the ISO 14001...

Those tools, specially the green performance map and product assessment are really the drivers for other Lean tools. (Valett, 2018)

When talking about the relationship between Lean knowledge and experience of an organization and sustainability the informant view is that the better Lean is applied, the better sustainable the company will be. And this can continue forever, there is no point where the job is done. There is no barrier where the improvements are not worth the effort. The markets change, the technology change, many things today are possible that were not yesterday. Moreover, talking in terms of financial situation, in good economic times, where the business is booming, waste is financially affordable. But it is in bad times, where the business is struggling, where waste is not affordable. So Lean and improvement systems are needed even more in bad times, where you cannot afford any waste at all. Those systems need to be working even better then. In good times some waste is actually affordable. This can be contradictory since many companies cut down the Lean initiatives when they are struggling. It should be working equally well in both times. (Valett, 2018)

Informant view on Lean Six Sigma sustainability integration:

The informant affirms that Lean and sustainability definitions of waste are basically the same, just using different units. Sometimes Lean waste can be time, pieces, money... Environmental units tend to be more CO₂, Kilowatt-hours, materials... (Valett, 2018)

The informant suggests that the conflicts and synergies between Lean improvements and sustainability can easily be seen with the example of safety and productivity. They can be perceived as a conflict. But they are a “healthy paradox”, they both have synergies. It is possible to improve both rather than having to choose just one, since they are supporting each other. If safety is improved, productivity will be improved as well, and the other way around. But they have to be improved in a good way. Just working faster to improve productivity will not get safety benefits, and even can trigger more accidents. It is about working better, to end being safer. The same can happen improving safety in a good way: things like leadership, behavior and operational discipline will be improved, things very beneficial for productivity. If the employees need to be constantly alert for safety risks to not get hurt, they will not be productive (Valett, 2018). Usually *“the safest companies tend to be the most productive ones. The ones with the lowest number of accidents usually have the highest productivity”* (Valett, 2018).

For combining Lean initiatives and sustainable initiatives, Haldex has a simple but effective logic, which the Haldex framework is based on, the RADAR logic (Figure 4.4). It starts and ends with Results, the objectives, what you want to achieve: it can be an improvement, a change, a strategic KPI... The first step then is to define that goal. After that, the next one is to select your Approach. It can be a Lean tool, a Six Sigma tool, a sustainability tool such as the Green performance map... It can be their “standards, methods, procedures, processes, roles and responsibilities”, one or several. The following step is the Deployment, where the approach selected has to be deployed and applied efficiently and effectively. Finally, the last step is to Assess & Refine, where the approach and its deployment is evaluated and assessed to generate the desired results. This is done by KPIs, audits, appraisals or reviews. According to that you refine the approach and Deployment to generate or sustain the results. (Valett, 2018)

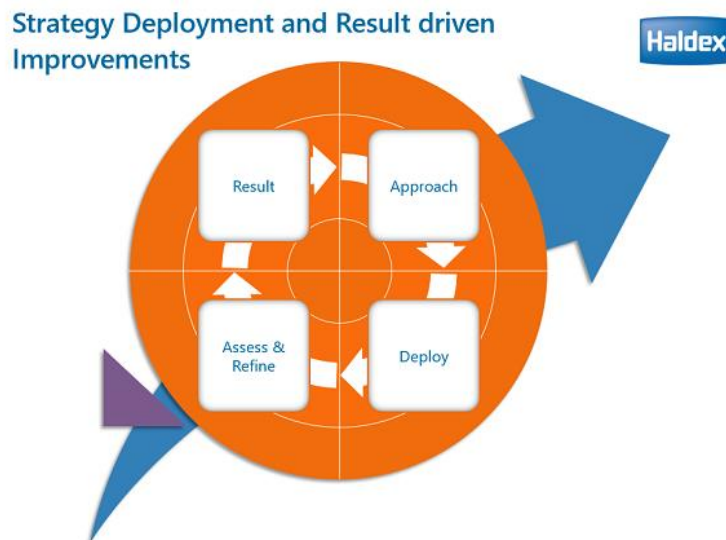


Figure 4.4. RADAR logic of Haldex (Haldex Way Introduction, 2018)

The difference that the informant from Haldex finds between this logic and other model such as DMAIC is that this logic starts and ends with results. That is why is called a framework for strategy deployment and result driven improvements. As an example, a **Result** could be to “reduce the carbon footprint”, then the **Approach** for that target should be studied (it could be to use Lean tools, a Six Sigma project, sustainability tools, or other methods and procedures), the approach should be **Deployed**, it should be implemented in a practical way. Finally, it should be **Assessed** to see if it’s working and if it’s applied effectively. That approach should be refined and improved to sustain the result. (Valett, 2018)

The informant thinks that this RADAR logic is one way to integrate Lean, Six Sigma and sustainability, but that there are also many other ways. He agrees that DMAIC, as the literature suggest, can be another way. Six Sigma is a very good method for the right problems. It is very effective. However, it has some deficiencies. It doesn’t start and end with results, making it more of a method for problem solving than a method for results driving improvements. It also needs a structure that supports it (sponsors, committees, project selection processes...), many projects need that anyway, but many actually don’t. Six Sigma and DMAIC can’t be on top and be used for all the problems, for them it is a subset of Haldex way. (Valett, 2018)

A form of determining which projects are appropriate for Six Sigma is to look at the root cause. If it is already known, there is no need to overcomplicate things. Another form can be to look at the complexity of the problem, if it is not complex it can be counterproductive to do a black belt project. It will only add lead time to solve it. (Valett, 2018)

As a personal opinion, the informant also thinks that Six Sigma maybe is not for everybody in the organization. It is a bit technical and not everybody will be green belts and black belts. Its application can depend on the problem at hand. (Valett, 2018)

In other matters, to balance the three sustainability pillars, the organization priorities need to be in place. For Haldex they are safety, quality and environment. They have more priorities, but will never interfere with the top three. In case of conflicts it is necessary to find a good way to do it. The informant says that sometimes, one way to solve a problem

often forgotten is to eliminate it. Not to improve it or minimize the effects, just to take the problem away. For example, if there is a risk of getting cut by a machine, the employees could wear gloves, but it is also possible to just cover the cutting parts of the machine and eliminate the problem. The target is to eliminate the root cause. (Valett, 2018)

There are also pros and cons to an integrated framework for Lean, Six Sigma and sustainability like the Haldex way, but that is perfectly fine. The benefit is that it becomes very efficient, and that at the end there are more synergies than conflicts. The disadvantage is that it can take slightly more effort to manifest that, to explain it to the organization so that everybody could understand. It is easier to have one system for production improvements and a separate CSR for the sustainability and ethics. But having both together as an integrated approach it's worth the effort, it is a good investment because it produces great results. (Valett, 2018)

4.4 Case IV: Sandvik

Sandvik is a high-tech company with world-leading positions on tooling systems for metal cutting, equipment and tools for mining and construction industries and steels, alloys and products for industrial heating. Their three business are “Sandvik Machining Solutions”, “Sandvik Mining and Rock Technology” and “Sandvik Materials Technology”. (Sandvik, 2018)

Their headquarters are in Stockholm, but this interview was done with the mining and rock technology section (SMRT) located in Svedala. (Sandvik, 2018)

Sandvik (SMRT) view on sustainability:

The sustainability vision of Sandvik Mining and Rock section, expressed in their Environment, Health and Safety vision (EHS) to *“always striving to eliminate harm to our people, our customers, our suppliers and to the environment in which we work”* (Rock Technology Sandvik, 2018).

Among their sustainability objectives are the reduction of energy and raw material consumption, reduce emissions and increase recycling. To create safer and healthy workplaces for the workers as well as safest products and services for their customers. For them “Safety first” is key, mining safety is very important and is integrated in their operations. (Rock Technology Sandvik, 2018)

Sandvik (SMRT) use of Lean, Six Sigma and its effect on sustainability:

For Sandvik mining and construction, they developed a production system based on Lean, Six Sigma and best practices. They don’t use it everywhere but it is a guideline in that area. As an example, the last year they used that system to do a project in the logistics area to reduce their air freight. Now they are doing a project in the machining area, to improve up time of machines, using for that a DMAIC structure. So they usually use Six Sigma for the larger projects, where further investigation is needed, otherwise they use a simple Plan Do Check Act (PDCA). (Kock, 2018)

They also have a system they call Sandvik Rapid Improvement, which they use many times. It is slightly based on a Six Sigma setup but looks more like a Kaizen event, where a team focus during 4 or 5 days to fix a problem. (Kock, 2018)

For prioritize their projects and work, the first thing is compliance. Then, the decision making process is a combination of efforts and potential, how much work will it be versus the potential benefits and the risks of not being successful. They use a sort of pyramid for projects classification. At the bottom there is the continuous improvement projects, small PDCA projects, for the shop floor. Then there are bigger projects with the Sandvik Rapid Improvement system, or green belt projects. Then there are the largest projects, that can be either a Six Sigma project for lower investments or a Sandvik project methodology if the investment is very high, to study more deeply the risk. (Kock, 2018)

The informant says that DMAIC can be the right method for sustainability focused projects depending on their size and how easy are to fix them. For example, if they have a leakage, they just have to close the hole, there is no need to apply anything. But DMAIC can be used to study the production of a foundry, in the case that energy prices go up, and costs get

higher. It can be useful to find solutions. Sustainability is part of their targets, they measure it, but the first things that they review are the savings, the waste reductions, efficiency increases, up times... (Kock, 2018)

When they look for waste, they don't differentiate the waste by its importance, but for what is needed in the moment. For example, if they need to produce more and increase the output, reducing waste in the form of idle time would be the target, but in a situation where they need to reduce the costs, reducing the waste in the form of quality rejects would be the target. (Kock, 2018)

The most important thing is that the coworkers have Lean thinking skills, that they know what waste is and where to find it in different processes. They train people for that, so they can drive continuous improvement in their organization. There will be never a point where improvements cannot be made, there is always room for improvements. That is also sustain by world changes and technology development. (Kock, 2018)

The informant affirms that for sure the improvements that Lean and Six Sigma provide to an organization have a positive impact on sustainability. They absolutely help for things like health and safety. About 20% of the ideas that Lean provides at shop floor or operations level are about safety, its improvement, and the wellbeing of personal. Sandvik has a huge focus on EHS (Environment, Health and Safety) and Lean definitely helps there. (Kock, 2018)

4.5 Sustainability metrics

This case it's not a particular study of a company, rather it is a study of sustainability metrics, how to define them and how to combine them. This can help to fill the gap stated by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) that there is a lack of performance measurement systems to measure Lean, Six Sigma and sustainability from economic, environmental and social aspects.

First, this section presents a tool for a complete evaluation of a supply chain initiative from the perspective of the three sustainability pillars. There has been models for supply chain assessment such as the SCOR (Supply Chain Operations Reference), but none of them has evaluated a supply chain from the three sustainability pillars perspective at the same time. (Chardine-Baumann & Botta-Genoulaz, 2014)

With the tool presented by (Chardine-Baumann & Botta-Genoulaz, 2014), a supply chain initiative can be characterized into the three sustainability pillars, to get a profile of the initiative. This way it could be compared with other possible projects to choose from, to see which one is the most "sustainable" or which one fits better with the needs of the company. Along with other decision factors, such as cost, urgency and risk, this tool could help with the prioritization of initiatives or projects, and later it can be a first step to define the relevant metrics for the project.

The article reviewed that presents this tool, "A framework for sustainable performance assessment of supply chain management practices", develops a multi-criteria framework for this assessment. This is the main source for the first part of this case, it presents the mathematical model for the sustainability evaluation of supply chain practices. (Chardine-Baumann & Botta-Genoulaz, 2014)

Supply chain management controls material and information flows from raw material extraction to product delivery. The supply chain performance of a practice is the combination of its impact on the economic, environmental and social pillar. In order to evaluate Supply chain management practices toward sustainability assessment there are few tools. The one that suits best, as said before, is the SCOR model (Supply Chain Operations Reference) with the addition of GREENSCOR model. But still, that does not integrate the three sustainability dimensions at the same time. To fill that gap, this article presented a framework for a simultaneous assessment of the three pillars for a Supply chain management initiative. Based on a literature review, it decomposes each dimension into 5 fields representing their main focus areas, each field is broken down as well into several sub-fields representing the subsets of those focus areas. In total it proposes 15 fields, 5 for each sustainability dimension, and a different number of sub-field for each field for a total of 67. A complete description of the meaning of each sub-field can be seen in the article. (Chardine-Baumann & Botta-Genoulaz, 2014)

The structure of the assessment areas of the framework, with all the sub-fields, is represented in the table 4.1. The goal with the assessment of all the sub-fields is to combine their values into three indexes, one for each sustainability dimension, so it can summarize and characterize an initiative within an economic index, an environmental index and a social index. (Chardine-Baumann & Botta-Genoulaz, 2014)

		i	j	Impact [-1, 0, 1]	Maturity [0, 1, 2, 3]	Weighted impact [-3, 3]
E c o n o m i c	Eco1	Reliability	Customer service	1	3	3
			Suppliers' service	0	0	0
			Reliability of stocks	0	0	0
			Reliability of forecasts	0	0	0
	Eco2	Responsiveness	Design responsiveness	0	0	0
			Purchase responsiveness	0	0	0
			Source responsiveness	0	0	0
			Production responsiveness	0	0	0
			Delivery responsiveness	-1	3	-3
			Sell responsiveness	0	0	0
			Return responsiveness	0	0	0
			Supply chain responsiveness	-1	3	-3
	Eco3	Flexibility	Suppliers flexibility	0	0	0
			Supply flexibility	0	0	0
			Production flexibility	0	0	0
			Delivery flexibility	-1	3	-3
	Eco4	Financial performance	Design cost	0		0
			Purchase cost	0		0
			Source cost	0		0
			Production cost	0		0
Delivery cost			1	3	3	
Return cost			0		0	
Eco5	Quality	Supply chain cost	1	3	3	
		Product/service quality	1	3	3	
		Quality performance of suppliers	0		0	
		Production quality	0		0	
E n v i r o n m e n t a l	Env1	Environmental management	Environmental budget	1	3	3
			Environmental certification	1	3	3
			Environmental compliance	0	0	0
			Workers implications	0	0	0
	Env2	Use of resources	Energy consumption	1	3	3
			Water consumption	0		0
			Materials consumption	0		0
			Recyclable outputs	0		0
			Recyclable wastes	0		0
	Env3	Pollution	Air pollution	1	3	3
			Water pollution	0		0
			Land pollution	0		0
			Other pollution	0		0
	Env4	Dangerousness	Dangerous inputs	0		0
			Dangerous outputs	0		0
			Dangerous wastes	0		0
	Env5	Natural environment	Eco-systemic services	1	3	3
			Respect of biodiversity	0		0
			Land use	0		0
			Development of urban and rural areas	0		0
S o c i a l	Soc1	Work conditions	Employment	0		0
			Work conditions	0		0
			Respect of social dialog	0		0
			Health and security	1	3	3
			Human resources development	0		0
	Soc2	Human rights	Child and forced labor	0		0
			Freedom of association	0		0
			Discrimination	0		0
	Soc3	Societal commitment	Involvement in local community	0		0
			Education, culture and technological development	1	3	3
			Job creation	0		0
			Healthcare	0		0
	Soc4	Customers issues	Societal investment	0		0
			Marketing and information	0		0
			Healthcare and security	0		0
			Protection of private life	0		0
	Soc5	Business practices	Access to essential services	0		0
			Fight against corruption	0		0
			Fair-trading	0		0
				Promotion of CSR in the sphere of influence	0	

Table 4.1. Adaptation in Excel of the framework for sustainable performance assessment of a supply chain. (Chardine-Baumann & Botta-Genoulaz, 2014)

This master thesis proposes a slight change in the environmental field of use of resources, adding energy, water and material consumption instead of “renewable energy”, “recycled water” and “inputs stemming from the recycling”; so this way the meaning is broader (including the previous recycling terms as well into the new ones) and the assessment can include changes in the amount of resources used as well.

To characterize each sub-field, there are two values, impact and maturity. And as a result of those two values, the third one, weighted impact is calculated.

First, the main problem to measure the impact that an initiative has on each sustainability pillar is that when combining and aggregating those metrics into a single one, they do not use the same units. As a result, it is difficult to combine them into a single value. To solve that issue, the impact that the supply chain initiative has on each sub-field should be determined within 3 values: negative, neutral or positive impact (-1, 0, 1). (Chardine-Baumann & Botta-Genoulaz, 2014)

Second, a supply chain initiative can be implemented in an organization with different degrees, from a small to a complete implementation along the whole supply chain. The maturity value is the parameter that measures this. In the following picture it can be seen how to rank this value from 0 to 3 depending on the scope (the boundaries of its implementation) and the stability (how often it is used) of the implementation. (Chardine-Baumann & Botta-Genoulaz, 2014)

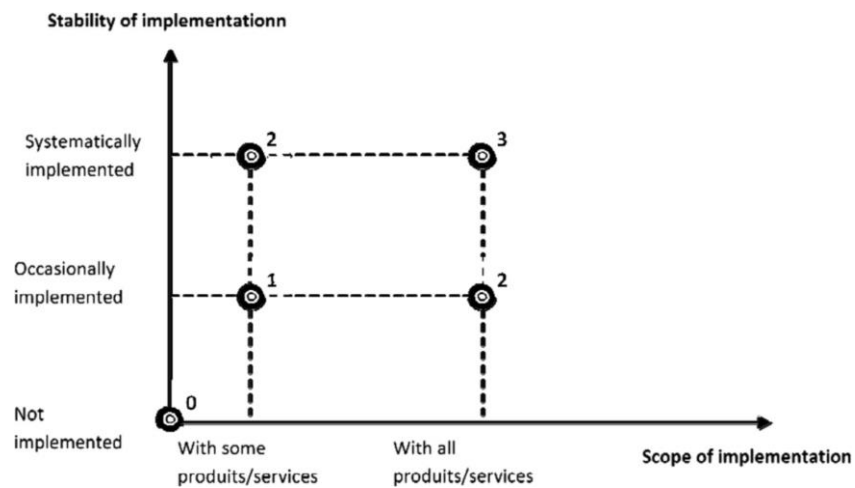


Figure 4.5. Maturity value, reflecting the implementation degree of an initiative, by (Chardine-Baumann & Botta-Genoulaz, 2014)

From those two values, the weighted impact can be calculated as their multiplication (impact x maturity). Then, with the known weighted value of each sub-field, the impact on each field can be calculated as the average of the weighted impacts of their subfields. Finally, the sum of the impacts of all the fields of one dimension will give their dimension index. As a result, three index values (economic, environment and social) are calculated, which summarize all the information of their fields into one value for each sustainability dimension. This can be seen in the following picture, figure 4.6. (Chardine-Baumann & Botta-Genoulaz, 2014)

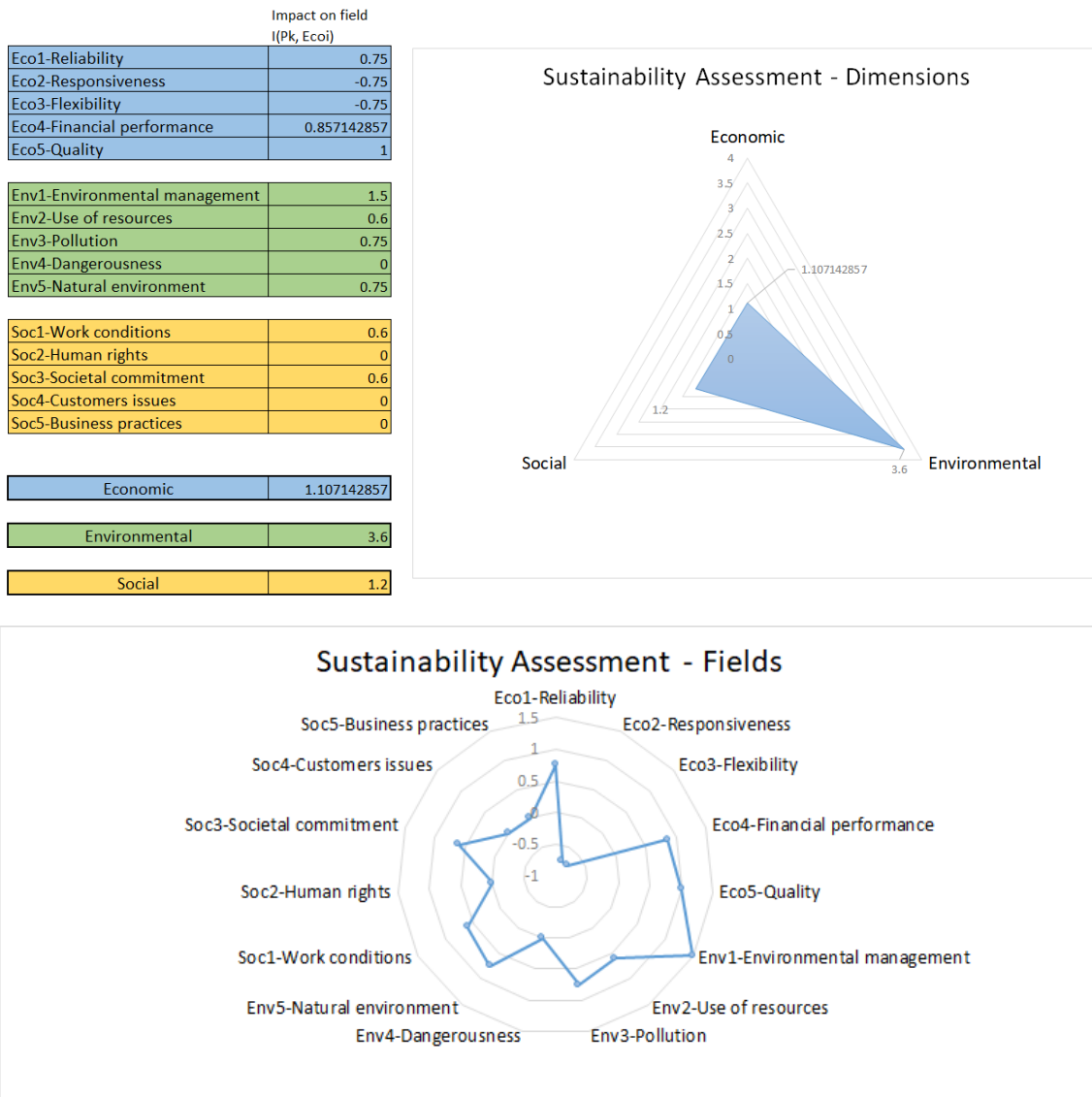


Figure 4.6. Adaptation in Excel of the Sustainability assessment result in each dimension, by (Chardine-Baumann & Botta-Genoulaz, 2014)

This three index assessment can show the information in a way that makes sustainability decision making easier for managers.

For this master thesis, this framework will be generalized and could be used for the evaluation of Lean Six Sigma Sustainability initiatives instead of only Supply chain initiatives. The integrated model for those initiatives presented on chapter 6 will use these ideas and procedures.

The maturity level, apart from the scope and stability criteria, could be viewed as a way to weight the impact on each subfield of the project, so it could be chosen with the manager criteria as well.

The subfields that will have an impact during the project (positive or a negative) will be relevant and shall be measured during its deployment. Some would be easier to measure for being physical (Kg, emissions, Energy...) but others more subjective could represent a challenge, usually the social ones. Once the managers understand which subfields will be

relevant for the project, the following structure can be used to choose the specific metric or metrics for each subfield and how to measure them (which unit). If there is no certainty of the effect of the project on one of the subfields, that subfield could get a metric as well to study whether or not it is affected.

The steps to determine sustainability metrics, proposed by (Reich-Weiser, et al., 2013), are the following:

Step 1: “Goal definition. Determine the goal of the assessment”: To determine the goal of the metrics. The selection needs to be made according to the sustainability strategy.

Step 2: “Goal definition. Choose a metric type”. Either in form of costs, physical unit, % availability...

Step 3: “Scope definition. Determine the manufacturing scope of the assessment”. From material extraction, transformation to end of life. There are different levels that can be assessed:

Machine tool scale (wasted material per part, energy used per part...), line scale (similar but for a bigger scale), factory scale (total energy consumption...), supply chain scale (metrics for the entire supply chain), life cycle scale (includes also product use and its disposal). Each one includes the effects of the lower scales.

Step 4: “Scope definition. Determine the geographic scope of the assessment”. Sometimes is necessary to define the geographic scope of the metric if that is relevant.

Once the goal, scope and the metrics are defined, basically the first step of a Life cycle assessment (LCA) is already made so the analysis can transition into the following phases of a LCA from this point. Further information of LCA is given in the appendix (A2). (Reich-Weiser, et al., 2013)

5 Analysis

This chapter develops a study of the problem definition and the 4 research questions of this master thesis throughout the four company cases. It answers them and compares the ideas given by the four companies with the ideas given by the literature. It is an analysis of the main points of the chapters 3 and 4 and an exploration of their relationships.

5.1 Problem definition

The basic idea that can be derived from the reviewed literature is that there is a need for improving the sustainability performance at companies and reducing their environmental and social impacts.

Traditionally profit, efficiency and customer satisfaction have been the main interest of companies. But lately greener operations and products made companies focus on those areas as well. Society and regulations demand more attention to these topics (Garza-Reyes, 2015). This is related as well with the problem definition of this master thesis.

From an empirical view, the problems and focus areas that the four companies analyzed have are similar to the ones exposed by the literature. All of these companies have sustainable goals and notice the importance of sustainable development for the future of their company. Concretely:

Tetrapack express their sustainability goals as protecting food, people and future. Reduce food waste, protecting their customers and employees and making sure that the environment is sustained are key things for them (Fox, 2018).

Höganäs want to position themselves having:

“A great and meaningful workplace, Building communities and responsible partnerships, Sustainable offerings and long-term profitability, Future-proof business and Climate neutral operations” (Bergman, 2018).

Haldex want to improve their sustainability through 3 areas that they define as Safe Haldex, Ethical Haldex, and Green Haldex, where they established key targets.

Their 3 top priorities are safety, quality and environment. But other parameters like profit, costs, delivery etc are also important for them (Valett, 2018).

Sandvik work *“always striving to eliminate harm to our people, our customers, our suppliers and to the environment in which we work.”* With a vision of Environment, Health and Safety (EHS) (Kock, 2018).

So both the literature and the companies interviewed recognize the need for sustainable development and initiatives that could help on that road. However, companies recognize and emphasize more on aspects such as health and safety of their coworkers than what the literature treats. They have those aspects as a priority which is not extensively covered on the literature reviewed which focuses more on the need to improve on environmental aspects.

The companies show an interest and an intent in sustainability development as it is discussed on the literature.

Each company give their attention to the sustainability aspects that are key for their business. But the three sustainability dimensions are covered. Social aspects, specially Health and Safety usually are less covered by the sustainability literature than what companies value them. They however consider them key aspects.

5.2 Research Questions

5.2.1 How and why do Lean and Six Sigma improve the sustainability of a company?

As it has been extended in the literature section, Lean benefits the triple bottom line of Sustainability (Sri Hartini, 2015). Lean companies easily accept environmental ambitions; it can be a catalyst for Green initiatives. There are many synergies (Garza-Reyes, 2015). Lean and Six Sigma tools have an impact on sustainable metrics, as it is extended by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) and summarized in the appendix (A3). However, not all Lean practices improve sustainability and Lean is not enough to fix all sustainable issues (Garza-Reyes, 2015).

From the companies analyzed point of view, all four of them agreed that Lean and Six Sigma support and enhance their sustainability performance. And that this impact can be generalized for other LSS companies as well.

Lean takes away the non-value adding activities and Six Sigma controls the process and maximizes its yield. Many times those wastes are emissions of many types, so these systems will reduce them (Fox, 2018).

Lean gives insights and improves processes and team work, connecting people. It improves the use of resources and energy, being beneficial for environment (Bergman, 2018). Furthermore, Lean is a good approach for environmental sustainability, safety, ethics, leaderships, behaviors... (Valett, 2018). And finally, many of the ideas that Lean provides at shop floor level are about health and safety (Kock, 2018). Nevertheless, one of them, also recognized that LSS won't take a company along all the road of sustainability and other initiatives are necessary (Fox, 2018).

In summary, both literature and companies recognize the benefits that LSS brings to the triple bottom line of sustainability. They recognize the sustainable effects that concrete tools of LSS have. And finally both notice how Lean and Six Sigma per se are not enough to solve all the issues and opportunities that sustainability offers.

There is a consensus that Lean and Six Sigma benefit the triple bottom line of Sustainability and that companies that deploy these systems are able to accept green or social ambitions easier.

They give structure and insights which are a solid foundation from which to build a sustainable business. However, they won't fulfill all sustainable ambitions and other initiatives are needed.

The following picture summarizes the main points of the analysis regarding this research question:

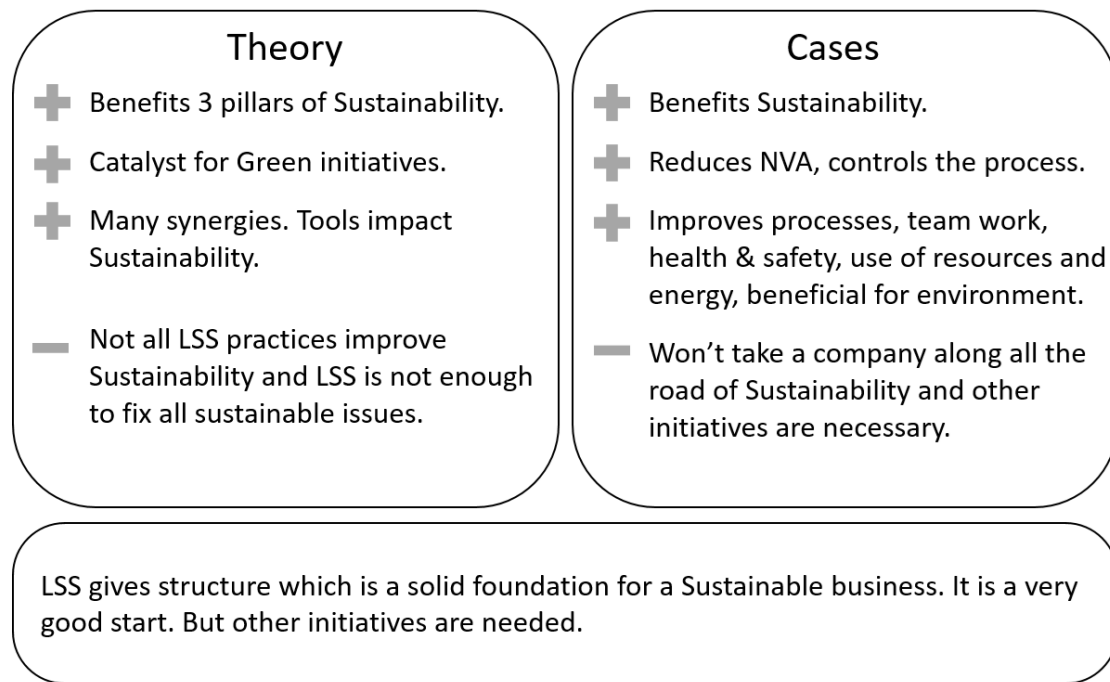


Figure 5.1. Summary of the first research question. Made by the author.

5.2.2 What are the limitations of Lean and Six Sigma on the improvement of Sustainability and how to overcome them?

The literature also recognizes some limitations of Lean and Six Sigma, the point made on the first research question, that they are not enough to fix all issues relating sustainability. The improvements brought by them will have an effect on the transformation process, the manufacturing of products. But their improvements mostly will have the boundaries of the factory. Lean and Six Sigma will have no impact on material selection, material extraction, product use and product recycle or disposal.

For such matters, companies need to add Green components (product and process redesign, disassembly, substitution, reduce, recycling, remanufacturing, consume internally, prolong use, returnable packaging, spread risks, new markets creation, waste segregation and alliances) to achieve better results (Sri Hartini, 2015).

The companies also note the same, Lean and Six Sigma can help achieve some goals but they lack a proactive approach to sustainability (promoting renewable sources, circular economies...). For Tetrapack, sustainability is more about the direction of the business, about their strategy, for the short, medium and long term (Fox, 2018). It's not only about fixing plant issues and having a more efficient use of resources. That's important, but an ethical development and direction of the business is key.

For example, (Valett, 2018) of Haldex explained how the design of their products affect the environmental footprint of their brakes during their use. So, having a sustainable mindset not only for the transformation process but for the raw material extraction, use of products and their disposal is as important. Lean and Six Sigma will have no impact on those areas. Therefore, a mindset to improve the complete life cycle of a product and not only the manufacturing part is necessary to be in an even better sustainable position.

Furthermore, companies agree that Six Sigma is a very useful tool for solving complex problems with unknown root causes, but it's a bad approach for the simple ones. Short projects with known root causes usually don't require heavy data analysis and statistical studies.

The literature reviewed doesn't make this distinction, and therefore focus only on the long complex projects. Those are very important, but the day to day issues that an organization faces (such fixing a leakage) can't be always confronted through a Six Sigma or a DMAIC solving approach. Neither new improvement initiatives or long projects with known root causes. Companies interviewed make this distinction and explain that there are specific solutions for them and other approaches more efficient. Sometimes, these simple problems result to be not that simple and then DMAIC can be very useful, but not as a use-for-all tool. So the use of Six Sigma and DMAIC steps should be applied only for the complex Sustainability projects with unknown root causes.

LSS is beneficial for sustainability, but alone is not enough to move a company to an excellence spot where the whole supply chain and the entire life cycle of their manufactured products is sustainable. Sustainability initiatives and principles need to be deployed along LSS to carry companies to their ambitions.

The following picture summarizes the main points of the analysis regarding this research question:

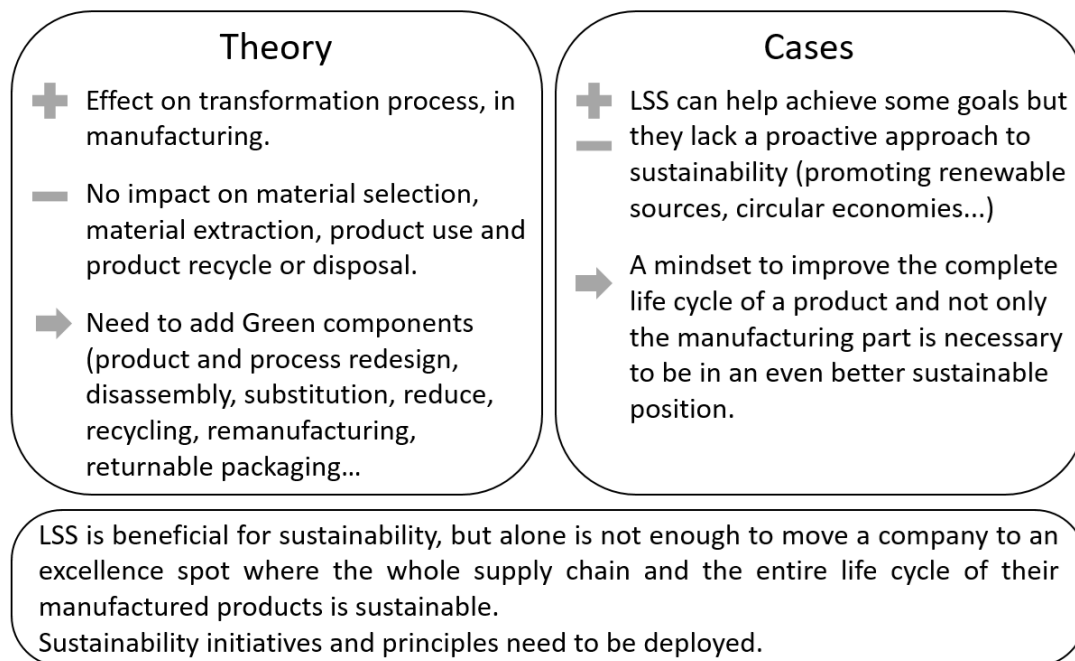


Figure 5.2. Summary of the second research question. Made by the author.

5.2.3 Is it necessary to add new tools to Lean and Six Sigma to address sustainability problems or opportunities?

The literature reviewed affirm that Sustainability and Green Engineering can't be seen as a toolbox but as a series of initiatives and principles with the use of a single tool: Life Cycle Assessment (Jose Garza-Reyes, 2016). The inclusion of these initiatives can add value since Lean and Six Sigma are not enough to fix all sustainable issues.

From the companies point of view, Life Cycle Assessment (LCA) is the key tool for sustainability assessment. They also developed and use an array of tools derived from LCA, those tools can help to make comparisons and promote improvements. Usually LCA drive to pick other tools. Some companies rename LCA, enhances it and customize it but fundamentally it's the same tool. For example, Höganäs uses a Sustainability Life Cycle Analysis, a LCA where all the dimensions are taken into consideration.

LCA or similar tools are the basic tools for sustainability. However, each company made the tools that they needed for their interests. Some are very industry specific but others can be generalized. As an example, Haldex uses an array of safety oriented tools (described in case III). Sustainable initiatives (such as recycling, renewable energy use...) and focus on sustainability KPIs are needed.

When talking about sustainability it is not that much about tools but about initiatives. It is about new ideas that could bring better sustainability performance inside and outside of the manufacturing process. It is about new metrics to measure; it is about new sustainable targets to improve. And at the end it is about having a sustainable direction of the business and strategies manifesting that.

The following picture summarizes the main points of the analysis regarding this research question:

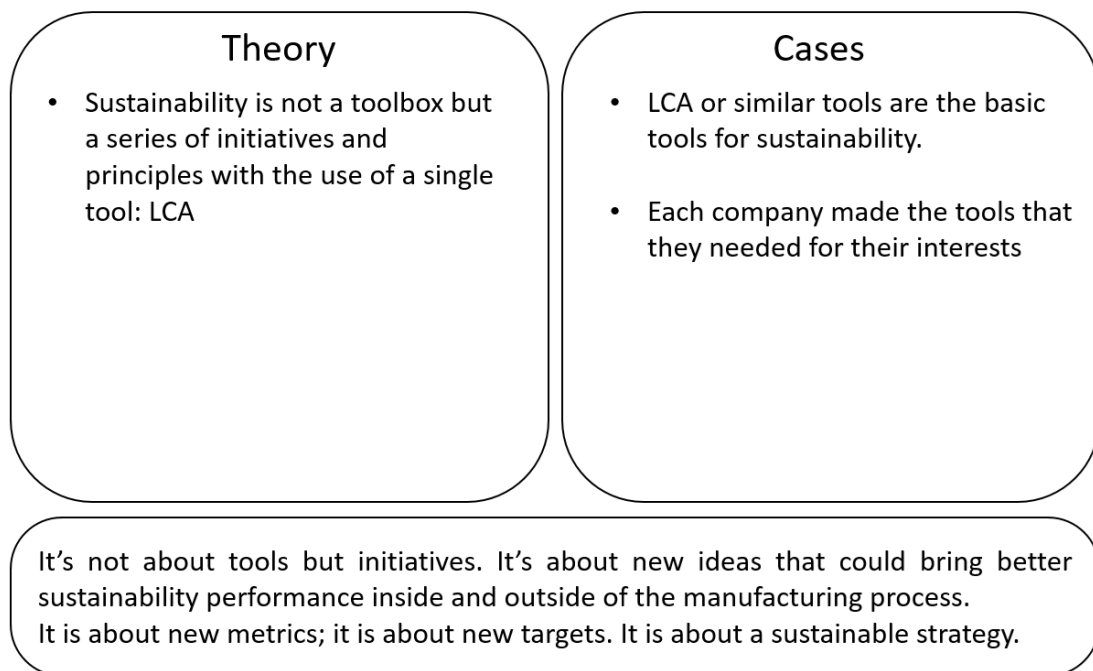


Figure 5.3. Summary of the third research question. Made by the author.

5.2.4 Which pillar of sustainability is affected the most with Lean and Six Sigma?

As is extended in the theory section, Lean and Six Sigma benefits the triple bottom line of Sustainability, mainly on the environment and economic aspect (Sri Hartini, 2015). This goes along with the opinion of the companies interviewed which is that it impacts the environmental, economic, and social (through health and safety) pillars of sustainability

(Fox, 2018). The pillars are interlinked and all improved with LSS. Improving social aspects for coworkers will turn into improvement of the other pillars (Bergman, 2018). But there is a small distinction, companies are very aware of the health and safety aspects of their coworkers. So they include health, safety and other social aspects of coworkers into the social pillar, which then benefits from Lean as well. The literature reviewed doesn't extent in those factors extensively.

In short, the deployment of Lean and Six Sigma into companies benefits the triple bottom line of sustainability. The pillars are interlinked and the improvements in one will have feedback on the others, feeding back their development.

The following picture summarizes the main points of the analysis regarding this research question:

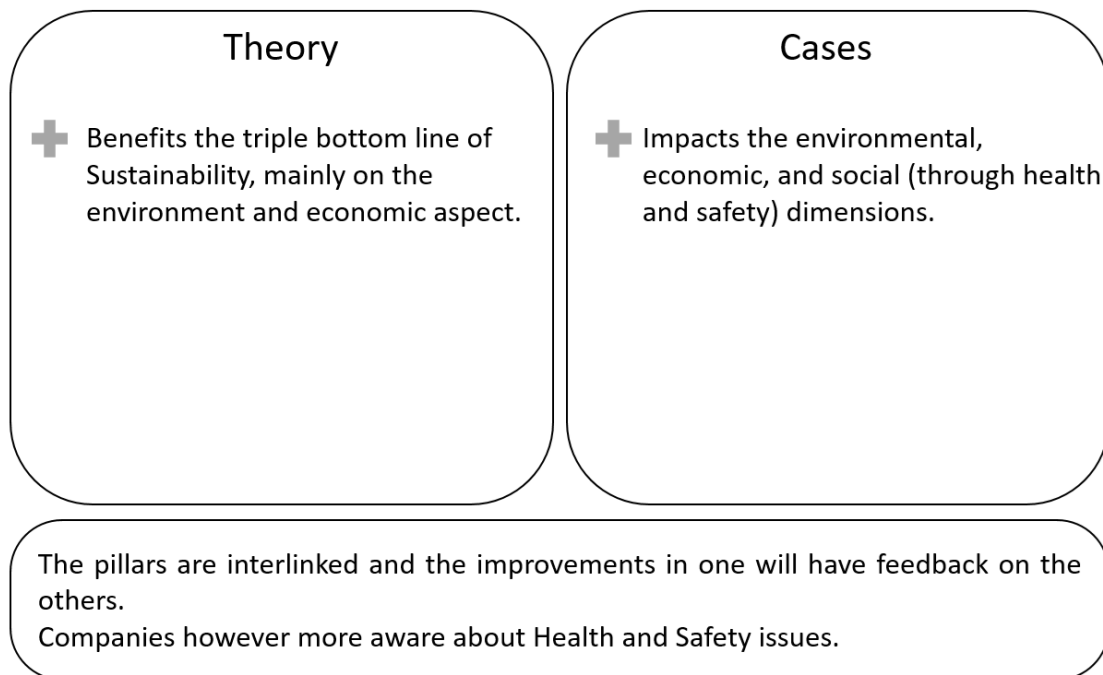


Figure 5.4. Summary of the fourth research question. Made by the author.

5.2.5 Summary of the analysis

The following table summarizes the 4 research questions:

Research questions	Theory	Empirical data	Conclusions
Problem definition: Sustainability is getting more importance for companies and LSS can help enhance their performance.	Need for improving sustainability performance. Integration of LSS + Sustainability could help.	Companies aim for reduce waste, increase safety, build ethical business and protect the environment.	Companies have an interest and intent in sustainability. Social aspects of safety and health key for companies.
1. How and why do Lean and Six Sigma improve the sustainability of a company?	Lean is a catalyst for Green ambitions. Many synergies. However Lean is not enough to fix all sustainability issues.	Improves use of resources and reduces waste. Good for safety, ethics, leadership. Not enough for sustainability excellence.	LSS gives structure which is a solid foundation for a sustainable business. But other initiatives are needed.
2. What are the limitations of Lean and Six Sigma on the improvement of Sustainability and how to overcome them?	LSS affects transformation process, not material extraction or product use. Need Green initiatives for better results.	LSS lack proactive approach for sustainability (Renewable sources, Circular economies...)	LSS doesn't affect entire product life. Sustainability initiatives are needed to move to an excellence spot.
3. Is it necessary to add new tools to Lean and Six Sigma to address sustainability problems or opportunities?	Yes. New initiatives and principles need to be add. Sustainability is not a toolbox, but many initiatives with a single tool: LCA Those can add value.	Necessary to add new tools for specific sustainability problems. LCA and similar tools are used. Sustainability initiatives are key.	LCA basic tool for sustainability. But other specific tools made by companies to fix specific issues. Need to focus on initiatives and sustainability KPI too.
4. Which pillar of sustainability is affected the most with LSS?	Lean benefits the triple bottom line of Sustainability, mainly the environment and economic aspect.	Benefits the environmental, economic, and social (through health and safety) dimensions.	The pillars are interlinked. The improvements in one will have feedback on the others.

Table 5.1. Summary of the problem definition and the 4 research questions from the literature and the empirical data.

5.2.6 Which improvement frameworks are used and why. How to combine the efforts of Lean, Six Sigma and Sustainability?

Literature focus on long complex projects, which are important for companies but not all of them are like that. Neither their sustainability initiatives. The literature argues that Six Sigma and the DMAIC methodology could be used as the framework where Lean and Green initiatives are implemented and sustained. The use of Lean and Green initiatives together have limitations that could be overcome through the use of Six Sigma. DMAIC could help to overcome these limitations providing a structured problem solving method (Jose Garza-Reyes, 2016). A framework for this integration was presented by (Cherrafi A. , Elfezazi,

Chiarini, Mokhlis, & Benhida, 2016) and is extended in the section 3.7, with its limitations and benefits.

Companies interviewed agree that Six Sigma and DMAIC could work as a framework for the three systems integration. However, that's not the framework which through Lean and Sustainability are deployed in those 4 companies analyzed. Rather, Six Sigma and DMAIC are a subset and are used for specific problems. Those problems are complex and with unknown root causes. For simple problems PDCA or similar methods are the right approaches. They think that DMAIC would be excessive and that it should be used only for the right problems (Fox, 2018) (Valett, 2018).

To combine Lean, Six Sigma and Sustainability, each company made its solution for the combination of these initiatives, as an example:

- Haldex framework is called Haldex Way. It uses the RADAR logic which selects the appropriate approach to use. That can be a Lean tool, a Six Sigma tool, a sustainability tool or other procedures.

The Radar logic is one way to integrate LSS and Sustainability, but there are other ways. DMAIC can be used, but it doesn't start and end with results (good for problem solving, not for results driving improvements). And not all problems are complex with unknown root causes. Having an integrated approach instead of a separate CSR, produces great results, creating synergies rather than conflicts (Valett, 2018).

- Höganäs developed their framework "More Höganäs", based on Lean principles with Six Sigma in pockets. Sustainability progress is anchored in their decision making, not on the side. LSS gives all the systems and mindsets that allows them to include any ambition. Such ambitions can be Sustainability ambitions, that need to be built in the organization, which will bring new KPI and areas to focus (Bergman, 2018).

The way in which LSS and Sustainability are deployed into an organization is key for its success. Literature promotes the benefits of having them as an integrated approach where DMAIC is the framework that structures the 3 systems. Some companies however have CSR separated from production continuous improvements programs such as LSS. Others integrated sustainability initiatives with LSS improvements, but used other frameworks instead of DMAIC to structure the integration such as The Haldex Way (with RADAR logic) or More Höganäs.

6 Proposition

In the following chapter a new framework is proposed for the integration of Lean, Six Sigma and Sustainability. First, the principles of sustainable production and services will be presented along with the areas where companies should focus their attention. These will be the foundations to the framework presented later.

6.1 Principles for sustainable production and services

In chapter 3 sustainability has been discussed along with some principles that could guide companies to improve in that area. However, there is a lack of structured principles that address the three dimensions of sustainability, with specific practices reflecting those principles and addressed to both large companies and small and medium enterprises (Alayón, Säfsten, & Johansson, 2017).

The principles that will be presented below for sustainable organizations are from the Lowell Center for Sustainable Production and borrowed from (Veleva & Ellenbecker, 2001). In order to understand how they are put into use by companies, a research was made by (Alayón, Säfsten, & Johansson, 2017) which reflect the specific practices deployed by companies to apply these principles, which are presented in the section 6.4. That study also empirically supports that these principles reflect the efforts of the companies for improving in the three dimensions of sustainability (Alayón, Säfsten, & Johansson, 2017).

These principles address the economic, environmental and social dimensions of sustainability; they are applicable for large, medium and small enterprises; and furthermore they take into consideration the whole product life cycle (Alayón, Säfsten, & Johansson, 2017).

Sustainable production is defined as:

“The creation of goods and services using processes and systems that are non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for employees, communities and consumers; and socially and creatively rewarding for all working people.” (Veleva & Ellenbecker, 2001)

The principles of sustainable production (Veleva & Ellenbecker, 2001):

1. *Products and packaging are designed to be safe and ecologically sound through their life cycles; services are designed to be safe and ecologically sound.*
2. *Wastes and ecologically incompatible by-products are reduced, eliminated or recycled.*
3. *Energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends.*
4. *Chemical substances or physical agents and conditions that present hazards to human health or the environment are eliminated.*

5. *Work places and technologies are designed to minimize or eliminate chemical, ergonomic and physical hazards.*
6. *Management is committed to an open, participatory process of continuous evaluation and improvement, focused on the long-term economic performance of the firm.*
7. *Work is organized to conserve and enhance the efficiency and creativity of employees.*
8. *The security and wellbeing of all employees is a priority, as is the continuous development of their talents and capacities.*
9. *The communities around workplaces are respected and enhanced economically, socially, culturally and physically; equity and fairness are promoted.*

Although these principles are named for a sustainable production, they can be used as well for the service industry as is indicated in the definition. To avoid narrowing the term, in this thesis the principles will be renamed as principles for sustainable production and services.

Since these principles focus on the three sustainability dimensions and consider the complete life cycle of products, they can be the foundations for a framework for Lean Six Sigma Sustainability integration presented in the following sections.

6.2 Areas to focus on for sustainable production and services

For an integrated framework of Lean, Six Sigma and Sustainability to work, a company must have a clear knowledge to where the efforts should be directed. It needs unambiguous sustainability areas to focus on, to set up metrics, establish targets, and to drive improvements to their accomplishment. These core areas should represent the three dimensions of sustainability and should make a company direct its attention to their fulfillment. This way, a company will know where to put their efforts to improve in the economic, environmental and social dimensions. These core areas will sustain the integrated framework.

The fields presented in the section 4.5 of Chapter 4 for that sustainability assessment framework can work as a way to decompose the dimensions into main areas and cover the whole scope of sustainability. Therefore, each dimension has 5 fields or areas to focus on (Chardine-Baumann & Botta-Genoulaz, 2014). Those are used to develop a new framework of core areas. In the Figure 6.1, the core areas from which the framework is developed are shown.

For a company, in order to be sustainable, it should be successful in the three dimensions, so the areas that cover those dimensions should be continuously improved.

As said in the Haldex case (Valett, 2018), to balance the three sustainability pillars, the organization priorities need to be in place. The sustainability areas of this framework can help in determining priorities.



Figure 6.1. Representation by the author of the three sustainability dimensions and the areas that represent, proposed by (Chardine-Baumann & Botta-Genoulaz, 2014)

From the areas represented in the Figure 6.1, a company shall select the ones that are key for their business. They shall recognize that their business is sustained thanks to being excellent in those areas. Nevertheless, failure to perform correctly in any of all these areas can be critical for a company's sustainability and survival. Consequently, not giving enough attention to the other areas can be disastrous.

This behaves in a similar way that Order Winners and Order Qualifiers do in the marketplace (Hill & Hill, 2009). A company must excel in what is key for their industry to win a position in the market, but it cannot forget about the other areas which qualify the company as a proper sustainable company.

Furthermore, these key areas will help to generate new values that will guide the company and help them in decision making. They can be the base from which new values can raise. If an organization believes that one or several areas are key for their business, values can be built from them. For example, as exposed with the Haldex Case (Case III) they have their top priorities (safety, quality and environment) to prioritize the projects that they promote. They recognize other important values such as cost, delivery and profit as well (Valett,

2018). All these values are or can be derived from the ones presented here or as a combination of some of them, making a company go in the right direction.

The areas are the main factors of the sustainability dimensions. But, in order to not be very restrictive in this framework, the several sub-fields that were introduced in the section 4.5 of Chapter 4 for each field should be seen as a guide. They could be used as well, but a company could make their own sub-fields if necessary.

6.3 Framework for Lean Six Sigma Sustainability integration

When using an integrated approach, the questions of when to use Lean, when to use Six Sigma, which tools are Lean, which are Six Sigma; those questions are unproductive. The key is to know how to use the integrated framework (Snee, 2010). The same can be said when integrating those systems with Sustainability altogether.

Instead of separating the three systems and knowing when to use each one, it is a better approach to make an integrated system that could manage projects, since that is the way how improvements are made. Therefore, the system should manage the project selection and their management. It should identify the right approach, the right team and the right tools to use. (Snee, 2010)

Improvements and the achievement of goals can come from two perspectives, from improving processes or from solving processes problems. Therefore, projects can arise to meet business targets or to fix performance gaps (Snee, 2010)

For this thesis, a similar logic as the Haldex' RADAR logic will be used to produce a framework for results driven improvements (Haldex Way Introduction, 2018), that do not focus only on solving problems but on improving processes to meet business targets as well. Therefore, the integrated framework of Lean, Six Sigma and Sustainability for results driven improvements presented here starts with the result that wants to be achieved, which comes directly from the sustainability areas presented in the last section. This step, "Result wanted", prioritize the projects that are related to the business targets and performance gaps through the 15 sustainability areas, prioritizing the projects that most likely affect the key areas, but not forgetting the improvement in all others as well.

The following figure represents the framework for the integration of Lean, Six Sigma and Sustainability. It is based in a framework for Lean Six Sigma integration through the use of value stream mapping by (Snee, 2010), starting and ending with results (Haldex Way Introduction, 2018), with the addition of the sustainability system. That is done with the addition of the sustainability areas from the dimensions fields of (Chardine-Baumann & Botta-Genoulaz, 2014), the Sustainable production principles of (Veleva & Ellenbecker, 2001), the addition of benchmarking of Sustainability practices done by companies of (Alayón, Säfsten, & Johansson, 2017) and the Lean Six Sigma Process Improvement Project form by (Wedgwood, 2016):

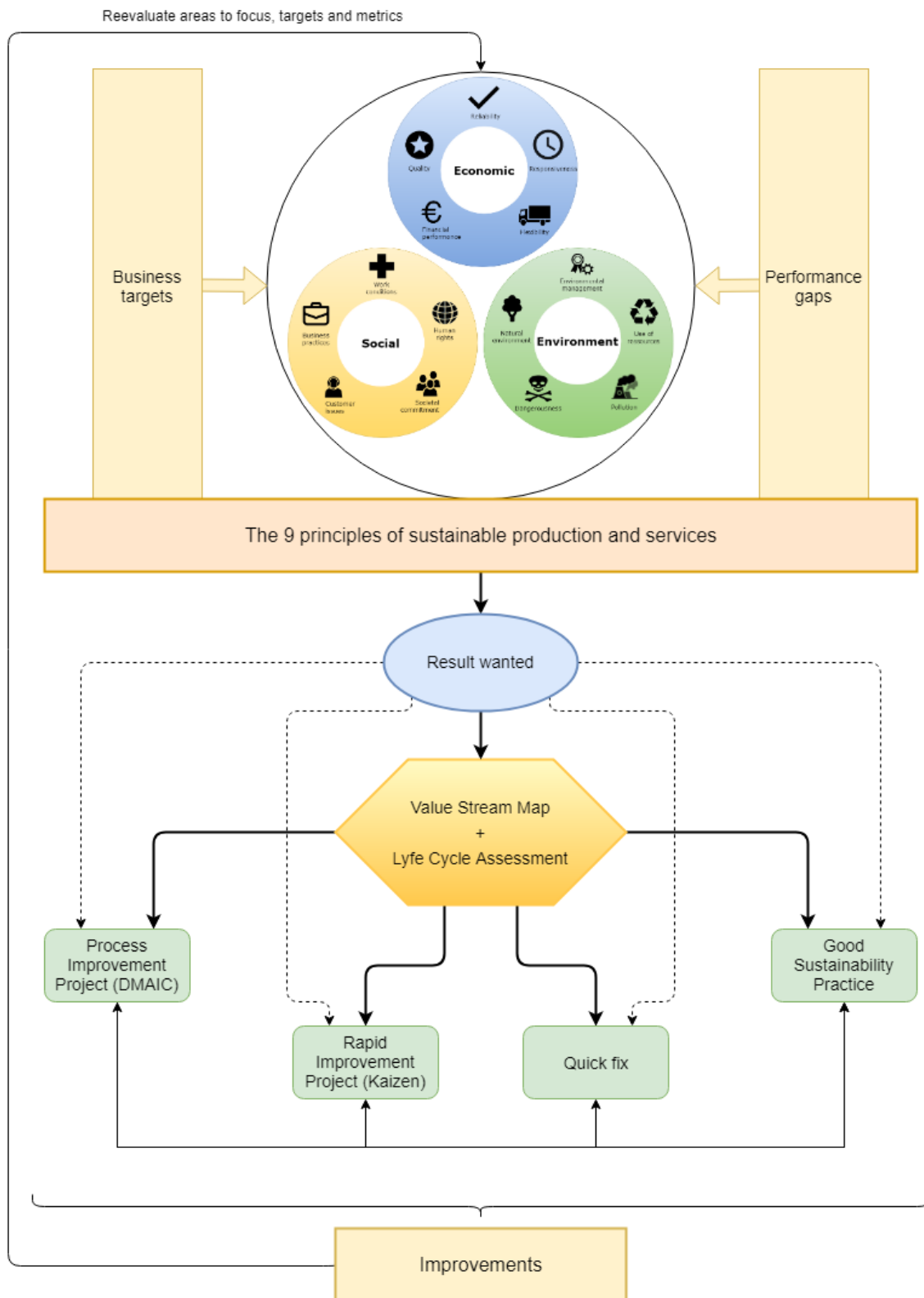


Figure 6.2. Framework for the integration of Lean, Six Sigma and Sustainability. Made by the author.

The sustainability areas presented in the last section are the inputs for the “Result wanted” step, providing the areas (economic, environmental and social) where the business wants to improve (business targets) and the areas where problems happen (performance gaps).

The areas that are key for the business should get metrics and the current performance be measured if that hasn't been done before. Those areas should get targets for improvement in the short, medium and long time frame. Ideally, with time, all the sustainability areas should be measured and have strategic goals to achieve. The 4 steps for determining sustainability metrics by (Reich-Weiser, et al., 2013) of the section 4.5 of Chapter 4 can be used here.

The principles of sustainable production presented before can guide the direction of improvements, being the foundation for the whole framework.

Then, the decision of which area should be improved at that moment should be made. Improvements and projects should be prioritized according to the benefits, risks, resources needed, time needed...

Then, the next step is to select the appropriate "Approach" (Valett, 2018) to improve in those areas. Therefore, depending on certain parameters, the project type selected can be between a Six Sigma project (DMAIC), a Rapid improvement project (Kaizen), a Quick fix or a Sustainability practice. As the company progresses, it could include other types of projects or approaches to bring improvements, for example, Sandvik has their own project methodology for the largest projects with high investments (Kock, 2018). With time and learning, all employees should be able to implement and follow up improvements in their work scope. That way more improvements can be made than with just Kaizen events (Valett, 2018). Usually those will be quick fixes that do not require huge time investments.

If there is a key area or areas that have a clear roadmap for their improvement, one approach or multiple of them can be selected. That is represented by the dashed lines connecting the "Result wanted" step with the four types of project improvements forms.

Otherwise, if the approach to be used is not clear, the step of "Value Stream Mapping and Life Cycle Assessment" can be the option to discover flaws on the processes, different types of waste and issues that could generate new projects to improve in key areas. VSM is a Lean tool for finding the activities that bring value to the end customer and the ones that are a waste (Wedgwood, 2016). Further information about LCA in the appendix (A2).

Depending on the nature of the flaws and waste detected with those tools, one or several project types could be selected.

The four main types of initiatives that this framework has and the main signs for their selection are:

Process Improvement Projects (DMAIC): These are the largest projects, usually taking from 3 to 6 months, but sometimes quicker. It uses a DMAIC process for making the improvements (Snee, 2010). This project uses an integrated Lean Six Sigma approach, with a DMAIC structure. Depending on the problem, Lean or Six Sigma related tools (or any other type of tool) will be the most used (Wedgwood, 2016).

This type of project should be selected if the problem is complex and the root cause is unknown (Valett, 2018) with an unknown solution (Snee, 2010). Furthermore, there is the possibility for data analysis and statistics to understand the issue and probably they will be needed (Wedgwood, 2016).

Rapid Improvement Project (Kaizen): Usually done in less than a month (Snee, 2010). Completed through three steps: Pre-event (preparations), Event (the improvement) and Post-event (controlling the change). This type of project should be selected if the problem is very specific in scope and data analysis is not necessary. These projects do not focus in variability related improvements, such as defects, rather they focus on improving flow or reducing complexity (Wedgwood, 2016).

Quick fix: These type of projects can be done in a very short period of time and require little resources (Snee, 2010). Usually, a PDCA solving method will be enough. Sometimes even simply doing the right thing will be enough. Employees should be trained to solve the small problems by themselves, so small problems could be fixed as soon as possible. This type of small project should be selected for simple issues from which solutions usually are easy to find and require very little investments.

Good Sustainability Practice: These are the initiatives required for having a sustainable business, that could be self-developed or obtained through benchmark. This type of initiatives should be selected if there is a strong need for improvements in the environmental or social dimensions of sustainability. Also, if the improvements in efficiency brought by Lean Six Sigma are simply not enough to meet the results wanted in the sustainability areas that the organization wants to improve. Further information in the following section of this chapter.

Each type of the four approaches can derive into an another type. For example, a rapid improvement project can discover an issue with an unknown root cause that could generate a new six sigma project if it is in line with the current priorities of the company. Or a Six Sigma project can generate several quick fix solutions, or it can show a need for a sustainability practice implementation. In the framework schema, this is represented by the arrows connecting all the projects from the bottom.

Once the improvements are made, the framework cycle starts again, going back to the start. The sustainability areas are reevaluated, new areas might get selected for improvement, getting new targets for improvements and new metrics. Areas that are already on a good spot should continue to be controlled and could get new targets from new business goals, or be reevaluated to solve new performance gaps.

6.4 Good Sustainability practices

Sustainability cannot be achieved only through the improvement of processes. It cannot be achieved only through the use of Six Sigma and Lean improvements. That is one part, but other initiatives and practices need to be in place, they are needed to address the complete lifecycle of products along with environmental and social concerns.

Similarly as the original concept of Good Manufacturing Practices (GMP), Good Sustainability Practices (GSP) can be a new concept and an answer to improve in sustainability. Those practices could be developed within the company or be generated through process benchmarking, where a company focuses on another firm's processes and initiatives and make a comparison, to gather ideas for improvements. They can study other

operations, technologies and strategies, to identify the best practices from one or more firms (Foster, 2013). In this specific case, the goal would be to imitate the best practices that enhance sustainability and gather ideas to improve in the three dimensions.

There are seven purposes of benchmarking, depending on the involvement in those activities (Figure 6.3). From learning internally to being a best-in-world company, as the company is more mature, achieving higher levels of quality. (Foster, 2013)

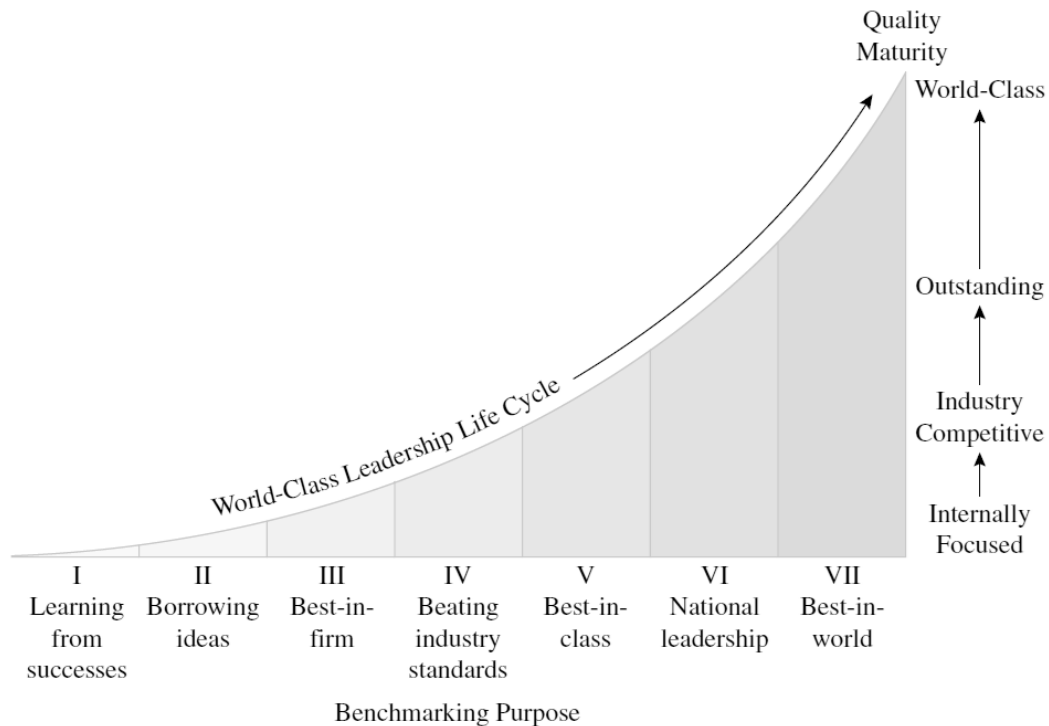


Figure 6.3. Benchmarking purpose and Quality maturity, by (Foster, 2013)

Therefore, starting with implementing Good Sustainability Practices, a firm could continue the path, benchmarking other companies, sharing improvements and developing new solutions. So in the future, aiming to be a Best-in-world company regarding sustainability.

In this section, several sustainable practices from (Alayón, Säfsten, & Johansson, 2017) related to each of the sustainable production principles are shown. As said before, these practices are needed because the scope of Lean and Six Sigma does not go that far. They can be seen as a starting point of “Best Practices” for companies that want to improve in the areas of the principles and in sustainability in general.

Generally speaking, the Lean Six Sigma methodology is meant to improve processes, their efficiency and variability, to prevent what is a waste and promote what is working well (Wedgwood, 2016); while these Good Sustainability Practices generally are meant to improve the management of inputs and outputs of those processes, their environmental impact, and the social dimension surrounding the processes.

Usually, these improvements address issues from outside the manufacturing facility boundaries. Therefore, these practices and initiatives mostly focus on the inputs (renewable raw materials and energy) and outputs (waste reductions, recycling, disposal) of products. Furthermore, they tackle topics such as sustainable product use (environmentally and

socially safe), eco-design and circular economies (further information about this concept in the appendix A1).

These practices should be deployed gradually into the organization in which Lean and Six Sigma improvements are taking place.

The following examples of Good Sustainability Practices can be used at the start as a benchmark to integrate the sustainable production principles (Alayón, Säfsten, & Johansson, 2017).

Principles	Sustainability practices
<p><i>1. Products and packaging are designed to be safe and ecologically sound through their life cycles; services are designed to be safe and ecologically sound.</i></p>	<ul style="list-style-type: none"> -Material usage according to legislation in processes and products -Hazardous substances substitution or elimination in products and processes -Considerations regarding disassembly, reuse and recycling during product design -Eco-design assisted by customers -Recyclability and reuse of incoming materials packaging -Design of energy efficient products -Packaging minimization -Design for the environment (DfE) -Extra services to reduce fuel consumption and emissions during product use
<p><i>2. Wastes and ecologically incompatible by-products are reduced, eliminated or recycled.</i></p>	<ul style="list-style-type: none"> -Component and product design optimization -Substitution of hazardous materials -Redesigning of components to reduce solid waste -Non-conforming products reduction -Reuse and recycle of direct and indirect waste -Employee training on sorting and waste reduction -Process water and emulsions close loop systems -External and on-site recycling -Biological process for processing waste waters -Donation of waste and by-products to other industries or institutions -Operational Performance Indicators -ISO 14001
<p><i>3. Energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends.</i></p>	<ul style="list-style-type: none"> -Employee training on energy savings -Mapping energy consumption for identifying energy savings -Renewable energy -Bio-oil based heating centrals -Heat recovery and recycle using heat exchangers -Ventilation systems upgrade -Equipment upgrades for improving efficiency -Preventive equipment maintenance -Energy-efficient building automation systems -Energy audits -Prevention and correction of leakages in air compressed systems -Energy metering -High efficient lamps and motion sensors -Material recycle and reuse -Material substitution for better efficiency -Material usage optimization -Process optimization -Monitor fresh water use -Recirculating water for cooling -Close loop water systems -Storm water usage for cooling processes -Operational Performance Indicators -ISO 14001

<p>4. Chemical substances or physical agents and conditions that present hazards to human health or the environment are eliminated.</p>	<ul style="list-style-type: none"> -Hazardous substances substitution or elimination in processes -Tracking chemicals in processes and products -Materials usage according to legislation in processes and products -Training on hazardous substances -Solvents substitution -Air filtration and cleaning systems -Heavy metals filtration -Closed-loop process water systems -Biological based wastewater treatment -Oil leakage prevention -Standard safety procedures -Operational Performance Indicators -Considerations of Carbon footprint associated with design of product (Valett, 2018)
<p>5. Work places and technologies are designed to minimize or eliminate chemical, ergonomic and physical hazards.</p>	<ul style="list-style-type: none"> -Robotic automation in hazardous activities -Internal safety inspections -External work environment audits -Mechanical lifting aids -Employees rotation among work stations -Process modifications to reduce noise and vibrations -Employee training on hazardous risks -Key performance indicators -Global accident communications (Valett, 2018) -Standardized work, to avoid safety risks (Valett, 2018) -The safety cross (Valett, 2018) -Quick safety risk assessments (Valett, 2018) -Safety risks observations (Valett, 2018) -Safety audits (Valett, 2018)
<p>6. Management is committed to an open, participatory process of continuous evaluation and improvement, focused on the long-term economic performance of the firm.</p>	<ul style="list-style-type: none"> -Strategic sustainability and functional goals display throughout the plant -Technology investments prioritization considering environment, safety, quality and economic aspects -Communicating employees about strategic plans, targets and results -ISO 9001 for managerial continuously evaluation -Financial key performance indicators
<p>7. Work is organized to conserve and enhance the efficiency and creativity of employees.</p>	<ul style="list-style-type: none"> -Work standardization -Work accountability -Employee improvement suggestions goals -Rewards for applicable improvement suggestions from employees -Team work -Improvement meetings -Key performance indicators
<p>8. The security and wellbeing of all employees is a priority, as is the continuous development of their talents and capacities.</p>	<ul style="list-style-type: none"> -Health and safety management system -Training plans -Career development programs -Employee rotation -Scholarships -Subsides for health and wellbeing purposes -Job satisfaction assessment -Performance appraisal -ISO 9001 supporting training and competence -Key performance indicators
<p>9. The communities around workplaces are respected and enhanced economically, socially, culturally and physically; equity and fairness are promoted.</p>	<ul style="list-style-type: none"> -Job opportunities for locals -Collaborations with educational institutions -Periodical meetings with local authorities -Volunteering work within local communities -Sponsoring local associations

Table 6.1. The Sustainability principles and the practices associated with them. Adapted table from (Alayón, Säfsten, & Johansson, 2017) with the addition of more practices obtained from the Case III (Haldex), which are referenced in the table.

6.5 Example of application

As an example to show how the framework can be used, assume a company that has a business goal to reduce their energy consumption. Therefore, it needs improvements in the area of “Use of resources”, concretely in energy consumption.

The “result wanted” could be to reduce energy consumption a 10%. A VSM and LCA analysis could discover wasteful areas where improvements could be done. Therefore, depending on the complexity of the improvements, several different projects would be done. From Quick fixes such as warnings to turn the machinery off when is not being used, to longer Process Improvement Projects where the energy consumption of all machines could be studied. For example, lowering machine capacity stabilizing the production through the day, producing during valley electricity periods, avoiding peak periods, optimizing processes...

7 Reflections

The last chapter explains the process for the implementation of the integrated framework. Then, the academic contribution of this master thesis is reviewed. Finally, reflections regarding future research directions for these topics are discussed.

7.1 Implementation

Assuming that an organization wants to implement all three systems, Lean, Six Sigma and Sustainability, my recommendation is to implement them gradually.

Change doesn't come in one day or one big effort during a short period of time, usually it comes with a series of continuous small improvements. Therefore, in order to implement the integrated system presented, it is better to improve a few key areas of the sustainability framework than to try to improve all the 15 areas at the same time in a wrong way.

Depending on the size of the organization (from small to big enterprises) some projects are not easy to implement. For small companies six sigma projects in its full extension probably are not an option since they usually don't have the resources and knowledge to perform long and complex projects. Furthermore, those improvements usually need long periods of time to pay off.

For this reason, assuming that a company is performing decent and doesn't has a forced agenda to keep it up with competition or regulations, it is better to start with quick fix projects and rapid improvement projects. Those will have a high return of investment giving many improvements in a short period of time. This will give momentum to the company, which will boost ambitions for further improvements. Depending on the current situation of the company, represented by their business goals and performance gaps, some sustainability initiatives might be useful if there is enough motivation and resources to improve in environmental and social areas. And finally, the most complex and largest projects could be realized.

In case that there are flaws on one or all the sustainability dimensions, some improvements might be mandatory for the survival of the company. Those could occur because of government regulations or a fierce competition, which would force a company to improve in certain areas. Those gaps should be addressed asap and therefore all the attention should be put there with the effort needed, either quick fixes, Rapid improvements, DMAIC projects or GSP. For example, this would be the case if the air pollution exceeds regulation levels and must be addressed.

Lean gives the appropriate mindset and tools to make an organization work on a structured and systematic way, and at the beginning, coming from a disorganized way of working, it will have huge impact (Fox, 2018). Therefore, Lean thinking and its philosophy should be the first system to be implemented. A Lean Six Sigma integrated approach can be an option as well, depending on the motivation of the company. This way, both systems and their tools

will be completely mixed and used when necessary. If not, classic Six Sigma would be the next system to implement to solve some specific more complex projects.

Meanwhile, Sustainability should be implemented gradually from the beginning, promoting new strategic goals, KPIs and new ambitions. Because, when Lean Six Sigma start to structure the way of working, *“If you have your systems in place and ways of working in place, then you can drop almost any ambition”* (Bergman, 2018). If the organization take into consideration the 15 sustainability areas of the framework and has the ambition to improve them gradually, the sustainability dimension will be already in place. Simultaneously, sustainable practices should be implemented progressively as well, deploying first the improvements that will pay off quickly and with time addressing bigger projects.

If one of those systems is already in place, the transition to the integration system should be easier. If Lean Six Sigma is already implemented, integrating the 15 sustainability areas into the organization and using the already in place Lean Six Sigma systems to improve them, while deploying gradually sustainable practices should be the roadmap.

7.2 Academic contribution

During the realization of this thesis the four research questions have been answered. An analysis of the up-to-date relevant literature of related topics was used along with the study of four company cases to back up the conclusions to those questions.

Furthermore, a framework for Lean Six Sigma Sustainability integration has been proposed with some indications for its deployment and use. With all this it is valuable to examine the gaps for further research proposed by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016) to examine in what extent this thesis has contributed.

The first gap was the lack of performance measurement systems to measure Lean, Six Sigma and Sustainability from the economic, environmental and social dimensions (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016). In this research, a system to measure the three dimensions has been used, derived from (Chardine-Baumann & Botta-Genoulaz, 2014), which is presented in the section 4.5 of Chapter 4, which forms the base for the 15 areas to focus in the proposed framework. Furthermore, the steps to define sustainability metrics of (Reich-Weiser, et al., 2013) could be used too. Finally, Life Cycle Assessment tools to assess the environmental dimension and Life Cycle Sustainability Assessment to assess the three dimensions can be an option to promote effective metrics. However, each industry will have their own types of metrics and is impossible to give specific metrics to tackle. So, at some extend this gap has been clarified.

The second gap was the need for a generic framework for the integration, valid for different industries. This gap has been solved with the framework presented in the Chapter 6. Moreover, that framework can be molded to focus on the areas more important for a company, being able to fit for different types of organizations. Furthermore, it can be customized adding new project solving methodologies and tools. It does not use only one

framework (DMAIC, Kaizen, PDCA...) instead it selects the right one for the right project. Therefore, this gap has been solved.

The third gap was taking into consideration SME with limited resources (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016). The focus as well on SME of the sustainable production principles presented can help to solve this gap. Many practices that reflect those principles can be used as well in small companies. Furthermore, the gradual implementation of the integrated system can make easier the transition process for SMEs.

The fourth gap was the lack of the integration for the service industry (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016). The 15 sustainability areas of the framework could be used as well for service industry. Lean and Six Sigma will bring benefits, and with the right sustainability ambitions, the areas will be improved. The foundation of the framework are the principles for sustainable production and services, which can be applied to service industry as well. Generally speaking, some areas such as Pollution, Dangerousness or Use of resources will get less attention, but other social related areas will get more attention. Nevertheless, all areas should be considered.

The fifth gap was the need to include more the social dimension in the framework (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016). This is fully achieved with the addition of the social areas, and the sustainable practices that tackle them. The companies interviewed had in great consideration health and safety issues and that has been explained along the thesis. Furthermore, the tools from Haldex (Valett, 2018) added to the ones already in sustainable practices by (Alayón, Säfsten, & Johansson, 2017) address health and safety issues.

Finally, another gap was the need for suggestions to implement these systems as an integrated one (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016). This has been evaluated though the section 7.1 of this chapter, giving a gradual implementation solution.

Currently, there are ongoing research projects in a similar area. For example, (Cherrafi A. , et al., 2017) presented a framework for the integration and implementation of Green, Lean and Six Sigma with the goal to improve the sustainability performance. It presents a methodological framework that guides companies through five stages and sixteen process steps to implement the three systems.

The five stages are:

- 0: Readiness for GL2S initiative.
- 1: Conceptualization stage.
- 2: Implementation design stage.
- 3: Implementation and evaluation stage.
- 4: Share knowledge and develop a culture of continuous improvement for sustainability.

This framework focusses its attention on the specific steps for a successful implementation of a Green Lean Six Sigma integration on a factory level. It allows to achieve a higher sustainability performance through an improvement of resources consumption, a decrease of environmental impact and an improvement of employee commitment. It has potential to expand it to multi-factories and a supply chain level in further research.

On the other hand, the framework presented in this master thesis focus its attention in promoting sustainability areas where an organization should focus to improve, and different initiatives to achieve that. Furthermore, it promotes Good Sustainability Practices, align with the 9 principles, which support the Lean Six Sigma improvements. With enough commitment and knowledge through benchmark, it could benefit the manufacturing processes at a factory level, the entire product life cycle and supply chain, the organization environment and its social surroundings. Instead of a framework with specific steps, it can be seen as a guide with general principles to bring awareness to the key areas and give directions towards a more sustainable organization.

7.3 Further research

This thesis focused mainly in the integration of Lean, Six Sigma and Sustainability in the facility scope. However, due to made delimitations, some other research topics couldn't be studied enough.

The integrated framework needs to be tested in a real company to see its applicability and flaws. So further research and possible changes could be included. Even better would be its test in different types of organizations and industries.

There is a need to research further the relationships of Lean, Six Sigma and Sustainability and the supply chain, the applicability of the proposed integrated framework for the whole supply chain. This gap was identified by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016).

Further research on relationships between other quality management systems and concepts and the ones presented here could be done.

As stated by (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016), there is a need to study the implementation of Lean, Six Sigma and Sustainability in developing countries. Further research has to be done to address the sustainability implications to outsource or not in those cases.

The relationship between a company operations strategy and their marketing strategy was studied by (Hill & Hill, 2009). Further research of how Sustainability and its inclusion on a company, with new goals and ambitions, could affect those two strategies could be worth the study.

Many other sustainability practices could be added to the ones researched by (Alayón, Säfsten, & Johansson, 2017) and the few more added in this thesis. For example, the transition from product economies to services economies that could reduce use of resources, being related to the principle 3. With time and new technologies, new opportunities could raise for new practices and improvements.

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Appendix

A1. Closed-Loop Supply Chains:

A Closed-Loop Supply chain functions as a backwards supply chain, with several operations for retaking the products in order to reuse them, reassemble them or simply recycle their material. It is a system to maximize the recovery of value over the entire lifecycle of a product. It should be dynamic, prepared to retake different volumes and types of products, which will change with the market behavior, so the system should be continuously changing as well. This initiative may give a company many benefits, not only environmental, but a higher profit and the control over the entire lifecycle of their products as well. So it can be an appropriate way to decrease the company's environmental impact while improving profits. (Abbey & Guide Jr., 2017)

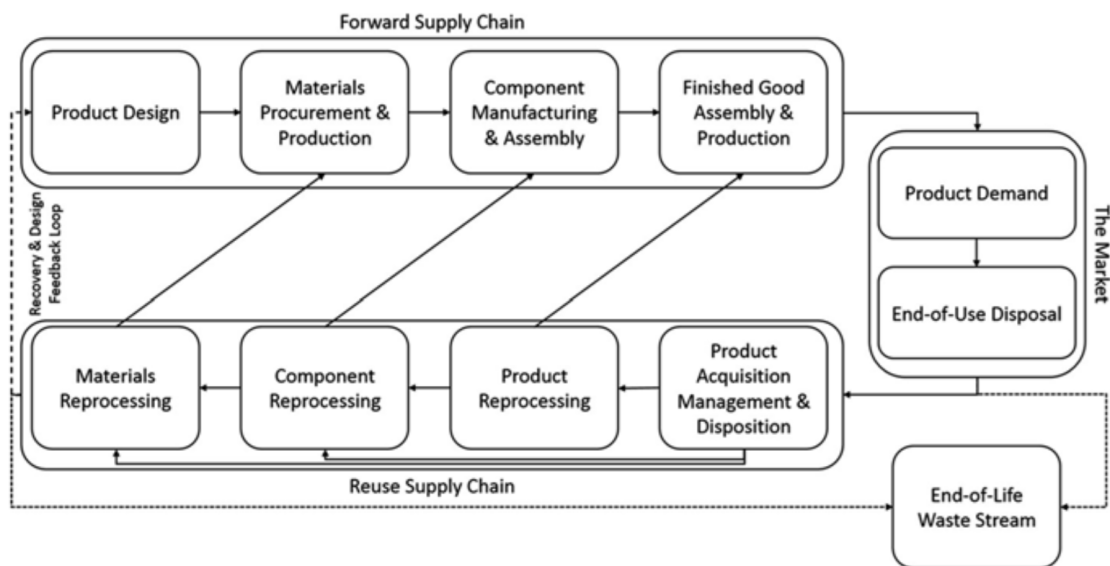


Figure A1.1. Closed-loop supply chain structure. (Abbey & Guide Jr., 2017)

A Closed –loop supply chain works as two supply chains, one forward to supply the manufactured products and one backwards to recover the damaged or not wanted products from the customers, figure A1.1. The main goal is to get as much value from a product as possible. For that matter, there are different ways to get the value back. Product and component reprocessing (replacing broken parts and repairing other defects) are the environmentally preferable options, since are less energy intensive than the materials recycling. At the end, there is always some quantity of waste that cannot be recycled and is used to generate heat to recover its energy or simply ends on a landfill. (Abbey & Guide Jr., 2017)

One obstacle of this initiative is the cannibalization of new products with the low price remanufactured products. This issue must be solved from a total profitability perspective and considering the depreciation of the products with time. Companies with high product depreciation such as technology must be very quick to recover their products and put them again on the market. (Abbey & Guide Jr., 2017)

The following picture represents four possible strategies for closed-loop supply chains depending on the design of products and the core competency of the firm. (Abbey & Guide Jr., 2017)

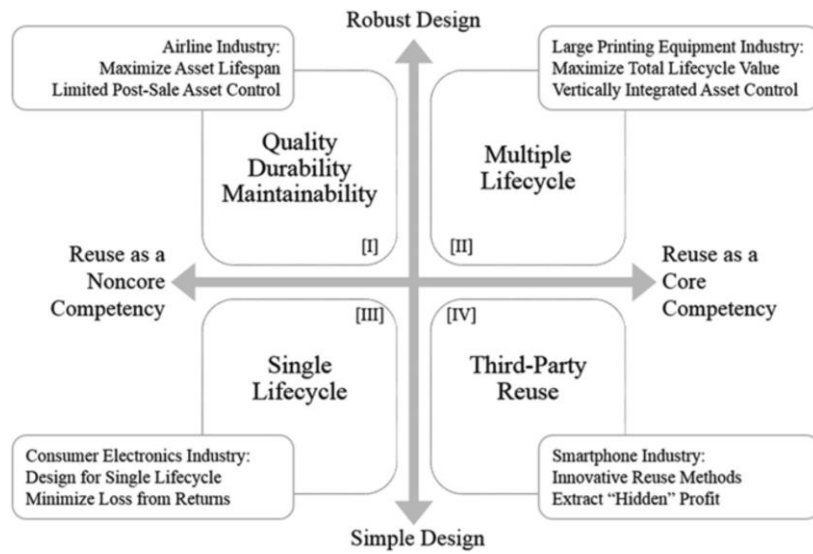


Figure A1.2. Four strategies for Closed-loop supply chains depending on Design and core competence. (Abbey & Guide Jr., 2017)

A2. Life Cycle Assessment (LCA):

LCA is a method for studying the environmental potential impacts of a product through its life cycle, from raw material, manufacturing, product use to disposal. It assesses only the environmental dimension of sustainability. It makes an inventory of inputs and outputs of a system to manufacture the assessed product, a product system. And then evaluates the impacts of those inputs and outputs and to interpret the results. (ISO International Standard 14040, 1997)

LCA can help in finding opportunities to improve environmentally on a product life cycle, can help in decision making, planning, product design, can help in selecting appropriate environmental metrics and can help with the marketing of the product promoting its eco-friendly characteristics. (ISO International Standard 14040, 1997)

The general phases of a LCA are the following (Guinée & Heijungs, 2017):

- Goal and scope definition.
- Inventory analysis.
- Impact assessment.
- Interpretation.

The general framework of LCA can be seen in the following figure, the phases are very iterative, so it is possible to go back and forth within the steps.

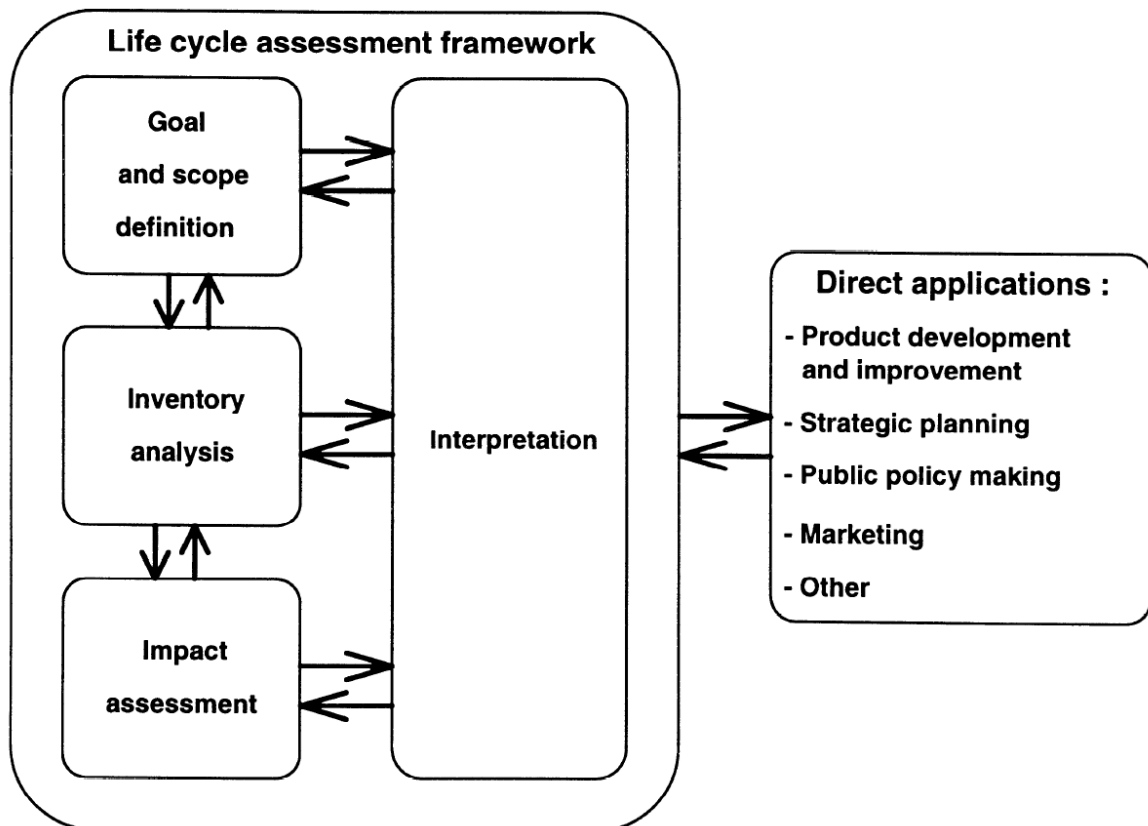


Figure A2.1. Life cycle assessment framework. (ISO International Standard 14040, 1997)

Goal and scope definition:

The first step of a LCA aims to plan the study as precisely as possible, defining its application, the reasons of the study, the audience aimed and if it will be disclosed to the public. It sets the boundaries of the study, the impact categories and how to treat the uncertainty that will appear. (Guinée & Heijungs, 2017)

In the section 4.5 of chapter 4 there is a description of the steps to define sustainability metrics, that can be used as the first step of a LCA analysis.

Inventory analysis:

“Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system”. (ISO International Standard 14040, 1997) The analysis is made on the basis of a unit process which is the minimum element considered for which inputs and outputs are considered and quantitative data gathered. LCA assumes linear technology so it can scale the data of a unit process by multiplying it. Finally, the result of this phase is usually a table with all the quantified inputs and outputs from and to the environment for a product system. (Guinée & Heijungs, 2017)

Impact assessment:

In this phase the goal is to understand and evaluate the environmental impacts of a product system through its life cycle. It converts the result of the Inventory analysis phase and aggregates them into the same unit or impact category so those results can be understood better. For example, giving a score for the analysis impacts in terms of climate change, toxicity... (Guinée & Heijungs, 2017)

Interpretation:

In the last phase the results of the inventory analysis and the impact assessment are evaluated and conclusions and recommendations given. Identifying issues, the consistency of the study, limitations... (Guinée & Heijungs, 2017)

LCA is evolving and developing towards a Life Cycle Sustainability Assessment where the other dimensions of sustainability, social and economic, are taken into consideration as well. However, further research still needs to be done. (Guinée & Heijungs, 2017) Nevertheless, as explained in Höganäs case (Case II), they are currently using this type of complete Sustainability assessment to help decision making in the most important decisions, so it is already an option.

A3. Environmental and social benefits of Lean Six Sigma tools:

“Environmental and social benefits that can be achieved after the application of Lean/Six Sigma tools” Adapted table from (Cherrafi A. , Elfezazi, Chiarini, Mokhlis, & Benhida, 2016):

<i>Lean Six Sigma tools and techniques</i>	<i>Environmental and social benefits</i>
5S	<ul style="list-style-type: none"> -Encourages maintenance of a clean and organized work environment, which can reduce input consumption and motivate employees to properly dispose of production rejects. - Can assist companies to improve energy and materials efficiency by reducing space required for the operation and calling attention to environmental wastes. A clean workshop will quickly show a leak in a system, where resources are being wasted. - Helps to improve the company’s handling and storage of hazardous materials and waste, and thus reduce the risks of spills and mishandling. - Can help organizations to reduce risks, improve waste management, and minimize risks to the health and safety of workers and the environment by providing clean and accident-free work areas. - Reduces the chance that materials expire or become off-specification before they can be used and then require disposal.
Kaizen	<ul style="list-style-type: none"> - Provides a problem-solving culture with scientific and structured thinking, which will help organizations to resolve environmental issues. - Develops the engagement of employees and unleashes their creativity leading to the promotion of innovation for environmental and social progress. - It helps to reduce material wastes and pollution, which ensures a safe and healthy place to work. - Can serve as the driving force for improving manufacturing process resource productivity by optimizing the performance of the supporting flows (i.e., material and energy consumption and waste generation) and reducing the environmental impact of the manufacturing process by reducing all environmental waste generated by production.
Value Stream Mapping (VSM)	<ul style="list-style-type: none"> - Facilitates identification and visualization of no value added in the production line, thus helping organizations to avoid excess consumption and environmental waste such as water, energy consumption, and solid and hazardous waste and air emission. - Through VSM, operators became aware of environmental impacts of production processes. This leads to training on how to correctly use the resources, which allows organizations to practically realize important environmental benefits. - VSM could be used as a support tool for life-cycle analysis. - VSM is one of the best visual tools that could be used to improve communication with stakeholders to understand the generation and flow of value and environmental wastes during processes. - VSM could help to improve ergonomics, worker health and safety.

<p><i>Kanban /Pull</i></p>	<p>- Practice focuses on reducing inventory levels and provides the right materials at the right time to support manufacturing needs. This concept could help to:</p> <ul style="list-style-type: none"> • Reduce potential waste from damaged, spoiled, or deteriorated products. • Lead to a slight increase in energy, water consumption and hazardous waste volumes. • Provide workshop space utilization. • Facilitate identification of failures and unnecessary actions in an organization's processes, thus helping it avoid excess consumption and waste.
<p><i>Cellular manufacturing</i></p>	<p>- Could help companies to reduce the set-up times and change over time, which contribute to a decrease in energy and resource consumption.</p>
<p><i>TPM</i></p>	<p>- Increased longevity of equipment decreases need for replacement equipment and associated environmental impacts.</p> <p>- Promotes preventive and proactive maintenance of equipment to increase its useful life and avoid process failures that generate scrap and rework, leading to a reduced amount of product, energy and raw materials waste.</p> <p>- Helps to reduce breakdown labor rates, lost production, thus reducing energy and material consumption.</p> <p>- Increases worker health and safety because new technologies are often substituted for old machines and there are fewer breakdowns with their potential for injury.</p>
<p><i>SMED</i></p>	<p>- The reduction of equipment set-up time helps to reduce both inventory and overproduction. These reductions naturally lower the materials and energy consumption while reducing emissions.</p> <p>- Could help to reduce several environmental impacts of the machines, such as oil leakage and emissions of dusts and chemical fumes into the atmosphere.</p>
<p><i>Supplier relationship</i></p>	<p>- Could help to extend environmental responsibility across the supply chain.</p> <p>- Introduction of Lean Six Sigma to existing suppliers would lead to better realization of environmental benefits (e.g., decreasing waste through fewer defects, less energy usage, less scrap, etc.) across the network.</p>
<p><i>Poka-yoke (errorproofing)</i></p>	<p>- Contribute to reduce defects hence less waste, low energy usage, less scrap, low emissions, etc.</p>
<p><i>Six Sigma</i></p>	<p>- Presents a structured framework for problem solving and organizational leadership and enables managers and leaders to use new ways of understanding and solving their sustainability problems.</p> <p>- Focuses on reducing defects to improve product quality, which helps to reduce environmental waste (i.e. material, water and energy consumption and waste generation).</p> <p>- Focuses attention on reducing the conditions that result in accidents, leading to safer and healthier working conditions for the operators.</p>

<p><i>Statistical Process Control (SPC)</i></p>	<ul style="list-style-type: none"> - <i>Could be used to monitor and to develop better understanding of critical environmental parameters such as water, energy and raw material consumption, CO2 emissions, etc.</i> - <i>Will help to drive improvements in both process control and environmental control.</i> - <i>Assess to understand the degree and causes of variation of environmental parameters and thus will provide a quantitative-scientific base for analysis, decision making and regulatory action.</i>
<p><i>Visual management (Andon line)</i></p>	<ul style="list-style-type: none"> - <i>Help to identify and eliminate unwanted entities hence less material usage and wastes.</i> - <i>The use of Andon line to stop production in case of quality problems until resolution of problem leads to reduced energy and resource needs.</i> - <i>Environmental issues can be integrated into Andon systems in order to call attention to environmental problems when they occur.</i>
<p><i>Analysis tools (5why's, Pareto charts, cause-and-effect diagrams...)</i></p>	<ul style="list-style-type: none"> - <i>Could be used to stimulate the development of solutions:</i> <ul style="list-style-type: none"> • <i>To reduce/eliminate environmental wastes identified in the manufacturing processes.</i> • <i>To improve ergonomics, worker health and safety, and staff morale.</i> - <i>Could be used to understand the root-cause of environmental wastes, which leads to reduced excessive use of energy, water, raw material, emissions, etc.</i>
<p><i>Standardized work /Qualification</i></p>	<ul style="list-style-type: none"> - <i>Promote the development of sustainable methods over time that will lead to reduced variation in the process and products, which reduces the amount of product, electricity consumption and raw materials waste.</i>
<p><i>Plant layout reconfiguration</i></p>	<ul style="list-style-type: none"> - <i>Can be a powerful way to help companies reduce wastes and improve environmental performance leading to reduced materials, emissions, energy consumption and cost savings.</i> - <i>Reduce risks and improve the working environment, leading to safer and healthier working conditions for the operators.</i> - <i>Improved ergonomics and staff morale.</i>

A4. Interview Guide:

Sustainability

1. Define sustainability in your own way, please.
2. Present your present sustainability goals, please
3. How do you measure Sustainability performance from social, economic and environmental aspects? Which are your metrics for those areas?

Lean and Six Sigma

4. Are you using Lean, Six Sigma or a combination of both?
5. How do you select and prioritize an LSS project over another and which are the main factors for decision making?
6. Does Lean Six Sigma indirectly improve the sustainability of a company? (as a side effect)
 - a. Will it help more in the case of a company that starts using LSS?
 - b. Can LSS be applied directly to do sustainability projects? Is the DMAIC methodology optimal to do sustainability projects? Or is it only for manufacturing improvements, is there any difference? (maybe suggest changes)
 - c. Is the LEAN methodology optimal to solve sustainability issues? (contrast it with Six Sigma)

Lean Six Sigma + Sustainability

7. Can LSS support or even be an advantage to help the projects/work with sustainability?
 - a. What's your main reason using LSS? (or the other way)
 - b. Which LSS tools are mostly used for this (give a list) (or the other philosophy tools)
8. What are the sustainability tools you use? LCA, Carbon footprint...?
9. Is it necessary to add these new tools to Lean Six Sigma to address sustainability problems?
 - a. Or is it LSS per se good enough?
 - b. Which dimensions of sustainability usually those tools can't cover?
 - c. Can those new tools add more value?
10. Does LSS impact on sustainability vary by the experience with this methodology of the firm?
 - a. Does sustainability improve in a short period of time with the LSS culture or does it need a long time, a deep understanding, and many LSS improvements in the firm in order to start noticing sustainability improvements? (too long question)
11. Which pillar of sustainability is affected the most with LSS? (Environmental, social, economic)
 - a. Why?
 - b. How does it affect each one?

- c. How could be improved the effect on the worst one?
12. What are the differences between the Lean definition of waste and the environmental waste? Does all the waste reduction that promotes Lean have a positive impact on sustainability?
 13. Do all the process improvements that promotes Six Sigma have a positive impact on sustainability?
 - a. Is “Improving at all cost” good or does sustainability awareness stop some improvements?
 - b. How do you balance waste reduction/improvements and sustainability?

Lean Six Sigma Sustainability framework integration

14. How do you combine the efforts of continuous improvement with LSS and sustainability issues, what is your framework/model if applicable or what’s the way you make the decisions?
15. How do you think an integrated model for Lean Six Sigma and Sustainability would look like? What would be their focus?
16. In an integrated LSSS framework: What will you define as the minimum outcome of each Sustainability Dimension in order to select a project?