

*DESIGN SUPPORT FOR ECO-EFFICIENCY*  
*IMPROVEMENTS IN MANUFACTURING*



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*dedicated to the country of freedom and friendship*

An inspiring Greek story for explorers...

“Ulysses”, by Alfred Lord Tennyson

*It little profits that an idle king,  
By this still hearth, among these barren  
craggs,  
Matched with an aged wife, I mete and dole  
Unequal laws unto a savage race,  
That hoard, and sleep, and feed, and know  
not me.  
I cannot rest from travel: I will drink  
Life to the lees: All times I have enjoyed  
Greatly, have suffered greatly, both with  
those  
That loved me, and alone, on shore, and  
when  
Thro' scudding drifts the rainy Hyades  
Vext the dim sea: I am become a name;  
For always roaming with a hungry heart  
Much have I seen and known; cities of men  
And manners, climates, councils,  
governments,  
Myself not least, but honoured of them all;  
And drunk delight of battle with my peers,  
Far on the ringing plains of windy Troy.  
I am a part of all that I have met;  
Yet all experience is an arch wherethro'  
Gleams that untraveled world whose margin  
fades  
For ever and forever when I move.  
How dull it is to pause, to make an end,  
To rust unburnished, not to shine in use!  
As tho' to breathe were life! Life piled on life  
Were all too little, and of one to me  
Little remains: but every hour is saved  
From that eternal silence, something more,  
A bringer of new things; and vile it were  
For some three suns to store and hoard  
myself,  
And this gray spirit yearning in desire  
To follow knowledge like a sinking star,  
Beyond the utmost bound of human thought.  
This is my son, mine own Telemachus,  
To whom I leave the sceptre and the isle,  
Well-loved of me, discerning to fulfil  
This labour, by slow prudence to make mild*

*A rugged people, and thro' soft degrees  
Subdue them to the useful and the good.  
Most blameless is he, centred in the sphere  
Of common duties, decent not to fail  
In offices of tenderness, and pay  
Meet adoration to my household gods,  
When I am gone. He works his work, I mine.  
There lies the port; the vessel puffs her sail:  
There gloom the dark, broad seas. My  
mariners,  
Souls that have toiled, and wrought, and  
thought with me  
That ever with a frolic welcome took  
The thunder and the sunshine, and opposed  
Free hearts, free foreheads—you and I are  
old;  
Old age hath yet his honour and his toil;  
Death closes all: but something ere the end,  
Some work of noble note, may yet be done,  
Not unbecoming men that strove with Gods.  
The lights begin to twinkle from the rocks:  
The long day wanes: the slow moon climbs:  
the deep  
Moans round with many voices. Come, my  
friends,  
'Tis not too late to seek a newer world.  
Push off, and sitting well in order smite  
The sounding furrows; for my purpose holds  
To sail beyond the sunset, and the baths  
Of all the western stars, until I die.  
It may be that the gulfs will wash us down:  
It may be we shall touch the Happy Isles,  
And see the great Achilles, whom we knew.  
Tho' much is taken, much abides; and tho'  
We are not now that strength which in old  
days  
Moved earth and heaven, that which we are,  
we are;  
One equal temper of heroic hearts,  
Made weak by time and fate, but strong in  
will  
To strive, to seek, to find, and not to yield.*

## DECLARATION

This dissertation is the result of my own work and includes nothing, which is the outcome of work done in collaboration except where specifically indicated in the text. It has not been previously submitted, in part or whole, to any university or institution for any degree, diploma, or other qualification.

In accordance with the Department of Engineering guidelines, this thesis does not exceed 65,000 words, and it contains less than 150 figures.

Signed: \_\_\_\_\_

Date: \_\_\_\_\_

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## ABSTRACT

Eco-efficiency improvements in manufacturing is a controversial subject for researchers, practitioners as well as policy makers. The widely accepted definition of "doing more with less" is not accurate enough to guide the design of improvements that can deliver products in a sustainable way. The outcome of these challenges is evident through significant environmental performance variations across various levels of manufacturing operations. The study is concerned with the complexity of manufacturing systems and the required practical support for companies that aim to improve eco-efficiency.

A maturity model has been developed in this work that simulates the influence of manufacturing practices on eco-efficiency. The model takes the form of a maturity grid (PMGE) that overviews practices at process level, management systems and top-management level and decomposes them into 15 dimensions of performance overall. Evidence shows that practices tend to evolve from reactive to proactive as manufacturing systems mature and embrace eco-efficiency as a systemic property. It was also found that mature companies achieve improvements in energy and resource efficiency by relying on existing internal capabilities. Tools to facilitate research and intervene with practitioners in real-life problems were developed and tested.

The researcher combined research findings and tools into a maturity-based method (PMGEM) for eco-efficiency improvements. The method intends to help practitioners plan and design eco-efficiency improvements aligned to existing internal capabilities and adopt a more proactive behaviour to environmental challenges. PMGEM was ultimately applied in two case studies with ultimate goal to help practitioners resolve real-life challenges. The applications were positively commented and encourage further work in this field.

The researcher envisages that methods such as PMGEM are deeply needed in manufacturing to support practitioners approach complex concepts such as eco-efficiency. Simplification and decomposition techniques with a clear intended use can facilitate the implementation of ambitious improvement strategies for sustainable development.

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On a personal note I feel that this work has been influenced by:

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the morality of practitioners in Agrino, IfM, Airbus, Toyota, Asics, Altro and

the physical strength of Cambridge University Amateur Boxing Club

Unlimited gratitude to Steve, who showed me why it is important not to rest.

Special reference to my old colleagues in Agrino that initially puzzled me with ideas such as the "zero-waste factory" and "eco-efficiency"; riddles that I wanted to find the answers to...

# CONTENTS

<b>1 INTRODUCTION TO THE RESEARCH INQUIRY .....</b>	<b>16</b>
1.1 INTRODUCTION TO THE CHAPTER .....	16
1.2 ENVIRONMENTAL PRESSURES .....	17
1.3 ENVIRONMENTAL PERFORMANCE VARIATIONS IN MANUFACTURING .....	20
1.4 ENVIRONMENTAL PERFORMANCE VARIATIONS AND ECO-EFFICIENCY .....	21
1.5 RESEARCHER’S PHILOSOPHICAL STANCE .....	22
1.6 CHAPTER SUMMARY .....	27
<b>2 LITERATURE REVIEW .....</b>	<b>28</b>
2.1 INTRODUCTION TO THE CHAPTER .....	28
2.2 LITERATURE REVIEW METHODOLOGY .....	28
2.3 SUSTAINABLE MANUFACTURING DEFINITIONS AND FRAMEWORKS .....	29
2.4 THE ROLE OF ENVIRONMENTAL PRACTICES .....	38
2.5 THE ROLE OF PRACTICES .....	39
2.6 RESEARCH QUESTION AND OBJECTIVES .....	41
2.7 CHAPTER SUMMARY .....	42
<b>3 RESEARCH DESIGN .....</b>	<b>43</b>
3.1 INTRODUCTION TO THE CHAPTER .....	43
3.2 RESEARCH KNOWLEDGE AREA .....	43
3.3 RESEARCH METHODS .....	43
3.4 DESIGN RESEARCH METHODOLOGY .....	45
3.5 RESEARCH PLAN AND DISCUSSION .....	47
3.6 AVOIDING BIAS .....	50
3.7 RESEARCH VALIDITY .....	50
3.8 REVIEW SUMMARY AND RESEARCH OPPORTUNITY .....	52
3.9 CHAPTER SUMMARY .....	55
<b>4 INTERVIEWS AND THEORETICAL FRAMEWORK .....</b>	<b>56</b>
4.1 INTRODUCTION TO THE CHAPTER .....	56
4.2 AUDIENCE, ACCESS AND DATA COLLECTION PROCESS .....	57
4.3 DATA ANALYSIS .....	66
4.4 THE RESOURCE-BASED VIEW THEORY AND ECO-EFFICIENCY .....	69
4.5 PRACTICES AND THE CONCEPT OF MATURITY WITHIN RBV .....	73
4.6 ORGANIZATIONAL MATURITY AND ECO-EFFICIENCY IN PRACTICE .....	74



4.7 THEORETICAL FRAMEWORK FOR ECO-EFFICIENCY .....	75
4.8 CHAPTER SUMMARY .....	79
<b>5 MATURITY MODEL DESIGN AND APPLICATIONS .....</b>	<b>80</b>
5.1 INTRODUCTION TO THE CHAPTER .....	80
5.2 INTRODUCTION TO MATURITY MODELS .....	81
5.3 LITERATURE REVIEW OF MATURITY MODELS .....	82
5.4 PMGE DESIGN PRINCIPLES AND DESIGN ASSESSMENT.....	87
5.5 MODEL SIMPLIFICATIONS AND ASSUMPTIONS.....	97
5.6 PROFILES OF PRACTICE MATURITY .....	98
5.7 SEMI-STRUCTURED INTERVIEW GUIDE.....	104
5.8 WORKSHOP PROCESS.....	105
5.9 CHAPTER SUMMARY.....	114
<b>6 CAPABILITIES FOR ECO-EFFICIENCY IMPROVEMENTS .....</b>	<b>115</b>
6.1 INTRODUCTION TO THE CHAPTER .....	115
6.2 TWO CASE STUDIES .....	116
6.3 COMPARATIVE DATA ANALYSIS .....	123
6.4 REVIEW OF FINDINGS AND CONNECTION TO THEORY .....	130
6.5 CHAPTER SUMMARY.....	133
<b>7 SYNTHESIS OF PMGEM.....</b>	<b>135</b>
7.1 INTRODUCTION TO THE CHAPTER .....	135
7.2 REVIEW OF PMGE APPLICATION PROCESSES .....	136
<b>7.3 VARIABILITY OF PRACTITIONERS’ PERCEPTIONS AND HORIZONTAL KNOWLEDGE</b> <b>TRANSFER .....</b>	<b>137</b>
7.4 IMPROVEMENTS BASED ON EXISTING CAPABILITIES .....	138
7.5 MEASURABLE SUCCESS CRITERIA FOR PMGE-BASED SUPPORT .....	139
7.6 METHOD DEVELOPMENT .....	140
<b>8 APPLICATION OF PMGEM .....</b>	<b>148</b>
8.1 INTRODUCTION TO THE SECOND DESCRIPTIVE STUDY .....	148
8.2 INTRODUCTION TO THIS CHAPTER .....	148
8.3 CASE 1 - BUILDING PRODUCTS COMPANY.....	149
8.4 CASE STUDY 2 - SPORTS APPAREL COMPANY.....	156
8.5 CHAPTER SUMMARY.....	163
<b>9 EVALUATION OF PMGEM APPLICATIONS.....</b>	<b>166</b>

9.1 INTRODUCTION TO THE CHAPTER .....	166
9.2 APPLICATION EVALUATION.....	167
9.3 DISCUSSION AND LIMITATIONS.....	177
9.4 REVIEW OF CONTRIBUTIONS TO PRACTICE POST-APPLICATION .....	178
9.5 CHAPTER SUMMARY .....	180
<b>10 CONCLUSIONS AND FUTURE WORK .....</b>	<b>182</b>
10.1 INTRODUCTION TO THIS CHAPTER .....	182
10.2 MAIN KNOWLEDGE AREAS .....	182
10.3 LIMITATIONS AND FUTURE WORK.....	187
10.4 ADDITIONAL DISCUSSION POINTS AND FUTURE WORK .....	188
<b>11 PUBLICATIONS .....</b>	<b>190</b>
<b>12 REFERENCES.....</b>	<b>192</b>
<b>APPENDIX A .....</b>	<b>214</b>
<b>APPENDIX B .....</b>	<b>215</b>
<b>APPENDIX C .....</b>	<b>216</b>
<b>APPENDIX D .....</b>	<b>217</b>
<b>APPENDIX E .....</b>	<b>218</b>

## LIST OF TABLES

TABLE 1-1 DIFFERENT TYPES OF ENVIRONMENTAL PERFORMANCE VARIATIONS (BOCKEN ET AL., 2013) .....	21
TABLE 1-2 METHODOLOGICAL STANCES ASSOCIATED WITH QUALITATIVE RESEARCH.....	23
TABLE 1-3 EPISTEMOLOGICAL RESEARCH APPROACHES (CROTTY, 1998).....	25
TABLE 1-4 RESEARCH PARADIGMS, COMPARISON OF POSITIVISM AND PHENOMENOLOGY AS IN SILVERMAN (1993). .....	26
TABLE 3-1 VALIDITY METHODS THAT HAVE BEEN USED IN THIS STUDY (IN ITALICS). .....	52
TABLE 4-1 PARTICIPATING COMPANIES AND SECTORS. THE TABLE DEMONSTRATES THE RANGE OF COMPANIES THAT WERE CONTACTED FOR THE DESCRIPTIVE STUDY AND THE DATA COLLECTED IN EACH CASE.....	58
TABLE 4-2 SUMMARY OF APPROACHES AND CHALLENGES REGARDING ECO-EFFICIENCY FROM THE CASE STUDIES IN TABLE 4.1. ....	65
TABLE 4-3 DESCRIBES THE INTERDEPENDENCIES IN FIGURE 4.2 AND PROVIDES SUPPORTING LITERATURE IN EACH CASE. THE LEFT COLUMN PROVIDES LITERATURE SUPPORT TO THE FRAMEWORK CONNECTIONS. THE RIGHT COLUMN COMMENTS ON THE RELEVANCE OF EXISTING LITERATURE TO THIS WORK. AREAS B AND C ARE FOUND TO HAVE RECEIVED LITTLE ATTENTION IN THE LITERATURE. THIS IS EXPECTED TO SOME EXTEND AS THE TOPIC OF SUSTAINABLE MANUFACTURING PRACTICES IS RELATIVELY NEW IN ORGANIZATIONAL AND STRATEGY LITERATURE. THE ADDITIONAL ELEMENT OF PRACTICE MATURITY FURTHER NARROWS THE EXISTING LITERATURE.....	77
TABLE 5-1 SELECTED PUBLICATIONS THAT HAVE INFORMED AND/OR GUIDED THE DEVELOPMENT OF THE MATURITY MODEL. THE RESEARCHER DESCRIBES WHAT THE CONTRIBUTION OF EACH PUBLICATION HAS BEEN AND DISCUSSES ON THEIR USEFULNESS WHERE APPROPRIATE. ....	83
TABLE 5-2 MATURITY GRID DESIGN TOOL APPLICATION ACCORDING TO MAIER ET AL. (LEFT-HAND COLUMN SHOWS THE DESIGN DIMENSIONS).....	87
TABLE 5-3 THE PRACTICE MATURITY GRID FOR ECO-EFFICIENCY (PMGE). ....	92

TABLE 5-4 THE MATURITY PROFILES FOR EACH COMPANY THAT TOOK PART IN THIS EXERCISE DURING THE CONFERENCE. THREE ACTIVE MANAGERS IN MANUFACTURING AND ONE UNIVERSITY PROFESSOR WITH MANUFACTURING BACKGROUND TOOK PART.....	101
TABLE 5-5 EXAMPLE OF DATA COLLECTION OUTPUT BASED ON PMGE TO GUIDE THE CASE STUDY.....	104
TABLE 5-6 FOR EACH ORGANIZATIONAL LAYER THE WORKSHOP PARTICIPANTS LISTED A SET OF CAPABILITIES THAT THEY SAW AS IMPORTANT FOR MOVING FORWARDS BETWEEN MATURITY LEVELS. ....	108
TABLE 5-7 WORKSHOP 2 FEEDBACK FROM THE SECOND WORKSHOP .....	112
TABLE 6-1 OBSERVED CHARACTERISTICS THAT THE CASES SHARE IN THIS CHAPTER. THE RIGHT HAND COLUMN DESCRIBES THE LINKS WITH LITERATURE AND POTENTIAL BIAS THAT THE CHARACTERISTICS BRING IN THIS WORK.....	116
TABLE 6-2 CROSS-REFERENCE OF WHAT WORKSHOP PRACTITIONERS CONSIDERED AS IMPORTANT CAPABILITIES FOR ECO-EFFICIENCY IMPROVEMENTS (TABLE 5.6) AND EVIDENCE FOUND IN THE CASE STUDIES IN THIS CHAPTER IN ALIGNMENT WITH PMGE. .	130
TABLE 8-1 PROCESS LEVEL INPUT DATA .....	154
TABLE 8-2 FACILITY AND SYSTEM LEVEL INPUT DATA.....	154
TABLE 8-3 COMPARISON BETWEEN EXISTING CAPABILITIES IN THIS MANUFACTURING SYSTEM AND DESIRABLE ONES FOR THE FUTURE. ....	155
TABLE 8-4 THE MATURITY PROFILES FROM THE THREE COMPANIES IN THE SUPPLY CHAIN (THE ORIGINAL COPIES AS RECEIVED VIA EMAIL). ALL THREE PROFILES HAVE BEEN DEVELOPED AFTER COMMON AGREEMENT FROM PRACTITIONERS IN EACH COMPANY. ....	159
TABLE 9-1. THE RESPONSES RECEIVED FROM THE PRACTITIONERS IN THE BUILDING PRODUCTS COMPANY (ANSWERS IN BOLD). THE SUSTAINABILITY MANAGER CAN BE CONSIDERED AND EXPERT IN THIS FEEDBACK AND THEREFORE A CERTAIN LEVEL OF BIAS IS EXPECTED. ....	169
TABLE 9-2 MAIER ET AL., PROPOSE TWO MORE PHASES IN THE DESIGN OF MATURITY GRIDS: AN EVALUATION PHASE AND A MAINTENANCE PHASE. THE EVALUATION PHASE IS IN ALIGNMENT WITH THIS CHAPTER, WHEREAS THE DIMENSIONS OF THE MAINTENANCE PHASE WOULD BE MORE APPLICABLE ONCE A COMPREHENSIVE SUCCESS EVALUATION IS	

PRODUCED. THE TEXT IN LEFT HAND COLUMN IS DERIVED FROM THE PAPER BY MAIER ET AL., 2012. PHASES I AND II REMAIN AS DESCRIBED IN SECTION 5.4.....172

TABLE 9-3 WORKSHOP ASSESSMENT BASED ON CRITERIA SET BY KERR ET AL. (2013).....174

TABLE 9-4 - REVISED CONTRIBUTIONS TO PRACTICE POST-APPLICATION .....178

TABLE 9-5. THE 5<sup>TH</sup> AND THE NEW 8<sup>TH</sup> PROPOSED TYPE OF DRM PROJECT.....180

## LIST OF FIGURES

FIGURE 1.1. THE POTENTIAL FOR COMPANIES TO IMPROVE AS DESCRIBED BY LAVERY ET AL. (2013). COMPANIES CAN BE DISTINGUISHED BETWEEN “LEADERS”, “STARS”, “SLOW & STEADY” AND “LAGGARDS”. LEADING COMPANIES EXHIBIT MORE THAN 50% REDUCTIONS IN ENERGY AND RESOURCES .....	19
FIGURE 1.2. ECO-EFFICIENCY AS THE INTEGRATION BETWEEN ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY. THE FIGURE IS TAKEN BY HOCKERTS (1999) AND IT ORIGINALLY DERIVES FROM THE WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT.....	19
FIGURE 2.1. SIKDAR DEMONSTRATES THE OVERLAP BETWEEN ECONOMIC AND ENVIRONMENTAL ASPECTS AS ECO-EFFICIENCY AND THE REQUIREMENT TO DEVELOP SUITABLE METRICS. THE FIGURE IS ALIGNED TO THE TRIPLE-BOTTOM LINE PERSPECTIVE OF SUSTAINABLE DEVELOPMENT (ELKINGTON, 1997) .....	32
FIGURE 2.2 ELECTROLUX PRESENTS A 300% VARIATION PER PRODUCT UNIT ACROSS 5 FACTORIES IN THE ECEEE INDUSTRIAL SUMMER STUDY 2012 (DAHLMAN, 2012) .....	33
FIGURE 2.3 ENVIRONMENTAL PERFORMANCE VARIATION ACROSS A RANGE OF CHEMICAL COMPANIES AND ACROSS A SET OF SPECIAL INDICATORS (DELMAS AND BLASS, 2010). THE NUMBERS ALSO INDICATE RANKING AS 1 FOR BEST PERFORMERS UP TO 15 FOR WORST PERFORMER.....	34
FIGURE 2.4 SAI GON IS USING 100% MORE ELECTRICITY, 30% MORE THERMAL ENERGY AND 100% MORE WATER PER PRODUCT UNIT WHEN COMPARED TO THE GERMAN JEVER. THE SAI GON SITE WAS ESTABLISHED IN 1999, SO FAIRLY NEW AT THE TIME OF THE STUDY (SCHALTEGGER ET AL., 2012) .....	35
FIGURE 3.1 DESIGN RESEARCH METHODOLOGY FRAMEWORK (BLESSING AND CHAKRABARTI, 2009A) .....	46
FIGURE 3.2. SEVEN TYPES OF PROJECTS, THEIR MAIN STAGES AND THE DEPTH/TYPE OF INQUIRY IN EACH STAGE (BLESSING AND CHAKRABARTI, 2009A). THE FIFTH TYPE OF PROJECT IS CHOSEN IN THIS WORK. ....	47
FIGURE 3.3. CHAPTERS AND INFORMATION FLOW BASED ON DRM FRAMEWORK (TYPE 5). DIFFERENT COLOURS INDICATE THE TRANSITIONS OF THIS WORK BETWEEN THEORY (RED) AND REAL-LIFE (BLUE). THE FIGURE ILLUSTRATES THE FOUR STAGES OF PROJECT TYPE 5 AND MAPS THEM ONTO THIS. ....	49

FIGURE 3.5 THE DIAGRAM DEMONSTRATES THE AREAS THAT HAVE BEEN EXPLORED IN THE LITERATURE AND THE CONNECTIONS BETWEEN THEM AND ECO-EFFICIENCY. THE RED LINES REPRESENT THE LITERATURE GAPS THAT HAVE BEEN IDENTIFIED OR ALTERNATIVELY WHAT THE DESIRED CHANGE MAY BE.....	53
FIGURE 4.1 INTERVIEW DATA ANALYSIS IN THREE THEMES.....	67
FIGURE 4.2 HART DEMONSTRATES HOW STRATEGIES WITH A DIFFERENT FOCUS AREA OF EP IMPROVEMENT ARE LINKED TO EACH OTHER. THIS INQUIRY IS FOCUSING MORE ON THE TOP-LEFT CORNER OF THIS FRAMEWORK WHERE POLLUTION PREVENTION IS ALSO SEEN AS A WAY OF MANUFACTURING .....	72
FIGURE 4.3 THE RESEARCHER GRAPHICALLY SUMMARISES HOW HE COMBINED LITERATURE AND EMPIRICAL DATA ANALYSIS INTO A HIGH-LEVEL FRAMEWORK THAT CAN BE USED TO NAVIGATE THIS INQUIRY FURTHER.....	76
FIGURE 5.1 MATURITY PROFILES BY BAUMGARTNER AND EBNER 2010.....	99
FIGURE 5.2 THE INTERACTIVE POSTER AFTER USE. ....	101
FIGURE 5.3 THE MATURITY PROFILES FROM TWO ENVIRONMENTAL MANAGERS IN A MANUFACTURER IN THE AEROSPACE SECTOR, SHOWING THEIR PERCEPTION OF THE MATURITY OF THEIR PRACTICES ACROSS THE FACTORIES THAT THEY OVERSEE (GLOBAL BUSINESS). ....	103
FIGURE 5.4 (A, B) THE CIRCULAR FORMAT OF THE PMGE FOR MANUFACTURING PROCESSES ECO-EFFICIENCY.....	111
FIGURE 6.1 THE AIRCRAFT COMPANY MATURITY PROFILES FROM FIVE PRACTITIONERS IN THE AIRCRAFT COMPANY. THE RESEARCHER FOLLOWED THE PROCESS AS DESCRIBED IN THE SECOND PART OF CHAPTER 5 (SEE SELF-ASSESSMENT PROCESS IN PARAGRAPH 5.1).....	118
FIGURE 6.2 ENERGY SAVINGS PER SITE AS COMPARED TO THE IMPROVEMENT TARGETS (LUNT ET AL., 2015). THE FIGURE DEMONSTRATES HOW THE EFFECTIVE THIS NETWORKING PRACTICE HAS BEEN FOR THE COMPANY IN ITS FIRST YEAR OF OPERATIONS.....	121
FIGURE 6.3. A CONSISTENT REDUCTION PATTERN ACROSS A RANGE OF ENVIRONMENTAL PERFORMANCE INDICATORS FOR THE EUROPEAN SITES. EVIDENCE ABOUT THE IMPROVEMENTS IN PLANTS IN NON-EUROPEAN COUNTRIES WAS NOT AVAILABLE. SOURCE: WWW.THERM-PROJECT.ORG.....	122

FIGURE 7.1 THE ECO-EFFICIENCY MATURITY CHART.....	142
FIGURE 7.2 THE PMGEM STEPS.....	147
FIGURE 8.1 AN EXAMPLE OF ONE OF THE MATURITY PROFILES FROM THE PRODUCT INNOVATION MANAGER (DOTS ARE CONNECTED FOR READABILITY).....	150
FIGURE 8.2 ALL SEVEN MATURITY ASSESSMENTS IN ONE GRID.....	151
FIGURE 8.3 ONE OF THE GROUPS DISCUSSING FUTURE IMPROVEMENTS AT FACILITY AND SYSTEM’S LEVEL. YELLOW POST-IT NOTES COLLECT PAST ACTIONS AND PINK ONES THEIR ENABLING RESOURCES. GREEN POST-ITS COLLECT FUTURE ACTIONS/PLANS OR RECOMMENDATIONS AND SUPPORTING RESOURCES/ENABLERS.....	153
FIGURE 8.4 A SIMPLIFIED VERSION OF THIS SPORTSWEAR SUPPLY CHAIN. THE PARTICIPANTS IN THIS STUDY ARE REPRESENTED IN BLACK BOXES. THE SERVICE PROVIDER HAS A MEDIATING ROLE BETWEEN THE TIER 1 AND 2 SUPPLIERS AND HAS BEEN EXCLUDED FROM THIS STUDY AT THIS POINT AS IT IS A SERVICE COMPANY RATHER THAN A MANUFACTURING ONE.....	158
FIGURE 9.1 THE REVISED PMGEM.....	178
FIGURE 10.1 - REVIEW OF THE THEORETICAL FRAMEWORK FROM CHAPTER 4. ....	186



## LIST OF ABBREVIATIONS AND ACRONYMS

AE	Application Evaluation
CEO	Chief Executive Officer
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
DRM	Design Research Methodology
DS	Descriptive Study
EFQM	European Foundation for Quality Management
EMAS	Eco-Management and Audit Scheme
EMS	Environmental Management Systems
EP	Environmental Performance
EPr	Environmental Practice
EPV	Environmental Performance Variation
FP	Financial Performance
IEEN	Industrial Energy Efficiency Network
IEMA	Institute for Environmental Management and Assessment
ISO	International Standardization Organization
KPI	Key Performance Indicator
LCA	Life-Cycle Analysis
ML	Maturity Level
n-RBV	natural Resource-Based View
NISP	National Industrial Symbiosis Program
PMGE	Practice Maturity Grid for Eco-efficiency
PMGEM	Practice Maturity Grid for Eco-efficiency Method
PS	Prescriptive Study
RBV	Resource-Based View
SE	Success Evaluation
SM	Sustainable Manufacturing
WMCSD	World Business Council for Sustainable Development
WRAP	Waste and Resources Action Program

# 1 INTRODUCTION TO THE RESEARCH INQUIRY

## 1.1 Introduction to the chapter

The first chapter of this inquiry describes how environmental performance in manufacturing is expressed as a phenomenon and how it is linked to issues such as climate change and economic growth. The middle ground between environmental and economic performance is the versatile concept of eco-efficiency or what the World Business Council for Sustainable Development refers to as “doing more with less” (WBCSD, 2010).

It is acknowledged that various routes of inquiry exist for eco-efficiency and this could have an impact on the course and outcomes of the study. This doctoral journey is part of a wider researcher plan involving many researchers. Therefore, there was some flexibility as to what philosophical paradigms could be followed by different researchers. In order to clarify the researcher's observational angle, the reader is introduced to the philosophical and methodological choices followed. Philosophical choices refer to the assumptions that the researcher makes about the reality of eco-efficiency. According to Van de Ven, "*underlying any form of research, is a philosophy of science that informs us of the nature of the phenomenon examined (ontology) and the methods for understanding it (epistemology)*" (Van de Ven, 2007). Methodological choices are relative to the type of information that has been acquired and processed and further affects the types of outcomes.

## 1.2 Environmental pressures

A starting point for this work is a reference to the overall socio-political trends that make environmental performance relevant to businesses and government. The World Business Council for Sustainable Development sees three factors affecting the pathway towards a sustainable future (WBCSD, 2010):

- Growth: Population, urbanization and consumption  
“Between now and 2050 the global population is expected to increase from 6.9 billion to more than 9 billion, with 98% of this growth happening in the developing and emerging world, according to UN estimates”.
- Inertia and inadequate governance  
“The governance and policy responses to manage this growth often happen in silos and are limited by short-term, localized political pressures, and thus fall short of the level of commitment needed to make significant progress”.
- Degradation: Climate change and deteriorating ecosystems  
“The Millennium Ecosystem Assessment found that 15 of the 24 ecosystem services they evaluated have been degraded over the past half century. A rapid and continuing rise in the use of fossil fuel-based energy and an accelerating use of natural resources are continuing to affect key ecosystem services, threatening supplies of food, freshwater, wood fibre and fish”.

At a regional level, the European Union states that it is aligned to world-wide efforts towards a more resource-efficient economy (“The Roadmap to a Resource Efficient Europe,” 2011):

- “Economic growth can be combined with avoiding unsustainable pressures on the quality and quantity of natural assets, according to the Organisation for Economic Co-operation and Development’s Green Growth Strategy 20.”
- “Phasing out inefficient fossil fuel subsidies, as a way to reduce budget deficits, deliver growth and reduce environmental harm according to the Group of 20 commitments.”
- “Greening ten central sectors of the economy, in order to shift development onto a low-carbon, resource- efficient path by investing 2% of the global Gross Domestic Product, according to United Nation's Environment Programme Green Economy Report 21”

### 1.2.1 The opportunities at business level

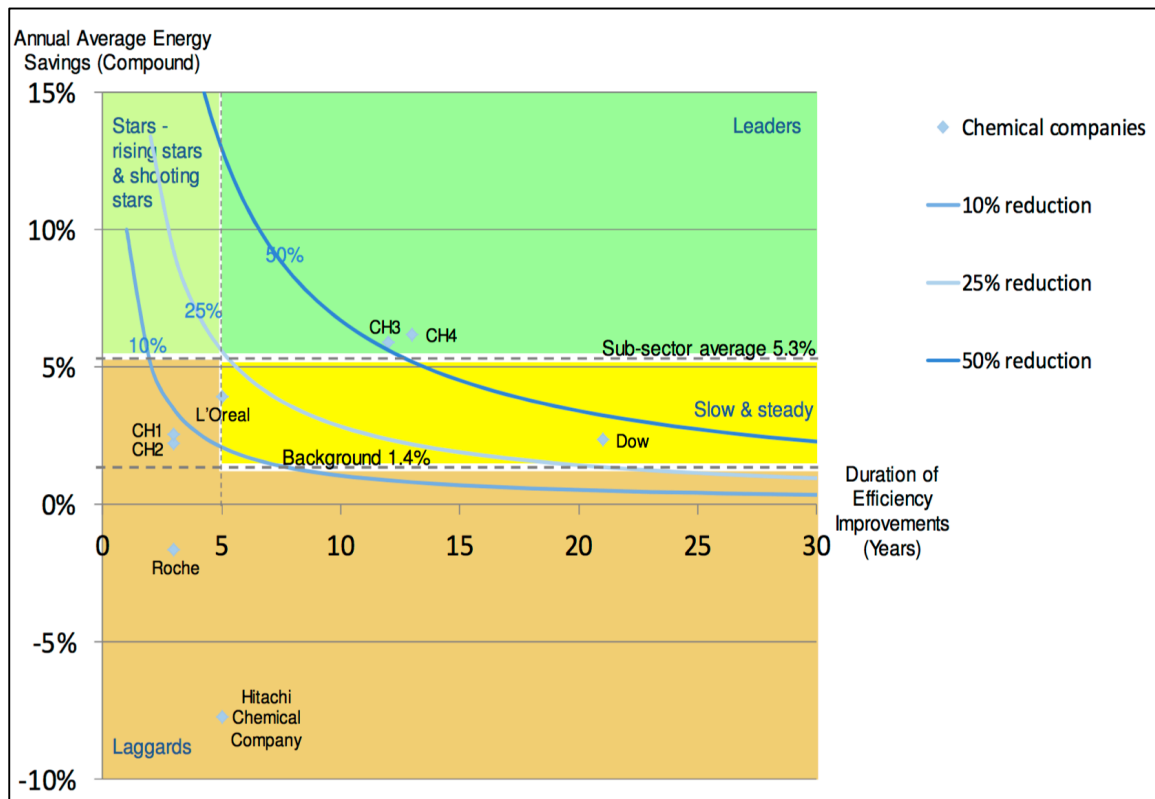
The aforementioned pressures may affect businesses at more local levels but it is yet not clear how companies adjust themselves internally to address environmental concerns. A recent study by Lavery et al., suggests that there is a potential for the United Kingdom (UK) market for (Lavery et al., 2013):

- £10 billion additional profits per annum for manufacturers – a 12% increase in average annual profits.
- 314,000 new manufacturing jobs - a 12% increase in manufacturing employment.
- 4.5% reduction of the UK's total greenhouse gas emissions since 2010.

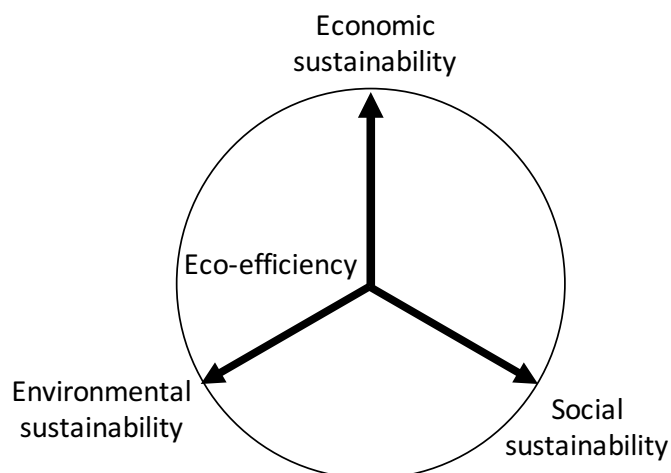
This potential is derived by comparable data between highly efficient companies and laggard ones. **Figure 1.1** demonstrates this variation for energy efficiency. A number of companies stand out as exceptional in their energy efficiency – both for their annual rates of energy reductions and the period over which they have sustained these improvements. Lavery et al., (2013) distinguish companies on **Figure 1.1** as “Leaders”, “Stars”, “Slow & Steady” and “Laggards”. The way that Lavery et al., (2013) describe the potential for improvement is aligned to the triple bottom-line perspective of sustainable development that Elkington coined in 1997 (Elkington, 1997a).

According to Elkington, a balance between economic, environmental and social performance is the basis for sustainable development. Dyllick and Hockerts look at sustainable development from the business perspective and focus more on the overlap between economic and environmental sustainability (Dyllick and Hockerts, 2002). In **Figure 1.2** Hockerts describes schematically the resultant between environmental and economic sustainability as eco-efficiency (Hockerts, 1999).

**Figure 1.1. The potential for companies to improve as described by Lavery et al. (2013). Companies can be distinguished between “Leaders”, “Stars”, “Slow & Steady” and “Laggards”. Leading companies exhibit more that 50% reductions in energy and resources**



**Figure 1.2. Eco-efficiency as the integration between economic and environmental sustainability. The figure is taken by Hockerts (1999) and it originally derives from the World Business Council for Sustainable Development.**



### 1.3 Environmental performance variations in manufacturing

There is a parallel stream of work to sustainable development that links eco-efficiency to environmental performance in manufacturing. A short exploratory study on environmental performance variation (EPV) preceded this doctoral study and described the phenomenon of how similar factories in technology and infrastructures may be using different levels of energy and resources to make the same products (Bocken et al., 2013). Table 1-1 shows what types of variations can be observed (not an exhaustive list). According to Table 1-1, one could be observing EPV in process behaviour charts, employee behavioural patterns (i.e. shifts in a factory) as well as equipment performance. For a practitioner, variations in environmental performance (EP) can be important as these can challenge their root cause analysis skills (Zutshi and Sohal, 2004).

The term environmental performance (EP) is used here to describe the ways that a manufacturing system interacts with the natural environment. It can refer to the way that energy is used to make products or support industrial operations (Abdelaziz et al., 2011; Yang et al., 2011). EP may also refer to the way that a factory is using raw materials or the types and amount of waste and pollution it may create (Hasanbeigi and Price, 2015). The levels of pollution can have immediate or long-term impacts on the natural environment and the lives of the people that live in the area (Azapagic, 2004; Hasanbeigi and Price, 2015).

Multiple studies have demonstrated how complicated it can be to measure and manage energy and resources in manufacturing (Abdelaziz et al., 2011; Boyd et al., 2008; Cagno and Trianni, 2012a). The design of manufacturing systems that have no negative environmental impacts has drawn the focus of many academics and governmental organizations (Ball et al., 2009; Gibson, 2001; Rossiter, 1995). Several studies however show significant inertia in current, wasteful manufacturing systems due to numerous barriers to improvement (Bey et al., 2013; Trianni et al., 2013). Barriers to improve EP may be organizational, managerial and technical (Chai and Yeo, 2012; Golev et al., 2014). In some occasions, EP is associated with the wider manufacturing supply chain performance (Brockhaus et al., 2013; Zhu and Geng, 2013). Overall, practitioners and researchers tend to investigate opportunities for improvement of: environmental performance as well as economic performance.

**Table 1-1 Different types of environmental performance variations (Bocken et al., 2013)**

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Type of variation	Explanatory comments
Within factory – across shifts	The role of individuals in shifts that can shape the environmental performance profile per shift.
Within one factory – over time	Comparing the factory site against itself over time can provide insights on the effectiveness of specific practices, such as training
Across production sites of the same company	Deviations from the company targets and management processes may be observed, lead sites and “sustainability champions” may be identified
Across factories within the same sector	In factories of sectors that use mature technology, variances in environmental performance may be observed.
Across industries of different sectors	What is driving performance in each industry (e.g. technology, policy)?
Processes	Some processes are common in many different industries (e.g. air compressing).

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## 1.4 Environmental performance variations and eco-efficiency

The discussion about EP in manufacturing is a significant part of a larger debate about the impact of industrial activities on the natural environment and society (Elkington, 1997a; Frosch, 1992; Glaser, 2006). As mentioned earlier (section 1.2), industrial activity has been associated with global warming and further climate change but also with benefits coming from economic growth (Ekins, 2005; Hukkinen, 2014; Jelinski et al., 1992). The World Business Council for Sustainable Development (WBCSD) therefore proposes a roadmap for improvement globally, that seeks to secure the needs of future generations (WBCSD, 2010). EP in this context is part of the eco-efficiency framework, “creating more value with less impact” or in Layman’s terms “doing more with less” (WBCSD, 2010).

As shown in Figure 1.1 and Figure 1.2, eco-efficiency is a concept that acknowledges the fact that production needs to continue in a way that satisfies rising human needs. At the same time, the use of resources and waste needs to be reduced compared to today levels. EPV as a phenomenon indicates that there are ways of making products in factories with less resources

and having less environmental impacts to the natural environment (as shown by Lavery et al., 2013). Dyllick and Hockerts review the ways that academics and practitioners can approach eco-efficiency (Dyllick and Hockerts, 2002; Hockerts, 1999, 2015). Various ways have been proposed to-date that look at eco-efficiency at the product level, production level or consumer level. More specific research challenges that arise for eco-efficiency are discussed in chapter 3, where the researcher reviews relative literature and highlights the research opportunity. Before that debate can take place, the researcher considers that philosophical and methodological concerns need to be clarified for the reader.

In 1990, the Intergovernmental Panel for Climate Change argued that global warming was linked to industrial activities of the twentieth century. At the same time, their own data showed a controversy that a similar phenomenon was observed 1000 years ago (Easterby-Smith et al., 2015). In this example, contradicting results from different studies ended up in the same report and made the report less trustworthy. What Easterby-Smith et al., demonstrate is that research boundaries need to be well-defined and that the researcher's viewing angle needs to be clarified every time. In the following paragraphs the researcher describes the adopted philosophical position in this work.

## 1.5 Researcher's philosophical stance

Hart argued that, as of the mid-1990s, "there were no examples, of large manufacturing firms committed to a vision of sustainable development. Research on sustainable development-based strategies, must necessarily take a more qualitative, case-comparative approach" (Hart, 1995). To clarify what the boundaries of this work are, the researcher describes the adopted philosophical stance here as well as the implications for this inquiry. The researcher is positioned within the manufacturing system and seeks to experience the phenomenon of eco-efficiency as a practitioner does. The aim is to achieve insights about EP and eco-efficiency that are balanced between theory and practice. Ritchie and Lewis classify this type of research as qualitative and support the definition by Denzin and Lincoln (Ritchie and Lewis, 2003):

"Qualitative research is a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that makes the world visible. These practices turn the world into a series of representations including field-notes, interviews, conversations, photographs, recordings and memos to the self. At this level, qualitative research involves an interpretive, naturalistic approach to the world. This means that qualitative researchers study



things in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them”. In order to give some structure to this definition, Ritchie and Lewis provide the following dimensions as generic associations between qualitative research and methodological stances. These dimensions and the choices made in this study are presented in Table 1-2 (Ritchie and Lewis, 2003):

**Table 1-2 Methodological stances associated with qualitative research**

Methodological stances	Research strategies followed in this study
Perspective of the researcher and the researched	Sustaining empathic neutrality whereby the researcher uses personal insight while taking a non-judgemental stance to interpret his observations.
Nature of research design	Conducting naturalistic inquiry in real-world rather than experimental or manipulated settings (though methods vary in the extent to which they capture naturally occurring or generated data) – see chapter 2 about research design and validity of naturalistic research (Guba, 1981; Guba and Lincoln, 1982)
Nature of data generation	Using methods of data generation which are flexible and sensitive to the social context in which the data are produced.
Nature of the research methods used	Main qualitative methods include: observation, in-depth individual interviews, focus groups, and analysis of documents and texts.
Nature of analysis & interpretation	Based on methods of analysis and explanation building which reflect the complexity, detail and context of the data.
Nature of outputs	<ul style="list-style-type: none"> <li>• Mapping meanings, processes and contexts</li> <li>• Consideration of the influence of the researcher's perspectives samples that are small in scale and purposively selected on the basis of salient criteria</li> <li>• Analysis which is open to emergent concepts and ideas and which may produce detailed description and classification, identify patterns of association, or develop typologies and explanations</li> <li>• Outputs which tend to focus on the interpretation of social meaning through mapping and 're-presenting' the social world of research participants.</li> </ul>

However, before one refers to the particular methods that can be used for research, as Saunders et al., quotes (primarily from Guba and Lincoln): *“both qualitative and quantitative methods may be used appropriately with any research paradigm. Questions of method are secondary to questions of paradigm, which we define as the basic belief system or world view that guides the investigation, not only in choices of method but in ontologically and epistemologically fundamental ways”* (Saunders et al., 2009). The questions about paradigm and basic belief system is explored in the following section.

### 1.5.1 Ontological considerations

In order to sustain consistency between the methodological stance and the researcher’s positioning, reference to the basic beliefs about reality is necessary. The researcher here accepts that there is a measurable output in manufacturing (environmental and financial performance) that can be quantified and monitored with technical means. Therefore, there is a reality which is external to the system under investigation (i.e. a factory and measured emissions). This reality exists independently to people’s beliefs and their understanding of reality. In other words there is a distinction between the way the world is and the meaning and interpretation of that world held by individuals (Ritchie and Lewis, 2003). This position is referred to as realism.

As a philosophical position, realism is aligned to the researcher’s own beliefs, work background and the intention to investigate eco-efficiency through real-life situations. At this point, one may comment that the way that the definition of reality is used in this study may not stand true within larger system boundaries (i.e. how EP can guide political decisions related to global warming and carbon emissions?). This loop of “experienced reality” versus “accepted reality” and it’s relevance to other socio-technical systems can be used as a link to other types of studies with positivistic or phenomenological orientation (Cupchik, 2001; Jonathan D. Owens, 2007).

The discussion about reality in this study is also important for the clarification of its boundaries (as in the earlier example by Easterby-Smith et al., 2015). For example, the energy usage, or the volatile organic compounds in a manufacturing process may be determined with technical means. This measurable output may influence the control of other manufacturing processes, the quality of the local natural environment or workers’ health and safety. People interfere with processes and control systems are designed to help practitioners

deal with such complex tasks. For the researcher, manufacturing systems are socio-technical systems, where people may influence process output and vice-versa.

The researcher here uses the description about the relationship between people and technical systems from Shafeey and Trott: “The environment is perceived as subjective, difficult to penetrate, or changing, and, thus, less analysable. It is, therefore, enacted, created by managerial cognition and action. Managers are entrepreneurs; they synthesize and create. They are architects. They design and construct organizational systems to enhance the productivity of whatever resources the firm acquires. They make their contribution largely through architecting and constructing capabilities internally” (Shafeey and Trott, 2014). It is also important to describe how the researcher interacts and senses the occurring phenomena. The epistemological approach requires further clarification within this ontological perspective.

### 1.5.2 Epistemological considerations

According to Crotty, research can be divided in three epistemological research approaches constructivism, objectivism and subjectivism. These approaches are based in the relationship of the researcher and the subject under investigation. Table 1-3 describes briefly each case (Crotty, 1998). The research tradition or epistemology that is better aligned to this research inquiry is constructivism. Constructivism aims to display 'multiple constructed realities' through the shared investigation (by researchers and participants) of meanings and explanations (Ritchie and Lewis, 2003).

**Table 1-3 Epistemological research approaches (Crotty, 1998)**

Objectivism	Objectivists “hold the meaning, and therefore meaningful reality, exists as such, apart from the operation of any consciousness. For the objectivists, meaning is already inherent with the object being examined and the properties of that object can be measured and quantified. From this perspective it is the researcher’s role to decipher and map out this meaning and reality. Therefore, objectivism is closely aligned to positivism and thus related to quantitative methodologies.
Subjectivism	The epistemology of subjectivism, suggests that meaning emerges from a vacuum. Meaning “does not come out of an interplay between subject and object, but it is imposed on the object by the subject. Here, the object as such makes no contribution to the generation of meaning.

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Constructivism In constructivism, truth or meaning, comes into existence in and out of one's engagement with the realities in one's world. There is no meaning without a mind. Meaning is not discovered, but constructed. In this understanding of knowledge, it is clear that different people may construct meaning in different ways, even in relation to the same phenomenon. In this view of things, subject and object emerge as partners in the generation of meaning.

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Another consideration that needs to be discussed further is in regards to the choice of research paradigm. In general, there are two distinct research paradigms: phenomenology and positivism. The differences between positivist and phenomenological paradigms is shown in Table 1-4, by Silverman, where the two paradigms are analyzed with respect to their basic beliefs, researcher's activities and methods of data bias reduction (Silverman, 1993).

**Table 1-4 Research paradigms, comparison of Positivism and Phenomenology as in Silverman (1993).**

	Positivism	Phenomenology (chosen paradigm)
Perception of the World	The social world is separated from human beings. Social reality can be investigated by the use of objective measures.	Humans are part of the social world, which exists due to the interaction and actions of human beings.
Objectives	Empirical testing of theories by process of verification or falsification for reaching a general principle.	The understanding of how members of a social group by actions enact meanings, beliefs and realities of the social world.
Research Methods	Hypothetical deductive approach.	Process of understanding how practices and meanings are formed by humans as they work towards common goals.
Methods of Data Collection	Sample surveys and questionnaires.	Interviews, documents and observations.
Methods of Analysis	Statistical models.	Interpretation, description and analysis of the social world from the viewpoints of the participants.
Role of Respondents	Information based on frameworks prepared by researcher through questionnaires.	Allow respondents to use their own ways of explaining their experiences and concepts of the social world.

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The phenomenological paradigm fits well with the philosophical stance and has been followed throughout the inquiry.

## 1.6 Chapter summary

Governmental and societal pressures have been rising in recent years and very few manufacturing companies have managed to show exceptional progress in the way that energy and resources are used efficiently. One way to observe this improvement potential is through environmental performance variations in manufacturing systems. In order to study eco-efficiency, the researcher chooses to position himself at the same level with practitioners in manufacturing and observe the challenges that they face. A phenomenological approach is chosen, within realism and a constructivist paradigm is followed to understand how eco-efficiency can be expressed and interpreted in manufacturing.

The following chapter fuels the exploration of eco-efficiency further through environmental performance variations with particular focus in the way that practitioners experience these. The following chapter describes this phenomenon in greater detail and sets research tasks. Philosophical and methodological considerations manifest in a research plan in chapter 3, influenced by the literature review chapter 2. In the following chapter a research design is introduced that can provide guidance and structure to this research endeavour.

# 2 LITERATURE REVIEW

## 2.1 Introduction to the chapter

This chapter overviews literature related to eco-efficiency in manufacturing and demonstrates what the research opportunity is. In the first chapter, the researcher presented evidence about the importance of eco-efficiency within the context of sustainable development. In this literature review chapter, the reader will be further informed about influencing factors and attributes of eco-efficiency. The chapter starts with an overview of sustainability in manufacturing as a research field. A range of popular frameworks is presented. The researcher then explains how environmental performance is related to eco-efficiency and seeks to adopt a usable definition of eco-efficiency for this research. Some important influencing factors of eco-efficiency are also presented. The overall aim is to demonstrate what the current research status is for eco-efficiency and the area of contribution of this work. At the end of the chapter a research question is established.

## 2.2 Literature review methodology

The researcher reviewed literature using the keywords: “sustainable manufacturing”, “environmental performance”, “eco-efficiency”, “green manufacturing”, “energy efficiency”, “management”, “performance”, “measurement”. The bibliographical, peer-reviewed resources (papers and well-cited books) used were: Scopus, Web of Knowledge and Cambridge University library catalogues. Non-peer reviewed publications were also studied from sources such as consultancy and government reports. This chapter contains 72 papers

that account for 10% of the researcher's overall bibliographical database and 30% of the overall bibliography presented in this thesis.

Paper abstracts were read to short-list relevant results in the data-base. As Scopus provides information about each paper's citations, this information was used to identify papers with a high-level of citations. Based upon citation (popularity), the researcher was able to locate key authors and their work. He was also able to see connections with other authors and review parallel work streams from the same research groups. This snowballing technique helped the researcher find authors that were more influential in the field than others and what the most influential papers were (based on number of citations). Nevertheless, on few occasions and depending on the study objectives, less cited papers were reviewed that covered more specific issues or to better understand the use of a research method in the field. Key journals were also traced through this process: "Journal of Cleaner Production", "International Journal of Production Economics", "International Journal of Operations & Production Management", "Journal of Environmental Management", "Journal of Industrial Ecology".

## 2.3 Sustainable manufacturing definitions and frameworks

In a recent doctoral thesis by Despeisse, 12 definitions of sustainable manufacturing are offered and briefly compared to each other (Despeisse, 2013). Each definition offers a differentiated perspective on sustainable manufacturing. These perspectives aim to improve manufacturing on dimensions that can be loosely clustered as (there are overlaps):

- transformation process of materials (Allwood, 2005)
- industrial eco-systems (Frosch and Gallopoulos, 1989)
- sustainable production (Glavič and Lukman, 2007)
- environmentally conscious manufacturing (Sarkis and Rasheed, 1995)
- product life-cycle (Rahimifard and Clegg, 2007)

In this work, the researcher adopts the United States' Department of Commerce definition for sustainable manufacturing (SM) as: "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound" (as found in Jayal et al., 2010). This definition is chosen for the triple-bottom balance it offers between economic, environmental and social performance, aligned to Elkington (1997). Aligned to this definition for sustainable manufacturing, a range of frameworks has been

developed. Smith and Ball identify 3 main frameworks that can guide improvement actions at a business and manufacturing level (Smith and Ball, 2012):

“The Natural-Step is a broad strategic framework for organisations, which provides high-level guidance for sustainability investments and initiatives. According to this framework, there are system conditions which must be met for society to become sustainable and a strategy is required to change the organisation in order to fulfil these conditions (understanding the conditions, understand a company's relative position, creating a vision and specifying an action plan)”.

“Industrial Ecology as a framework, consists of three models that describe the resource flows from the natural environment to the technical environment of production and consumption. The framework views that resource flows can become cyclical and return back to the natural environment in a closed loop. The Industrial Ecology concept has not been applied at factory level yet and therefore whilst conceptually it is of relevance there is no guidance for its deployment in companies.”

“Sustainable Manufacturing (based on environmental conscious manufacturing) is broad in scope, taking a high level view of manufacturing and including all three elements of the triple bottom line (Elkington, 1997a). Sustainable manufacturing (SM) looks beyond the boundaries of a single facility and considers the entire material cycle from material extraction through processing and use to subsequent disposal.”

Within the third 'SM' framework, four strategic objectives have been identified by Abdul Rashid et al., (2008) as the most favourable for manufacturers that intend to control their environmental impacts: a) waste minimization, b) resource efficiency, c) material efficiency and d) eco-efficiency. The latter is seen as the most popular of these strategies and this is one of the reasons that it became the focus on this work.

Nevertheless, the industrial and academic community does not offer a widely adopted operational definition of eco-efficiency. In the following sections, the researcher comments on the work that has been done so far to define eco-efficiency as a strategy and practice (Abdul Rashid, 2009). As a practice, Despeisse et al., observe that there is a gap in the availability of methods that can operationalize eco-efficiency as a sustainable manufacturing strategy (M. Despeisse et al., 2012).



### 2.3.1 Eco-efficiency definitions and approaches

In chapter 1, the researcher introduced eco-efficiency through observations of environmental performance variations. In this section, eco-efficiency is approached as a sustainable manufacturing strategy. WBCSD proposes that: “*Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth’s estimated carrying capacity*” (WBCSD, 2010). WBCSD outlines seven targets/objectives of eco-efficiency:

- Reduce material intensity (make more goods with fewer inputs)
- Reduce energy consumption (make more goods with less energy)
- Reduce dispersion of toxic substances (make more goods with less poisonous waste)
- Enhance recyclability (make the goods recyclable)
- Maximise use of renewables (make goods out of materials that won't run out)
- Extend product durability (make goods that last)
- Increase service intensity (meet demand with a service and not with goods)

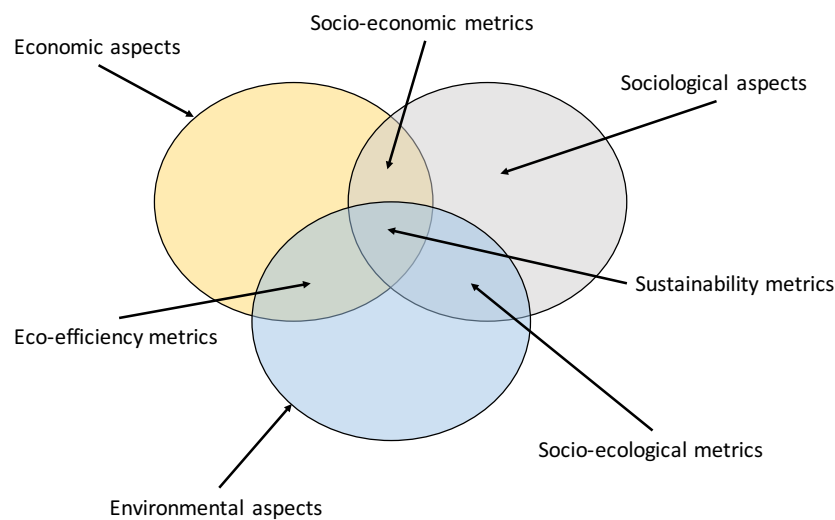
Nevertheless, the overall objective of “doing more with less” does not provide clear instructions to manufacturers that want to improve their eco-efficiency. Numerous researchers focused on ways that eco-efficiency can be better defined and quantified so that it can become a measurable, and more tangible target. According to Huppes and Ishikawa, eco-efficiency may have four expressions, depending on the organizational approach (Huppes and Ishikawa, 2005a):

- Environmental productivity
- Environmental intensity of production
- Environmental improvement cost
- Environmental cost-effectiveness

The same authors propose that these definitions require a wider social consensus from interested parties (Huppes and Ishikawa, 2005a). Based on such operational definitions of eco-efficiency, several authors set out to quantify the eco-efficiency of manufacturing systems (see (Charmondusit and Keartpakpraek, 2011; Figge and Hahn, 2005; Garcilaso et al., 2006; Kamande and Lokina, 2013). However, quantification studies seem to be more valuable for companies that have developed deeper understanding of their EP and the economic value of their production system capabilities (Saling et al., 2002). Sikdar in Figure

2.1 views eco-efficiency metrics as the convergence of economic and environmental metrics (Sikdar, 2003). Different metrics are applicable for economic or environmental improvements and new ones need to be created to quantify improvements for eco-efficiency.

**Figure 2.1. Sikdar demonstrates the overlap between economic and environmental aspects as eco-efficiency and the requirement to develop suitable metrics. The figure is aligned to the triple-bottom line perspective of sustainable development (Elkington, 1997)**



### 2.3.1.1 Approaching eco-efficiency through benchmarking

Environmental performance variation (EPV), as introduced in the first chapter, offers a quantification of environmental and economic aspects of sustainable manufacturing. This particular viewing angle permits the reader to witness the improvement potential that can be unlocked and the available routes through which, this potential may be achieved. Through variation and EP benchmarking, industries may be informed about practices that offer superior performance potential and then to adopt them into their own organization processes (Nachiappan and Anantharaman, 2006; Schaltegger et al., 2012). There can be three types of benchmarking which are commonly performed in companies:

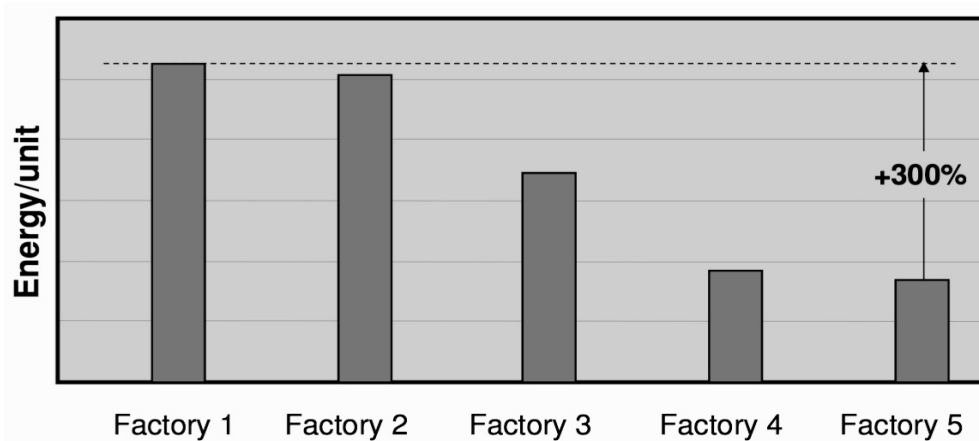
- internal benchmarking, whereby a multi-site manufacturer sets company-wide performance standards for each of the sites to follow, and then charts each site's performance against that standard (similar to Figure 2.2);

- industry benchmarking, where a company’s performance is measured against those of other organizations in the same industrial sector (as in Figure 2.4); and
- best practice benchmarking, where performance is measured against those of other companies considered to be the leaders in that industry, regardless of the end product or provide service of that particular business (as in Figure 1.1 and Figure 2.2).

For example, in Figure 2.2, Dahlman, director of global energy strategies for Electrolux, presented the energy consumption per production unit between five manufacturing sites which can vary up to 300% (Dahlman, 2012). It is not clear whether this level of variation percentage is an observation in Electrolux manufacturing sites or an idea that the author was trying to convey to his audience based on their experiences. As a practitioner, Dahlman proposes, that there are certain key success factors that can help practitioners implement “climate programs” (Dahlman, 2012):

- Management decisions and clearly defined targets. Targets should be short and/or medium term
- Engaged drivers from respective parts of the organization. Regular meetings of core team – keep momentum
- Follow up key performance indicators in a standardized format. Report progress to local and central management on regular basis
- Include green programs into business systems
- Communication: Encourage good projects through recognitions (Awards, employee magazines, etc.)

**Figure 2.2 Electrolux presents a 300% variation per product unit across 5 factories in the ecee industrial summer study 2012 (Dahlman, 2012)**



Researchers Delmas and Blass offer an overview of EP variation across a range of customized indicators for several listed companies in the chemical sector. Figure 2.3 groups these companies in three groups (different grey scale shades indicate low to high performance). Their findings show how well one firm can perform across a range of indicators constructed for eco-efficiency benchmarking. The findings in this work can be used by investors to better understand face trade-offs between different investment options (Delmas and Blass, 2010).

**Figure 2.3 Environmental performance variation across a range of chemical companies and across a set of special indicators (Delmas and Blass, 2010). The numbers also indicate ranking as 1 for best performers up to 15 for worst performer.**

Firm	Rank based on TRI total release/sales (lb/\$)	Rank based on RSEI risk score/sales	ECHO (average non-compliance quarters/facility)	Reporting (7 criteria)	REC ER <sup>2</sup>	KLD total strengths	KLD total concerns
Avon Products, Inc.	1	1	6	12	N/A	8	1
Clorox Company	3	7	2	14	12	8	1
Colgate-Palmolive Company	2	6	5	7	5	8	1
Dial Corporation	N/A	N/A	1	7	14	N/A	N/A
Dow Chemical Company	13	12	15	2	3	1	14
DuPont Company	14	14	14	1	1	2	13
Eastman Chemical Company	11	13	12	12	9	8	7
Ecolab Inc.	4	5	7	3	11	2	1
International Flavors & Fragrances Inc.	9	4	3	14	13	8	1
Johnson & Johnson	5	2	9	3	8	2	6
Lilly (Eli) and Company	7	8	11	3	4	8	7
Merck & Co., Inc.	8	3	13	3	7	8	12
Pfizer, Inc.	12	9	10	7	6	2	11
Procter & Gamble Company	6	10	4	7	2	7	7
Rohm and Haas Company	10	11	8	7	10	6	7

**Table 2.** Rankings – comparison<sup>1</sup>

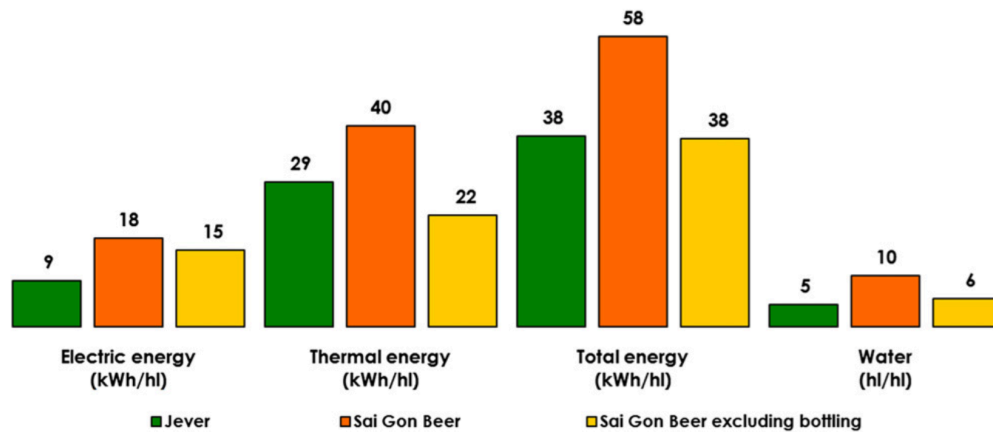
<sup>1</sup> Rank = 1 represents the best performer; rank = 15 represents the worst performer.

<sup>2</sup> Roberts Environmental Center (REC) environmental reporting scores (ER).

Another study on EP in a state-of-the-art beer brewing company in Vietnam shows how managers were driven by the gap in energy and water use to achieve improvements through cleaner production projects (Schaltegger et al., 2012): “*The production manager, was alarmed by international benchmark figures for electricity and water consumption of beer brewing as he noticed that the company was performing poorly. In fact, he observed that the total water and energy demand per unit beer produced was at least twice as high as the*

*international benchmark figures.*” In Figure 2.4, company Sai Gon is compared to its German competitor (Jever) for energy and water use.

**Figure 2.4 Sai Gon is using 100% more electricity, 30% more thermal energy and 100% more water per product unit when compared to the German Jever. The Sai Gon site was established in 1999, so fairly new at the time of the study (Schaltegger et al., 2012)**



Geffen and Rothenberg explored the way that three companies in the automotive collaborate with their suppliers. They specifically looked at the paint-booth process in one of the plants in each company and found a 300% variation in normalized emissions data across the three plants (Geffen and Rothenberg, 2000). The authors suggest that plants should learn to work with their suppliers in order to achieve environmental goals faster than their competition. They also imply that the results of such collaborative projects are hard for competition to pick up and replicate. More examples that involve environmental benchmarking with quantitative methods were found by various other authors (Honkasalo et al., 2005; Nagel, 2003; Samuel et al., 2013; Van Passel et al., 2007). Their approach is to construct performance indicators and environmental performance models that offer a level of predictability for the factory.

However, qualitative studies of EP variations have also been reported (i.e. (Baumgartner and Ebner, 2010; Sardinha et al., 2011). Qualitative types of studies on EP variations were found to be less frequent in the literature search. The attention in qualitative studies is not on the variation itself or its size, but rather on the ways that practitioners control EP and implement efficiency measures in factories. At this point, the literature search focus shifted to studies with qualitative character, aligned to the researcher’s philosophical stance. The focus of the literature search moved into more qualitative studies that would explore drivers and barriers

of eco-efficiency improvements in manufacturing. For example, the role of policy in EP for manufacturing companies (Ruiz-Tagle, 2008). A greener policy was found to have a direct and positive influence on both the greener ships and the greener suppliers (Lirn et al., 2014).

#### 2.3.1.2 Barriers to eco-efficiency

There is a well-researched body of knowledge that reflects upon the barriers that stop manufacturers from improving their energy and resource efficiency or sustaining a desirable level of performance. There is particular focus on energy efficiency but there are implications for material consumption as well. United Nations have researched into the barriers for energy and resource efficiency (Sorrel et al., 2011) and from an industrial policy perspective they identify several barriers to energy efficiency such as:

- Risk of investment
- Imperfect information and opportunity cost
- Hidden costs and over-estimations
- Access to capital – internal or external funding for projects
- Split incentives between stakeholders
- Bounded rationality in decision making for better projects

Chai and Yeo further elaborate on such barriers and propose that there are connections between the barriers that make them even more persistent and hard to overcome. Some authors propose that these interactions transcend organizational layers and affect stakeholder behaviours, that require attention (Chai and Yeo, 2012). A behavioural approach to barriers of eco-efficiency has also been proposed in another study where Cagno et al., stress the importance of the real and perceived values of barriers by its stakeholders in manufacturing systems (Cagno et al., 2013). Cagno et al., present the behavioural and tacit elements of eco-efficiency improvements through a taxonomy of barriers and the use of the taxonomy as a tool for research.

#### 2.3.1.3 Environmental management systems as drivers for improvement

Literature search about environmental performance frequently led the researcher in the area of Environmental Management Systems (EnMS). These are often linked to management standards such as ISO14001 for environmental management (Zutshi and Sohal, 2004) or ISO26000 for corporate responsibility (Hahn, 2013). However, there are survey-based studies that have challenged the effectiveness of the system with mixed results (Link and Naveh,

2006; Newbold, 2006; Tung et al., 2014). In fact, a study by Hertin et al., shows that there is currently no evidence that EnMS have a consistent and significant positive impact on environmental performance (Hertin et al., 2008). In order to clarify what factors can help companies lead a smooth, faster, effective and sustainable implementation of an EnMS, Zutshi and Sohal suggest that attention needs to be paid to (Zutshi and Sohal, 2004):

- Management leadership and commitment, supported by practices:
  - o Cultural change and organizational vision
  - o Allocation of resources
  - o Appointment of a champion
  - o Communication with internal external stakeholders
  - o Avoidance of personality clashes
- Learning from other organizations' experiences and benchmarking, supported by practices:
  - o Reference to industry standards and guidelines
  - o Employee induction and training
  - o Training and awareness for other stakeholders and suppliers
- Internal analysis, supported by practices:
  - o Conducting cost-benefit analysis and environmental gap analysis
  - o Identification of environmental aspects and impacts along with setting of objectives and standards
  - o Internal regular audits
  - o Document control system
  - o Integration of existing management systems
- Sustainability embedded vision supported by practices:
  - o Life-cycle analysis
  - o Design for disassembly
  - o Industrial ecology

The analysis of success factors by Zutshi and Sohal indicates how EP management is a multi-dimensional challenge for companies and involves the engagement from multiple stakeholders. This observation about the nature of the proposed success factors is aligned to the nature of the barriers for improvement as presented in the previous section (Cagno et al., 2013). It is also noticeable that Zutshi and Sohal refer to specific environmental management practices such as “life-cycle analysis” or “internal audits” as success factors. The authors also refer to practices that are applicable in other manufacturing areas such as: “Conducting cost-benefit analysis” and “employee induction and training”.

The following sections discuss on these two categories of practices and the relationship with economic performance and eco-efficiency. It should be noted that the latest revision of ISO 14001:2015 requires companies for the first time to analyse the context of the organization

and the identification of interested parties needs and expectations that could affect the achievement of the intended results of the system. Ultimately, the latest revision of this standard intends to better integrate its principles into the core business functions rather than require business conformance as an external authority. The latest revision also highlights the importance of alignment of the standard to the business strategy (“ISO 14001, 2015 Revision,”).

## 2.4 The role of environmental practices

There is evidence that a firm’s financial performance (FP) can be enhanced by improved EP (Ahuja and Hart, 1996; Ambec and Lanoie, 2008; Claver et al., 2007). Evidence has been produced through surveys, showing that companies that take care of their environmental impacts (i.e. pollution prevention programs) have actually witnessed bottom-line improvements. These improvements are not easy to quantify and little guidance exists for practitioners to understand how improvements came to effect. Potentially, bottom-line improvements are not the only metric to pay attention to when looking for benefits from EP improvement programs (Molina-Azorín et al., 2009).

The importance of certain environmental manufacturing practices to the firm’s economic performance has been investigated through a survey-based study by Montabon et al., (2007). Montabon et al., found that remanufacturing, environmental design, design goals, and surveillance of the market for environmental innovation were positively associated with the firm’s FP. These practices are more specific to environmental management standards and potentially easier for companies to adopt. The same authors divide environmental manufacturing practices into: operational, tactical, strategic and performance measures. This categorization is aligned with the views of Porter and van de Linde that there is a positive relationship between environmental performance and enhanced economic performance (Porter and Linde, 1995). Moreover, proactive corporate environmental strategies or a pattern of environmental practices that went beyond compliance with environmental regulations were found to be associated with improved financial performance (Aragón-Correa and Sharma, 2003). Aragón-Correa and Sharma observe that:

“...several firms have moved from minor changes in practices (as required by regulations) to adoption of an easier standard (i.e. ISO 14001), and then shift to another, more difficult standard. However, this complexity of shifting standards has prevented many firms from



undertaking a systemic and coordinated investment of resources in building the environmental capabilities necessary for a proactive environmental strategy”.

Their observation may partially explain why environmental management standards were found to have limited effectiveness (Hertin et al., 2008). Sambasivan et al., survey 291 companies in Malaysia and conclude that environmental proactivity is positively related to operational performance, organizational learning, environmental performance, stakeholder satisfaction and financial performance (Sambasivan et al., 2013). According to Sambasivan et al., environmental proactivity refers to “*voluntary actions beyond compliance that a firm undertakes to minimize or eliminate the negative impact of its activities and/or products on the natural environment*”. Therefore, environmental proactivity becomes a catalyst for reaping benefits other than just financial performance. Buysse and Verbeke, (2003) consider that this proactive behaviour may require a voluntary collaboration between companies and government.

The link between EP and stakeholder satisfaction and particularly employee integration in EP improvement processes is investigated within proactive environmental strategies, in a survey by Alt et al., (2014). Their study indicates that employee suggestions and information will only translate into environmental performance improvements if managers integrate these into firms’ strategic planning and implementation. To et al., find that there is a lack of literature that describes how environmental practices are perceived by employees (To et al., 2015). This could be a missing link in understanding how environmental practices can become more effective in eco-efficiency improvement and it is further aligned to the perception issues mentioned earlier about efficiency barriers.

## 2.5 The role of practices

In parallel to more direct studies on environmental management systems (EnMS), researchers have explored the contribution that other management systems and practices may have on a manufacturing site’s EP (Laugen et al., 2005). Canato et al., define practice as “*behavioural routines, tools and concepts that are used to accomplish a certain task*” (Canato et al., 2013). To distinguish manufacturing practices from environmentally-oriented practices Walls et al., make the following distinction: “*Environmental practices tend to differ from other social practices since they are technical, require specific firm capabilities and significant capital investment, are guided by regulation, and have their own reporting criteria*” (Walls et al., 2011).

Lean management (see Ball, 2015; Bandehnezhad et al., 2012; Hajmohammad et al., 2013; Nagel, 2003), quality management ( see Craig and Lemon, 2008; Lu et al., 2011; Ormazabal and Sarriegi, 2012), production costing and asset management (see Ciroth, 2009; Liyanage, 2007; Nachiappan and Anantharaman, 2006), have been gradually embedded into manufacturing systems and can be considered more traditional today when compared to EnMS or even sustainable manufacturing management principles (Jayal et al., 2010). Indeed, researchers have previously looked into the influence of various manufacturing practices on the plant's performance (measured as quality, flexibility, speed and cost, see (Laugen et al., 2005). Laugen et al., find that product focus, pull production, equipment productivity and environmental compatibility qualify as best practices for economic efficiency. Environmental compatibility is operationalized as “putting efforts into and commitment to improving the company's environmental compatibility and work place health and safety.

Environmental improvement programs were found to have positive influence on most action programs in the factory. However, these are seen as quality management practices rather as part of a standalone EnMS (Laugen et al., 2005). Referring back to EP variation, there are studies that observed the use of “six-sigma” methodology to reduce EP variation in manufacturing (Jami et al., 2012; Kumar et al., 2011). Brunet and New observe that the practice of the Japanese origin “kaizen” provides support for training. Kaizen allows the inclusion of non-performance oriented projects such as for safety, health or environment which may otherwise be overlooked by teams and their managers trying to achieve production objectives (Brunet and New, 2003).

The “balanced scorecard” is a tool that can be used for corporate strategy implementation (Kaplan and Norton, 1992). Its usefulness to connect non-monetary success factors with economic performance has been tested in the area of sustainable manufacturing strategy implementation (Figge et al., 2002; Möller and Schaltegger, 2005). Evidence from using the balanced scorecard effectively to improve EP are scarce in the literature. However, the attention that it has received so far, mainly from academics, can be seen as another well-established practice in companies that can be used to guide EP improvements. The format of the balanced scorecard allows verification of the existence of links between the broad strategic objectives and performance references with specific objectives, measurements, initiatives and achievements (Dias-Sardinha and Reijnders, 2005).

From a human resources management point of view, there are indications that HRM practices can further facilitate EP improvements (Collins and Smith, 2006; Paillé et al., 2014; Radnor

et al., 2005). More specifically nurturing teamwork and practicing reward schemes can assist the facilitation of environmental programs (Daily and Su-chun, 2001). Attention to human resource practices can also indirectly influence EP through improved kaizen practices, as mentioned above (Farris et al., 2009).

There have been efforts to clarify the relationship between EP and FP for manufacturing systems. For example, Albertini, in a meta-analysis of 52 studies over a 35-year old period, concludes that there is positive relationship between EP and FP (Albertini, 2013). On the other hand, Iwata and Okada survey 268 firms from 2004 to 2008 and suggest that even though there may be a positive relationship between FP and EP, this would be subject to various contextual and firm specific properties that enable that connection to be positive. (Iwata and Okada, 2011).

## 2.6 Research question and objectives

This chapter has expanded on the initial observations made on environmental performance variations through a review of relative publications in the literature. Via this literature search, the researcher departed from the original quantitative nature of EPV and expanded further in the qualitative nature of the variations. Publications on the role of management systems, practices and barriers to eco-efficiency were further explored. However, very few publications explored how eco-efficiency is practiced effectively in manufacturing today in a systematic or repeatable way. Support for practitioners in the literature was found to be very brief and with unclear theoretical grounds and boundaries. Therefore, the researcher set the following research question:

“What kind of practical support may further enable companies to improve the eco-efficiency of their manufacturing systems?”

The researcher envisages that the support will enable practitioners to design customised solutions for improvements in factories with environmental and economic benefits. The researcher, through the eyes of a practitioner, sees the research questions as a design challenge. The research question further implies two research objectives that need to be satisfied. These are seen as necessary requirements to answer the research question:

Research objective 1: The research question implies that practitioners in manufacturing could assess current eco-efficiency levels and understand their improvement options. Therefore, an assessment capability for eco-efficiency is required (see chapters 4-6).

Research objective 2: It is implied that the support is applicable in real-life situations and it needs to be usable by practitioners in manufacturing. Therefore, the researcher needs to offer guidance for practitioners on how to systematically and effectively apply such support (see chapters 7-10).

Viewing the research opportunity as a design challenge offers another level of novelty in this work and this view is explored in the following chapter in more detail. This viewing angle is consistent with the researcher's positioning (see section 1.5.1 definition by Shafeey and Trott, 2014). Design researchers study interventions in practice, with the dual goal of progressively refining the design of an intervention itself and the theories of learning and teaching that inform the design (Bielaczyc, 2013)

The researcher intends to approach eco-efficiency improvements in factories as a systems' design challenge. Such an attempt differentiates this study from the literature that typically intends to offer quantitative tools that support eco-efficiency improvements (see sections 1.3, 1.4, 2.3.1.1, 2.3.1.3, 2.5). The implications for this approach are reflected in the following chapter that deals with the selection of an appropriate research methodology that takes into account the requirements set in this section.

## 2.7 Chapter summary

In this chapter the researcher sought to better understand what the research opportunity for eco-efficiency is and explored various routes in the literature aligned to the researcher's positioning. This initial literature review helped the researcher to identify the main research question and stemming research objectives. This chapter concludes the research clarification phase of the research design.

The scope of the inquiry is to support practitioners in manufacturing to design effective eco-efficiency improvements. The researcher has to take into account the complexity that surrounds eco-efficiency in manufacturing and find ways to simplify and operationalise eco-efficiency for practitioners.

# 3 RESEARCH DESIGN

## 3.1 Introduction to the chapter

This chapter aims to describe the research plan that has been followed in this work. The research plan is aligned to the researcher's positioning to investigate eco-efficiency in manufacturing systems as an embedded observer. The philosophical and methodological choices influence the research design and help to further narrow the research focus. This chapter can be considered as parallel to the following chapter. The result of these two chapters is a clarification of the research scope and objectives. The main focus here is to describe the phases of the research design.

## 3.2 Research knowledge area

The research scope in this work is to better understand how eco-efficiency is expressed in factories and manufacturing systems today. This would enable the researcher to make recommendations for faster and wider advancement of eco-efficiency in industry, aligned to the aims of the World Business Council for Sustainable Development. Speed and scale will help manufacturers to deal effectively with environmental and societal pressures (section 1.2). The researcher will be generating knowledge within the fields of industrial sustainability and environmental management.

## 3.3 Research methods

Empirical data input for this work was achieved through interview transcripts, e-mail correspondence, hand-written notes from meetings and interviews, corporate newsletters and

academic periodicals as well as workshops with practitioners. The process of acquiring access to cases and practitioners and the data analysis process is described in each occasion. Practitioners in manufacturing companies was the main audience for this work. It was seen more appropriate to consider any type of manufacturer as potential data source, as the breadth of the types of companies would make findings more generalizable in the long run (Yin, 2003).

Under the chosen research paradigm of constructivism, more emphasis was given to research methods such as interviews and workshops, with varying levels of participation by the researcher. Other research methods such as surveys and statistical analysis were not seen as applicable at this level of research maturity. The researcher acknowledges that quantitative methods could apply in this work but preferred to remain clearly under the chosen paradigm. In the long-run the researcher sees that this work can accommodate more quantitative methodologies (examples are Munda, 2005; Pigosso et al., 2013).

In regards to data collection techniques, these are described in each case and are subject to the research objective. For example, in chapter 4 a research guide for semi-structured interviews with practitioners was developed through literature review in chapter 3. As the research activities become more focused (chapter 5 onwards), the researcher is using more particular techniques (such as focus groups in chapter 6 and workshops as in chapters 5 and 8) to inform this work. Details about data collection and processing are described in each case.

### 3.3.1 Triangulation

The matter of triangulation of research workings is critical for the validation of results in this work. Throughout this inquiry, the researcher strived to acquire a level of confirmation about his workings from many sources. Peer and non-peer reviewed literature was collected from academia and/or consultancy companies. Moreover, practitioners from various companies have been interviewed regardless of size, sector or markets. As mentioned earlier, more than generalizability of findings, the researcher used the audience variability as a way of gaining more perspectives about EP in different contexts (Lincoln, 1995). Specific reference to the validity considerations through triangulation techniques is described separately in section 2.7.

### 3.3.2 Unit of analysis and research plan requirements

The unit of analysis in this work is eco-efficiency improvements in manufacturing systems (see section 3.4). The researcher focuses on the methods and techniques that may be applied in factories to improve eco-efficiency and learn about their effectiveness and conditions of application. In each company visited in this study, a different perspective about improvements was introduced due the different contextual conditions and people involved. The amount of research work that had to be undertaken was not pre-defined at the beginning of this doctoral journey. The researcher had to adopt to a research plan that could cope with a wide array of companies and with various real-life situations in order to practice case study research (Yin, 2003). A rigorous research plan would maintain a logical and coherent course of action and sustain linkage between theory and practice. Applications of interventions (practical support) in real life situations would need to be assessed for effectiveness.

Review of existing literature that aimed at developing supporting methods or tools (interventions) to practitioners was explored in order to structure the research plan. Very few academics have dealt with this type of requirement in participatory action research (Platts, 1993a) - the assessment of the intervention - and offer a tested solution for researchers (Blessing, 2015; Blessing and Chakrabarti, 2009b).

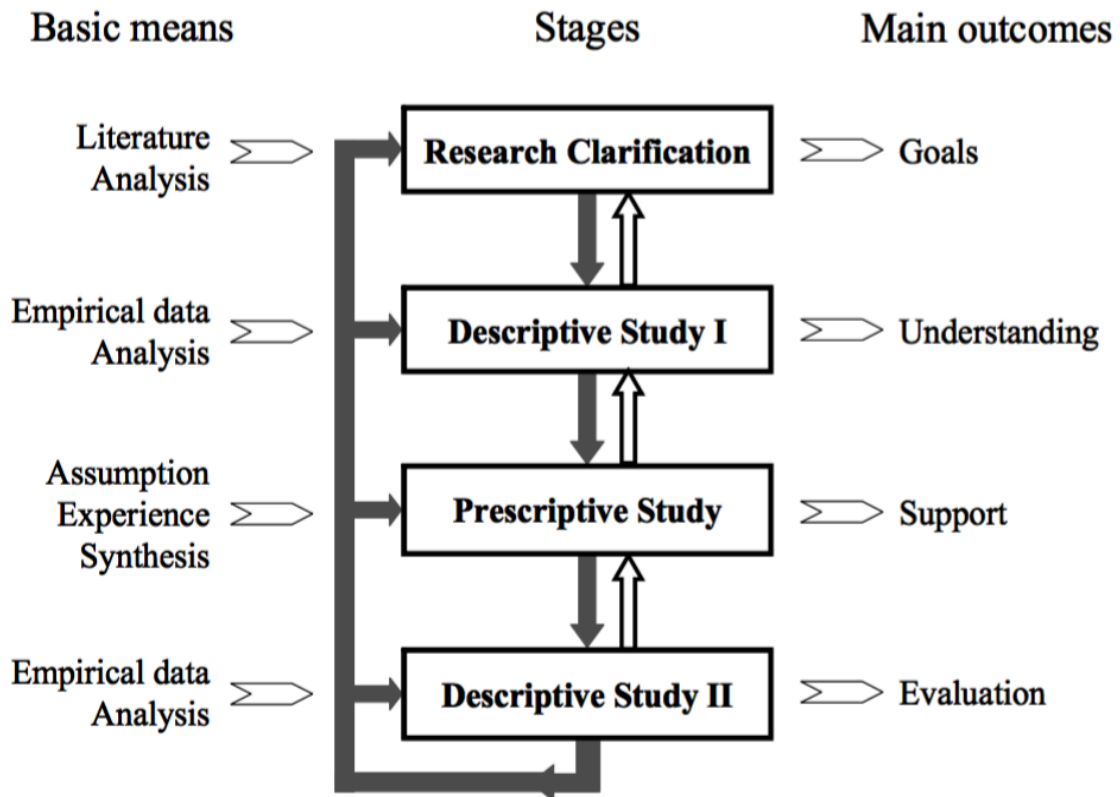
## 3.4 Design research methodology

Developing support for practitioners is one of the key objectives of the Design Research Methodology (DRM), introduced by Blessing and Chakrabarti in 2009. (Blessing and Chakrabarti, 2009a) DRM is a structured methodology that can guide research in real-life situations (**Figure 3.1**). The publication of this research framework is recent (2009) and its logic and structure has been applied to support several doctoral studies (for example Siyam, 2014). However, Blessing and Chakrabarti (2009) do offer a range of examples of doctoral thesis in their book that cover a wide range of projects, all of which intend to develop and test a new intervention.

Even though DRM has emerged from engineering design schools, its applicability has been extended in other disciplines (i.e. manufacturing management). It provides a rigorous structure and research design options that can be used for various research tasks. One of the key characteristics in this framework is the development of support for practice that is driven by intended use. DRM can help researchers better define the intended use of their research

output and strive for usability and usefulness. Figure 3.1 shows the basic elements of DRM (means of inquiry, stages and expected outcomes per stage).

**Figure 3.1 Design Research Methodology framework (Blessing and Chakrabarti, 2009a)**



The framework provides a range of possible scenarios that can be adopted for various research plans. In general, a DRM-based inquiry consists of a research clarification stage, two descriptive studies and one prescriptive study as shown in Figure 3.1. There are two-way connections and circular loops between the stages (represented by arrows) that allow researchers to explore phenomena by using various routes of this process. Depending on how far a researcher can elaborate in each stage of the inquiry, in terms of detail and results, Blessing and Chakrabarti propose 7 types of projects. **Figure 3.2** lists the proposed project types.



**Figure 3.2. Seven types of projects, their main stages and the depth/type of inquiry in each stage (Blessing and Chakrabarti, 2009a). The fifth type of project is chosen in this work.**

Research Clarification	Descriptive Study I	Prescriptive Study	Descriptive Study II
1. Review-based	→ Comprehensive		
2. Review-based	→ Comprehensive	→ Initial	
3. Review-based	→ Review-based	→ Comprehensive	→ Initial
4. Review-based	→ Review-based	→ Review-based Initial/ Comprehensive	→ Comprehensive
5. Review-based	→ Comprehensive	→ Comprehensive	→ Initial
6. Review-based	→ Review-based	→ Comprehensive	→ Comprehensive
7. Review-based	→ Comprehensive	→ Comprehensive	→ Comprehensive

### 3.5 Research plan and discussion

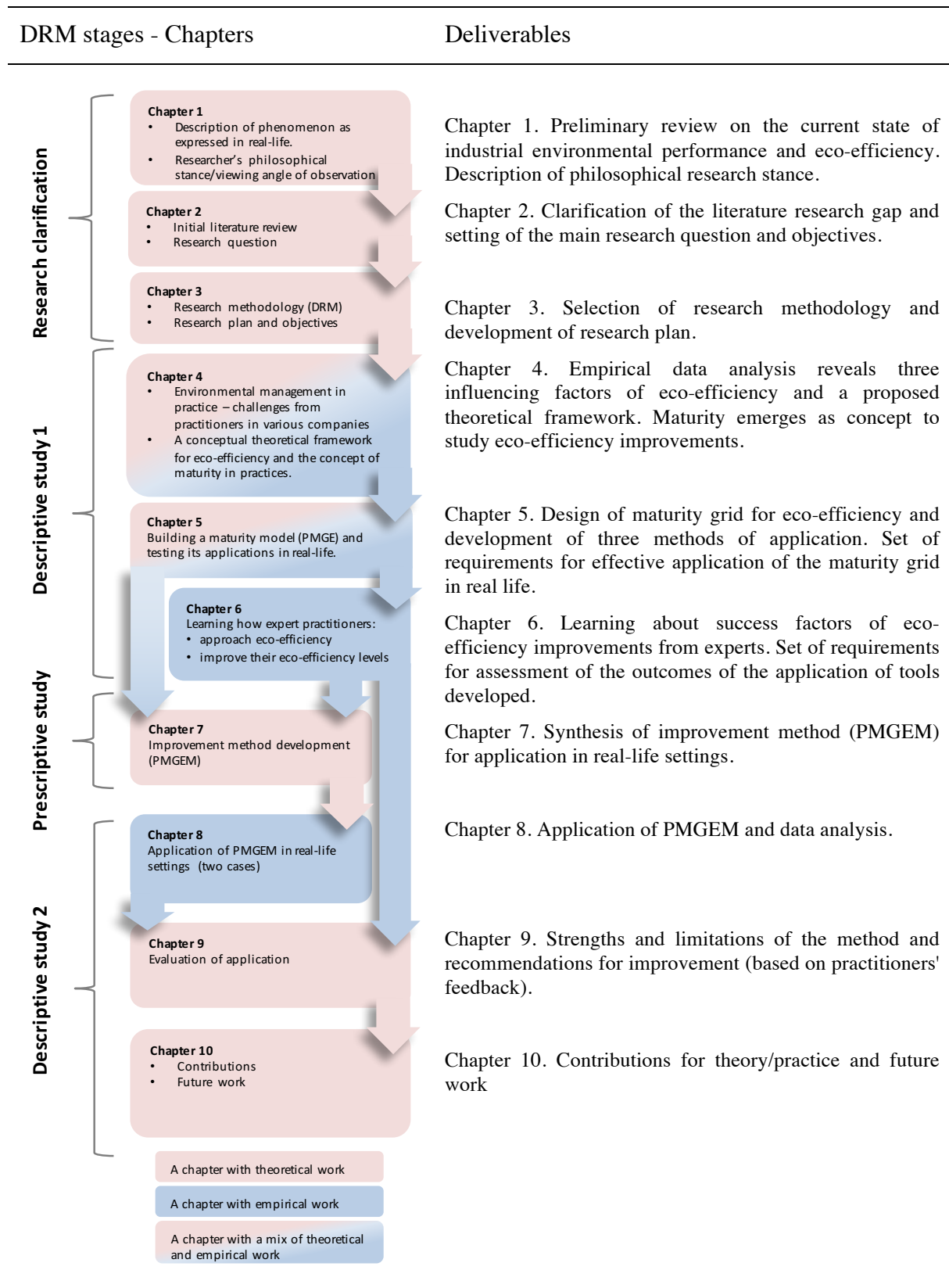
In this study, the fifth type of project was chosen (**Figure 3.2**). The first three stages are informed with literature and empirical work carried out in the descriptive study I (DS1) and the prescriptive study (PS). The descriptive study II (DS2) remains at initial level. Time restrictions did not allow the researcher to fully evaluate the outcomes of this work but indications of utility are discussed in chapter 9. In **Figure 3.3**, the researcher presents the overall research plan against the DRM stages with a short description of the chapter contents. The reader can also observe the flow of information between the chapters (how each chapter is informed from previous ones). Theoretical chapters in **Figure 3.3** intend to review literature or connect research findings to theory. Further literature support is presented throughout the chapters to clarify evolving research objectives or connect research findings back to theory. Chapters with empirical work contain the researcher’s interactions with practitioners in real-life situations.

Alternative research methodologies that have been explored include engaged scholarship (Van de Ven, 2007) and soft-systems methodology (Checkland, 2000). Potentially, both

alternatives could have been used but with DRM the alignment to the research objective was seen as more appropriate. DRM offers a more structured framework as it guides the researcher through his case studies and offers a good level of flexibility. For example, the researcher can do parallel work in the prescriptive and descriptive stages and inform his work or review his findings accordingly. Engaged scholarship was seen more appropriate for more theory oriented work on change management. For example, it could be used to navigate this work with emphasis on how companies may change their processes towards higher eco-efficiency levels. Alternatively, soft-systems methodology can be used for more narrow, problem-solving and participatory type of work (Blessing and Chakrabarti, 2009a). In this context, soft-systems methodology may have been useful in the case studies in chapter 9 to develop improvement solutions. Between these two options DRM seems a more balanced approach.

Nevertheless, Blessing and Chakrabarti acknowledge that DRM has not been used extensively for development of improvement methods and are more confident using it for product design research (Blessing and Chakrabarti, 2009a). Siyam further indicates that DRM does not offer an elaborate and detailed evaluation plan or discuss heavily on the applicability of findings in other real-life contexts for the fifth type of research project (initial DSII) (Siyam, 2014).

**Figure 3.3. Chapters and information flow based on DRM framework (type 5). Different colours indicate the transitions of this work between theory (red) and real-life (blue). The figure illustrates the four stages of project type 5 and maps them onto this.**



### 3.6 Avoiding bias

According to Miles and Huberman there are three archetypical *sources of bias* in qualitative research (Miles and Huberman, 1994):

- a) "*The holistic fallacy: interpreting events as more patterned and congruent than they really are*". This risk was observed in the case studies in chapter 4 and therefore the thematic analysis remained at a low level of resolution and a generic theoretical framework was produced.
- b) "The elite bias: over-weighting data from articulate, well-informed, usually high- status informants". This risk was observed in chapter 6 where the inquiry is informed by field experts. It is acknowledged that the cases in chapter 6 may influence the generalizability of the research output and additional cases are necessary to make more valid assumptions.
- c) "*The going native bias: losing one's perspectives and being co-opted into the perceptions and explanations of local informants*". This is another risk that the researcher was cautious about for two reasons. Firstly, as an ex-practitioner in manufacturing, the researcher's own perspective is already biased through own past experiences. Secondly, as the researcher spent more time with the practitioners in the case studies in chapter 8, caution was required to exclude the native bias from the observations. Third parties were consulted about this work in chapter 8 and feedback is presented (see section 9.2.1).

### 3.7 Research validity

The researcher is positioned within the settings where the phenomenon is observed. The data collected are influenced by people's perceptions or interpretations and therefore divergence of findings is expected rather than convergence to a single truth (Guba, 1981; Guba and Lincoln, 1982). Guba proposes four dimensions of validity in this type of research (Guba, 1981). These dimensions are presented below with a comments of how the researcher addressed these in this work:

- a) credibility: "*testing the data with members of the relevant human data source groups*". Researcher has presented this work in four academic conferences that supported peer-review processes and received feedback on content and applicability. In addition, the work up to chapter five has been published in a peer-reviewed journal.

- b) transferability: “form working hypotheses that may be transferred from one context to another depending upon the degree of "fit" between the contexts”. The theoretical propositions that have been developed through this work have been tested with several practitioners and in a range of companies. The researcher was interested in applicability of the propositions in different contexts. In chapters 5, 6 and 8 the applications are described. In chapter 7 the researcher describes the conditions for transferability in different contexts.
- c) dependability: “a concept that embraces elements both of the stability implied by the rationalistic term reliable and of the trackability required by explainable changes in instrumentation”. In order to secure internal consistency of the workings and findings, the researcher performs cross-case analysis in chapter 6 to finalise the first descriptive study (DSI). Additional analysis is performed in chapter 9 for the second descriptive study(DSII).
- d) confirmability: “requiring evidence not of the certifiability of the investigator or his or her methods but of the confirmability of the data produced. Data about the companies that offered the data in this work have been collected that offer a level of data confirmability”. Some of companies in this work (i.e. the automotive company in chapter 6) have been referenced by other companies here as exemplar for the practices they employ and the quality of their manufacturing system.

Building upon from Guba’s framework, Creswell and Miller propose an array of methods to check for validity that crosses research paradigms (Creswell and Miller, 2000). Overall, what Creswell and Miller propose is that even within a specific research paradigm (constructivist in this case), one may be open to review of validity processes from other paradigms.

In Table 3-1, the researcher reflects upon the validity methods that have been used in this study by cross-referencing the lens of the research stakeholders (left column) to the research paradigms that Creswell and Miller broadly fit research into (top row) (Creswell and Miller, 2000). Creswell and Miller suggest that it is beneficial to acquire as many tests as possible within an inquiry (however not all tests have been applied here).

**Table 3-1 Validity methods that have been used in this study (in italics).**

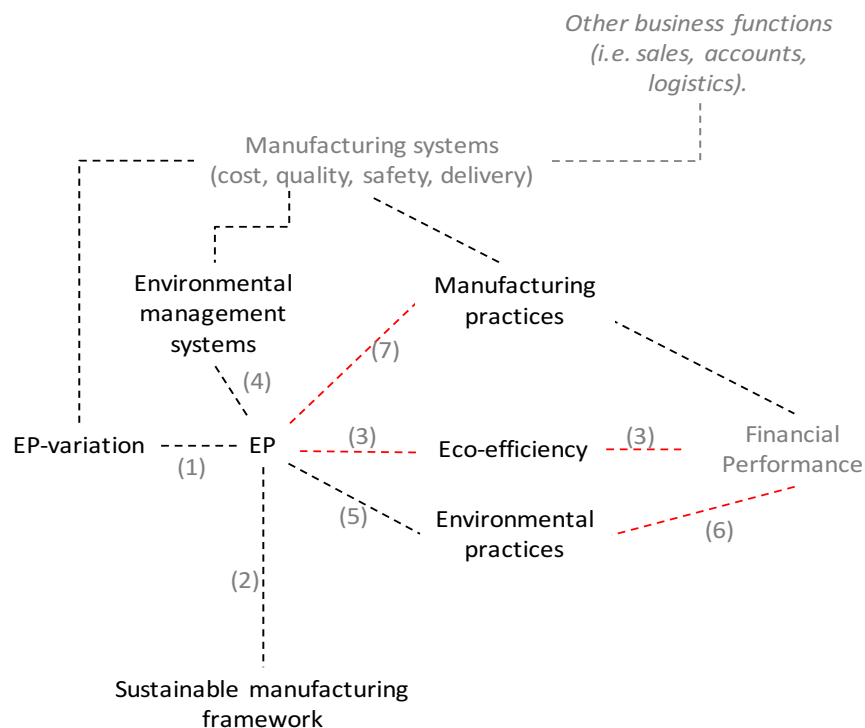
	Post-positivist or Systematic Paradigm	Constructivist Paradigm	Critical Paradigm
Lens of the Researcher	<p><b>Triangulation</b></p> <p>Some numerical data have been used to understand the connection between high EP and firm's performance. (i.e. graphs in chapter 7 for the automotive company).The graph provides confidence in the inductive analysis in chapter 4.</p>	<p><b>Disconfirming evidence</b></p> <p>Limitations in chapter 9 are presented in regards to the applicability of this work for certain audiences.</p>	<p><b>Researcher reflexivity</b></p> <p>The researcher was an ex-manufacturing practitioner and a certain level of bias was expected in the interpretation of findings. The researcher was relying on past industrial experience to make the tools more applicable to the audience by testing the tools on himself as a potential research participant. However, at the same time when it came to interpretation of findings, the personal bias remained a challenge.</p>
Lens of Study Participants	<p><b>Member checking</b></p> <p>Feedback on the methods has been requested from participant practitioners in all parts of the study. This method has also been used purposefully to check internal consistency in chapter 6 with one case.</p>	<p><b>Prolonged engagement in the field</b></p> <p>Time restrictions made the relationship with participating companies difficult. For example in one of the case studies in chapter 8, some of the participants were quite remote to build more effective relationships and this affected the overall process (had to be modified).</p>	<p><b>Collaboration</b></p> <p>In the prescriptive study the researcher was influenced to some extent by the two case studies. Expert views were very important both for internal validity but also for re-adjusting the researcher's viewing angle.</p>
Lens of People External to the Study (Reviewers, Readers)	<p><b>The audit trail</b></p> <p>N/a</p>	<p><b>Thick, rich description</b></p> <p>The level of detail in the maturity grid could have been thicker. It is one of the recommendations for future research to enrich the tools with more data and dimensions.</p>	<p><b>Peer debriefing</b></p> <p>This work has been reviewed in two PhD curriculum milestones (1<sup>st</sup> year report and 2<sup>nd</sup> year report) with the assigned PhD supervisor and advisor. Peer-reviewed papers have been written and helped the researcher to test and share the ideas with the wider research community (see list of publications).</p>

### 3.8 Review summary and research opportunity

Looking back into the literature chapter 2, the various topics that have been reviewed can be represented with an association diagram (figure 3.5). These diagrams are used in DRM to describe what the current status is and what the desired change will look like. In Figure 3.4, the reader can review the topics that this initial literature review has covered so far as links to

eco-efficiency. Starting from observed EP variations in various manufacturing settings, the researcher was led to find out more about EP under a framework that is consistent with his ontological and phenomenological perspectives (chapter 1). Sustainable manufacturing as a framework enables the researcher to interpret observations about EP and guide further research actions (section 3.3). The next step in this literature review is to better understand how environmental management systems have dealt with eco-efficiency (section 3.4.3). The effectiveness of EnMS has been challenged by various authors. On the contrary, researchers have focused on more specific environmental practices and behaviours (EPrs) to understand what may drive EP improvements. EPrs, being standalone features within a manufacturing system, are a sub-total of manufacturing practices (MPrs) (To et al., 2015). The latter have also been reviewed in terms of their contribution to EP improvement potential. The link between EPr and economic value is also inconclusive in the literature.

**Figure 3.4 The diagram demonstrates the areas that have been explored in the literature and the connections between them and eco-efficiency. The red lines represent the literature gaps that have been identified or alternatively what the desired change may be.**



It is further illustrated how EP and FP could be linked with alternative routes (i.e. through environmental practices or via manufacturing practices). Grey coloured areas (such as Financial Performance) are acknowledged but are not the focus areas of this work. The

narrative that unfolds based on this initial literature review follows the numbered links in Figure 3.4:

Link 1: EP variations allow us to explore the ways that EP can be expressed in various industrial contexts and conditions. Studies that reveal EP variation can be found in literature and guide researchers into underlying factors that influence EP in manufacturing (see section chapter 1 and section 3.4.1).

Link 2: Sustainable manufacturing as a framework guides research in addressing eco-efficiency issues in factories (section 3.3). Improvement methods for sustainable manufacturing have received little attention so far from researchers and very few (quantitative) studies exist that demonstrate how sustainability can be practiced in manufacturing (Despeisse, 2013; May et al., 2015; Thiede et al., 2013). Nevertheless, the potential for EP and financial performance (FP) improvement has been demonstrated by certain manufacturing companies (section 1.2.1).

Link 3: Eco-efficiency has been defined generically as “doing more with less” in the official reports and some of the literature (section 3.4). Various authors have tried to define quantitatively and translate this term in industrial context but there seems to be little agreement amongst researchers on what eco-efficiency is or how it can be practiced manufacturing. The researcher accepts the definition of “doing more with less” to bridge two measurable attributes of eco-efficiency: environmental and economic performance (see chapter 2 about accepted reality).

Link 4: Environmental management systems (EnMS) have been found to have contradictory environmental impacts and there are studies that imply that little or no improvements have been delivered through EnMS implementations (section 3.4.3). Potentially, EnMS can be one of the routes that can influence EP and FP in manufacturing. However, the conditions that support such systems need to be better understood by practitioners and academics. In Figure 3.4, EnMS is linked to other manufacturing systems as a standalone sub-system rather as a contributor to the overall manufacturing performance measures.

Links 5 & 6: There are examples of environmental practices in the literature that have been studied as standalone best practices in managing and improving EP (sections 3.4.4 and 3.4.5). To some extent EnMS can be considered as an environmental best practice that is typically optional for companies to choose and support. However, it is not clear in the literature how environmental practices can help manufacturers improve their FP.



Link 7: Manufacturing practices are traditionally and directly linked with FP and manufacturing systems. There are studies in the literature that attempt to link the effect of certain manufacturing practices on EP (section 3.4.5). Further empirical investigation is required to indicate whether or how this route can help manufacturers improve their EP and FP or alternatively their eco-efficiency. The lack of knowledge here has been previously flagged by Despeisse et al., when reflecting on the use of appropriate methods that enhance sustainable manufacturing (Despeisse, 2013).

Links 3,6,7 in red dotted lines in Figure 3.4 indicate possible routes to influence eco-efficiency or alternatively link environmental and economic performance. These specific links are weakly documented in the literature and highlight the research opportunity in this study.

### 3.9 Chapter summary

This chapter presented the research plan that guides this inquiry on eco-efficiency. It is based on Design Research Methodology (Blessing and Chakrabarti, 2009a). The study overall consists of four main stages: a research clarification stage (chapters 1-3), two descriptive studies (chapters 4-6, 8-10) and one prescriptive study in chapter 7. Validity considerations have also been presented. Validation of the workings from following chapters is discussed in chapters 9 and 10. This chapter can be considered as parallel to chapter 3, where the researcher intends to clarify the objectives of this study and the current knowledge gaps. The researcher acknowledges the influence of the chosen research design on the outcome of the literature review in chapter 3 and the research clarification phase. The following chapter initiates the first descriptive study of this work (chapters 4, 5, 6) and responds to the first research objective. The researcher initiates engagement with practitioners in various real-life settings and informs the inquiry with empirical data collection and analysis.

# 4 INTERVIEWS AND THEORETICAL FRAMEWORK

## 4.1 Introduction to the chapter

Chapters 4, 5 and 6 are components of the Descriptive Study 1 (DS1). In the first part of this chapter, data are collected through interviews with practitioners that are directly involved in projects for energy and resource efficiency in manufacturing systems. The researcher seeks to learn more about the challenges they face and how these are overcome. The interviews introduce a range of perspectives on eco-efficiency. The researcher explores what the challenges and contextual conditions are in each case.

In the second part of this chapter data are analysed. The researcher aims to understand the influencing factors for eco-efficiency improvements. The analysis is linked to theories that may further support the objectives of this inquiry.

## PART A. EMPIRICAL DATA ACQUISITION

### 4.2 Audience, access and data collection process

The selected companies are manufacturers or manufacturing service providers that have publicly expressed their interest or work in eco-efficiency. Their relationship with eco-efficiency was indicated either by being affiliated with an organization that promotes environmental management or being known for their own sustainability initiatives (for example environmental awards). More specific selection criteria were not defined at this phase. However, limitations such as geographic location of manufacturing sites did exist as most companies contacted had their headquarters in the United Kingdom (UK). Another limitation is the control that the researcher had over the type of manufacturing activity or type of product i.e. continuous, mass production versus discrete and modular production. Companies that cannot be considered as manufacturers but instead provide an environmental-oriented solution/service (i.e. energy auditors) to manufacturers were also invited. The latter offered their opinions about manufacturing systems and eco-efficiency, based on their experience through consultancy services.

The companies presented in this chapter are all anonymized to maintain the requested level of confidentiality across all participants. These are described in Table 4-1. At this phase, an interview guide was developed to help the researcher have semi-structured interviews. The interview guide can be found in Appendix A. It consists of open questions regarding EP variation. EP variation, as described in Table 1-1, can take various forms and was used as a way of describing the research challenge and gaining access for interviews. It was found to be easier to describe EP variation than trying to define eco-efficiency. The interview guide was sent out approximately a week before the interviews. The researcher allowed time for interviewees to consider material issues of EP variation in their factory that they would like to discuss. Table 4-1 describes the 9 companies that took part in this phase of the study. Each case is briefly presented to provide some contextual information to the reader.

**Table 4-1 Participating companies and sectors. the table demonstrates the range of companies that were contacted for the descriptive study and the data collected in each case.**

Company	Industry	Type of manufacturing	Interviewee experience in eco-efficiency projects	Length of interview (minutes)	Artefacts
<b>1. Car 1</b>	Automotive	Discrete	No	60	notes
<b>2. Construction company</b>	Construction projects	Discrete and service provider.	Yes	60	transcript
<b>3. Energy management consultancy</b>	Energy efficiency auditing	Service provider	Yes	30	emails, reports, factory audit
<b>4. Pumps manufacturer</b>	Pump manufacturing and solution provider	Discrete & service provider	No	90	transcript
<b>5. Car2</b>	Automotive	Discrete	Yes	120	notes
<b>6. Civil aircraft manufacturer</b>	Aerospace	Discrete	Yes	60	notes
<b>7. Grain mill</b>	Food (commodity)	Process	No	60	notes
<b>8. Waste management organization</b>	Working with companies, individuals and local authorities	Service provider	Yes	-	Emails-project report
<b>9. Industrial Community</b>	Industrial Community	Service provider	No	60	Emails and access to community forum

#### 4.2.1 Car manufacturer 1 (Car1)

The company is a UK multinational automotive company headquartered in the United Kingdom, and is a subsidiary of an Indian group. The interviewee was one of the production managers who is set responsible for driving and implementing the environmental strategy in the factory where he is positioned. The interview focus was more on measurable targets and specific measures that the company implements. They have been certified with ISO14001 since 1998 and their targets with a 2007 baseline are:

- 25% CO<sub>2</sub> reduction in operations by 2015
- 25% reduction in joint fleet average carbon dioxide (CO<sub>2</sub>) by 2015
- 25% reduction in waste to landfill by 2015
- 10% reduction in water consumption by 2015

The practices for sustainable manufacturing that he would like to implement are:

- Plasterboard technology for use in regulating indoor temperatures
- Rainwater harvesting
- Solar thermal heating
- High efficiency lighting
- Spray foam insulation
- Wind powered engine plant

The factory he runs has delivered 50 projects in 5 years which have saved over 5m tonnes of CO<sub>2</sub>. Their aim is to save 9 million tonnes of CO<sub>2</sub> by 2014. Projects include:

- Variable speed drives onto motors – in particular with air compressors.
- Gas heaters installation, as external boiler houses are being phased out.
- Combined heat and power is used in some locations.
- Solar panels in roofs

The interviewee considers automakers Toyota and BMW to be pioneers in eco-efficiency and environmental benchmarking at least in the automotive sector. One of his challenges is to share best practice across their sites and he was concerned with the production benchmarking process on cost, quality, safety, morale and environment as in: *“having accurate and meaningful indicators”*.

#### 4.2.2 Construction company

This family owned company operates in the construction sector primarily in the UK and employees approximately 1000 people. It consists of four divisions: buildings, highways, plant and construction equipment and consulting services for the sector. The company had won several awards for its environmental improvement efforts and quickly accepted the invitation to participate to this study. The interviewee was the environmental, health and safety manager who had been working there for 8 years at the time of the interview. The company is developing its construction sites in every contracted project in various locations in the UK with an average of 100 people each. A certain level of standardization is required each time and a way to control operations is also necessary as each project is unique. Best environmental practice is one of the areas they want to improve and this also affects the corporate headquarters (offices and buildings).

The 2008 financial crisis made the company realise that cost savings can be made when improving energy and resource efficiency. The drive to be more efficient was supported from the owner of the business who represents the environmental function at board level. Practices such as “environmental champions”, quick-wins and rewards were additionally implemented at headquarters, to influence behaviours towards environmental improvements. Top-management ran a survey to learn what their employees could propose to save energy and resource. Three environmental improvement objectives, coming from employees, were included amongst the 15 corporate future objectives overall.

#### 4.2.3 Energy management consultancy

The researcher had the opportunity to learn about energy efficiency from a company that provides energy auditing, monitoring and consulting services in manufacturing. Through a government funded scheme this service provider was performing a series of energy monitoring and mapping audits in scheme participating companies. The researcher was invited to observe their work in a textiles factory operating in the UK for the past 250 years. The company was fully funded from government to undergo the energy audit and there is some doubt to whether this would have happened without any external financial support.

Energy meters were installed for monitoring energy usage on production equipment and the results were translated in cost saving opportunities. The output and recommendations of this work were also presented in cost savings to top-management. This cost-driven presentation was designed to enhance the engagement with managers more effectively and gain their attention for improvements due. The initial results from the audit were shared with the researcher. The latter was also invited at the presentation of the results to the factory directors. During the presentation of results (for example showing machines performing the same task at different energy requirements) managers and directors found it very difficult to explain some of the results and finally decided to carry out all the improvements specified.

The energy auditor himself was also interested in academic research on eco-efficiency as he felt that theoretical research work would help him identify and carry out improvements better. He was also interested in growing his business in the energy efficiency consulting area. He felt that it would be helpful to learn about it from the academic community.

#### 4.2.4 Pumps manufacturer

The company supplies pumping systems in various industries and further offers aftersales service. As pumps are widely used in industry today, pump efficiency is important because of the scale of such application and the misuse that occurs in pumping systems (Kaya et al., 2008). This case study was a valuable addition to this research phase, as the interviewee (the business manager for energy systems) had gained a wealth of experience in this sector from visiting factories. As in the case of the energy auditor previously, the interviewees were people that had observed energy and resource misuse in industry and repeatedly mentioned non-technical barriers to energy efficiency aligned to the ABB report of 2010 (*ABB Energy Efficiency Solution*, 2010).

The company had set a strategy to provide, integrated pumping solutions having examined the customer requirements and market trends. In the manager's view this was the best way forward for them. However, not a lot of information was revealed about the company's environmental performance at a manufacturing level. Instead the manager was happy to discuss about his observations in the field for the past 25 years. For example, the case of a factory technician that would not let his superiors know about a quick fix that he made in a pump, out of fear of losing his job. This quick fix was found to be costing thousands of pounds per year to the company.

Pumping systems belong to a range of ancillary equipment that can be found across many industrial sectors, along with motors and air compressors (*ABB Energy Efficiency Solution*, 2010). It can be debated whether some industries have managed to make more efficient use of this equipment. According to the business manager in this case study hotels probably excel in this dimension of pump use: “*..hotels will probably be way ahead of other people because they are incredibly price conscious...they will be innovators of this [use of pumping systems]*”.

#### 4.2.5 Car manufacturer 2 (Car2)

The company is a leading global automotive manufacturer and a lean management pioneer. They are actively pursuing environmental and social sustainability improvements and other companies find their methods inspirational or exemplar. The interviews were held with the environmental and social responsibility manager for Europe and one of their factory managers in the UK. The company has been continuously improving on various environmental indicators for the past 20 years and they feel that the environmental proactive

thinking already lies within the way their practitioners work. Being able to quantitatively assess improvements on energy and resource efficiency is a challenge and naturally escalates when one has to measure efficiencies across multiple production sites (9 sites in the European branch). However, according to the factory manager, they do acknowledge that sometimes measurement may not be the key ingredient in efficiency efforts:

“I believe that companies are looking at theoretical frameworks as a means to achieve certain quantifiable targets or goals. It's difficult to assess the effectiveness of a system without a measurement baseline and tracking systems. On the other hand, I also agree that some quantitative indicators could be misleading or even influenced by external factors of production systems, which do not reflect the improvements of the system in place.”

As there was access to people involved in corporate sustainability in key positions the researcher was able to extend this particular case study in the Prescriptive Study (PS) in chapter 6.

#### 4.2.6 Civil aircraft manufacturer

This aircraft manufacturer operates eleven production facilities across four European countries and has developed and sustains an environmental sustainability strategy since 2006. The interviewee was an energy efficiency specialist in one of their UK sites. Several eco-efficiency projects had been initiated across all sites. There was strong effort to monetise the allocation of human and material resource per improvement project and per employee. Managers had to make sure that this resource allocation was matching the expected improvements and savings. Processes were in place to support these projects and meet savings expected.

A lot of effort was also being placed in supporting good communications and information flows between manufacturing sites and keep people connected (newsletters, collaborative electronic platforms, television channel). Industrial internal networks had been created for various functions of the business i.e. technology management, innovation or even gender equality). Similarly, to the previous case, this case was taken forward to the prescriptive study to learn more about eco-efficiency across such manufacturing networks.

#### 4.2.7 Grain milling company

The company operates in the commodity sector (wheat products) and owns twelve sites in the UK. It had recently been acquired by a large UK food manufacturing group. The researcher



met with two managers in one of their sites who were interested in learning more about the research on eco-efficiency. This is a process type of industry that depends heavily on equipment that few suppliers can provide. The interviewees demonstrated good technical knowledge on product-making and were well-aware of the energy consumption at process level caused by raw materials quality variation, seasonality of demand and overstocking. However, the energy and resource efficiency strategy they were trying to implement was not meeting its targets as fast as they had scheduled, with the exemption of the zero-waste-to-landfill project they achieved in 2010.

As the company runs multiple sites in the UK, that make similar products with similar processes, there is a level of differentiation between sites that have different customers. For example, the sites that make product in large quantities (bulk packaging) have better energy utilization per kilo of product. The company is aware of this difference in energy use but it was not clear during the interviews whether this was an issue they were trying to resolve. Overall, there was little evidence of an improvement strategy behind their improvement initiatives (mostly on energy efficiency).

#### 4.2.8 Waste management organization

This is a government led organization that is tasked to drive energy and resource efficiency across a range of industries and connects industrialists with policy makers and academic communities. A meeting with one of their representatives and emails exchange with another senior member of the organization were established through the Centre for Industrial Sustainability at Cambridge University. The organization is concerned with funding new research projects that have easy industry adoption and develop further guidance for practitioners. It operates as a charity organization and is accountable to its stakeholders, (primarily government) for the funding they provide to businesses. Funded projects are assessed and great effort is made to maintain records and track results against targets.

The case study here reports the learnings from one of their sub-programs that ran in the UK between 1994 and 2009. The program was funded by government and claimed to have saved 2 billion pounds through energy and resource efficiency savings in companies nationwide. During the program, approximately 250 improvement guides were published with a focus on energy and resource efficiency in factories. In addition, tools were developed to share this type of information. The aim was to interact faster with the target audience (industrial practitioners). In terms of efficiency and value for money this represents a saving of £38 for

the business for every £1 invested by government. Since 2007 approximately 20% of the total target market used the programme's services.

The official program aims were:

- to convince businesses about the benefits of resource efficiency;
- to provide businesses with accurate, credible and action orientated advice;
- to provide better integrated advice and support to business through partnerships
- to ensure outcome targets are being achieved through impact assessment;
- to ensure credibility as a recognised and valued provider of practical, independent and confidential advice; and
- to increasingly embed resource efficiency into everyday business practises.

The program was trying to achieve these aims through work on various organizational levels namely:

- Process or product improvement (mainly)
- Product or service redesign
- Technology change
- Systems design

#### 4.2.9 Industrial community

This organization runs and supports a collaboration platform for manufacturers and businesses with over 49,000 members from 178 countries and promotes energy and resource efficient economic systems. They run large-scale programs and provide member services that enable thousands of people to solve problems, share best practice and collaborate to procure solutions. As a result, they claim that their members and clients are able to accelerate their sustainable business strategies to innovate and cut costs, risks and impacts, whilst at the same time drive shareholder value up. The primary contact for this forum was one of the project managers with key portfolio, at the time of the study, to drive and improve the sustainability of a large retailer's supply chain in the UK.

The data from one of their workshops related to eco-efficiency are used in this study to understand the organizational and business challenges for eco-efficiency improvements. The results from the workshop suggest that one has to consider improvements in 3 organizational levels, namely: shop-floor, middle management and senior/board directorship.

#### 4.2.10 Cases summary

The cases presented in the first part of this chapter showcase the way that eco-efficiency is approached in various industrial settings by companies and professionals. The data from interviews and material collected are analysed in the second part of this study (see summary in Table 4-2). The aim of this analysis is to better understand the support requirements that can facilitate eco-efficiency improvements in manufacturing.

**Table 4-2 Summary of approaches and challenges regarding eco-efficiency from the case studies in Table 4-1.**

Company	Eco-efficiency improvement approach	Challenges relevant to this study
Car1	Environmental benchmarking across and within manufacturing sites.	Sharing best practice and tracking results across sites (follow up in prescriptive study)
Construction company	Capturing information across projects and engagement with people. Rewarding contributions and top-management commitment.	Scaling improvements across construction projects
Energy solutions provider	Installing metering equipment and producing improvement scenarios. Process level improvements but missing a robust and standardized improvement method.	Guiding companies into better, sustainable energy management rather than delivering one-off energy efficiency improvements.
Pumps manufacturer	Being aware of the issues in oversized and abused equipment in factories the company changed their business model to provide support for practitioners to find the right pump for their needs.	Very hard to educate people into using their equipment efficiently and design efficient systems.
Car2	Standardization and benchmarking across manufacturing sites	(follow up in prescriptive study)
Civil aircrafts	Engaging people in energy efficiency and sharing best practice.	The scale of operations (11 manufacturing sites) makes improvements difficult to track and scale-up. This is however true for more traditional manufacturing
Grain mill	They've set energy and resource reduction targets and an improvement strategy. However, this process was lacking support from top-management and was rather slow.	Not a clear indication of a long-term strategy behind their targets. Not clear sense of direction, reasoning or urgency.
Government led body	Funding valuable projects and tracking savings. The organization is developing long term planning solutions for a range of industrial sectors and is currently adopting a circular economy type of approach for the environment and natural resources.	Developing large scale programs with high-potential. It is an organization that seems to be adapting to business trends.
Industrial community	The community manager is building a best-practice sharing platform for eco-efficiency for one of the retail market leaders in the UK. They are currently collecting best practices from the retailer's supply chain factories and try to promote these to other factories through this online collaboration platform.	In the context of improving the environmental performance of the retailer's supply chain overall, a lack of a coherent improvement strategy was observed.

## PART B. DATA ANALYSIS AND CONNECTION TO THEORY

### 4.3 Data analysis

Interview data were recorded with permission by the practitioners and transcribed. If recording was not an option, hand-written notes were kept during the sessions. In some cases, data were collected by email exchange (see Table 4-1). The diversity of the audience and industries involved were such that only a thematic sorting was seen as possible at this stage. The data analysis process was inductive (Thomas, 2006). This type of analysis can provide simple and systematic procedures to analyse qualitative data (Siyam, 2014). The process the researcher followed consists of three steps:

1. The researcher read all data carefully and repetitively until he memorised what each interviewee described in good detail.
2. All transcribed data were compiled in one table in excel.
3. Broad themes were developed within that table and each bit of interview information was then sorted accordingly. The researcher made notes in a separate column that helped him control the overall process and critically question/interpret the interview data.
4. The categories and comments helped the researcher explore non-interview data (i.e. corporate document and reports) and populate the information database.

All transcripts were read multiple times so that the researcher would familiarize with the content and evidence collected. The data was divided in 3 themes in an excel sheet namely:

- “Practice description”, where the interviewee describes a method or a tool or a routine (as per the definition of a manufacturing practice by Walls et al., (2012). See section 4.3.1.
- “Indication of strategy/purpose”, where the interviewee mentions the reason why a particular practice exists or the purpose it serves. See section 4.3.2.
- “Indication of organizational capability/resource”, where the interviewee describes how a practice is supported by the organization (i.e. technologically, culturally). See section 4.3.

The analysis table contains 257 rows, 3 columns and overall 13206 words in 771 cells. Example of the analysis table is given in **Figure 4.1**. Non-interview data, such as reports, emails and corporate documents were analysed and used to shape the analysis output. The

following three sections focus on each one of the themes that have been identified as a common pattern in the cases.

**Figure 4.1 Interview data analysis in three themes.**

Practice description	Indication of strategy or purpose	Indication of organizational capability/resource
<i>Evidence, comment, underlying practice</i>	<i>Evidence, comment</i>	<i>Evidence, comment</i>
<i>delays are being analyzed continuously to try and form this continuous improvement he is looking at all of our accreditations and all of our quality improvements that they are applicable too</i>	Sharing best practice from a model factory	<i>as a measure of this investment we now have a continuous improvement manager so a young lad, graduate that's focusing on that...but his role is also global</i>
<p><i>Monitoring and targeting</i></p> <p><i>We recommend that this is a compulsory step as what you don't measure you cannot manage. It isn't an 18 month project anymore but more than likely an 18 day project – we can install into most operations within a day.</i></p> <p><i>This is also something that needs to be ingrained into the culture (which does typically take 18 months to succeed).</i></p>	<p><i>(a basic cost-based manufacturing strategy should have this)</i></p> <p><i>Accountability for controlling energy consumption should rest with the people who use it, namely the brewery's departmental managers. The plant controller should also be involved since this is the person who will want to know how these controllable costs are managed.</i></p>	<p><i>Metering equipment is necessary as well as trained people to install this, otherwise outsourcing this process (like with Ecopare).</i></p> <p><i>(Brewer's guide:) "The fundamental principle of M&amp;T is that energy and other utilities are direct costs that should be monitored and controlled in the same way as other direct production-related costs such as labour and malt. As such, actual energy use should be included in the management accounts in the same way as labour or malt is included."</i></p>
<p><i>initially looked at carbon a couple of years ago in terms of measuring it...we found there were lots of different ways of measuring carbon...cradle to gate...cradle to grave...and it was that...what do we do...where do we go with this...who is asking for this information</i></p> <p><i>with some plans now we use the e-carbon calculator...yet not every customer is asking for that and being honest we don't do it to every project..but we do have one client that wants to measure that from the start of the project to the end and throughout the installation we've put in..</i></p>	<p><i>this is guided by the client (business case is granted)</i></p>	<p><i>Systems to monitor/measure carbon or other env.perf.indicators</i></p> <p><i>so we do use the e-carbon calculator to measure that</i></p>

### 4.3.1 The role of practices in eco-efficiency improvements

The first theme describes what can be categorised as practices in manufacturing following the definition adopted by Canato et al., 2013 (see section 3.4.5). The differentiation implies that environmental practices are a subset of manufacturing practices. The definition by Walls et al. further highlights the social side of practices (section 3.4.5).

From chapter 3, Figure 3.4, it was concluded that eco-efficiency can be influenced by generic manufacturing practices as well as environmental-oriented practices. Both types of practices can influence environmental and economic performance. Potentially, certain practices may have a stronger influence on eco-efficiency than others or may be more preferable in some

companies than others. This potential may then be characterised by a degree of maturity that each practice requires. The degree of maturity would indicate how easy or hard it can be for some companies to implement the practice at full potential. Practice maturity here refers to the sophistication of the routines, tools and concepts that are used to accomplish a certain task (using the definition above by Canato et al., 2013).

#### 4.3.2 Strategic intent

Scope and alignment of performance improvements to manufacturing and business strategy has been a key driver in many change initiatives and it is perhaps not a coincidence that it has appeared in this study (Ahuja and Hart, 1996; Aragón-Correa and Sharma, 2003; Paiva et al., 2008; Perego and Hartmann, 2009). The interviewees in most cases would refer, directly or not, to the link between EP and their manufacturing strategy or purpose. For example, the strategic differentiation of production i.e. bulk vs specialty products between sites had an impact on the environmental performance of each site. In bulk production, big batches were allowed with less changeovers and delays in production, ultimately using less energy per kilo of product compared to specialty, smaller batch production. The word “strategy” was also found to be an indication of purpose behind some actions without evidence of organized actions or evident competence in planning ahead. Like in the example below, purpose behind actions taken or practice performed was not always clear:

“... at that time we were engaged with NISP and Envirolink and also we got involved with WRAP because we did the "halving waste to landfill" initiative so was part of that we had a package to work with a consultancy to improve some of our policies, look at supply chain, look at how we were vetting waste management companies and developing our systems for capturing information”. – Environment, Health & Safety manager in construction business (see section 4.2.2). It is assumed that it is the alignment of manufacturing practices to a key strategic purpose that may add economic value to a particular environmental improvement plan.

#### 4.3.3 Organizational resources and capabilities

The third column gathered evidence about the organizational resources and capabilities that are available or missing from the manufacturing system and thus support or delay eco-efficiency improvements. The age of certain assets (equipment or buildings), availability of

experts (i.e. dedicated energy manager) and/or measurement systems are some of the necessary resources that the company owns or leases to carry out improvements:

“Metering equipment is necessary as well as trained people to install this, otherwise outsourcing this process”. – Energy consultant (see section 4.2.3)

Certain resources are necessary to support specific practices. These can be tangible or rely on people’s skills and expertise. However, resources can be also costly and it was found that not all companies can resource practices at the same degree or achieve equivalent levels of performance. It is assumed that there are various ways of supporting a practice, depending on availability of organizational resources and capabilities.

#### 4.3.4 Data analysis summary

Overall, the data analysis indicated three broad factors that influence eco-efficiency: organizational resources/capabilities, strategic intent/purpose and practice maturity. In order to better clarify their role, this researcher reviewed relative literature using combinations of keywords: strategy, competence, capabilities, maturity, practices, manufacturing, eco-efficiency. The snow-balling technique as described in chapter 3 led to a deeper investigation of these three factors. In the following paragraphs the researcher explains which theoretical concepts are aligned with the data analysis and how they link back to the objectives of this inquiry.

#### 4.4 The resource-based view theory and eco-efficiency

Reflecting back to the original issue of EP variation and environmental benchmarking between companies the element of competition surfaced after the interviews. In the late 1980s a theory emerged to explain why companies with similar physical assets may show variation in manufacturing performance. This theory focused in internal capabilities and how companies may leverage their know-how to gain competitive advantages in the market. The core-competency perspective focused attention on the importance of knowledge creation and building learning processes that would lead to competitive advantage. (Bartlett and Ghoshal, 2002). The resource-based view (RBV) of the firm emerged and proposes that firms that build their strategies on assets that are path dependent, socially complex, and intangible, can outperform firms that build their strategies only on tangible assets (Barney et al., 2011; Wernerfelt, 1984).

Specific organizational resources (tangible or intangible assets) and strategy (path dependency) were mentioned during the interviews. The connection between strategic intent and organizational resources has been explored in the literature and its importance here needs to be clarified. The first distinction that needs to be made is between different types of resources. From a business perspective, resources are the “*tangible and intangible assets that a firm owns or accesses to conceive and implement strategies*” (Barney, 2001). Intangibles have four intriguing features that distinguish them from tangible resources:

1. “Intangibles do not deplete or deteriorate with use. For example, a person’s skills may improve with use. Hence, intangibles are expected to confer benefits for an undefined time frame as opposed to tangible resources, which have expected depreciation. (Gautam Ray et al., 2004)
2. Multiple managers can simultaneously use intangibles. For example, the use of a brand does not make that brand less available to other managers. (Gautam Ray et al., 2004)
3. Intangibles are immaterial (inaccessible to the senses). Immateriality makes intangibles difficult to exchange, as they often cannot be separated from their owner. Indeed, to acquire an intangible such as a brand, firms must often purchase the organization. (Gautam Ray et al., 2004)
4. Finally, resources and capabilities within an organization are embedded in the organization, and the degree to which they are able to add value may depend upon the presence of complementary assets and supporting routines (Christmann, 2000). Aragón-Correa and Sharma further notice that “complementary process capabilities may contribute to cost advantage when a firm implements best practices for environmental management” (Aragón-Correa and Sharma, 2003).

Competency-based strategies are dependent on people. Scarce knowledge and expertise drive new-product development, and personal relationships support key clients at the core of flexible market responsiveness (Bartlett and Ghoshal, 2002). It is important to understand how social and organizational processes (i.e. internal learning) influence eco-efficiency and how these have evolved over time within one company (path dependency). Copying practices that work well in one company may not work equally well in another as these may be “*idiosyncratic and path dependent*” (Gautam Ray et al., 2004; Schroeder et al., 2002). Therefore, the influence of the organizational specific conditions is important to be acknowledged in this work. Profits may be generated through copying of best practices but



not value (Gautam Ray et al., 2004). An example of value generation within the RBV theory can be the increase of intellectual capital and its influence on firm's performance (Carlucci et al., 2004; Figge and Hahn, 2004; Pike et al., 2005).

In 1995 Hart suggested that RBV is a theory that is constrained by the limits of the natural environment where companies operate (Hart, 1995). Barney et al., observe that: *"models of sustainable competitive advantage need to be expanded to include the constraints and challenges that the natural environment places on firms, and how resources and capabilities rooted in the firm's interaction with its natural environment can lead to competitive advantage (Barney et al., 2011)*. Hart proposed three applicable strategies that can be followed within this extended version of the natural-RBV theory (n-RBV), see Figure 4.2:

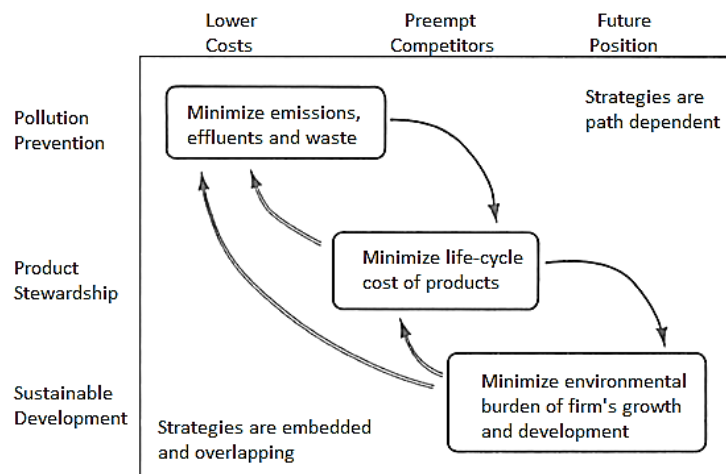
- a) pollution prevention, where companies seek to improve internally and become more efficient in using energy and resource and producing less waste and pollutants to the natural environment.
- b) Product stewardship, where companies seek to improve the environmental performance of the product throughout its life-cycle (life-cycle analysis is a practice that can facilitate this process).
- c) Sustainable development, where companies seek to eliminate their environmental burden as they grow.

The researcher has chosen to align this inquiry with the RBV and specifically its extension n-RBV as it offers a clear link to cost-advantages through pollution prevention and follows an internal view of the manufacturing system. The latter property is important as it sets well-defined boundaries for the inquiry: the eco-efficiency improvements within the manufacturing system of a business. As there is particular attention to the influence that practitioners have in the improvement process as intangible assets, n-RBV is well-aligned to the researcher's philosophical stance.

Other relevant theoretical frameworks such as industrial ecology (Frosch, 1992; Jelinski et al., 1992) or systems thinking (Checkland, 2000; Senge and Sterman, 1992) could be alternative theoretical options here and there are some methodological overlaps. However, industrial ecology has a broader perspective of the manufacturing system as it tends to incorporate more businesses in the improvement efforts. Eco-efficiency synergies between companies have been studied in the literature but the economical side of the synergies is not always clear (Despeisse et al., 2012; Golev et al., 2014). On the other hand, systems

thinking as a concept focuses on problems that are well-bounded and specified (Blessing and Chakrabarti, 2009a). System's thinking would be more appropriate methodology for use within a particular company.

**Figure 4.2 Hart demonstrates how strategies with a different focus area of EP improvement are linked to each other. This inquiry is focusing more on the top-left corner of this framework where pollution prevention is also seen as a way of manufacturing**



Another reason to align this work to n-RBV is the link that it offers to strategy and purpose. Environmental strategy can be different to manufacturing strategy (i.e. the capabilities that a factory has to generate competitive advantages (Schroeder et al., 2002). As one moves from pollution prevention to sustainable development, in Hart's framework, environmental strategy is integrated into manufacturing strategy as it becomes part of the business growth. This particular observation is explored further in chapter 6. Indeed, Sanchez argues that because RBV lacks adequate conceptual basis for constructing such chains of causality, "the core proposition of the RBV is simply theoretically unjustified, and therefore the RBV provides no actual basis for enacting the core proposition in practice" (Sanchez, 2008).

From a high-level view, it seems logical to consider that the effectiveness of organizational capabilities and resources can be leveraged if these are aligned to a strategic goal (Trevor and Varcoe, 2016). Sanchez, has criticized this link however for lack of clarity and there are not many detailed studies in the literature to show how resources are strategically used to achieve competitive advantage (Sanchez, 2008). Strategy formulation can be constrained by social and organizational practices and this could potentially explain the lack of clarity that Sanchez observes (Vaara and Whittington, 2012). Nevertheless, the researcher did observe the

connection between practices and alignment (or lack of alignment) in the companies that were introduced in the first part of this chapter.

#### 4.5 Practices and the concept of maturity within RBV

The RBV theory expresses the idea that companies can obtain competitive advantages through the development of internal competencies. Barney and Grant in the late 1980s and early 1990s started developing this theory through the viewing angle of core capabilities and competence (Barney, 2001; Grant, 1991). The rigidity that this theory implied for the core strengths in the manufacturing system was addressed by Helfat and Peteraf in 2003 with the introduction of dynamic capabilities as change enablers in the system (Helfat and Peteraf, 2003). The implication for the RBV was the development of a theoretical branch about operational and business capabilities and routines and how these may form internal competitive advantages. This is the link to manufacturing practices according to the earlier definition of practices by Walls et al. Helfat and Peteraf describe an organization as mature when capabilities can be maintain and are time-persistent (Helfat and Peteraf, 2003). They use the metaphor of an athlete that exercises (they would be using the word “exercise” to imply practices):

“The maturity stage entails capability maintenance. This involves exercising the capability, which refreshes the organizational memory. If exercised regularly, the capability becomes more deeply embedded in the memory structure of the organization. Routines may become more habitual, requiring less and less conscious thought. Over time, the ability of the team to recall the development path may fade and the capability may become more tacit in nature. This shift to reliance on 'softer' forms of organizational memory does not imply any change in the level of capability. Evidence from experience curves shows that under conditions of continuous production, productivity declines do not set in. Interruptions in production, however, do lead to organizational forgetting and declines in productivity. By implication, how well the capability is maintained depends on how often and how consistently the team exercises the capability” (Helfat and Peteraf, 2003).

A similar way of describing internal capabilities (i.e. through regular exercise) has been expressed in the work of Ferdows and Thurnheer (2011) using the notion of “factory fitness”. In a 15-year case study across 42 aluminium plants, Ferdows and Thurnheer propose that a factory can learn to continuously accumulate capabilities and use those as skills for further improvement Ferdows and Thurnheer (2011).

The concept of maturity has also been used in other types of studies to describe the way that a process evolves in time. It has been applied in risk management for projects (Yeo and Ren, 2009), intra-organizational collaborations (Campos et al., 2013), performance measurement (Bititci et al., 2005) as well as product eco-design (Pigosso et al., 2013). Definitions of maturity can be given through a maturity model, where the typical behaviour is exhibited in a number of levels of 'maturity', for each of several aspects of the area under study (Fraser et al., 2002). In each aspect and level of the maturity model a description of how maturity is expressed is given by the researchers. A maturity model can be developed that describes how organizational maturity and practices influence eco-efficiency. Practices at low-maturity levels would then show a negative or neutral potential for eco-efficiency, whereas high-maturity practices would have a positive improvement potential. *Advancing on the evolution path between the two extremes involves a continuous progression regarding the organization's capabilities or process performance* (Becker et al., 2009).

As this remains a qualitative study, the researcher acknowledges that the potential for improvement can also be case specific. It is also acknowledged that the use of maturity as a vehicle to describe manufacturing practices implies that these are seen as a dynamic rather than static elements of the manufacturing system (Ven and Poole, 2005). This dynamic view of manufacturing practices is aligned to the RBV theory and dynamic capabilities (Peteraf, 1993; Teece, 2007).

#### 4.6 Organizational maturity and eco-efficiency in practice

Following the assumptions in section 4.3.1, in order to examine the link between eco-efficiency and practices in manufacturing, the researcher explored the concept of maturity further. Manufacturing strategy and organizational resources may facilitate the adoption and maintenance of high maturity levels in practice. This abductive reasoning about practice maturity was developed through examples from the empirical data analysis as well as supporting literature. For example, building and maintaining a system like ISO14000 for environmental management can be useful for companies that align its purpose to their strategic plans and provide adequate resources for its support. It has been observed that ISO14001 is a common practice in manufacturing environments. It is used to drive environmental performance improvements but evidence in the literature suggests that it doesn't always deliver what is expected from its adoption (Barla, 2007; Boiral, 2007). This was found true in cases Car1, Car2 and Aircraft. However, in other cases like Pumps and

Grains, the practice of maintaining such system standards was perceived to be equally valuable (Craig and Lemon, 2008):

“ISO14001...that's just a piece of paper... [Pumps]

“After 2006 the company decided as part of its strategy to obtain the ISO14001” [Civil aircrafts]

This variability in the way companies undertake and perceive manufacturing practices to improve EP, was further investigated by Walls et al., who showed data both from government sources such as the Environmental Protection Agency's Toxic Release Inventory and from ratings agencies. The data was used to enable longitudinal studies on EP, allowing researchers to test for causality in the relationship between environmental and financial performance in a way that was not possible in earlier studies (Walls et al., 2011). *“This research has begun to uncover evidence regarding the antecedents of environmental capabilities, for example, by demonstrating that firms develop capabilities in response to stakeholder pressures, which are perceived differently by firms at different levels of eco-efficiency. (Hart and Dowell, 2011; Walls et al., 2012). The heterogeneity and the link to the capabilities that Walls et al., offer is well-aligned to RBV theory: “Firm-level heterogeneity encompasses not only heterogeneity in the existence of resources or beliefs about resources’ value but perhaps more importantly heterogeneity in the ways that firms use their resources. As such, one could argue that RBV is a theory of interactions rather than a theory of main effects”. (Ray et al., 2004)*

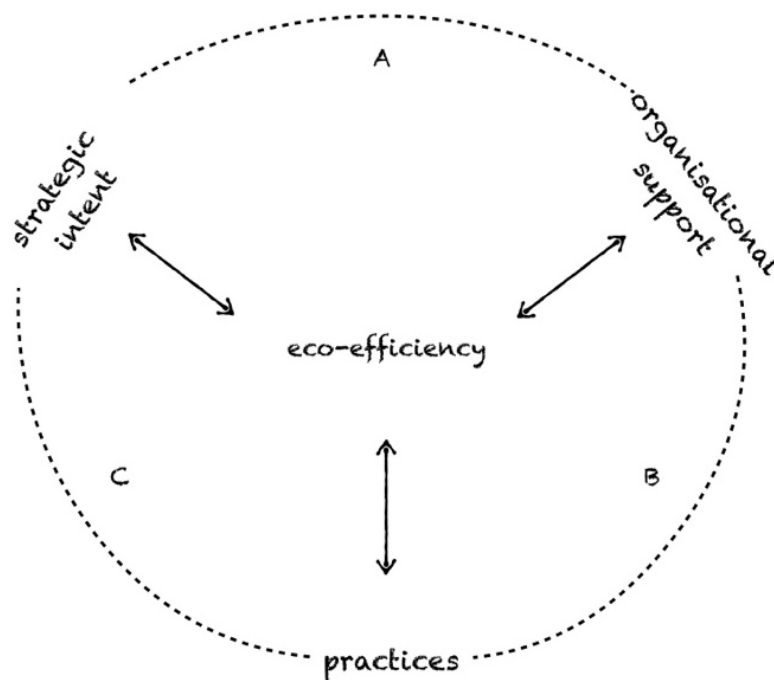
#### 4.7 Theoretical framework for eco-efficiency

Pursuit of eco-efficiency solutions seems to originate from the process level and expand to other areas of the manufacturing system. Companies at first hand try to reduce their environmental impacts, which is the environmental footprint of their processes. This is perhaps why monitoring and tracking of data related to energy and resource efficiency are important practices. However, transformative manufacturing processes is also an area of core capabilities and competitive advantage (Grant, 1991). Hart supports that in the early stages of pollution prevention, there is a great deal of "low hanging fruit", which are fairly easy to reap and result in good environmental benefits at relatively low cost. As the firm's EP improves, further improvements become progressively more difficult, often requiring significant changes in processes or even entirely new production technology (Hart, 1995). Such evidence

was found in the case of the Car2 company. Having achieved satisfying results from EP improvement projects the environmental manager mentioned that: “*we became hungry... [for more improvements]*”.

In **Figure 4.3**, the researcher brings together the factors identified in a generic framework for eco-efficiency. Eco-efficiency may depend directly from these three factors (organizational resources, strategic purpose and practice maturity) but also from interdependencies between them. It is assumed that there may be synergies between these themes (dotted lines with letters A, B, C). The framework summarises the initial indications about the influence of practices and eco-efficiency. A literature search has been performed for each area in order to establish the novelty and research opportunity. **Table 4-3** summarises this research opportunity.

**Figure 4.3** The researcher graphically summarises how he combined literature and empirical data analysis into a high-level framework that can be used to navigate this inquiry further.



**Table 4-3 Describes the interdependencies in Figure 4.2 and provides supporting literature in each case. The left column provides literature support to the framework connections. The right column comments on the relevance of existing literature to this work. Areas B and C are found to have received little attention in the literature. This is expected to some extent as the topic of sustainable manufacturing practices is relatively new in organizational and strategy literature. The additional element of practice maturity further narrows the existing literature.**

Supporting references (not an exhaustive list):	Researcher's comments and relevance to this work
<p>Link between “Strategic intent” and “eco-efficiency”</p> <p>(Abdelaziz et al., 2011; Abdul Rashid et al., 2008; Baumgartner and Ebner, 2010; Bereketli and Erol Genevois, n.d.; Grant, 1991; Sharma and Vredenburg, 1998)</p>	<p>Researchers propose that there are reactive and proactive strategies for eco-efficiency improvements. This interaction was evident in cases: Car1, Car2 and civil aircraft. These companies actively pursue eco-efficiency improvements across a range of business functions and there was a clear sense of strategy or purpose to support these improvements.</p>
<p>Link between “Organizational resources/capabilities” and eco-efficiency</p> <p>(Cagno and Trianni, 2012b; Crick et al., 2013; Farris et al., 2009; Hart, 1995; Russo and Fouts, 1997; Trianni et al., 2013)</p>	<p>Authors focus on the study of internal competences to explain efficiency improvements. Technology, capital investments, cleaner production projects as well as improvement methods that rely on certain organizational resources are found in this type of literature. Essentially, the success of an improvement process is directly related to the level of resource that has been assigned to it.</p>
<p>Link between maturity of practices and Eco-efficiency</p> <p>(Baumgartner and Ebner, 2010; Ngai et al., 2013; Ormazabal and Sarriegi, 2012)</p>	<p>The idea of a maturity for sustainable manufacturing strategies was conceptualized in 2010 by Baumgartner and Ebner. Their work connects manufacturing strategy to sustainability in 5 levels of organizational maturity (see next chapter). Maturity models can be found in</p>

various contexts in the literature (i.e. risk management, sustainable products or quality management).

However, there seems to be a gap in the literature in terms of describing practices through the lens of maturity.

#### Interaction area A

(Aragón-Correa et al., 2008; Brown and Blackmon, 2005; Elliot, 2011; Grant, 1991; Russo and Fouts, 1997)

A typical link between organizational resources and manufacturing strategy. This strong link between the two constructs implies a reinforcing effect on eco-efficiency and it will be explored to some extent in the following chapters.

As mentioned earlier, the link has been criticized for lack of clarity and there is little evidence in the literature to show how resources are strategically used to achieve competitive advantage (Sanchez, 2008).

#### Interaction area B – limited literature

(Abdul Rashid et al., 2008; Dangayach and Deshmukh, 2001; Baumgartner and Ebner, 2010)

This is a relatively novel approach in the literature that the researcher will explore further in this study. The researcher assumes that there is a connection between these constructs which reinforces eco-efficiency improvements in factories. Potentially, different strategies would nurture different types of practices or exclude other options for manufacturers. See chapters 6 and 10.

#### Interaction area C– limited literature

(Barney et al., 2011; Fraser et al., 2002; Hart and Dowell, 2011; A. M. Maier et al., 2012; Păunescu and Acatrinei (Pantea), 2012; Subic et al., 2012; Witcher et al., 2008)

Another idea that this work brings forward is the link between practice maturity and the organizational resources & capabilities. The way that resources are organized and managed in factories is linked to the organizational maturity reflected in practices. The interview with car2 manufacturer highlighted that the maturity of practices in manufacturing was not the same across all business units and in return this delayed improvement projects for the environment.



## 4.8 Chapter Summary

The first part of this chapter investigated how practitioners today approach eco-efficiency and how they may support eco-efficiency improvements. Data from 9 diverse cases were collected and analysed. Three key influencing factors are identified through an inductive data analysis. These factors guided an additional literature search in applicable theoretical frameworks. The result was to consider these factors within the natural resource-based view of the firm. This internal view of the manufacturing capabilities focuses on competitive advantages that stem from efficiency gains and pollution prevention strategies.

It was also found that the role of practices in manufacturing is not well documented in the literature and specifically within the context of eco-efficiency. Moving forward, the focus of this work is to understand the role of practices in eco-efficiency improvements through the lens of organizational maturity. Aligned to the first research objective (section 3.5) the researcher will be using the concept of maturity to assess eco-efficiency potential for improvements.

# 5 MATURITY MODEL DESIGN AND APPLICATIONS

## 5.1 Introduction to the chapter

This chapter describes how the researcher embedded the evolving relationship of maturity in manufacturing practices and eco-efficiency into a maturity model. The chapter is divided in two parts. The first part describes the design of a maturity model for eco-efficiency. The researcher reviewed literature on maturity models and describes how the model was developed and what design principles it adheres to.

In the second part of this chapter, the researcher explores how the maturity model can be applied in real-life. Application designs are guided from literature evidence and are modified accordingly. The goal is to better understand what types of real-life applications can support the inquiry further. The researcher observes how practitioners interact with the maturity model within each application and consideration is put into the procedural element of the application. Finally, the researcher offers feedback points on the model's utility from practitioners.

## PART A. MATURITY MODEL DESIGN

### 5.2 Introduction to maturity models

Following up from chapter 4, the researcher intends to make the evolving concept of maturity useful for practitioners to support further research activities. Modelling practices may help the researcher better understand how improvements for eco-efficiency can be more effective under varying conditions. Maturity models have been used to simulate how organizational routines and practices evolve within organization in stages. This staged approach was originally used by Crosby in the discipline of quality management and extensively applied in other disciplines such as software assessment processes by the Software Engineering Institute – Carnegie Mellon University (Crosby, 1979; Humphrey, 1988). Subsequently, maturity models have been designed to assess the maturity (i.e. competency, capability and level of sophistication) of various organizational processes, based on set of criteria. Maturity models *"use qualitative assessment or statements but may also be supported by additional descriptive accounts and also by quantitative measures"* (Srai et al., 2013).

Maturity model application has been extensive and can be summarised into three groups based on the intended use (Becker et al., 2009; A. M. Maier et al., 2012; Röglinger et al., 2011):

- a) Descriptive models: assessment of phenomenon under investigation against certain criteria (diagnostic tool)
- b) Prescriptive models: provide guidance for change i.e. towards higher levels of eco-efficiency, essentially the improvement mechanisms.
- c) Comparative models: a platform for benchmarking, in this case across different manufacturing systems (i.e. different factories).

The aim in this work is to start with a descriptive model and further aim to add prescriptive capabilities in the long-run. Ultimately, the model could be used as a benchmarking standard for manufacturing practices.

### 5.3 Literature review of maturity models

In order to understand more about how maturity models can be used in qualitative research and how these can interact with practitioners, the researcher sought to review relevant publications. The main aim of this literature review is to collect information about eco-efficiency practices in manufacturing and how these can be graded in a maturity ladder (i.e. in five steps) or find existing maturity models that focus on eco-efficiency, industrial sustainability or environmental improvement and inform this work. The same technique to search literature was used as in chapter 3. The keywords in this search were: maturity, maturity model, eco-efficiency, practice, organizational maturity, maturity stages, CMM, tool, performance, assessment.

One of the aim in this literature review was to understand more about the use of maturity models in qualitative research, examples are: (Ngai et al., 2013; Pigosso et al., 2013; Srari et al., 2013). Therefore, some papers were found to be influential in terms of: content and/or maturity model design properties and/or intended use. Even though maturity models have been widely used in research, there are some concerns that need to be acknowledged as well. Röglinger et al., review maturity model literature and raise 5 points/objections related to the use of maturity models (Röglinger et al., 2012):

1. they have been characterized as “step-by-step recipes” that oversimplify reality and lack empirical foundation
2. maturity models tend to neglect the potential existence of multiple equally advantageous paths
3. maturity models should be configurable because internal and external characteristics (e.g., the technology at hand, intellectual property, customer base, relationships with suppliers) may constrain a maturity model’s applicability in its standardized version
4. maturity models should not focus on a sequence of levels toward a predefined “end state”, but on factors driving evolution and changer.

Table 5-1 In Table 5.1 the researcher presents and comments on a selection of publications on eco-efficiency that have influenced the construction of the maturity model in this chapter. This selection of papers serves the development of the maturity model (presented in Table 5-3). Some of the studies follow the maturity route and some others an approach that reflects upon the structure of the organizational and operational systems. There are also some papers

that enhance the theoretical links of this study with the resource-based view and the theoretical framework described in the previous chapter.

**Table 5-1 Selected publications that have informed and/or guided the development of the maturity model. The researcher describes what the contribution of each publication has been and discusses on their usefulness where appropriate.**

Source	Contribution in this study
(Chrissis et al., 2007; Curtis et al.)	<p>One of the key textbooks on capability maturity models integration (CMMI) for processes and human resource management. The authors guide practitioners into the application of capability maturity models for organizational process improvement. Two types of models are introduced based on the way that improvement is expected to occur: continuous or staged. The difference between the two types of representation is in regards to the expected improvement path. Across a level of improvement dimensions, the user assures that all dimensions reach a certain level of maturity before pursuing further improvements (staged representation) or allow the dimensions to vary in maturity (continuous representation). The important learning from this source is the characterisation of attitudes that describe each maturity level. Continuous representation process levels are: 0) Incomplete, 1) Performed, 2) Managed and 3) Defined. In staged representation process levels are: 1) Initial, 2) Managed, 3) Defined, 4) Quantitatively managed and 5) Optimising. Users may choose either type of representation but that choice needs to remain consistent throughout the application of the model. For this research, it is not obvious why all process dimensions need to reach the same maturity level before moving on to the next one. This distinction between different representation options brings a level of complexity that may not be well-received in real-life applications. Indeed, this is addressed by Maier et al., (2012) who offer the maturity grid alternative (see following paragraph). Nevertheless, in regards to maturity models, the lesson for this work is the behavioural element that characterises each level (i.e. initial or optimising). This behavioural element exists in each level of maturity models and helps the researcher group eco-efficiency practices accordingly. Maturity model users can use that information to understand the content of the maturity model better.</p>

(Claver et al., 2007) The authors describe tangible and intangible resources and capabilities and the connection between maturity models and RBV. They follow a qualitative assessment approach. Content for capabilities and practices is adopted from this work.

(A. Maier et al., 2012; Moultrie et al., 2016, 2007a) This group of authors has common research roots in the Cambridge Engineering Design Centre. The authors offer a critical review on maturity models and their use across a range of industries and management processes. In particular, they offer a distinction between maturity models and maturity grids. Maturity grids are seen as more flexible tools for carrying out participatory action research (as pioneered by Platts (1993).

According to Maier et al., grids overcome the rigidity that CMMI literature presents for process improvement, as practitioners find them easier to understand and engage with. The paper by Maier et al., (2012) has been used in this inquiry to guide the researcher through the key requirements of such a tool (maturity grid for eco-efficiency). Key requirements refer to structure, content and intended use of maturity grids. The researcher also obtained an overview on research use of maturity grids and aligned this work with that literature.

(Baumgartner and Ebner, 2010) Baumgartner and Ebner develop a theoretical maturity grid that describes different types of sustainable manufacturing strategies. The authors follow a triple-bottom line structure (Elkington, 1997b) to describe various objectives/dimensions of corporate sustainability strategy. They also link their work with competitive advantage, which is consistent with RBV theory. The key learnings from this work is the behavioural characterisation of various sustainability strategies, the theoretical link to RBV theory and finally an idea of how to use maturity grids in real-life conditions (maturity profiles, see part B,

(Campos et al., 2013) The authors develop a maturity grid as the core of a toolkit for action research. Measurement within each maturity level is performed through the views of the managers involved in this action research who contribute and evaluate to the model. Their figures 2 to 7 provide insight of how a maturity grid can be a part of a toolkit for action research and discuss on the methodology of performance measurement and self-assessment. However, facilitation of the application process is not very clear in this study.

- (Ngai et al., 2013) Ngai et al., describe the behavioural change that a company undergoes on the road to sustainability. Ngai et al., present a quantitative, maturity grid for energy and utilities. The maturity grid is used here to enable research with practitioners in real life situations. The authors develop a maturity grid based on Capability Maturity Model Integration (CMMI) terminology (Chrissis et al., 2007). The key learnings from this work is the example itself of using a maturity grid to drive the research inquiry deeper. The study has inspired the second application in section 5.4.2.
- (Ki-Hoon and Cheong, 2011) Carbon footprint measurement framework in supply chain at Hyundai Motor Co. 5 levels of maturity are offered across 3 tiers of the supply chain with emphasis in measurements and information management. A quantitative perspective on a carbon footprint framework. This is an example of a maturity grid that spans across 3 tiers of the supply chain (not just one company but over a manufacturing system). The authors however do not emphasize how they have developed the framework or the improvement mechanisms.
- (Yeo and Ren, 2009) Yeo and Ren describe risk management practices in complex product systems projects, sorted in maturity order. The authors discuss the maturity model they created based on CMMI, the assumption about robustness, security and capability areas and the necessary improvement mechanisms to move the system forward in maturity. The key learning from this study is how authors combine various knowledge disciplines in a coherent framework to facilitate practitioners to manage complex projects.
- (Subic et al., 2012) Subic et al., develop a capability assessment tool and perform an environmental gap analysis across suppliers in the sportswear apparel industry. Their grid consists of three sub-grids representing energy and resource efficiency, emissions reductions and management practices. The assessment is based on a 1-5 scoring scale for each supplier. The key learnings in this study are: the connection of practices to eco-efficiency and the tool design that binds three improvement areas together. It can be highlighted here how their maturity grid reflects the organizational hierarchy.

- (Duflou et al., 2012) Production facility as a complex control system (fig 16, 17, 18, 19). Two areas are described in their maturity model (process and multi-machine). This study has inspired the researcher to apply the maturity approach in multiple areas of manufacturing and creating 3 maturity grids within the maturity model.
- (Pigosso et al., 2013) The authors describe the development and use of an eco-design maturity model. They offer insights about the development of the tool for eco-design. It is an action research approach with guidance for users. Practices for eco-innovation are presented in a maturity model and a quantitative benchmark is developed. This is one of the rare examples in the literature that exhibits how the maturity model is put into practice for process improvement (in this case the eco-innovation process in manufacturing). The paper offers insights about the application of the maturity model and how to process data post application.
- (Veleva and Ellenbecker, 2001) Discussion on environmental performance in 6 process areas (aspects of sustainable production) and the indicators that represent these:
- Energy and material use
  - Natural environment (including human health)
  - Economic performance
  - Community development and social justice
  - Workers
  - Products
- Insights in the possible process areas for sustainable production. Again little is known about the mechanisms of improvement to the next maturity level.
- (Ormazabal and Sarriegi, 2012) The authors offer dimensions for eco-efficiency improvement: 1) Environmental Compliance, 2) Training, 3) Systematization, 4) Eco-Innovation 5) Leading Green Company. These dimensions are used in the development of the maturity grid in this study.
- 

The researcher's intent is to project the maturity concept on eco-efficiency and describe the various states of eco-efficiency in maturity levels. In the following section, the researcher describes the design process followed to develop the maturity model which links the use of maturity grids with intended use. The design process helps the researcher to retain structure



in the development process and build internal consistency in this work with a verifiable process. Validating the description of practices in a specific order is not intended. Some flexibility within the maturity model is permitted and it is open for users to develop further and improve.

## 5.4 PMGE design principles and design assessment

Maier et al., and Röglinger et al, have studied the way that maturity models are designed as these seem to appear more and more frequently in the literature and possess common characteristics (A. M. Maier et al., 2012; Röglinger et al., 2011). The guidelines that Maier et al., provide have been used in this study to build the Practice Maturity Grid for Eco-efficiency (PMGE), as in Table 5-3. The study by Maier et al., has also been used here as it offers methodological compatibility with the Design Research Methodology and appears to have more structural elements in its composition than the one offered from Röglinger et al. Certain criteria that have been identified from reviewing maturity frameworks by Maier et al., were used to guide the design of PMGE ( Maier et al., 2012). These serve as a benchmark for the design of such tools. The review of the current maturity grid against those criteria is presented in **Table 5-2**. **Table 5-2** describes the planning and development phases of the PMGE. Evaluation and maintenance phases are discussed in chapter 9 as part of the overall evaluation process of this work.

**Table 5-2 Maturity grid design tool application according to Maier et al. (left-hand column shows the design dimensions).**

Decision points	Comments in relevance to the PMGE design
Phase I - Planning	
1. Specify audience	The audience for the PMGE are practitioners who work in manufacturing companies and have a certain level of authority to make improvements.
2. Define aims	The grid aims at providing practitioners with a starting ground to consider various improvement areas and dimensions of eco-efficiency. Therefore the initial aim is to generate awareness about eco-efficiency. A secondary aim that links this work further with the research question is benchmarking. Benchmarking includes comparison against an identified best practice example and making statements about performance of a whole industry

sector in terms of a certain process or capability (Maier et al., 2012).

3. Clarify scope  
Scope here refers to the use of the maturity grid within a specific context (i.e. a specific industry). The researcher remained at a generic level of scope and as it was intended to make the maturity approach applicable to various industrial contexts.

4. Define success criteria  
The researcher proposes practice maturity can be a proxy to eco-efficiency in manufacturing. Success in the design of the grid is to enable users to describe the strengths and weaknesses in a manufacturing system and propose actionable future improvements. It is recognised that the success of the grid may be difficult to assess in the timeframe of this thesis. Evidence about the usability of this work (the degree to which users understand the language and concepts used) are pursued through the evaluation of its application in the second part of this chapter.

#### Phase II – Development

1. Select process areas (components and theoretical framework)  
The dimensions of the grid were selected by literature review and the empirical data analysis. These were then clustered in 3 groups that reflect organizational layers in manufacturing systems. The clustering in three groups reflects the evidence from chapter 4 (see case of industrial community). It needs to be clarified that the three sub-grids are loosely connected. This means that these could be used independently from each other i.e. if someone explores the maturity of practices in manufacturing processes then only the process-level maturity sub-grid (Table 5-3a) can be used.

2. Select maturity levels  
Justification of the choice of the levels and the content is provided in the last column in Table 5-3 as well as supporting literature presented in ter.

**Table 5-1.** The overall description of each level vertically follows this sequence from left “business-as-usual” to right “leading performance” practices. In each level a certain type of behaviour is expected in terms of practices (underlying rationale):

- Maturity Level 1: The company supports initiatives on a trial and error basis – data availability/analysis is limited.

- Maturity Level 2: Some more coordinated improvement efforts appear and companies over-resource activities to gain results faster (unsustainable in the long-run). Effort to understand the system better through data acquisition and analysis capabilities.
- Maturity Level 3: Consistency in performance levels is being achieved through deeper understanding of the manufacturing system and its capabilities. Aiming for standardisation, practice of management tools and techniques.
- Maturity Level 4: Production agility and control are systemic properties with support from cross-functional teams. The researcher assumes that there is some alignment to manufacturing strategy and better utilisation of available resources and capabilities.
- Maturity Level 5: Environmental performance improvements are aligned to manufacturing strategy. Inclusive strategic planning of EP improvements. It is assumed that no business decision impacts EP negatively.

3. Formulate cell text

The description of practices within the cells indicates a certain type of behaviour which is the expression of the underlying rationale of PMGE. Ultimately, the grid aims to offer support for practitioners and therefore prescribe how to improve. Potentially, once the underlying rationale is understood, the improvement steps can be deducted by the users. As a model (Table 5-3), PMGE is a descriptive model according to Maier et al., but the potential application of the grid can be prescriptive for practitioners (Maier et al., 2012).

4. Define administration mechanism

Focus on the process of assessment (e.g. Face-to-face interviews, workshops) or focus on end results (e.g. Survey). PMGE has been designed to facilitate qualitative research with industrial practitioners. In Part B of this chapter the researcher will demonstrate the way it can be applied. Three processes are tested in Part B and the results are evaluated to drive further research activity.

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Phase III (evaluation) consists of two parts: validation and verification of the maturity grid.

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Validation in this context means: correctness of results and evidence of correspondence between the researcher's intent and user's understanding. Verification, in this context, requires correspondence with specified requirements. Phase III is examined in chapter 9 where the intended use becomes more clear through empirical work (second part of this chapter and chapter 7).

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Phase IV requires maintenance of the maturity grid. The researcher can show how the grid is updated and cells descriptions are adjusted and/or how the database of results from use is maintained (if applicable). Finally, how the development process is documented and communicated (this is audience specific).

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Phase III and IV will be presented in Chapter 9 as part of the evaluation of this work before

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The review on sustainable manufacturing (chapter 3) and maturity models from Table 5-1, was combined with data from the interviews in chapter 4. The researcher identifies four elements of manufacturing systems (for example see Bartlett and Ghoshal, 2002; Smith and Ball, 2012): energy and material flows, production systems (i.e. equipment or information systems) and people. The organizational structure (see section 4.2.9) is projected on these elements and this generates 15 dimensions of performance split in 3 groups:

- a) Process and operation practices (or Processes) [see cross-references in Table 5-3]
  1. Energy consumption
  2. Materials usage/consumption
  3. Water usage/consumption
  4. Process waste/pollution
  5. Human factor impact / workers & operators
  6. Process equipment procurement/performance
- b) Production and management systems (or Facility and systems)
  1. Energy management systems
  2. Resource management systems
  3. Waste management systems
  4. Human resources management
  5. Factory suppliers
- c) Higher management level functions (or top-management and leadership)
  1. Information systems and knowledge management
  2. Company norms and values
  3. Supply chain configuration
  4. Product and process development

These dimensions are combined in a maturity grid that consists of 3 sub-grids (to represent each group) and follows a 5-step maturity ladder. The cells of the grid provide descriptive text about practices at each level, also known as a “behaviourally anchored scale”(Maier et al., 2012). This means that the description in the cells is an indication of what types of practices one can expect to find in each maturity level in manufacturing systems. The description is not definitive and can be subject to change by the user of the PMGE.

The three-group structure is in alignment with work from other authors that see the manufacturing system as a pyramid that consists of multiple organizational sub-structures (Taticchi et al., 2012). The decomposition between 3 layers intends to simulate the scale of influence on eco-efficiency (process level practices have limited influence to eco-efficiency and practices at top-management level have a much higher and escalated influence to eco-efficiency). The decomposition approach has been followed in other studies in the field of sustainable manufacturing and eco-efficiency as well (Campos et al., 2013; Subic et al., 2012).

In Table 5-3, the researcher proposes the practice maturity grid for eco-efficiency (PMGE). For each of the 15 dimensions in total, the maturity levels are developed based on literature and interview findings. A column at the right side of the maturity tables has been added with literature references about each particular row/dimension to link the dimension to literature. The levels from left to right have not been given a title (as in CMMI literature) but a numerical sequence has been used from 1 to 5 for distinction. The first maturity level describes the less mature state and the fifth level the highest maturity state. The description of practices in the cells has been modified to make the language easier for users to understand (as in (Moultrie et al., 2007b)). The progression of the maturity levels and underlying conditions are described in Table 5-3.

**Table 5-3 The Practice Maturity Grid for Eco-efficiency (PMGE).**

a) Process practices and operations						
Maturity Levels	1	2	3	4	5	Supporting literature
Energy consumption	Maybe some data available but not meaningful or trustworthy.	Energy monitoring is happening at some level. (i.e. smart metering, tracking bills)? Identify inefficient equipment or use of equipment from leaking air-compressors to switch-off of idle machines between production cycles.	Understanding the energy efficiency of your sector or competitors (main processes or auxiliary systems i.e. pumping, boilers). Learning about your sector/competition's energy performance through networking or similar activities. Able to convert inefficiencies to cost per unit of product.	Looking for opportunities, savings and re-configuring the energy supply for unit/process. Link these numbers with cost savings. Possible research into the thermodynamics or chemistry of the process may help identify more sustainable technologies. Process energy is seen as any other valuable resource to make product in a cost-effective way.	Energy is a regulated resource within a whole systems design approach. Further research for high energy-efficient processes and equipment is on-going. Ask for help from experts.	(Herva et al., 2011; Postelnicu et al., 2012; Zhang et al., 2012)
Material usage/consumption	Material usage control based on cost accounting principles	Understanding real-time consumptions or materials mass balances per process. Identify lags and bottlenecks in stocks. GMP's and good housekeeping practices are explored.	Understanding how changes in materials affect efficiencies in resources. Consider the trade-offs with quality, cost and time. Add environmental restrictions in the production function and suppliers. Recyclability of materials. Reducing variation within production with statistical tools.	Look for saving opportunities in the process or in other processes with complementary properties in materials. Established KPI system to direct/support improvements. Link to the waste stream is important to decide actions (i.e. if process waste can be commercialized it could have a rebound effect on material efficiency at process level). Learning about material properties from suppliers and customers (links to quality control?).	Improve process to maximize resource efficiency to a theoretical minimum. Design implications that expend to recyclability opportunities – whole systems design. Ideally materials are recycled in a closed loop system (research scope).	(Martins et al., 2007)
Water usage/consumption	Maybe not enough data about water consumption. Perhaps not a valuable resource (or abundant)?	Monitoring of water consumptions per process and costs related. GMP's and good housekeeping practices explored.	Defined water flows and recycling ratios. Understanding of current water system and water source. Qualities and properties of water used (i.e. distilled vs reversed osmosis).	Source water from other processes or establishments (i.e. rainwater collection pool). Re-configure the water system and optimize for cost. Calculation for water efficiency available. What water quality is necessary for our process?	Recycle water within the factory following a closed loop paradigm. Engage with surrounding community regarding water efficiency. Corporate Social Responsibility activities.	(Ingaramo et al., 2009)

Process Waste / pollution	Landfill, or disposal – Limited information about waste streams is available.	Partial recycling of process waste. Identified the barriers and controls to improve recycling ratios. Re-work all that is possible. GMP's and good housekeeping practices explored.	Satisfactory recycling ratios. Waste segregation. (i.e. use separate bins under each machine for discarded and rejected items). Convert waste into resource for other processes. Changeover waste is identified and is one of the problems to solve.	Zero waste to landfill is an example. Zero-cost to the environment or zero-emission targets are in place and trying to achieve. Business opportunities happening. Using waste emission properties (such as temperature) back into processes (i.e. circulate hot flue gas instead of heated air)	Prevention of unmanageable process waste within the manufacturing perimeter. Eliminated process waste. Conditions to convert to material for other processes or added value products are met. Continuous improvement is the target for this level.	(Kliopova and Staniskis, 2006)
Human factor impact /workers and operators	Untrained personnel. They have limited control over the process. Random selection of operators for specialized tasks.	Training in maintenance and energy/materials savings. Keeping training records for all.	Training personnel to improve equipment performance. Training on efficiency and reporting back to floor managers with recommendations for best practice. Establishing of standardized procedures and consistency of practices (make them routines).	Cross-functional teams of people that look for opportunities for improvements. Understanding people's skills at this level is also important for higher integration at other organizational areas.	Continuous improvement efforts from authorized cross functional personnel.	(Daily and Su-chun, 2001)
Process equipment procurement/performance	Limited information on equipment specifications from suppliers or optimum ranges of operation. What are the most valuable assets to the business?	Regular maintenance, record faults and leaks, cost analysis of these (savings opportunity). Monitoring equipment performance. GMP's and good housekeeping practices explored. Mapping of assets and their limitations	Environmental footprint of our physical assets. i.e. What does underperformance in a packaging process mean in terms of energy and materials to be saved? Set operating standards that maximize resource-efficiency that relate to equipment handling. Overall equipment efficiency measurements.	Explore options to replace greener equipment or supporting infrastructure. Cost benefit analysis and long term planning capabilities should involve additional corporate responsibility dimensions and trends in legislation. Coordinated use of sensor technology helps regulate production, maintenance quality etc.	Equipment can be leased and the company that makes best use is rewarded. In conjunction with energy and materials efficiency this level targets work on continuous improvement on equipment efficiency and involves . automation and controls?	(Saidur et al., 2009, 2010)

## b) Production and management systems

Maturity Levels	1	2	3	4	5	Supporting literature
Energy management systems	Non-standardized consumption data collection (if any)	ISO, EMAS type of system implementation (not necessary to have certification). Data are available and recorded and reviewed for consistency and reliability. Set indicators for energy flows Energy audits across production units.	Improved data quality and level of detail that reveals inefficiencies and variations. Actions of energy consumption across all processes through standardized manufacturing best practices. Formal energy management department (or similar authorized organizational structure). Saving energy through improved process technology.	Eco-efficiency calculations are available and reliable (top-management can rely). Energy is a regulated resource. Leading the competition in the sector. Substitution with renewables (may reduce risks/add flexibility to system boundaries/time frame).	Energy efficiency is part of an integrated asset management system. On-going research at this level will reveal more on the opportunities available for high eco-efficient production systems. Energy optimization is part of a closed loop system.	(Energy Management Matrix, 1998; Ngai et al., 2013)
Resource management systems	Cost accounting, product quality. No environmental performance data for output	Indicators for material flows are set and visible to all. Deploy charts on the shop floor if information systems are not available. Follow ISO, EMAS guidelines for compliance. "good housekeeping rules" in place.	Improve data quality and resolution. Data should indicate root causes of inefficiencies. Mass balances in place and updated? Implemented lean manufacturing principles like Value Stream Mapping, Factory Layout, 5S (sort, flow, systematic cleaning, standardize, self-discipline) safety, security, satisfaction (target), Set-up Time Reduction (based on changeover improvements)	Production set up that minimizes environmental impacts and costs. Quality, cost, environment are built in qualities of the production system. Reconfigurations are taking place through inter-organizational initiatives. Handling complexity through system design (i.e. Toyota and Dell manufacturing systems aid operators to choose the right parts for assembly).	Asset (tangible and intangible) management is addressing materials, equipment, skills and capabilities. There is on-going research into production models that incorporate energy and resource efficiency principles.	(Fliedner, 2008)
Waste management systems	Waste disposal aligned to legal requirements for compliance.	Set indicators for waste flows that are visible to all (managers and staff). Good understanding of the source of waste (materials and energy).	Coordination with production and supply-chain. Waste management initiatives like "lean and green" or green supply chain. Consider "corporate social responsibility" reporting in the long run.	Treating waste as a valuable resource for another process (up-cycling or treatment for recycling). Asking procurement and sales to help identify possible clients for your waste. Invest in win-win solutions for treatment and	Optimization for waste management within a framework for closed loop economies. Cradle-to-cradle approaches. On-going research topic.	(Gibson, 2001; Kurdve et al., 2015; Rossiter, 1995)



Human resources management	Inconsistent management practices. Aiming for cost reduction. Communication is not a formal process.	Personnel trained in identifying opportunities in energy/resources savings and pollution prevention. Understanding people management through repeatable practices. Organizing social events for people. Aim for interactions. Customized information system to support knowledge sharing.	Setting up teams that control environmental performance (energy team, materials team, waste management team). View the production system through eco-efficiency ratio. Competency management through understanding of competency-based practices. Encourage social events in terms of trust development. Aim for knowledge sharing platform.	Empowerment and initiatives from personnel on opportunities for improvements. Measured and empowerment practices lead to capabilities. Social events are driven by people. Trust and openness facilitates improvement. Informal sessions authorized by top-management help generate more ideas for improvement.	Links to continuous improvement work and change management capabilities. Expedient adoption to environmental and business challenges. Organizational models like matrix organizations are used to deliver improvements.	("Beyond the matrix organization I McKinsey & Company," n.d.; Lu et al., 2009)
Factory suppliers	Cost based supplier search and selection	Understanding the effect of the supplies in the EP of the system. Introduce quality, environmental and corporate responsibility criteria for selection.	Minimum stocks, rework Lean management practices. Aim at a direct pull system from suppliers that minimizes paperwork (indicator of good collaboration)	Collaborations with local suppliers that improves times and product carbon footprint. Develop collaborations that improve EP in the factory with main suppliers.	Sustainable supply chains guide the opportunities within the production system to optimize for eco-efficiency. On-going research topic.	(Geffen and Rothenberg, 2000)

### c) Higher level functions

Maturity Levels	1	2	3	4	5	Supporting literature
Information systems & knowledge	Facility compliance indicators. Legal compliance should be top priority at this level.	Facility level material/energy use performance indicators. Feedback from operations on environmental impact.	Facility effect indicators. Links to cost savings. Understanding the material issues in production regarding eco-efficiency calculations and targets.	Supply chain and product life-cycle indicators. Linking production KPIs with product life-cycle analysis. Research into possible options for further development.	Sustainability system indicators (subject to research).	(Micheli and Manzoni, 2010)
Company norms and values	Limited awareness of employees on eco-efficiency targets.	People's skills and expertise on environmental knowledge	Manager's commitment to change and sustainability objectives	Cross-functional coordination and communication	Use of management accounting practices on eco-efficiency	(Adams and Whelan, 2009)
Supply chain configuration	No data on the impact of suppliers to the EP. Unexplored firm's impact in the supply chain (life-cycle approach)	Standardization protocols such as ISO and EnMS produce data and screening capabilities for suppliers. This will lead to improved understanding of critical control points for suppliers regarding energy, emissions, resource consumptions.	Target setting for suppliers regarding environmental impacts. Cost/benefit analysis with a long-term view on the operational sustainability. Tools such as a sustainability-balanced scorecard can be used to facilitate decision making on eco-efficiency.	Collaboration with supplier to minimize energy and resource consumptions -research initiatives	Closed loop supply chain. Ongoing research and links to circular economy.	(Brockhaus et al., 2013; Cai and Yang, 2008; O'Rourke, 2014).
Product & process development	Reduced resource utilization	Recyclability of returned product.	Reusability of returned product	Recoverability of returned product for further processing	Re-manufacturability of returned products as usable product	(Sugiyama et al., 2008)

## 5.5 Model simplifications and assumptions

There are some assumptions that have been made in this model. It is a continuous representation model according to CMMI literature (see

Table 5-1). Companies can appear to be more mature in some dimensions of performance than others. Nevertheless, the researcher assumes that companies will strive to become more mature across all dimensions in pursuit of higher eco-efficiency levels (as proposed in Baumgartner and Ebner, 2010). The researcher considers that there may be an interconnection and integration of practices from the process layer to top-management layer (a similar concept exists in Taticchi et al., (2012)). As the maturity grid represents some aspects of manufacturing systems it is expected that low maturity level practices in one organizational layer will impact eco-efficiency in other layers.

The overall description of each maturity level (regardless of layers and dimensions of performance) loosely follows the CMMI sequence of: 1) initial, 2) managed, 3) defined, 4) quantitatively managed and 5) optimized (see Table 5-3). At this phase of development (prior to testing), the researcher allows some flexibility as to how each level can or should be named.

There is also a missing element in PMGE: the improvement mechanism between levels. In chapter 6 this will be explored with companies that demonstrate a high-level of competence in the way they deal and energy and resources in manufacturing.

In the second part of this chapter the researcher describes three types of applications that have been explored in real-life conditions. During the applications, the researcher seeks to assess how effectively PMGE functions as the interface between theory and real-life. Data about manufacturing practices and eco-efficiency are also collected (the collection process is also part of the tool efficiency assessment).

## PART B – APPLICATIONS

The PMGE has been developed to help the researcher answer the research question. It offers the possibility to assess eco-efficiency through maturity assessment. In the second part of this chapter, the researcher sought to understand how the PMGE can be applied in real-life conditions. The focus is more on the procedures of the application rather than successful intended use. Therefore, the researcher is not participating in solving a real-life problem. The researcher remains an observer of the interaction of practitioners with the maturity grid through its applications. Better understanding of the intended use and success factors is material to the researcher.

Three application options are explored, aligned to the researcher's philosophical stance:

- a. maturity profiling through quick self-assessments (inspired by the work of Baumgartner and Ebner, (2010) as well as Goodson, 2002; Jørgensen et al., 2003; van et al., 1996),
- b. as guide for case study research (Ngai et al., 2013), and
- c. as an interactive workshop process with practitioners (inspired by the work of Kerr et al., 2013; Platts, 1993).

Further discussion to the background of its application is presented in each of the following sections 5.4-5.6.

### 5.6 Profiles of practice maturity

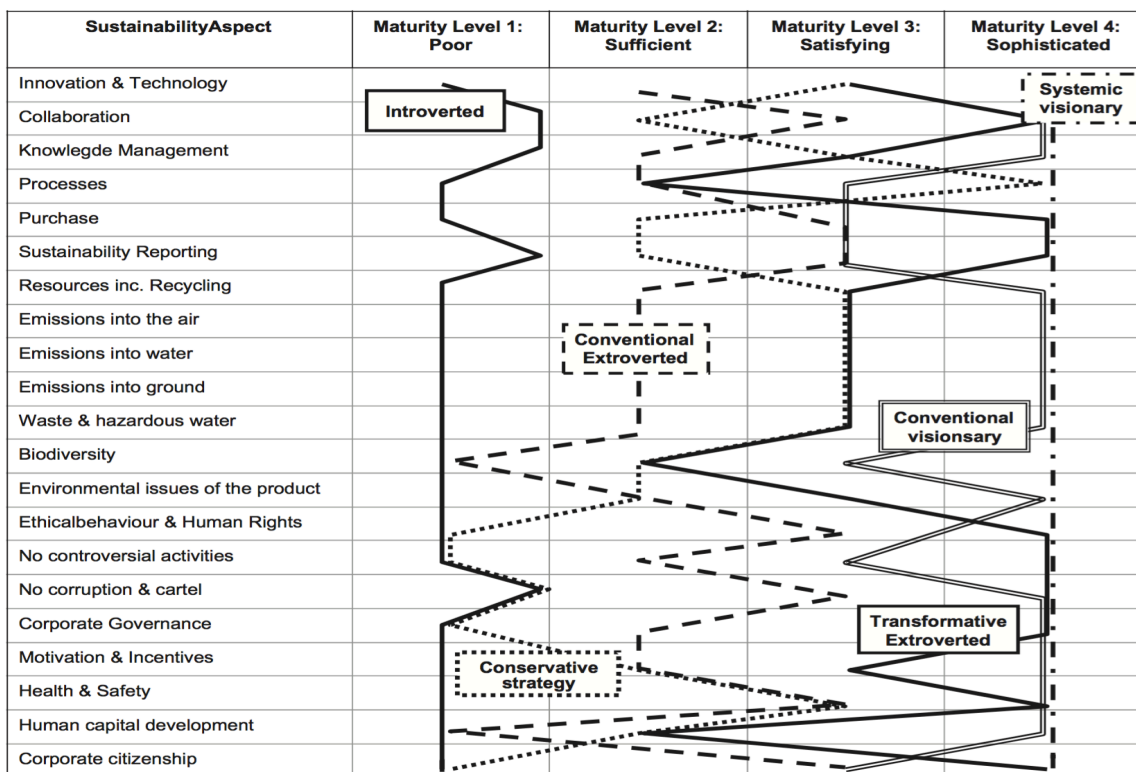
In the theoretical work by Baumgartner and Ebner, the authors develop archetypes of sustainability strategies in the form of maturity profiles with support from the resource-based view theory (Baumgartner and Ebner, 2010). Each maturity profile describes how the corporation operates or behaves across a range of sustainability dimensions. The maturity levels being used in their work are: 1) Poor, 2) Sufficient, 3) Satisfying and 4) Sophisticated. In Figure 5.1 the reader can see what these behavioural profiles look like. Ultimately, the authors argue that a successful sustainability strategy is aligned to the overall corporate strategy. (Baumgartner and Ebner, 2010)

The work by Baumgartner and Ebner is not informed empirically. Their maturity grid covers many areas of environmental and social responsibility and there is little guidance of how this

concept can be used to drive research. The researcher used the idea of maturity profiles to facilitate the application of the maturity grid in real-life situations within a narrower environment (improvements within the manufacturing system compared to the overall business). The work by Baumgartner and Ebner, as a base for this study and evidence of compatibility:

- has common theoretical backgrounds (resource-based theory as a source of competitive advantage) and
- uses a maturity model to describe sustainability strategies qualitatively in phases
- the linear maturity profiles vertically across cells can be a way of quickly describing the performance across various dimensions that are interlinked. It further links to the initial discussion about EP variation and benchmarking.

**Figure 5.1 Maturity profiles by Baumgartner and Ebner 2010.**



The work in this thesis differentiates from Baumgartner and Ebner as:

- It is narrower in its field of application (focus in the manufacturing system rather than the whole business).
- It aims to develop (in the long run) prescriptive improvement support for practitioners rather than describing maturity levels for corporate strategists.

The work by Baumgartner and Ebner remains influential for this study as it is aligned with the eco-efficiency framework presented in chapter 4 and proposes a qualitative and visual route to investigate behavioural variations in manufacturing systems. The behavioural characteristics of a system (expressed in their wording i.e. as “extroverted”) could further imply a link to practices and the way these shape the system’s sustainability behaviour. The word “behaviour” may be a more suitable term in this qualitative approach to eco-efficiency than “performance”.

### 5.6.1 Self-assessment

As simple self-assessment process was developed, asking practitioners to create their own maturity profiles as in Figure 5.1, by using a printed version of the PMGE. Van de Wiele et al., use the self-assessment definition by the European Foundation for Quality Management (EFQM): *“a comprehensive and systematic review of an organizations activities and results referenced against a model of business excellence. It allows the organization to discern clearly its strengths and areas in which improvements can be made and culminates in planned improvement actions which can be monitored for progress”* (van der Wiele et al., 1996). Moultrie et al., follow the self-assessment work by van der Wiele et al., to assess design for companies by using a maturity-based assessment tool, similar to PMGE. (Moultrie et al., 2007c)

The practice maturity grid for eco-efficiency (PMGE) was used in three applications to assess the usability of the PMGE self-assessment process. The first application was in a sustainability academic conference through an interactive poster (Figure 5.2). The second and third types were practitioners who were briefly introduced to this work through the conference poster (Figure 5.2). They requested a template via email to use it in their companies (one in the aerospace sector and the other one in electric equipment manufacturing sector). The practitioners in the second and third application were active environmental and sustainability practitioners in senior management roles. The self-assessment process was facilitated by the researcher only in the first case. The practitioners in the second and third case received a PMGE template via email with brief instructions for use. The use of PMGE was allowed with and without facilitation by the researcher in order to understand the researcher’s influence on the outcomes. Overall the self-assessment was used with 7 practitioners in six companies.

### 5.6.1.1 Facilitated process of self-assessment

The maturity grid was displayed in a conference as a poster where people had the opportunity to draw the profiles of their manufacturing system. A racetrack background was used to capture the attention of the conference attendees and imply the relationship to competition and performance (Figure 5.2). In Table 5-4 the maturity profiles of 4 different practitioners/companies are presented and described in more detail.

Figure 5.2 The interactive poster after use.

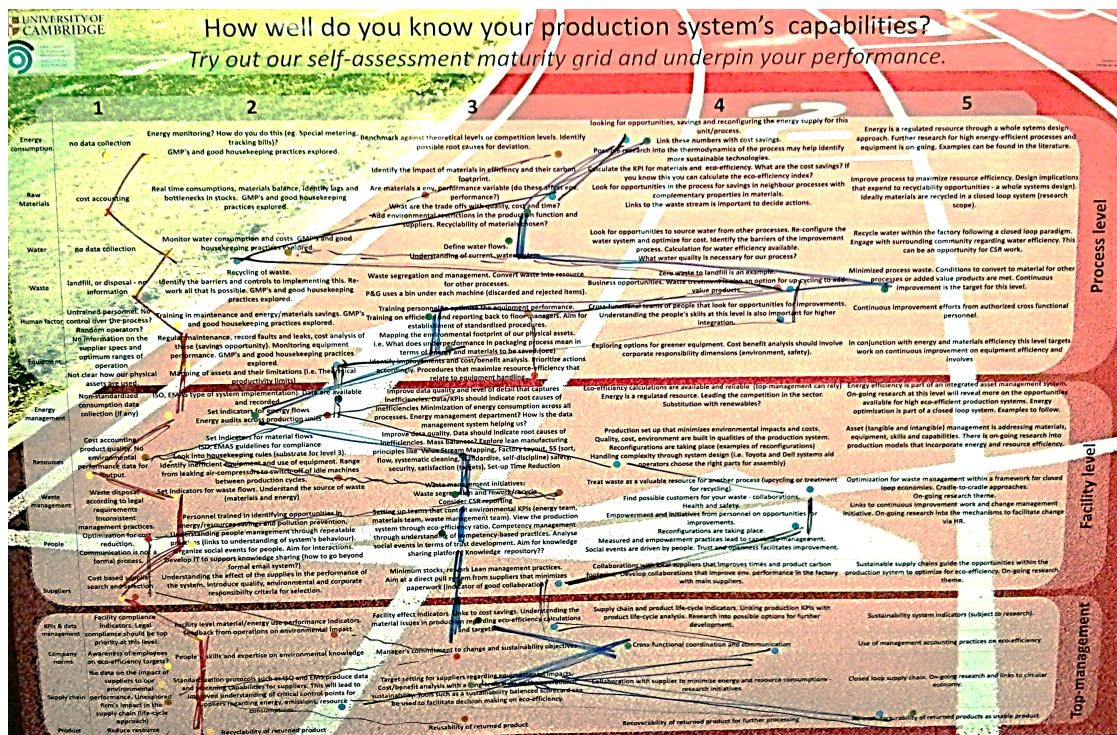
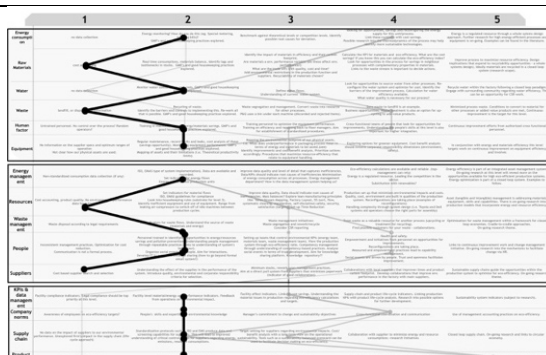
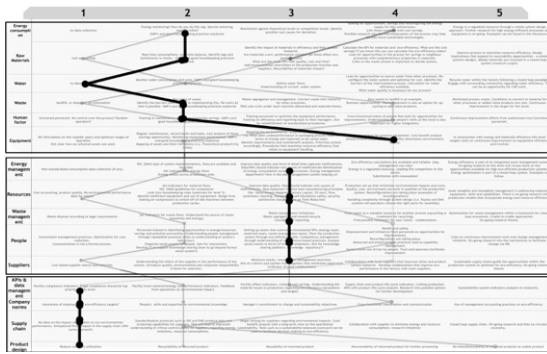


Table 5-4 The maturity profiles for each company that took part in this exercise during the conference. Three active managers in manufacturing and one university professor with manufacturing background took part.



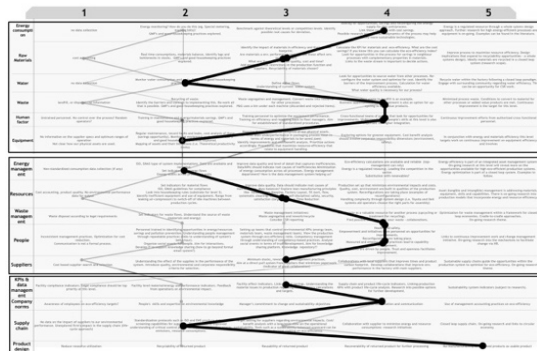
#### Automotive company

External assessment on manufacturing practices in the automotive sector. The participant (currently in academia) provided her view on the maturity of manufacturing practices in the automotive factory that she had formerly worked for. The researcher allowed this assessment to be part of this study as it demonstrates that a third-party assessment is one of the possible applications. In this case the results indicate low or business-as-usual practice implementation across most of the EP dimensions of the maturity grid.



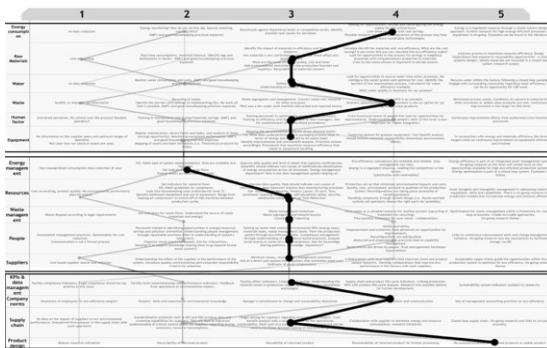
**Optics manufacturer**

The production manager of a large manufacturing facility of optic systems assessed the maturity of practices they implement across the organization. A strong signal that top-management is not supporting implementation of energy and resource efficiency practices, even though his assessment suggests that middle manager's competence at facility level is much better. Another issue is noticed as more attention is given to equipment performance than other areas of the grid.



**Building products manufacturer**

This is the maturity profile that the production manager from a building products company in the UK produced. The assessment indicates that there is a clear interest across all organizational layers to deliver improvements on energy and resource efficiency. The profile indicates practices between maturity level 2 and 5. The researcher noticed that the product's nature allows for re-manufacturability and this can be considered as the catalyst for certain types of higher-level practices, particularly in the area of waste management (achieving maturity levels of 3 and 4 in the grid).



**Metal packaging company**

The technology manager of a packaging solutions manufacturer shows that his company is already working on energy and resource efficiency and most of the EP dimensions of the maturity grid include practices in levels 3 (10 out of 15 areas) and level 4 (3 out of 15). There is an inconsistency of maturity of practices related to energy consumption at process level (ML 4) and energy management (ML 2) which calls for further investigation. The product (metallic) allows for re-manufacturability (ML 5) and this is reflected at process waste (ML 4) – internal re-cycling and collection of returned/re-called products or recycled products, zero-waste to landfill.

5.6.1.2 Application as self-assessment template – not facilitated by the researcher

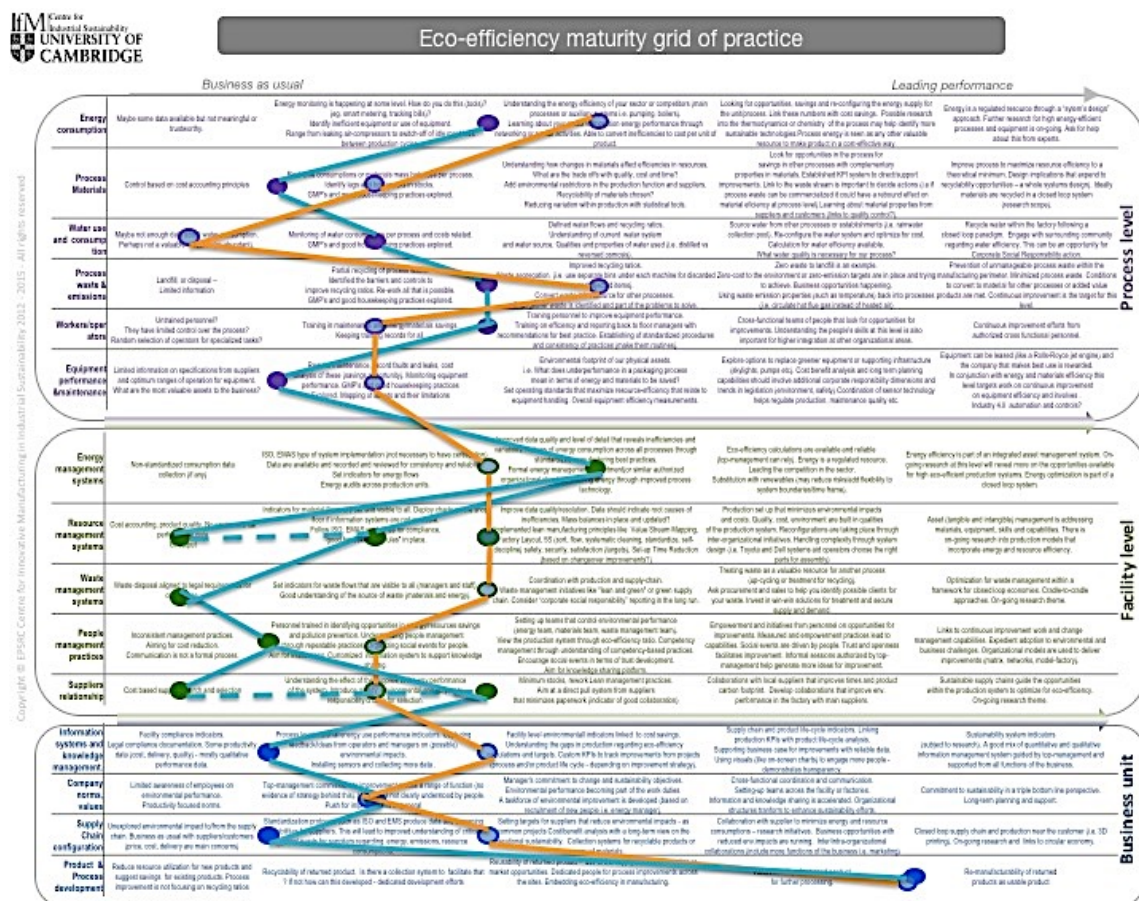
The self-assessment was also performed in a global company in the aerospace sector that makes engines. Their head of environment was attracted by the maturity profiles as seen in Figure 5.2 and found the profiling idea interesting enough to request to test it internally. With a brief description of the process requirements via email, the researcher received the feedback from that assessment as seen in Figure 5.3.

The self-assessment was completed by the head of environment and one of his associates in the same function. It has to be noted that these two practitioners work closely together in the same function and are based in the UK headquarters. Even though the maturity profiles do not vary significantly (1 level plus or minus) it is clear that there is very little overall



agreement on the maturity levels in each dimension. In some of the dimensions, semi-levels were used to indicate that there is work in progress towards higher-level practices.

**Figure 5.3** The maturity profiles from two environmental managers in a manufacturer in the aerospace sector, showing their perception of the maturity of their practices across the factories that they oversee (global business).



5.6.1.3 Application in the electronics industry – not facilitated by the researcher

A template of the PMGE was requested by the lead environmental executive in an other global electronics equipment manufacturer. The practitioner had a chance to use the maturity grid in a different way than expected. There were no maturity profiles generated but feedback on the utility of the PMGE was received:

“I have used the maturity grid to help me to shape some ideas as part of the planning for future Environmental Programs. I hope to build this into our plans for the future as a way of measuring our progress.”

This application had a different type of use compared to the previous two applications. PMGE was used to facilitate planning for environmental programs. This outcome may have not emerged if the process was facilitated by the researcher. Nevertheless, the self-assessment process was found to be understandable by practitioners and could be followed without facilitation. The implications of this observation are discussed further in chapters 7 and 9.

### 5.7 Semi-structured interview guide

The researcher used the PMGE as an interview guide with a drinks manufacturer in Italy to assess the practices employed in that factory and try to develop recommendations for improvement. Two practitioners (the production manager and the maintenance manager) were introduced to the research agenda and the PMGE was sent via e-mail a few days prior to the initial meeting. The research plan was to conduct interviews with employees from different management layers, assess that information, and present the results back to the team responsible for EP in the factory for further discussion. During the interviews, the practitioners were asked to describe the manufacturing practices they use to manage environmental performance. A group of Masters’ level engineering students from the local Italian university were involved in this process and were present during the interviews as observers. They were all interested in learning about eco-efficiency particularly at process level and each student delivered a thesis as requirement for their studies curriculum.

One of the limitations that the authors observed in this application is that the interviewees were not able to comment on all dimensions of the PMGE. This was either because of lack of data or because some dimensions were not considered important for that particular facility. However, since the PMGE covers 15 dimensions of eco-efficiency, indications of the practice maturity were observed and guided the development of recommendations. In Table 5-5 the reader can see a selection of the interview output, following the PMGE dimensions.

**Table 5-5 Example of data collection output based on PMGE to guide the case study.**

Processes	
Process water	Washing for microbiological cause and allergens. They have made a test to minimize the washing cycles. They received the supplier’s recommendation about the washing cycles. It is also an optimized process per product. There is an understanding of using different qualities of water (distilled, osmosed, city, dwelled).
Production and management systems	

Energy management	There is a real-time energy monitoring system (the data are not monitored by someone – so it is reactive). They fear that there are a lot of small losses that are missed (not seen).
Top-management	
Supply chain configuration	Target is to reduce stocks. Some materials are locally sourced but this is not a norm and can be price driven. 65% of the production is exported). They changed harbour (shipping hub) to feed Russian market from the sea. Again this was due to price rather than opportunity to reducing the carbon footprint.

The students followed up from the researchers visit and used the maturity grid to guide their thesis. It remained unclear how the PMGE was useful to them but it was certainly an early sign of utility and a sign that it was applicable as a technique in a real-life situation.

## 5.8 Workshop process

The third application for PMGE was a workshop process. Two variations of the process were executed in two separate occasions. It was already observed from the self-assessment process that speed is an important factor for the application. The researcher aimed for collection of data from participants about eco-efficiency, enhance horizontal communication between peers about eco-efficiency and reduce facilitation as much as possible. The design process of the workshop followed the seven design criteria that Kerr et al., set in their work on principles for developing technology management tools (Kerr et al., 2013):

- a) Human centric
- b) Workshop based
- c) Neutrally facilitated
- d) Lightly processed
- e) Modularity
- f) Scalability
- g) Visuals

A mix of practitioners from a range of industries and backgrounds was invited in this process. They all had a common interest in sustainable manufacturing and eco-efficiency but they were not necessarily experts in this field. The first case was hosted by an organization that provides consultation for companies on environmental management and assessment. The second case was hosted within a conference about energy and resource efficiency.

### 5.8.1 Workshop version 1

The researcher organized a workshop through a professional industrial network, the Institute of Environmental Management and Assessment (IEMA). The institute provides consultancy

services on environmental assessment for companies in the private and public sector. The organization has an international network of members for whom they offer educational seminars for continuous professional development in the broader field of environmental management.

An invitation that outlined the scope and objectives of the workshop was posted on IEMA's website and was further circulated to their network of practitioners via e-mail. The workshop attendees were: 3 practitioners from industry (2 from construction materials and 1 from steel processing), 2 environmental consultants, 1 senior environmental and quality manager from a borough council, and 1 senior researcher from a UK university. The attendees and companies retain their anonymity throughout this work. The attendees covered roles mainly in middle management. It was assumed that they would be able to provide views about manufacturing practices that occurred across many organizational areas (process, facility, and top management). It should be noted that they were already members of the IEMA and therefore some bias about their perceptions towards environmental performance was expected.

The maturity grid was printed and mounted on the wall (in 3 rectangular, A0 size posters one for each sub-grid) and coloured repositionable notes (post-it notes) were handed out to the delegates. The post-it notes were color-coded: yellow for current/scheduled practices and blue for future ones (indicating stretch practices). The workshop contained three main exercises (one hour per exercise). The first one was about collecting data about past or current best practices in manufacturing. The second one was about collecting data about future or stretch practices. The third exercise was about re-arranging the data collected, via discussions between participants, about the maturity sequence of the practices. The sequence was described as starting from "business as usual" to "leading performance". At this point, a maturity sequence and clusters of practices start to develop for each dimension of the maturity grid.

The time axis (past, present, future) was used to convey the idea of a maturing organization that continuously improves its environmental performance. It was intended to help practitioners consider how their companies evolved through time and how they may use existing internal capabilities to enhance environmental performance. Based on the theoretical assumptions of n-RBV, looking at past and present practices, a practitioner is bounded by choices that occurred in the past and have an impact on EP for the future (path dependency as in section 4.3.2). At the end of the workshop, the practitioners reviewed the inputs and clusters by reflecting on the question of "What we need to be good at to improve our eco-

efficiency?”. The question aimed at collecting further information on the capabilities that are perceived as important enablers of eco-efficiency improvements.

All data were tagged according to the nature and scope of the practice described (i.e. “review of waste contractor for recycling facilities” was assigned the tag “Audits”). Data, by default, were split into future and present practices (colour coding of the post-its made this possible). The findings from the workshop were consolidated in a pivot table. The structure of the grid made that possible. The analysis helped the researcher observe some trends in the maturity of practices:

- Management systems become more and more important in dealing with energy issues in factories.
- Reporting and collaboration with stakeholders could support energy efficiency more rather than regulation, policies, and top-management commitment.
- Top-management “commitment” and “team-work” as current distinct practices converge into a collaborative work as practice. This implies cross-functional teamwork across various management layers in the factory.
- Current practices of monitoring, reporting, policy incentives, and sourcing of renewables or clean energy are well supported in present and future. It was further noticed that as organizational maturity grows in dealing with energy efficiency, systems rely more on management attributes such as communication and well-designed procedures rather than KPIs, costing, and measurements (present).
- Sourcing becomes even more important with particular interest in recycled materials that become a primary source of input.
- Internal recycling is not viewed as a practice that could help improve on eco-efficiency in the future. It can also be considered as a shadow practice that will become the business-as-usual scenario in manufacturing (in some cases it already is).
- Collaboration with suppliers and customers to improve resource efficiency followed by life cycle thinking seems to support sourcing practices in the future.
- Standardization of processes and procedures, audits, and customer requirements form the basis of ISO management systems. It could be assumed that these can be supporting practice to resource efficiency management.

The final workshop step was about capabilities that may enable the transition between maturity levels. This step aimed at informing this work with ideas about practice enablers for

maturity progression. In Table 5-6 the workshop participants presented their views about enabling capabilities. These are answers to the question: “what do we need to be good at to improve on eco-efficiency”. The question follows the logic of “What should we be doing?” which is associated with strategic thinking (Normann, 2001).

**Table 5-6 For each organizational layer the workshop participants listed a set of capabilities that they saw as important for moving forwards between maturity levels.**

Process level capabilities
<ul style="list-style-type: none"> <li>• Data management, monitoring and analysis</li> <li>• Technical expertise and staff training</li> <li>• Staff understanding of process improvement methods</li> <li>• Knowledge sharing and collaboration</li> <li>• Worker’s proactivity - Enforcement authorities to prevent rather than react</li> <li>• Reporting conformity</li> </ul>
Production facility and systems
<ul style="list-style-type: none"> <li>• Include sustainability to business and furthermore to people’s roles</li> <li>• People understanding how their work effects overall business performance</li> <li>• Providing responsibility of ownership</li> <li>• Empower staff to influence performance</li> <li>• Capabilities of a learning organization</li> <li>• Capture and analyse information and performance data</li> <li>• Carry out effective and accurate cost-benefit analysis</li> <li>• Accurately calculate whole-life cost.</li> <li>• Afford and capability of up-scaling environmental awareness</li> <li>• Supply chain performance management skills</li> </ul>
Top management
<ul style="list-style-type: none"> <li>• Management commitment - make the business case to address sustainability/eco-efficiency issues</li> <li>• Confidence in data; reliable analytics</li> <li>• Moving responsibly to all the departments performance/efficiency</li> <li>• Finding ways around payback period; wider factors, new financial models</li> <li>• Capability to make long term decisions (more than 2 years horizon)</li> <li>• Influence stakeholders with real vision</li> <li>• Influence investors to accommodate long term requirements.</li> <li>• Sustainable leadership capabilities</li> <li>• Reconstruct outside the current business model</li> </ul>

A summary with the data analysis was sent out to IEMA for further circulation along with a feedback form about the workshop. This was a standard feedback form that IEMA uses for all the training workshops they perform:

Feedback from practitioners about the workshop quality (1: very low, 5 very high):

1. How useful did you find the content of this event?

1. 0%
2. 0%
3. 25%
4. 50%
5. 25%

2. How would you rate the content given by the presenter at this event?

1. 0%
2. 0%
3. 25%
4. 75%
5. 0%

3. How satisfied were you with this event overall?

1. 0%
2. 0%
3. 40%
4. 60%
5. 0%

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4. Please add any further comments that you may have (anonymous information)

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**Participant A:** "The approach was a bit confusing to start with but turned out to be a very good stimulant for useful discussion".

**Participant B:** "Not sure whether it helped us more or the presenters. I was expecting to attend this event to gain some practical tips on how to improve eco-efficiency within a manufacturing environment from the Centre for Innovative Manufacturing - not having to provide the information myself. (Though this may change when the results of the session are sent out - hopefully with some recommendations?). It would have been better to have more attendees from a manufacturing background to give more rounded views - perhaps marketed to a more specific audience. Some parts of the session were too long, and since the group was small would have benefitted from more group discussion rather than going round re-ordering priorities which I assume is to help the researchers, rather than the attendees to come away with more practical knowledge."

**Participant C:** "I felt, like a previous workshop I attended, that the event was very much geared to allow IEMA to collect our ideas for their research, rather than to give new information to the practitioners. The only factor that would change my opinion is if I am

subsequently sent a detailed list of all the suggestions made by the group, which I could then use in my workplace".

**Participant D:** "Looking forward to receiving info from the information gathered".

### 5.8.2 Workshop version 2

A second workshop was organized within an annual conference about energy and resource efficiency. The workshop was attended by 15 conference delegates who covered a range of roles within manufacturing and the service sector. More specifically, the workshop was attended by 5 industrial practitioners, 5 consultants and 4 academics. Compared to the first focus group, this one consisted of people whose work experience was more focused on sustainability from a business perspective rather than just manufacturing. They were people that would spend more time working and communicating with practitioners at the business front of the organization rather than the manufacturing front. In this execution of the workshop, the researcher printed the maturity grid posters in A0 size but gave the template a circular format instead of a grid (see Figure 5.4). This change was necessary as there was no option to hang posters on walls for people to wander around. There was no time or space allowed for repositioning post-it notes on the template like in the previous case. No time for discussion at the end was available either, so the process had to be adjusted. The researcher wanted to allow time for practitioners to discuss about practices and maturity levels. In order to retain consistency with the workshop in case 1, the researcher decided to execute only the first exercise and request participants to hand-write their contributions on the posters. In order to allow some mobility of data between maturity levels, arrows were used to demonstrate alternative opinions about maturity levels. Three tables were used to organize people into three groups (4-5 people in each group). The posters were laid on top of the tables and the groups would rotate every 20 minutes. In order to constrain the inputs, questions were written on the sides of the poster to guide the participants. To summarise, the steps followed:

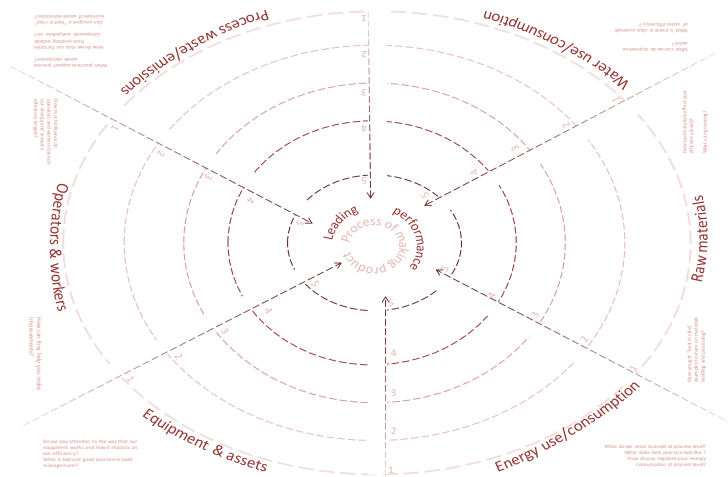
1. The researcher gave an introduction to the scope and aims of the workshop
2. A0 sized posters were printed with the dimensions of the maturity grid in a circular format instead (see figure 5.4).
3. Instructions were given to rotate the posters every 20 minutes to allow everyone to write on each dimension



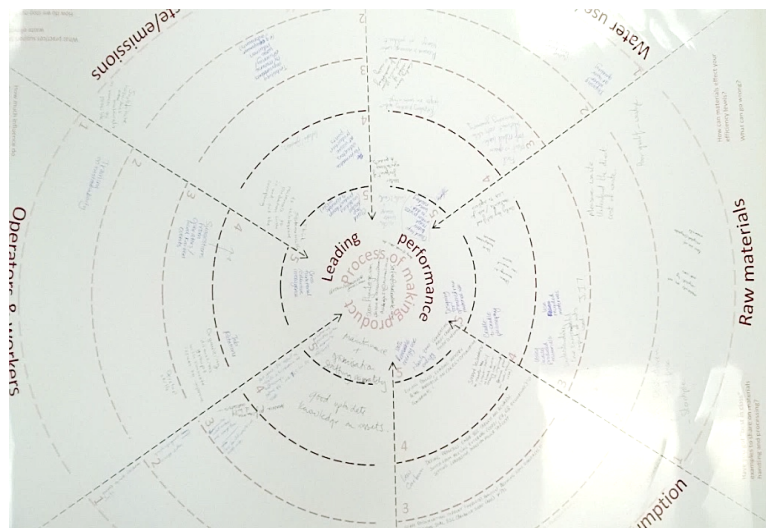
- Each group had 20 minutes for people to discuss with each other and write on the poster on each maturity level the manufacturing practices they thought belonged in that level.

**Figure 5.4 (a, b) The circular format of the PMGE for manufacturing processes eco-efficiency**

a) before the workshop



b) after the workshop



Compared to the first workshop this one did not achieve as much data input mainly due to time constraint. Two participants commented that it was a rather short session (90 minutes). Nevertheless, the workshop provided the opportunity for the researcher to: i) experiment with a shorter variant and ii) collect some data on manufacturing practices and eco-efficiency. The

table of processed data can be found in Appendix B. Compared to the first workshop, the researcher made three observations about eco-efficiency:

1. Companies should be embracing a more proactive behaviour through their manufacturing practices in dealing with environmental issues. There is a reactive to proactive direction which has been incorporated in the thinking behind the PMGE and it is now again evident in the workshop data.
2. Measurement and standards are increasingly important capabilities in gaining efficiencies in energy and resources. However, words that have been used such as “constant”, “planning”, “define”, “systematically” indicate further capabilities in the way that manufacturing practices are executed.
3. Words like culture and behaviour are found within the dataset i.e. “Culture that doesn't care” or “create culture [to achieve ...]”, “behave as partners”, “changing behaviour”.

Workshop 2 feedback was received through emails exchange and it was not as structured as workshop 1- mainly to time and resource constraints (Table 5-7).

**Table 5-7 Workshop 2 feedback from the second workshop**

Participant’s profession	Workshop feedback	Researcher’s comments
1.Doctoral student investigating eco-efficiency in supply chain.	"It was a bit challenging for others to start putting into the model. Some people came to listen and I think they were not ready to put thoughts. I am not sure how much did they got back on that session since we didn't have time to challenge content on site. Overall, they had idea of how important is the model for the Manufacturing field. Many thanks."	A similar comment was received from one of the participants in workshop 1. A level of confusion was expected due the variability of the audience. Additional work on facilitating and presenting the content will help the researcher be more effective in delivering the scope of the exercise quicker. In both cases though, once the process starts, people seems to follow up faster once they see how it works in practice".

<p>2. Designer working on sustainable architecture</p>	<p>"Thanks for a great session!"</p>	<p>This designer had little experience in manufacturing systems and her positive comments are encouraging enough to suggest that the overall process and content were relevant to her work.</p>
<p>3. Product designer</p>	<p>"I enjoyed really a lot the workshop (even it was really short time) and I think it was valuable for what I would like to engage with, that is remanufacturing and in general Circular Design. The only thing I didn't like it was about the general topic, I couldn't really focus about an innovative design strategic action, instead if I had maybe an object (for example washing machine) or a subject (washing machine industrial system) I could think about something better. But maybe this is just my problem, so perhaps you want it to force people think more "outside of the box."</p>	<p>This participant understands the basic ideas behind the workshop but evidently prefers this to be applied in a specific manufacturing system so it can be more concrete and relevant.</p>
<p>4. Sustainability advisor/consultant coming from electronics industry</p>	<p>"I did find the workshop useful, thank you. I think that is going to be really useful to have in mind as companies look to develop greater circularity in their processes - realizing that not only within their organizations but also outside, there are different views on where the opportunities are. I'd be interested to hear as you continue your research on how companies that are at "business as usual" but want to be "leading performance" decide where to focus - especially if they are relatively immature in a lot of ways."</p>	<p>This participant had experience working on sustainability in manufacturing supply chains and offers her thoughts. She mentions that the workshop was useful but it is not clear what exactly that means for her. A positive comment nevertheless for the process and content.</p>
<p>5. Experienced energy management consultant</p>	<p>"The workshop was interesting and it was an occasion to meet people and exchange ideas. To be honest I was not particularly surprised about the content, because I basically work on the same subjects and therefore I couldn't find any breaking news. You might consider working a little bit further in building the case (why your approach is making a difference) in order to be able to introduce the topics more effectively and with less slides. It would be great to have a summary of the things written in the posters, always good</p>	<p>This comment is seen as very useful for evaluating the process. The consultant is already aware of issues and challenges in sustainable manufacturing and runs an energy management consultancy in Italy. He finds the content very familiar which means that the process is relevant and applicable. Furthermore, he admits that it facilitates the</p>

to see what comes out of such a mixture of profiles."

5.Porcelain manufacturer (CEO)

"Thank you for the workshop, it was really interesting indeed. A bit short though, to fully understand the ideas you propose. If possible, could you please send me the slides you used? It would be interesting for me to apply this method in my company, to see in what extend are we aligned with the sustainability goals."

occasion of people meeting and discussing on such topic which was the intended use of the workshop.

This general manager of a Spanish manufacturing company found the content interesting and asked to run the self-assessment process with his employers to see how aligned they were to the sustainability goals that the workshop sets ("leading performance" column). His comments link this work with the idea of alignment and benchmarking of manufacturing practices to sustainability goals.

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## 5.9 Chapter summary

Driven by empirical data analysis and theoretical support, this chapter offers a model that projects the concept of organizational maturity on manufacturing practices for eco-efficiency improvement. The researcher described how the practice maturity grid for eco-efficiency was developed and what design and theoretical principles it adheres to. In order to understand how such a model can be used in real-life, three types of applications were explored. The utility that these applications exhibited is reviewed in chapter 7 to serve the prescriptive study (PS). In addition, this chapter calls for further research action. It remains to be clarified in more detail how companies can move forward between maturity levels (prescriptive use as per Röglinger et al., 2011). The following chapter aims to provide such insights and satisfy the first research objective. The researcher investigates how more mature companies approach eco-efficiency and what capabilities can be used for that purpose.

# 6 CAPABILITIES FOR ECO-EFFICIENCY IMPROVEMENTS

## 6.1 Introduction to the chapter

The aim of this chapter is to provide additional support to PMGE, by collecting the views of expert practitioners in two cases. The practitioners actively work on the area of energy and resource efficiency in manufacturing. The chapter intends to inform this inquiry on how companies can mature their internal processes and be more eco-efficient. It also serves as a transitional chapter to the following synthesis chapter. The researcher comments on the cases and links this chapter with literature and previous research findings.

In the first part of this chapter, two case studies are introduced from the aircraft and automotive manufacturing sectors. The companies in these cases have publicly committed to reduce their energy and material footprint (for production and product level). The chapter focuses on the observation of certain practices that used in these companies to support energy efficiency projects. PMGE is also applied in one of the cases to build a level of trustworthiness into the maturity grid.

The second part of this chapter examines more closely the factors that help these companies improve on energy and resource efficiency. The observations help the researcher verify some aspects of the maturity grid and build stronger connections to the RBV theory.

## PART A

### 6.2 Two case studies

Two companies that actively pursue manufacturing excellence and are concerned with the impact of their operations on the environment were approached. The first one is a company that operates in the aerospace sector and the second one in automotive. Table 6-1 demonstrates some of the characteristics that were found to be common in these companies and how these are important for this work. It is acknowledged that these similarities may influence this work. The right column in Table 6-1 discusses the potential implications of these characteristics for this work.

**Table 6-1 Observed characteristics that the cases share in this chapter. The right hand column describes the links with literature and potential bias that the characteristics bring in this work.**

<b>Observed characteristics relevant to the study</b>	<b>Comments and relevance with this work</b>
Discrete manufacturers (vehicles and aircraft) with international suppliers and customers as well as members of global parent companies. Formally committed to their stakeholders about reducing their environmental impacts.	Both companies issue social corporate responsibility reports for their region and report efficiency numbers for energy, CO <sub>2</sub> , and Volatile Organic Compounds (VOCs). Both support actions on Climate Change and have dedicated departments for environmental management at facility level.
Both companies employ lean manufacturing practices.	It is observed by various authors that an effective lean environment can be a nurturing ground for EP improvements or EP benefits (Bandehnezhad et al., 2012; Baumgartner and Zielowski, 2007; Hajmohammad et al., 2013; Lunt et al., 2015)
Both companies operate multiple manufacturing facilities across various European countries and there is material flow between the factories towards final product assembly.	Therefore, the boundaries of their manufacturing systems expands beyond national borders (different languages per site) and one factory can be the internal customer/supplier of another.
Both companies support environmental management systems and are ISO14000 accredited for their manufacturing practices.	ISO14000 has been positively linked to eco-efficiency as a supporting factor in some cases but there is doubt in literature about its effectiveness (section 3.4.3)..

Practitioners from middle and senior management were interviewed about their improvement journey on eco-efficiency (in chapter 3, using open-ended questions of how and why). All practitioners in these two cases were chosen for their involvement in environmental

performance management and managing energy and resource efficiency projects. Data availability and time restrictions allowed the researcher to investigate energy efficiency more than resource efficiency in these companies and therefore some limitations may apply to the conclusions of the study here. It was known that both companies are active in waste reduction and resource efficiency.

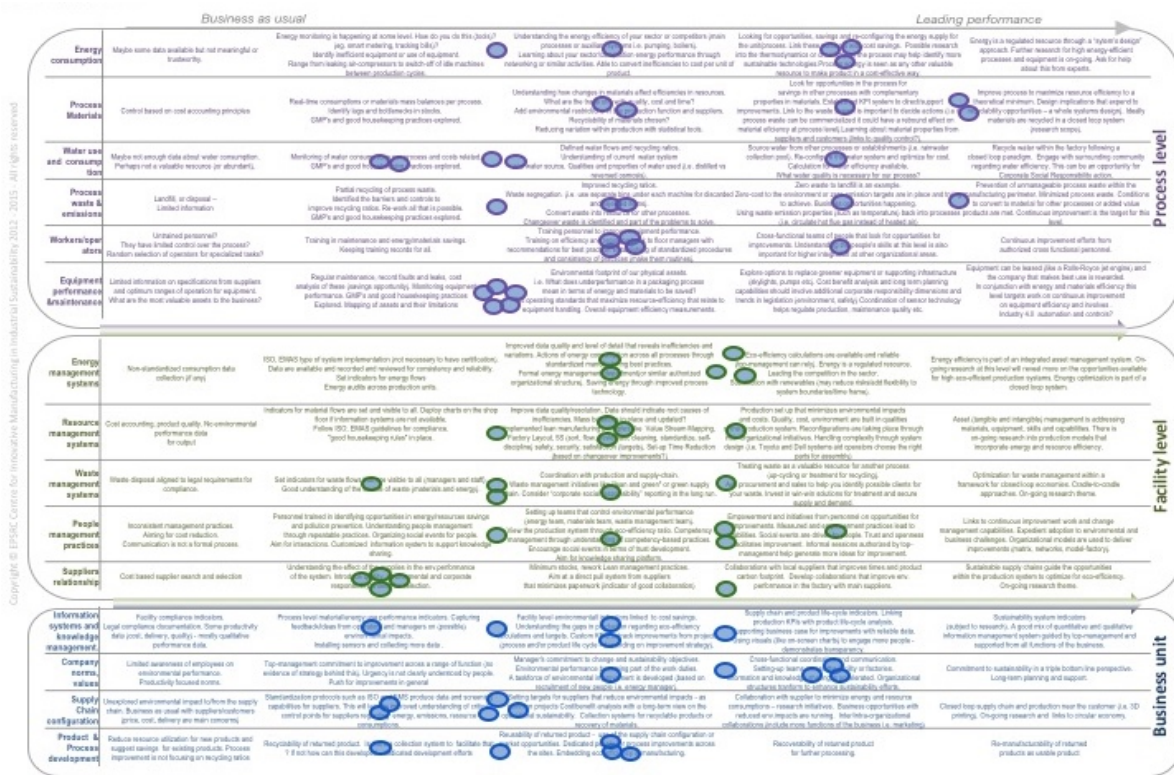
Transcribed interviews, emails, official corporate publications (i.e. corporate newsletters and corporate social responsibility reports) and one focus group (in the case of the aircraft company) were the main sources of data. The following sections describe two improvement projects on energy efficiency across several manufacturing facilities. Through the study of these projects, the researcher was able to reflect on the success factors that enabled the projects to emerge and disseminate across manufacturing sites.

The inquiry here had a more specific scope than in the cases in chapter 5. The researcher was leading the discussions and was also searching for clues to understand how these companies improve on energy efficiency in practice. The maturity framework was applied in the case of the aircraft company as a self-assessment tool with 5 environmental management practitioners representing five different manufacturing sites (out of eleven). The results gave the researcher an indication of the practice maturity in this company (Figure 6.1). Based on the words of the aircraft energy efficiency group leader, the automotive company was perceived to be even more mature in their manufacturing practices and environmental strategy:

“The initiative in the UK plant therefore made extensive reference to the approach as coming from the automotive company to generate buy in and avoid the perceived fear of implementing something that will not work”.

Thus it was deduced that the automotive company would be the most mature company between the two. From a methodological perspective, the researcher tested the assumption that the aircraft company would be heading towards leading performance on the PMGE across all dimensions. Indeed, Figure 6.1 indicates a middle to high maturity level assessment. The representation of linear maturity profiles (as in study by Baugardner and Ebner, 2010) was exchanged with dots for better readability of the visual output.

**Figure 6.1 The aircraft company maturity profiles from five practitioners in the aircraft company. The researcher followed the process as described in the second part of chapter 5 (see self-assessment process in paragraph 5.1).**



In Figure 6.1, the results verify the assumption that the company is active in energy and resource efficiency and it is an indication of the grid's effectiveness to capture that information. The figure communicates that the practice maturity in this case ranges from maturity level 2 to maturity level 4.5 (half levels were allowed as an indication of work in progress). The dots represent the perceptions of practitioners about the practices that are being used in their manufacturing sites. They were able to relate to all the dimensions of the grid and find a cell with a description of a practice that they employ in their site.

### 6.2.1 The aircraft company

The company operates in the aerospace sector and runs 11 manufacturing sites that employ approximately 50000 people across four European countries. Most of the sites are responsible for specific parts of the aircraft i.e. fuselage, wings. These parts once manufactured are sent to two final assembly sites. Addressing energy efficiency in manufacturing has practically been a major concern for the company for several years. It was not until 2006 that a corporate



policy was developed that would formalize efforts towards energy efficiency and set a 20% reduction in energy by the year 2020 across all manufacturing sites. An environmental steering committee at board level was set up which also overlooked waste reduction and resource efficiency. The year 2006 became the baseline year for energy savings and performance measures. Energy saving projects were initiated then, across multiple manufacturing sites. These were carried out as project based activities, locally guided by the heads of each division and function per site. A corporate protocol for developing the business case for each project is an initial part of the process. It is designed to assign particular resources and accountabilities to the people in charge of the improvements. Up to 2012, improvement initiatives had a local focus per site and an awareness-raising character. It was agreed that in order to replicate local improvements across the plants a process of cross-plant coordination was necessary. A study on the barriers to energy efficiency in this company revealed three important barriers which needed to be addressed (Lunt et al., 2014):

- Lack of accountability: The site energy manager is responsible for reducing the site's energy consumption but only has authority to act within a facilities domain—that is, by improving facilities and services, such as buildings and switchgear. He is not empowered to act within a manufacturing operations perimeter. Therefore, no one is responsible for reducing energy demand.
- No clear ownership: Many improvements are identified but then delayed due to a lack of funding to carry out the works. This is because neither facilities nor manufacturing operations agree whether the improvement is inside their perimeter: typically, facilities claim that it is a manufacturing process improvement, and operations claim that any benefit would be realized by facilities. Both are correct, hence neither will commit resources to achieve the improvement and own the improvement.
- No sense of urgency: A corporate target exists for energy reduction—but the planned date for achieving this is 2020.

The solution that the environmental steering committee decided to support, was the creation of an industrial energy efficiency network (IEEN). The company had previously done something similar when seeking to harmonize its manufacturing processes through process technology groups (Lunt et al., 2015). This approach consists of each plant nominating a representative who is taking the lead and coordinating activities. It is expected that the industrial network would contribute to a significant 7% share out of the 20% energy reduction target for the year 2020 since its establishment as an operation in 2012.

The network's operations are further facilitated with corporate resources such as online tools that help practitioners report and track the progress of current projects, review past ones and learn about best-available techniques. This practice evolved into an intranet web-site that is further available to the wider community of practitioners in the manufacturing perimeter and aims to generate further interest and enhance the flow of information back to the network. In addition to that, a handbook to guide new and existing members in engaging effectively with the network and its objective has been developed for wider distribution. These tools are supported by training campaigns across the sites.

Most of the network members also act as boundary spanners (Gittell and Weiss, 2004) in the sense that they have established connections to process technology groups or they are members of these groups as well. This helps the network establish strong links with other informal groups within the organization and act as conductor for a better flow of ideas between these groups and the network. Potentially, network members have a chance to influence core technology groups towards energy efficiency at product level.

On average, a 5-10% work-time allocation is approved for all network members to engage with the network functions. In case a member is not coping in terms of time management there is the option of sub-contracting the improvement project to an external subcontractor who is hired for that particular purpose and the subcontractor's time allocation to the project can be up to 100%.

“...by having the network we meet and we select together a list of projects that we want to put forward to access that central pot of money. So we know roughly how much will be allocated to industrial energy efficiency and so we select projects across all of the sites that we think will get funded and we put them all together as a group...so rather than having lots of individual sites making individual requests for funding and being rejected, by going together as a group and having some kind of strategy as well...”

Figure 6.2 shows the savings achieved by the different plants in the first year of implementation. Figures have been normalized against the savings target of Plant A. The energy savings are shown here as evidence of the effectiveness of this solution. Overall, the practice of networking across a number of manufacturing sites has proven to be effective in this case. However, limitations need to be acknowledged. The information collected was limited by the time the researcher had to interview and meet with the members of the

network. More organizational characteristics were difficult to explore that would demonstrate how this practice could improve or be sustained in the long-run.

**Figure 6.2 Energy savings per site as compared to the improvement targets (Lunt et al., 2015). The figure demonstrates how the effective this networking practice has been for the company in its first year of operations.**

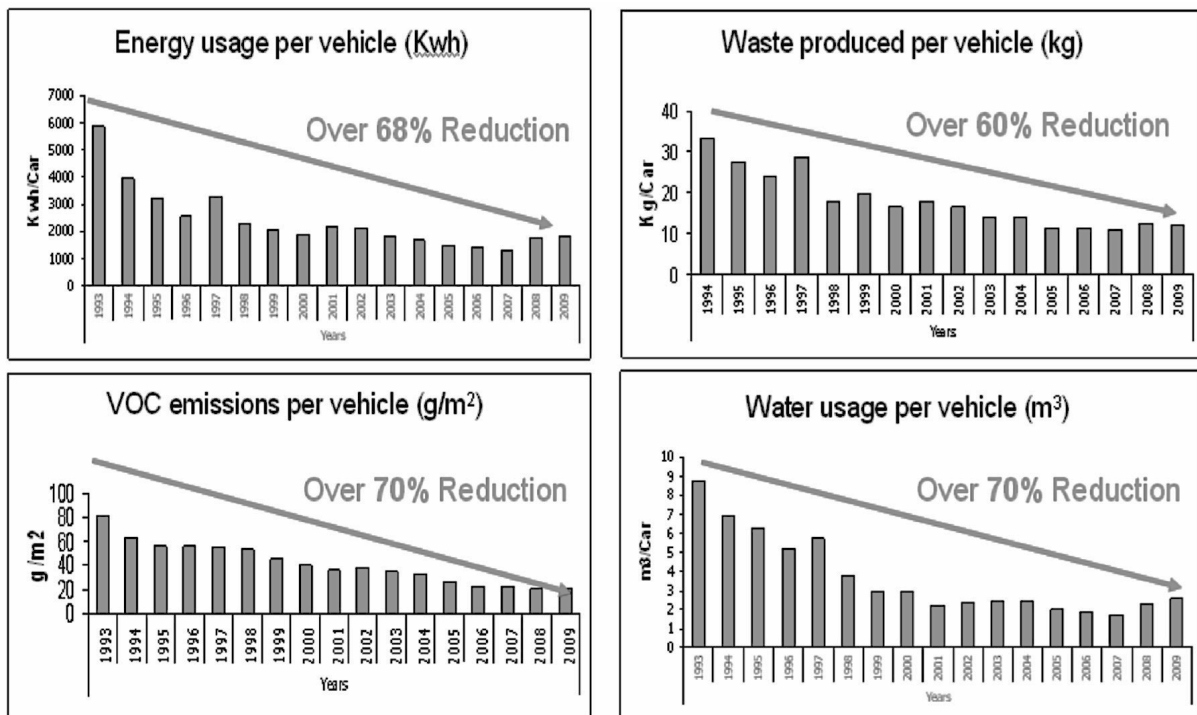
Site Reference	Savings Target	Actual Savings	Savings cf. target
Plant A	1.000	1.712	171%
Plant B	0.001	0.006	500%
Plant C	-	-	-
Plant D	0.375	0.083	22%
Plant E	0.125	0.122	97%
Plant F	0.208	0.208	100%
Plant G	0.167	0.392	235%
Plant H	0.286	0.224	78%
Plant I	0.108	0.108	100%
Plant J	-	-	-
Plant K	2.917	4.167	143%

### 6.2.2 The automotive company

The automotive company is a Japanese global manufacturer and a lean management pioneer. The company actively pursues environmental and social sustainability improvements and other companies find their methods inspirational or exemplar (Dyer and Nobeoka, 2002; Lunt et al., 2015). In the past, the company's European branch had collaborated with the aircraft company in the previous case, on research projects on energy and resource efficiency for manufacturing facilities. The interviews were held with the environmental and social responsibility general manager for Europe, one of their factory managers in the UK and a manager from the corporate planning function. The company has been continuously improving on various environmental indicators and they feel that the environmental sustainability proactivity thinking already lies within the staff. The company operates 9 factories across the broader European region with some of them making engines and transmissions that are then shipped to the other car assembly factories.

In terms of environmental performance improvement, the UK plant for example, between 1993 and 2013, reduced its energy usage per vehicle by over 70%. In the same period it also reduced water use per vehicle by over 75%, and waste produced per vehicle by nearly 70% (Hope, 2013). Figure 6.3 demonstrates their improvement journey from 1993-2009 across a range of environmental indicators (energy, waste, volatile organic compounds and water):

**Figure 6.3. A consistent reduction pattern across a range of environmental performance indicators for the European sites. Evidence about the improvements in plants in non-European countries was not available. Source: www.therm-project.org.**



Two factories in Europe have been designated by top-management as model factories for energy (UK) and water efficiency (France). The decision to assign the title of a model factory to those sites made further business sense (i.e. the cost of energy in the UK is a potent driver for energy efficiency whereas the French site was much newer technologically). A specific energy efficiency improvement actioned focused on the plant’s control systems in the paint booth process. An opportunity to improve was at hand but the financial risk of failure to achieve the calculated benefits was difficult for the factory’s budget to bare. However, the environmental general manager for Europe decided to raise the funding centrally for the trial to occur in one of the paint booths in the UK site:

"We need to make the step change. This is the amount of money we will pay. We will invest this money one time in one paint booth only in UK as our model plant".

The fact that the UK site was already assigned as a model factory made the choice for experimentation even more justifiable. The results were very good and the site managed to improve the efficiency of the paint booths by 40%. The improvement was then justifiable at plant level and then cascaded across all the plant's paint booths, thus achieving better scales of efficiency. Through standardization and continuous improvement practices, the achievements became the new energy-efficiency standard in the paint-booth processes. In addition, the achievement was communicated through formal intra-organizational environmental networks in the company and this was then replicated in other sites where the improvement was relevant.

Another scope that the model factory serves is technology management. For example, the model factory in the UK serves as a testing hub for improvements through conventional technologies for other sites with similar technology readiness levels. The site in France is the newest one in Europe and therefore it is portrayed as a model factory for advances in car manufacturing technologies. The distinction facilitates the decision making process and makes it easier for other sites to know where to address specific environmental efficiency issues related to technology improvements.

The idea of the model plant further facilitates the budgeting process for improvement projects. Even though there is local budget per plant for improvements, there is a budget range that could be considered too risky for the plant. This means that plants may be in competition in the eyes of top-management when it comes to asking for centrally governed funds. Having a pilot to test ideas such as the model factory serves as a way to reduce that internal pressure for budget allocation.

## PART B

### 6.3 Comparative data analysis

The second part of the chapter seeks to identify capabilities that work to enable energy and resource efficiency improvements within and across manufacturing sites. The element of multiple sites was considered as crucial at this point to investigate. It links this work with the original observation of EP variation across sites and further generates information about

scaling up improvements faster. Four key capabilities emerged from the data and are described in the following sections.

### **6.3.1 The capability to align practice with organizational strengths**

The industrial energy efficiency network is not the only network that operates within the aircraft company. For example, in March 2015 a network to improve gender balance in the workforce was launched. It was confirmed from the energy network leader that this is a common practice in the company as it is a way of keeping all sites informed about new projects and maintain a level of harmonisation in practices. It is a practice that has been nurtured over the years and is used to promote collaboration and communication internally and across sites. It was confirmed from the energy network leader that he made a conscious choice not to create an energy-model-factory (he was aware of the automotive company's approach, the model factory). He saw the network as a better cultural fit for that activity instead of promoting the site he worked at as the energy efficiency model factory.

Advanced networking capabilities were also noticed in the case of the automotive company. A form of a matrix organization system emerged in 2008 (“Beyond the matrix organization | McKinsey & Company”). This matrix system reduced the time it took for people who worked on environmental issues to seek advice or receive feedback from peers in other plants:

“You don't have to wait for the top-management to come back...you can communicate horizontally to team member level or team leader level...so process operators, process owners or group leaders and engineers can actually communicate with their peers (in other plants) without having to go through their top-management all the time.”

The company enables practitioners to communicate horizontally by introducing quarterly meetings between environmental representatives from each site. These communications became part of their formal procedures to a level where progress meetings were held with deliverables.

During the interviews the researcher observed a difference between the two cases, though both companies demonstrated networking capabilities. The energy network was relying more on its social character to sustain its functions. There was strong emphasis and pride by its leader on keeping the network operation as informal as possible for the members and he strived to maintain a sense of entertainment and informal attitude towards the members (for example hosting one of their regular meetings within an academic institution). Overall,

networking was a preferred option in the aircraft company that strived to keep its sites across Europe connected in multiple ways. Networking was a preferred route of enabling cross functional and international collaborations for projects such as technology improvements, gender equality and energy efficiency.

On the other hand, the environmental manager in the automotive company describe the networking functions of their environmental representatives with a sense of formality, time-keeping of schedules and process standardization. According to him, the framework that supports their operations consists of four elements:

- Policy, philosophy and vision
- Member awareness, training, motivation and recognition
- Process knowledge, mapping of data
- Strategic action, planning methods, tools, feedback and methods for sharing and collaboration

The researcher concludes that combining the best of both approaches is necessary in order to achieve the functionality that was described above in pursuit of energy and resource efficiency improvements. It is a balance that must be fuelled by its people at all levels:

“...with passion and dedication, who are collaborative, have a willingness to learn...and can demonstrate open and lateral thinking...whilst singing off the same hymn sheet!” (Hope, 2013).

Compared to the aircraft company, the automotive relies more on their core capabilities of standardisation and continuous improvement to sustain networking functions internally and across remote sites. These observations seem to confirm the RBV theoretical proposition that companies may apply existing capabilities on new areas in the business in order to address new challenges (Canato et al., 2013; Claver et al., 2007). Companies at high practice maturity levels, are expected to rely on core competences to address eco-efficiency challenges. The two case studies here express two possible routes of that process.

### 6.3.2 The role of lean principles and process harmonization

Both companies employ lean manufacturing principles to make product (Andersson et al., 2006). This approach was applied in the case of energy efficiency and a method was developed which was aligned with the waste hierarchy. The automotive company applied lean thinking to develop a method consistent to their lean principle. This principle evolved in

the form of six attitudes for energy efficiency: 1) Stop, 2) Eliminate, 3) Repair, 4) Reduce, 5) Pick-up and 6) Change (Hope, 2011). These attitudes have also been adopted in the aircraft company and were renamed to: 1) Stop, 2) Remove, 3) Repair, 4) Reduce, 5) Trade and 6) Change (Lunt and Levers, 2011). The copy from the automotive was not accidental. It was enabled by a common research project that both companies supported, related to process modelling for eco-efficiency (Ball et al., 2013). The flow of that process from the automotive to the aircraft company further indicates the maturity and credentials of the first one in dealing with environmental concerns (Lunt et al., 2015).

With lean management and process standardization, both companies value the idea of having environmental performance standards. However, both companies realized how difficult it would be to benchmark a process or a plant against another. The main reason was that there was no identical process or plant for benchmarking. Plants may be very similar but not truly identical. A workaround of this issue was observed in the aircraft company with the use of the word “harmonization” and the idea of harmonizing instead of standardizing processes and plants to a way of conduct instead of a standard. The substitution of standardization with harmonization conveyed the mental image that processes, people and plants would be part of an orchestra that would have to synchronize to a pace set by the orchestra conductor (Paquin and Howard-Grenville, 2013).

A similar approach seemed to exist in the automotive company. It was noticed through the words of the environmental manager for Europe: “...*whilst singing off the same hymn sheet*”. However, the idea of harmonization had not yet surfaced in the case studies here before. It was observed and brought up for discussion by the researcher. It was proposed that the concept of harmonization may be a substitute to standardization when it comes energy and resource efficiency across manufacturing sites. Operationally, it is not clear how this can be achieved or described in practice. What can be proposed, is the mental image of an orchestrated system that finds its pace under the facilitation of its conductor. This enables people to examine issues in a similar way across a range of processes or plants. It also enables them to understand the operational level of performance and avoid the risk of comparing like-for-like when identical systems and configurations are not in place. Harmonisation can be considered as a practice of high maturity as it involves coordination and use of common language across various functions of the manufacturing system. In the case of the aircraft company, the use of ISO14000 system was seen as a common language



being used across sites and enabled the proceedings of the industrial energy efficiency network.

Some studies have investigated the link between lean management and standardisation in the context of environmental performance or eco-efficiency (Andersson et al., 2006; Hahn, 2013; Hajmohammad et al., 2013; Link and Naveh, 2006). An alternative concept to standardisation has been described by both companies as harmonisation of practices in manufacturing sites. The concept follows the description of an orchestrated system by a central conductor, trainer or even a code of conduct (Ferdows and Thurnheer, 2011; Paquin and Howard-Grenville, 2013; Probst and Borzillo, 2008). Companies at high maturity levels deal with complexity and heterogeneity (which is difficult to benchmark) within manufacturing systems by practice harmonisation.

Harmonisation is potentially a proxy for process standardisation. It is perhaps a more useful concept for eco-efficiency improvements (which is not a traditional performance dimension compared to cost, delivery etc.). The implication of this observation for PMGE may be relevant to the way that the maturity profiling works. In the study of Baumgardner and Ebner, one may observe that at high maturity levels, companies are proactive and deal effectively with all dimensions of sustainability. One may also observe how the maturity assessments move from low to high maturity levels across all dimensions (see Figure 5.1). In time, companies with harmonised practices may see all dimensions of PMGE moving towards higher maturity levels. Having areas of both low (i.e. level 1) and high (i.e. level 4) practice maturity requires further investigation from the company.

### 6.3.3 The supporting role of corporate financial systems

“Financial systems” refers to the ways that the company enables plant managers to finance improvement projects for energy efficiency. The financial support mechanisms in both cases were risk-averse. Any expenditure had to be well-documented and tested before it can be eligible for finance. However, a level of experimentation was allowed so that improvement initiatives would have a chance to establish the gains calculated. In the case of the aircraft company, the energy efficiency network would agree on how the available budget would be distributed to projects across plants.

“...by having the network we meet and we select together a list of projects that we want to put forward to access a central pot of money. So we know roughly how much will be allocated to industrial energy efficiency and so we select projects across all of the sites that

we think will get funded and we put them all together as a group...so rather than having lots of individual sites making individual requests for funding and being rejected, by going together as a group and having some kind of strategy as well...”

The difference in the automotive company was the use of the model factories that would be looking into eco-efficiency improvements more specifically (i.e. the UK plant for energy efficiency). These factories would absorb additional funds for testing new ideas prior to wider implementation. This distinction reduced the competition between plants who were interested in fund allocation to implement their own process changes/improvements:

“Probably it would be fair to say that France (plant) does not feel in competition with UK (plant) on the current car model or something like that but if some investment is coming towards the region...then the plants are in competition and they all would like to improve their businesses and secure their future...”

In this work, financial supporting mechanisms are seen as a valuable internal capability that indicates high organizational maturity. It acknowledges the risk of spending funds for eco-efficiency improvements by developing safety nets around them. The “model factory” or a “model production line” can be seen as a testing ground that reduces financial risk and validates savings made to other factories or production lines. Harmonisation, as described previously, would then allow the rapid replication of improvements across factories and production lines.

A link between EP and FP has been discussed in chapter 3, where various authors sought to better understand how these two areas of performance can be coupled and calculated ((Figge and Hahn, 2013; Huppel and Ishikawa, 2005b). In the case studies here, practices were developed to assist practitioners become financially accountable for energy-efficiency projects. Both companies see improvements as short-term and well-defined projects, aligned to a certain goal. For example, a model-factory helps the automotive company test and validate improvements before replicating to other sites. Practitioners follow rigorous financial accounting processes to establish and authorise improvement projects as well as allocating resources. The implication of this observation for this study relates to the alignment of EP improvement projects to manufacturing strategy (Brown et al., 2007; Perego and Hartmann, 2009).

### 6.3.4 Internal knowledge sharing

One final observation was found to be relevant to the objective of the cases introduced. Carrying out improvements for energy efficiency in both cases was facilitated by knowledge sharing internally and across sites. Two elements of this type of support were identified. The first one was the information system used and the second one was the right selection of people that can support horizontal and vertical knowledge transfer.

#### 6.3.4.1 Information systems

The researcher observed the role of information systems in accelerating improvement projects as a resource in the aircraft company. It was noticed that the members of the network had managed to influence the procurement process for capital equipment through the corporate planning system (another internal competence). A list with selected suppliers and energy efficiency equipment was part of the corporate supplier's list. For every new equipment procurement, there was an energy efficient option (where applicable). This capability within their system was seen as a very positive achievement due to the large size of the organization.

Another example of information system support was the way that energy efficiency improvements were tracked across 11 manufacturing sites in the aircraft company. An intranet website to share that information was set up and work was in progress to enable more users (non-network members) to access that information. This information sharing was found to be an eligibility factor for factory selection when it came to technology upgrades in the automotive factories as well:

“...even if it is maybe a replacement model or a new product YES they (the factories) do feel some pressure to make sure they are performing and this is another important role that senior management can play. Because senior management can compare the normal KPIs (profitability, labour, cost) all those things on the list...but actually some of the behaviours should also be part of that evaluation...Does this plant participate in sharing knowledge well...does it cooperate with other plants and training them and advance people in new technologies, if those things are considered as well, the plant is more likely to cooperate...”

This type of attitude suggested that deeper capabilities need to resonate in the organization. Such attitude can be supported by a careful selection of lateral thinking people.

#### 6.3.4.2 Lateral thinking people – recruitment

Being able to identify and recruit people that tend to think laterally and share knowledge, was observed to be a key enabler for information sharing in the case of the automotive. Aligned with the matrix organizational structure, the company strives to internally recruit people that can think laterally. They are trained to work across sites on eco-efficiency projects and train other like-minded individuals to do like-wise. The practice of “*train the trainer*” has been used with success in recent years in the company. It is another indication of high-level organizational maturity in practice.

Overall, knowledge and information sharing in manufacturing systems has been a focal point for various theorists of the RBV (Banker et al., 2006; Canato et al., 2013). As a final observation through the case studies here, it is one that seemed very difficult to develop and implement. There is the hardware element of information systems (i.e. computers and servers etc.) which seemed to be related to the size of the organization. Both companies here would rely on their computer systems to structure their work and make sure that projects would be sufficiently documented, integrated and aligned with other functions (i.e. procurement or engineering). The more difficult part of this capability had to do with the way the information sharing process is humanly resourced. People’s characteristics were outlined with detail in the case of the automotive and shows how mature manufacturers would select people to support knowledge sharing processes.

### 6.4 Review of findings and connection to theory

Practice characteristics of mature manufacturing systems have been identified through the case studies in this chapter. These characteristics enable a result-driven attitude for energy and resource efficiency improvements. Signs of high practice maturity have been identified such as “training the trainers” or process harmonisation.

Reflecting back to the results from the first workshop (chapter 5, part 2) the researcher performed a cross-reference between the case studies here to what the workshop practitioners considered important capabilities in the previous chapter (Table 5-6). The aim of Table 6-2 is to demonstrate that there is internal consistency in this inquiry and compliments the maturity assessment in Figure 6.1.

Table 6-2 Cross-reference of what workshop practitioners considered as important capabilities for eco-efficiency improvements (Table 5-6) and evidence found in the case studies in this chapter in alignment with PMGE.

Workshop output from Table 5-6	Observations in the case studies
<b>Process level capabilities</b>	
Data management, monitoring and analysis	Both companies would rely heavily on data quality to perform improvements.
Technical expertise and staff training	Training individuals at a level where they can also train others (“train the trainer”).
Staff understanding of process improvement methods	Within a lean manufacturing environment, there was already a specific set of tools for process improvement (i.e. kaizen, 5s)
Knowledge sharing and collaboration	See paragraphs 6.3.4. Automotive manager mentioned that they encourage people to “copy with pride” internally when it comes to best practice.
Worker’s proactivity - Enforcement authorities to prevent rather than react	Non-available data
Reporting conformity	Non-available data
<b>Production facility and systems</b>	
Include sustainability to business and furthermore to people’s roles	It was mentioned in the automotive company that EP had become one of their core performance indicators since 1993 and everyone in manufacturing knew this (figure 6.2 demonstrates such drive). A similar attitude was observed in another function of the business (corporate planning).
People understanding how their work effects overall business performance	No clear indication found in data however this potentially ties with the previous point.
Providing responsibility of ownership	This was observed in the aircraft company from one of their members who designed one of the most energy efficient paint-booths in the world. He was the project owner and talked about this achievement with great pride.
Empower staff to influence performance	The industrial energy efficiency network was an expression of such capability (see comment on budget allocation in 6.3.3)
Capabilities of a learning organization	Non-available data
Capture and analyse information and performance data	Both companies employ sophisticated data analysis systems
Carry out effective and accurate cost-benefit analysis	A rigorous business case study process was described in both cases
Accurately calculate whole-life cost	Non-available data – ambiguous terminology
Afford and capability of up-scaling environmental awareness	Environmental awareness campaigns communicated through corporate newsletters.

Supply chain performance management skill	Non-available data
Top management	
Management commitment - make the business case to address sustainability/eco-efficiency issues	Eco-efficiency is supported by top-management committees in both cases.
Confidence in data; reliable analytics	Non-available data. However, both companies seemed to rely heavily on data to support improvements.
Moving responsibly to all the departments performance/efficiency	See paragraph 6.3.4 about cascading information vertically and laterally in the organization
Finding ways around payback period; wider factors, new financial models	Not very clear in the data. Very rigorous financial systems were in place for all types of improvements and both companies here would comply with these systems.
Capability to make long term decisions (more than 2-year horizon)	Non-available data. Improvements would have to have a short payback and ways of reducing risk were found (i.e. the model factories).
Influence stakeholders with real vision.	Non-available data – ambiguous terminology
Influence investors to accommodate long term requirements.	Non-available data
Sustainable leadership capabilities	Non-available data – ambiguous terminology
Reconstruct outside the current business model	Non-available data

Overall, evidence suggest that there is a good alignment between what mature companies do and what practitioners in the case studies perceive as important capabilities. This observation helps the researcher to retain empirical internal consistency. Some gaps in Table 6-2 exist either because the dimension was not covered in the case studies or because the capabilities are too ambiguous (i.e. sustainable leadership capabilities).

In order to examine the alignment and connection to RBV theory a literature review was performed. This review clarifies how the case studies in this chapter are theoretically consistent with the selected RBV theory.

#### 6.4.1 Relying on internal capabilities to develop solutions

This observation confirms studies that predict such organizational behaviour within the RBV theory (Banker et al., 2006; Claver et al., 2007). Both companies here were observed to use pre-existing internal competences to address eco-efficiency challenges. The researcher sees

this as a safe approach for work in a developing subject area such as eco-efficiency. Companies may be more inclined to use what they are already good at in order to address eco-efficiency challenges. Both companies in this chapter exhibited elements of this behaviour. The researcher sees this route as one with reduced organizational friction, as long as companies are able to recognise what they are good at. Relying on internal capabilities to develop solutions can be a vehicle for improvement. Maturity assessments for companies that are already aware of this improvement route may not be enough to drive further improvements. Maturity assessments may be more useful for companies that are at low maturity levels and need more support to understand how to design improvement projects for eco-efficiency.

## 6.5 Chapter summary

To summarise, the case studies informed the researcher on how the concept of practice maturity may be operationalised and how it is connected to RBV theory. The cases studies demonstrate critical characteristics of mature manufacturing systems that can drive eco-efficiency improvements effectively. These characteristics offer a level of validation of the theoretical assumptions of PMGE and translate them to actionable information. This chapter shows evidence that RBV theory can support eco-efficiency improvements in manufacturing.

This chapter meets the first research objective. PMGE offers practitioners a way of assessing the eco-efficiency levels of their system and further shows the potential to improve (as a planning tool). The improvement potential depends on how effectively practitioners can leverage their existing internal capabilities to improve.

The following chapters build upon the findings and information collected so far to make the PMGE the basis of a more structured approach for eco-efficiency improvements. The main argument from RBV theory, that practitioners can leverage existing internal capabilities to improve, needs to be systematised into an improvement method with clear steps for practitioners to follow. Effective application of such a method can meet the requirements of the second research objective and conclude this inquiry.

2nd Research Objective: The support should be applicable in real-life situations and be usable by practitioners in manufacturing. Therefore, the researcher needs to offer guidance for practitioners on how to effectively apply the support.



# 7 SYNTHESIS OF PMGEM

## 7.1 Introduction to the chapter

This is a chapter about synthesis of research findings and emerging concepts into a method that brings the researcher closer to the answer of the research question. The chapter serves as the prescriptive study for the DRM framework. The researcher introduces key learnings from previous chapters and embeds these into a method that can support the design of eco-efficiency improvements in manufacturing. The chapter describes the intended use and success criteria of the method, prior to further testing in the second descriptive study that follows (chapters 8-10).

The main research question intends to fill the knowledge gap that may enable practitioners to balance the benefits from improvement projects between environmental and financial performance (see **Figure 3.4**). Filling the knowledge gap means that practitioners are enabled to reduce environmental performance variation and sustain more economic value for the business.

Main research question:

“What kind of practical support may further enable companies to improve the eco-efficiency of their manufacturing systems?”

Tentative contributions to practice and theory are also introduced throughout the chapter and reviewed in chapters 9 and 10 respectively. These are relevant to the intended use of the

method as well as its theoretical grounds. The researcher distinguishes the contributions to knowledge and practice with the method's success criteria even though overlaps may be noticeable.

## 7.2 Review of PMGE application processes

In chapter 5, three possible ways to apply PMGE were presented: a) self-assessment, b) case study and c) practitioners' workshop. The objective of the application was twofold: firstly, to learn more about manufacturing practices in the context of eco-efficiency and secondly to learn how easily these applications can be followed by participants/users. The level of facilitation of the applications was found to be a critical factor of their effectiveness. The self-assessments and the workshops were the less time-consuming applications and yielded satisfactory amount of information. Using the maturity framework to guide an in-depth case study was the most demanding in terms of facilitation and resources. Some utility was evident in that application but the long-term effects were not easy to evidence.

The researcher found that the self-assessment exercise was quickly communicated to practitioners based on the time and effort it took to explain the process and receive feedback (15 minutes on average). The exercise seemed to be easier to facilitate when practitioners could physically interact with the material (i.e. draw or write on a piece of paper or poster). Providing an example of a maturity profile was also found be useful as a way of presenting the PMGE. As a standalone tool, the maturity grid can generate a self-assessment profile for a manufacturing system as perceived by the tool user.

Another application that worked well (based on feedback) was the workshop with practitioners. The objective of the workshop was to collect and grade a range of manufacturing practices on a maturity ladder starting from a "business-as-usual performance" to "leading performance". The data helped the researcher verify the sequence of practices per maturity step and the behavioural attitude of a manufacturing system from reactive to proactive. The workshop further enabled horizontal communications between practitioners which were positively commented. Therefore, two attributes in this process were considered as important by participants: a) allowing different perspectives to surface within a group of peers and b) the horizontal knowledge transfer that was embedded in the process.

A limiting factor in the application of the workshop became apparent when analysing the data collected. Even though there was structure in the data, due to the maturity grid dimensions

(row/columns), the connection to organizational capabilities was loose. It was difficult to connect the capabilities (as in Table 5-6) with the manufacturing practices and the organizational levels. Therefore, the data collection process required improvement. In order to achieve more accurate and meaningful inputs regarding manufacturing practices, the workshop process and structure were revised. The overall factor that drives this change is the quality of acquired information. High quality information may enable the user to make meaningful recommendations for improvements.

Tentative contribution to practice 1: PMGE application needs to be timely and produce contextual information about eco-efficiency improvements. The users need to have clear expectations from the application and a specified goal.

### 7.3 Variability of practitioners' perceptions and horizontal knowledge transfer

A practitioner's familiarity and awareness with the actual practices that take place across a range of performance dimensions (i.e. process level or supply chain practices) may be limited and also a certain perception bias is expected (Craig and Lemon, 2008; Henriques and Sadorsky, 1999; Papagiannakis and Lioukas, 2012). The maturity profiles within a specific context can be a start for a discussion for applicable improvements. Indeed, this was observed in the case of the jet engine company in chapter 5 (see Figure 5.3). Even a small level of variability between practitioners' perceptions about the practices can trigger a discussion about the actual, expected and perceived system's performance.

Three types of variations about performance have been observed so far in this work: a) within one manufacturing system, performance levels may vary (i.e. environmental performance variation as in Table 1-1) b) practitioners' perceptions may also vary about the practices that are actually being employed (horizontal variability on the maturity grid) and c) the execution level of a specific practice can also vary (see section 4.6 attitudes about ISO14000 in two different companies). This conflict between perceived practices and perceived level of execution of the same practice was also found in the work of Ferdows and Thurnheer. The latter also suggest that high-performing factories will demonstrate high performance levels on all performance dimensions (Ferdows and Thurnheer, 2011).

In the case of a PMGE self-assessment, a company may be found to vary in maturity in practices. This can be a sign of the practitioner's biased perception about employed practices (see Table 5-4, second example). The person that carries out the self-assessments will have to acquire more contextual information about the maturity profiles in order to understand the variation. The workshop process can be a way of acquiring such information. The first two types of variation (a and b) are further explored in this work. The third type of variation is not being covered further as the level of information that needs to be acquired grows significantly. Nevertheless, the researcher sees that all three types of variations may be connected.

Practitioners were found to value the peer-to-peer discussions and the knowledge sharing process in the workshop. The workshop offered a structure around the discussions about eco-efficiency which made discussions timely and more purposeful. The researcher found that mature systems (i.e. the cases in chapter 6) acknowledge and support knowledge sharing between practitioners. This attribute can be embedded in a design exercise for eco-efficiency improvements as it may simulate this collaborative environment. Therefore, a high level of interactions between practitioners can be considered as an important factor for the design process of eco-efficiency improvements.

Tentative contribution to theory 1: Variability of perceptions between practitioners is an inhibiting factor for eco-efficiency improvements. A sharing and collaborative environment can help practitioners align their perceptions and focus on improvement.

## 7.4 Improvements based on existing capabilities

Chapter 6 produced evidence that mature companies can drive eco-efficiency improvements by relying on existing internal system capabilities. This key learning from chapter 6, on existing capabilities, can be used to interpret the results from the applications of PMGE in real-life situations. Mature systems are expected to demonstrate high-maturity practices across all dimensions of the PMGE. In addition, alignment of practitioner's perceptions about maturity levels is expected (vertical alignment) and along all PMGE dimensions (see Figure 6.1 and Figure 6.3). RBV theory can be used in this context to make recommendations for improvement. Users of PMGE can propose solutions for lagging areas by understanding what capabilities enabled some dimensions of performance to utilise more mature practices.

Tentative contribution to theory 2: Mature eco-efficiency practitioners have largely relied on their core strengths to shape programs of action (thus confirming the grounds of RBV theory). PMGE can help practitioners identify such core capabilities and facilitate the design of effective eco-efficiency solutions.

## 7.5 Measurable success criteria for PMGE-based support

Methods that facilitate the design of eco-efficiency improvements are lacking in the literature and do not incorporate practitioners' perceptions about environmental and economic performance benefits. A successful PMGE application can be characterised by the identification of key capabilities in a manufacturing system and the facilitation of design for eco-efficiency improvements. Such application satisfies the research question and objectives.

Measurable success criteria, as defined by Blessing and Chakrabarti (Blessing and Chakrabarti, 2009b), are proxies to the success criteria of the developed support. These can be used as substitution criteria to gauge the chance of success. Mainly due to time limitations, the research plan does not go beyond an initial type of success evaluation (see section 2.5). Therefore, indicators of success have been used to approximate success and yet satisfy the research question:

1. Assess the levels of practitioner's understanding about the influence of current practices on eco-efficiency and help them identify what they need to achieve in the future to reach higher maturity levels in practice.
2. The support needs to be timely and require as little facilitation as possible. This criterion indicates how likely it is for practitioners to use the support on their own and with peers. Platts refers to this dimension of assessment as "How easily can the process be followed?" (Platts, 1993b)

These two indicators are used to guide the construction of a maturity-based method that aims to answer the main research question. The following paragraphs describes the design of a method that intends to provide the required support to practitioners. Research findings and information from previous chapters are collated into a four-step process that aims to solve real-life problems.

## 7.6 Method development

The researcher considers that the self-assessment tool and the workshop would be the two most appropriate tools that can be combined into a PMGE-based method (PMGEM). The audience for PMGEM are practitioners working in manufacturing and seek to design improvements with environmental and financial performance benefits. The system may be a single manufacturing site or multiple sites that work together towards making a specific product (supply-chain). PMGEM targets the practitioners that deal with energy and resource efficiency improvements at various organizational levels (process to top-management). Four main steps are developed and justified in the following paragraphs.

### 7.6.1 Step 1- Industrial challenge clarification and maturity assessment

The aim of the first step is to identify suitable challenges in manufacturing settings with key objective to improve the eco-efficiency of the system. Maturity profiles from various practitioners in different positions in the organisation are necessary to gain a perspective of the system's potential improvement areas. A copy of PMGE is circulated to interested practitioners. This can be done either by the researcher or via a practitioner who can facilitate the overall process. Instructions are provided to participating practitioners on how to read and use the PMGE (see example email in Appendix D). Maturity profiles are collected and projected on the PMGE (using dots as in Figure 6.1) (Baumgartner and Ebner, 2010).

The assessment provides an initial indication of the organizational maturity. Based on previous maturity assessments in chapters 5 and 6, maturity profile variation is expected. The researcher is interested in observing the areas/dimensions where the company employs more mature practices. This typically indicates the dimensions that are more material to the business (i.e. a pollution prevention or energy management).

This step should be repeated with a range of people with different roles in the manufacturing system. Saturation of profiles is expected after a short number of iterations. The user can decide when to stop this exercise with key consideration being the timely application. As this is not a survey, it is not the intention of the researcher to collect as many profiles as possible and/or compare against an ideal profile (Baier et al., 2008). The intention is to quickly gain insights about the variability of people's perceptions about practice maturity.

### 7.6.2 Step 2. Maturity analysis

As in the case of Goodson on lean performance assessment, a set of indications about maturity enables the user to understand the potential for improvement. (Goodson, 2002) A graph was developed as a quick guide that can help PMGEM users interpret the results from the self-assessment process (Figure 7.1). The chart is inspired by the work of Zadek and intends to illustrate the variation of perceptions about the maturity of manufacturing practices employed (Zadek, 2004). The researcher shows how perceptions about manufacturing practices may vary on a three-dimensional chart. The chart may be applied for any single horizontal performance dimension of the PMGE. The left-hand horizontal axis represents practices that offer clear financial benefits to the company. The right-hand horizontal axis represents practices that offer clear environmental benefits to the company. The left-hand vertical axis and the right-hand vertical axis are complementary and demonstrate the maturity levels 1 to 5 (left axis) and the type of organizational behavior that one may expect in each level.

Tentative contribution to practice 2: At high maturity levels the variation of practitioners' perceptions is reduced significantly as internal information flows improve (see chapter 6.3.4 about knowledge sharing). At high maturity levels, perceptions about practices are aligned and converge. At lower maturity levels, perceptions can be scattered at various maturity levels or converge strongly to either side of the chart (indicating an imbalance between environmental and economic performance).

The reader may observe that the chart becomes greener as maturity levels advance and eco-efficiency improves. A traffic-light system has been used to codify the chart (red to green). As companies advance in maturity two assumptions can be made: a) practitioners' perceptions about practices and benefits converge and b) financially and environmentally driven practices lead to eco-efficiency (as per definitions by Huppel and Ishikawa, 2005).

**Figure 7.1 The eco-efficiency maturity chart.**

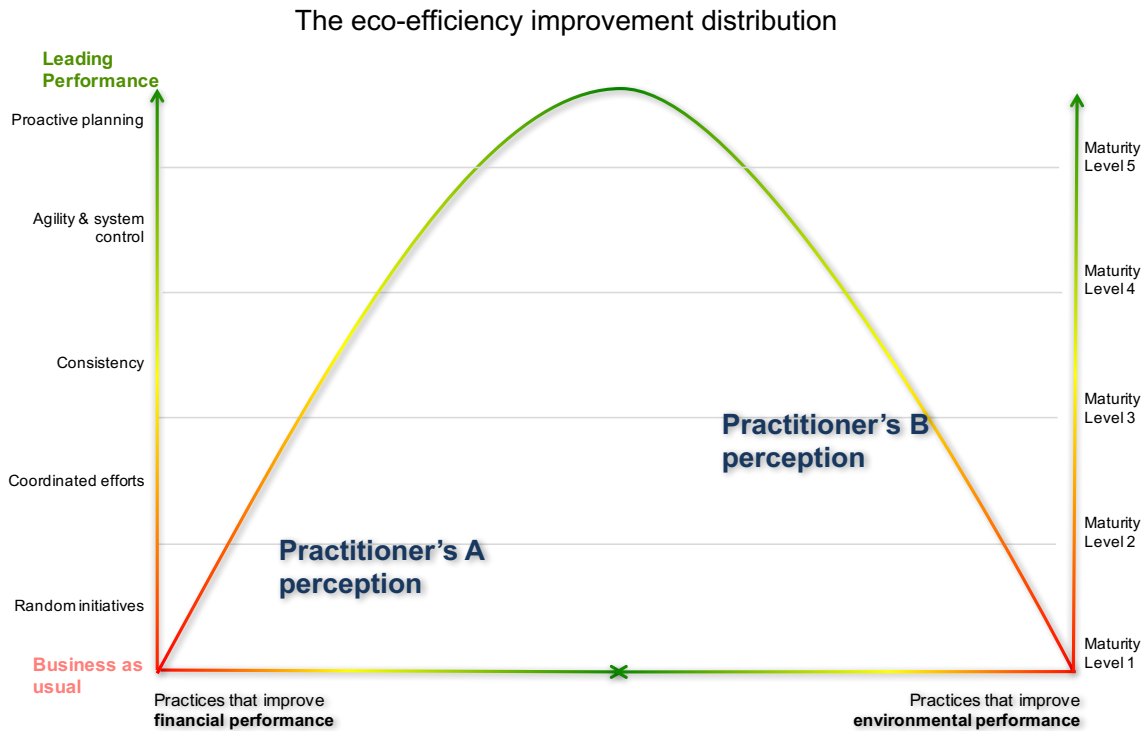


Figure 7.1 has been developed to facilitate the analysis for the inexperienced user of PMGEM. As a maturity model, PMGE differentiates here from the classical CMMI literature (seeter.

Table 5-1) in steps 3, 4, 5 - influenced by the case studies in chapter 6. The researcher also adjusted the language to make the descriptions more relevant to eco-efficiency improvements. Behaviours that are expected in each maturity level are characterized as:

1. Maturity level 1: Random initiatives for improvement ["Initial" in CMMI language as per (Chrissis et al., 2007)]. A level of experimentation is expected from manufacturers to learn more about eco-efficiency.
2. Maturity level 2: Coordinated efforts for improvement. ["Managed" in CMMI language as per (Chrissis et al., 2007)].  
More coordinated initiatives for improvement are observed in the company at various organizational areas. Coordination implies that practitioners follow a planning process for material improvements and allocate resources accordingly.
3. Maturity level 3: Consistency in practice. [novel use of this term for maturity level 3].  
Common agreement between practitioners about material practices is evident.



Indications of common language and use of common management and analytical tools (section 6.3.2 about harmonisation).

4. Maturity level 4: Agility and control. [novel use of this term for maturity level 4]. Different behaviours can be applied in different improvement scenarios at will (see chapter 6 on model factory for automotive and industrial networks). Practitioners control the process of improvement through a portfolio of practices and tools (section 6.3.1).
5. Maturity level 5: Proactive planning. [novel use of this term for maturity level 5]. Companies show proactive behaviours and take action before issues escalate. A level of integration to the business strategy is expected. Alignment of manufacturing and business strategy is also expected (chapter 6, automotive company case study). Research practices to understand future developments and business risk aversion.

The behavioural descriptions above, for each maturity level, have been developed through the applications in chapters 5 and 6 as well as Table 5-3. The researcher has also used a language that highlights the behavioural aspect of this work. The descriptions are subject to further testing in the following chapter of PMGEM application.

Tentative contribution to practice 3: Maturity levels 3 and 4 are crucial for a company's transition from business-as-usual to leading performance. Gaining more contextual information is critical to help the users of PMGEM clarify what improvements can be proposed.

From the analysis of maturity profiles, the user can decide whether a workshop is appropriate. As the workshop can be more resource intensive, it can be optional for some companies. The output of this step here is a sense about the maturity of manufacturing systems.

### 7.6.3 Step 3 Workshop with peers

This step intends to bring practitioners from the same manufacturing system in discussion through a workshop about eco-efficiency. Based on the workshops feedback and assessment in chapter 5, a refined workshop version is described here. The objective is to review past and current manufacturing practices under the light of eco-efficiency and set objectives for improvements for the near future horizon (next 5-10 years). It is the intent of the researcher to

develop recommendations about eco-efficiency improvements that are aligned to core system strengths. In this paragraph the researcher describes the design principles of the workshop, the workshop procedure and the refinements made from previous applications.

#### 7.6.3.1 Workshop design principles

Kerr et al., suggest that such applications can generally follow 7 principles. The researcher describes how this part of PMGEM is aligned to these principles:

- a) Human centricity: All input required is based on the people's knowledge and perceptions about their manufacturing system. No quantitative information or analysis is requested (but it is welcome). People from a range of roles are invited in this process: engineers, managers, marketing analysts etc.
- b) Workshop based: A workshop has been re-designed and modified in this chapter to support horizontal knowledge transfer and help practitioners develop actionable recommendations for improvement.
- c) Neutrally facilitated: The user's role in this process (may be the researcher or a practitioner) is to provide guidance on the exercises of the workshop and keep time. It is not the user's role to interfere with the process content and influence people.
- d) Lightly processed: The PMGE structure and color-coded post-it notes facilitate the process and make the data easy to view, collect and analyse. It is therefore important for the user to make sure that every participant has clearly understood how to use the workshop materials.
- e) Be modular: The maturity levels as an element of PMGEM is kept constant for all parts. This enables the logical connection between the tools of PMGEM. PMGEM is modular as the tools complement each other and create a narrative about eco-efficiency.
- f) Scalable: The workshop as well as the overall process can be used in various contexts (as in chapter 5) and with a mixed audience. There is no restriction for this to be used with any type of audience. However, the outcome may be different each time as the participants vary in roles and perspectives.
- g) Visual: As mentioned in principle (d), the post-it notes are color-coded to reflect different types of input (i.e. blue for practices and yellow for enablers). Different colors also apply to the different sections of the maturity grid.

Tentative contribution to theory 3: PMGEM confirms the importance of modularity that Kerr et al., set as design principle for intervention tools (Kerr et al., 2013). The researcher sees the self-assessment module as a tool informing practitioners with data based on literature whereas the workshop is a tool where practitioners inform the tool.

### 7.6.3.2 The workshop procedure

Workshop materials required:

- 3 printed A0 size posters of the maturity sub-grids with blank cells. The posters need to be mounted on walls with enough space area around them to accommodate 4-6 people. The vertical axis (left-hand column) is the titles of the performance dimensions (Table 5-3). The horizontal top row is a time-scale. The user can define this being 10-15 years prior to the workshop date and 10-15 years post-workshop date. The time scale can also be split in five equal time segments (representing 5 maturity levels).
- Coloured post-it notes and black pens. 3 different colours need to be used. One colour (A) for past practices, one colour (B) for future/stretch practices and one colour (C) for practice enablers.
- Flipchart/whiteboard to summarise workshop output.

#### 7.6.3.2.1 Exercise 1

Participants are split in 3 groups of 4-6 people. More than 18 participants can be difficult to coordinate with one facilitator. Each group rotates round the posters every 20 minutes. Participants are asked to attach A-colour post-it notes on the poster to refer to specific past and current practices along the poster dimensions at different time segments. They are not allowed to consult each other. For each A-colour post-it note they need to provide some indication of the practice enabler or resource using C-coloured post-it notes. For example, if the practice is about “energy monitoring” then an enabler can be “information system upgrade”.

As groups rotate every 20 minutes, participants are asked to read and review existing inputs and add more information in the same way. Three 20-minute rotations, conclude this exercise and there is a 15min break.

#### 7.6.3.2.2 Exercise 2

This time, participants are requested to talk to each other and within each group agree on future practices that they think that can be realised soon. Agreement is used here as a proxy for alignment of perceptions. Participants are expected to review propositions in each group and agree on what they would like to be doing in the future (B-color post-its) and what the enablers/resources can be of that practice (C-color post-it). Again groups rotate three times every 20 minutes. Each time they are additionally tasked to review what is on the poster and make adjustments. At the end of the three rounds it is expected that some agreed practices for future development will have surfaced that every participant will be informed about. The resources for these practices have also been described.

#### 7.6.3.2.3 Workshop Summary

For the closing act of the workshop the facilitator asks participants two questions and lists the answers on the flipchart/board in two columns: 1) “What are we good at?” and 2) “What do we need to be good at in the future?”. The questions are driven by the RBV theory and further challenge the PMGEM's theoretical fit to RBV.

Tentative contribution to theory 4: It is observed that at high maturity levels, key enablers for improvements are aligned to core system capabilities and business objectives.

#### 7.6.4 Step 4 - Recommendations for improvement

The output of PMGEM is a set of recommendations for improvement. The facilitator/user is responsible for this step. The maturity profiles provide a sense about how easy or difficult the improvement journey may be (for instance if a company starts from low maturity levels). Chapter 6 provides practice support for the development of recommendations. For each dimension of the grid the next target can be set.

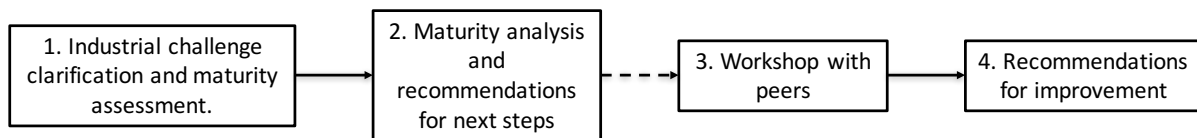
According to Goodson, Ferdows and Thurnheer on lean improvements, solutions must be designed in such a way that all dimensions are perceived to have reached the same level of maturity and make sure that there is no lagging dimension/row (Ferdows and Thurnheer, 2011; Goodson, 2002). This is a staged type of maturity model representation according to Chrissis et al., (2007). In the PMGEM, this would be observed in the long run as high agreement of maturity profiles and vertical alignment along the grid. Therefore, recommendations must start with areas that are perceived to be lagging and make sure these

can be appropriately resourced/supported. For the success of PMGEM it is critical to make realisable recommendations for improvements that rely on existing internal capabilities (RBV theory). This is why the workshop can be a useful step. It highlights system strengths and weakness which will be more detailed and contextual than the maturity profiles. The workshop intends to help practitioners see how eco-efficiency is relevant to their roles in the business. It intends to enable them to find the best way forward by shaping a common view of the system's maturity.

### 7.6.5 PMGEM overview and chapter summary

The flowchart in Figure 7.2 demonstrates the sequence of PMGEM steps. As a process it is intended to meet the second research objective and guide practitioners through the development of applicable solutions to improve eco-efficiency. Steps 3 and 4 are necessary if the output from step 2 is not conclusive or too generic. Running the workshop depends on the time availability of the practitioners and/or the resources available to execute this.

Figure 7.2 The PMGEM steps.



The challenge from this point onwards is to test the process in real life problems. The aim is to generate realisable recommendations for improvements and evaluate the usefulness of PMGEM as perceived by practitioners. It is also key to better understand to what extent the tentative contributions for knowledge and practice stand true to the chosen theoretical grounds of this work and the intended use of PMGEM. Two companies exhibited interest in this method and each presented a different challenge to address. These cases are presented in the following chapter.

# 8 APPLICATION OF PMGEM

## 8.1 Introduction to the second descriptive study

This chapters initiates the second descriptive study of this work. It is the final phase of the design research methodology and aims to assess, at initial level, the effectiveness of PMGEM. According to Blessing and Chakrabarti, this research phase aims at understanding a situation in which a support for practice is introduced, in order to assess its ability to improve the existing situation and to provide suggestions for improvement of the support (Blessing and Chakrabarti, 2009a).

## 8.2 Introduction to this chapter

The researcher presents how PMGEM was applied in two case studies in different manufacturing contexts. These are two different real-life situations where environmental performance improvement is an important objective for the companies involved. The expectations from the application are different in each case for the practitioners and the researcher. These cases were seen as an opportunity to evaluate PMGEM under different conditions and get wider insights about the usability and usefulness of PMGEM. Practitioners from both companies were attending the annual conference organized by the Centre for Industrial Sustainability at Cambridge University in September 2014. The maturity profile exercise was introduced to them as a poster and the idea behind it was explained. They each then presented this back to their peers in their companies and decided to explore this further to address a more specific challenge.

## 8.3 Case 1 - Building products company

### 8.3.1 Introduction to the industrial context

This company manufactures vinyl flooring and wall cladding products and it is located in the UK. It has been family-owned for the past 100 years and is expanding its manufacturing capacity in support of a six-fold revenue growth target for the next 20 years. The company's director (also 3<sup>rd</sup> generation owner) believes that the company can achieve this growth target. This level of growth was achieved twice before in their history and therefore it is believed it may happen again. Currently, the company supplies markets globally and aims to add even more global customers and make more exports in the future to support their growth vision. Main raw materials for the company are poly-vinyl chloride powders and plasticisers in liquid form. The company employs approximately 500 people globally and approximately 300 in the UK manufacturing site. Their manufacturing director who visited the conference and had a chance to see the maturity profile exercise was the one to request his managers to support this case study. Letters of invitation were emailed to a selected audience of practitioners with main objectives to enhance their awareness on environmental performance and assess the maturity of their manufacturing practices.

### 8.3.2 The application steps

The four steps of PMGEM are documented in the following paragraphs as prescribed in chapter 7.

#### 8.3.2.1 Step 1- Industrial challenge and maturity assessment

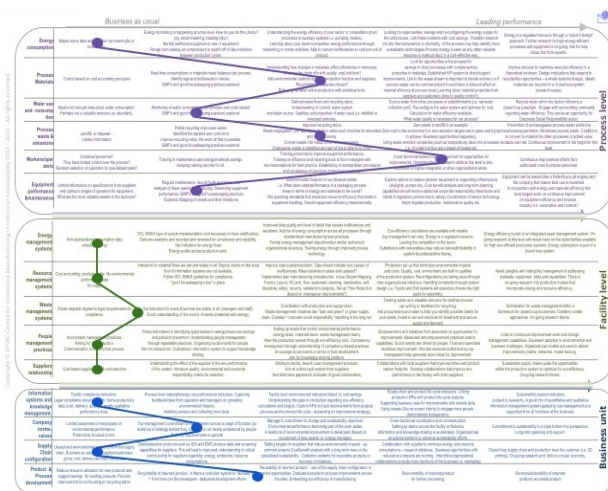
One of the main challenges that the company was facing was at the time of the study was identifying and supporting improvements on energy efficiency and management of process waste. A sustainability program was launched in 2006 but this had not being supported since 2012. An in-house recycling unit was built in 2008 but the recycled content in the product remained low. In addition, the people on the production floor had little experience in dealing with EP issues. For the researcher, the size of the company, its long history in manufacturing and the ambitious vision for the future seemed to be a good testing ground for PMGEM.

Industrial challenge: Help practitioners understand eco-efficiency better and develop recommendations to support future growth plans with reduced environmental impacts.

The following paragraphs describe the application steps in more detail. The aim is to describe to the reader the conditions of the application and how these may have interfered with the PMGEM procedures.

Seven practitioners overall, with management roles in manufacturing, were introduced to the framework on one-to-one tape-recorded sessions. Their experience within this company was between 4 and 20 years. The research scope was explained and they were introduced to the maturity assessment. On average the complete session with the assessment lasted 15 to 20 minutes with the maturity assessment for each individual taking approximately 10 minutes. The sessions were arranged to fit into people’s daily tasks and be as less intrusive as possible in their calendars. This was facilitated internally by one of the practitioners whom the researcher liaised with. A visit in the manufacturing floor was also arranged after the sessions for the researcher to have a closer look at the production lines. An example of the maturity assessment and the overall output is presented in Figure 8.1 and Figure 8.2.

**Figure 8.1 An example of one of the maturity profiles from the product innovation manager (dots are connected for readability).**



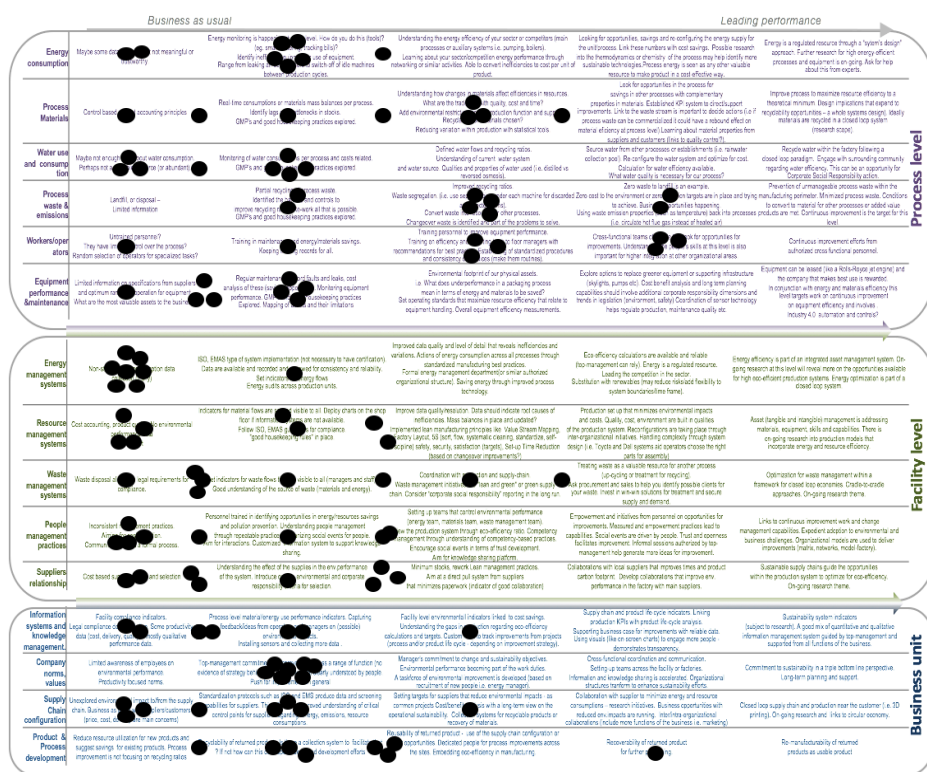
In figure 8.1 the researcher demonstrates the maturity variation of practices along the grid’s dimensions and areas for one of the participants. From this maturity profile one can observe that the company seems more active in energy and resource efficiency at process level (purple area) but with great variation between dimensions of environmental performance (i.e. maturity level 4 at “Workers and operators” and maturity level 1 at “Energy consumption”). Energy was admittedly being a weak area for the company, as they didn’t fully understand the issues related to energy efficiency. In addition, the assessment of management systems at facility level (middle section) indicated low maturity across all dimensions (levels 1-1.5)



whereas a bit more variation is observed at top-management level (bottom section, levels 1-2.5). Half-levels were permitted to indicate work-in-progress towards higher levels.

Figure 8.2, summarizes the results of all seven assessments in one sheet. Very little agreement is observed on the maturity of manufacturing practices. There is only one dimension where all assessments were in total agreement; in the dimension of “Company norms and values” all practitioners pointed that “*there was a top-management commitment to improve across a range of functions that lacked strategic intent, the urge was generic and not clearly understood by people*”. This was received by the researcher as a strong signal for lack of support by top-management on improvement planning and execution.

Figure 8.2 All seven maturity assessments in one grid.



Alignment of profiles was not easy to interpret in a combined profile image like Figure 8.2 and no safe prediction could be made in regards to the potential for improvement due to the extent of variability.

Nevertheless, the level of agreement in each row may be an indicator about practice consistency. High-maturity practices may have been used or tested in the past but were not sustained. If a practitioner had observed a high-maturity practice in the past, that perception of high-maturity may remain and be found on the PMGE. If this practice was left

unsupported and abandoned, then other practitioners would report a more business-as-usual practice or a lower maturity practice in the same dimension.

#### 8.3.2.2 Step 2 - Maturity Analysis and recommendations

Based on the output of step 1 and the interview data, the researcher made two observations:

1. The company had made some EP improvements in the past that could not sustain – mainly on material efficiency and process waste. The reason was probably related to a lack of support from top-management and potentially some lack of awareness about eco-efficiency across the manufacturing floor.
2. Management and information systems also seemed to be between maturity levels 1 and 2, leading to a low level of support at process level practices. In chapter 7, integration of practices with information systems and was seen as success factor for eco-efficiency.

Evidence indicate that energy efficiency at process and system's level is not well-supported and resource efficiency has a reactive behaviour. It was rather unclear how one could start developing an improvement plan. The assumption that companies can leverage existing capabilities and resources to improve EP remained to be tested. It would seem that this idea is well aligned to the beliefs of the company's chairman. Looking back at the company's history since 1920s, high growth periods had been recorded and it is perceived that the company is capable of achieving a six-fold revenue growth vision within the next 20 years. However, energy and resource efficiency had never been a target or a vision for the company so it is reasonable to be perceived as low competence area on the maturity grid by members of staff. Potentially, eco-efficiency improvements may be possible if it becomes an integrated component of the growth vision and a clear relationship can be established between the two. In order to examine this opportunity further, the manufacturing director agreed in hosting the workshop within their premises.

#### 8.3.2.3 Step 3 – Workshop with peers

The workshop was carried out one month after the maturity assessments due to busy calendars and eleven practitioners joined this event. Only four out of eleven had taken part in the maturity assessment and the rest were new to the overall process. Again, the attendees held a variety of roles in the business, mainly within manufacturing but marketing and innovation functions were also represented. The workshop process involved:

1. Workshop process introduction
2. Exercises description and group setting
3. Workshop output
4. Workshop conclusions

Two emails were sent out to participating practitioners to prepare the ground for the workshop. The intention was to inform the audience about the process and draw their attention to a particular type of information (manufacturing practices). The self-assessments and the factory walk in step 1 helped the researcher make the outline email more relative (i.e. mentioning curing process) to the audience to prime their thinking further. The emails can be found in the Appendix C as examples for future use.

Participants were split from the beginning of the workshop into two groups of 5 and 6 people respectively. In the first part of the workshop they were asked to rotate from poster to poster every 20 minutes and individually populate the time-scaled posters with manufacturing practices and events (or accomplishments) that occurred since 1999 (15 years ago) until presently. Each time they would rotate, they could read what others had posted on the posters and receive information about past manufacturing practices. The process followed was as prescribed in chapter 7.4.3. In Figure 8.3 a photograph of one of the groups is shown in front of the poster about manufacturing practices at facility/systems level.

Figure 8.3 One of the groups discussing future improvements at facility and system's level. Yellow post-it notes collect past actions and pink ones their enabling resources. Green post-its collect future actions/plans or recommendations and supporting resources/enablers.



Table 8-2 and Table 8-3 the researcher shows examples of how the data was captured during the workshop. Yellow colour indication past and current practices, green colour for future ones and orange colour for enabling capabilities.

**Table 8-1 Process level input data**

	1999	2008	today	2020	2025
Process energy consumption	Don't measure it!	OPB (packaging)	Recycling increased energy consumption.	Fundamental re-design of equipment for energy efficiency	
		Reduced labor, increased energy	100% recyclable packaging (reduced labour, increased energy efficiency)	Examine & invest in new plant heating system	Prioritise specific projects + resources
		Better control over required output + waste material	Better control over required output and waste material		
			Introduction of EC5 Resource hungry process Recycling machine energy Measurement capabilities. Energy plus efficiency Resource Training		

**Table 8-2 Facility and system level input data.**

	1999	2008	today	2020	2025
Human resources management	Office air-conditioning system	5s implementation	Introduction of lean processes	Use technology instead of travel	Training & awareness of waste management practices
	Increased energy consumption	Standardisation and process on lean- time saving	Focusses on doing more with less 20 keys of improvement 2014 Dedicated lean administrator resource Good communication & engagement of all employees on the shop floor	Right facilities Change of attitude	Identification of experts for collaboration
			Reduced variation, doing more with less		

At the end of the 3-hour session, the researcher summarized the workshop proceedings by generating two lists (see Table 8-3). By reviewing the posted notes, the audience was asked to list things that they considered that “they are good at” and things that “they need to be good at” in pursue of eco-efficiency (following Normann, 2001). The intention was to observe the type of change that was necessary to improve on eco-efficiency (step-change or gradient evolution).

**Table 8-3 Comparison between existing capabilities in this manufacturing system and desirable ones for the future.**

We have been good at:	We need to be good at
<ol style="list-style-type: none"> <li>1. Saving money, cost savings</li> <li>2. Meeting deadlines for launches</li> <li>3. Troubleshooting (process, crisis management)</li> <li>4. Controlling product weights (technically)</li> <li>5. “we make it work”</li> <li>6. Communicating changes internally - honest</li> <li>7. Prepare to investing quickly</li> <li>8. Long term views</li> </ol>	<ol style="list-style-type: none"> <li>1. Measurement</li> <li>2. Accountability and KPIs</li> <li>3. Trade-offs</li> <li>4. Fully engaged, collaborate</li> <li>5. Clear strategy/integration</li> <li>6. Become sector leaders</li> <li>7. Corporate responsibility reporting</li> </ol>

#### 8.3.2.4 Step 4 - Recommendations for improvement

There are two strong signals within the right-hand column in Table 8-3. The first one is about acquiring hard evidence of performance based on reliable measurements which can support decision making (points 1, 2, 3).

The second one is about aligning actions to business strategy and markets (points 5, 6, 7). In the left-hand column there is also evidence of reactive system behaviour (i.e. “we make it work” and “troubleshooting”). The reactive behaviour is further supported by the maturity profiles in Figure 8.2 from the self-assessments.

For the researcher (and facilitator) the self-assessments and the workshop pointed out the need to improve the measurement techniques in the factory. Higher-quality of information was the main recommendation made to the company. It was found that this was acknowledged by the manufacturing director in recent times and six-sigma training had already began in the company, well-aligned to the output of the PMGEM. More recommendations for improvement were not made to this company as it was clear that the company would have to train and practice measurement and better understand the value of accurate information exchange internally (see CMMI maturity level 2 - "managed" in Chrissis et al., 2007).

## 8.4 Case study 2 - sports apparel company

The second case study is focused on the supply chain operations of a global sporting goods company (sport shoes, clothes, gear). The corporate headquarters are found in Japan while there are central offices in Europe and other continents. The study was authorised by the European business branch. Two senior environmental managers initiated and facilitated the study with interviews and meetings. Emails for data collection from the tier factory managers were provided (visiting them in East Asian countries was not possible mainly due to time limitations). Their motivation was to understand how they could better engage with their tier factories and potentially nurture a way of working with them on eco-efficiency.

### 8.4.1 Introduction to the industrial context

One of the difficulties the headquarters faced was the traditional way of price-driven negotiations of outsourced production. If their suppliers could achieve improved environmental performance and financial savings this would be reflected in their corporate product life-cycle assessments. However, this could also be used as leverage from their purchasing function to request price discounts - a scenario that would not be seen favourably by the latter.

The sporting goods industry is characterized by mass volume production and distributed manufacturing across different geographical regions, which involves high levels of resources consumption, waste and other environmental emissions (Subic et al., 2012). In a recent review study on the apparel industry O'Rourke identifies several issues that need to be addressed in the context of sustainable manufacturing (O'Rourke, 2014). Within this industrial context, operational practices that support greener operations need to be assessed on alignment to manufacturing strategy and the overall business strategy (Shi and Gregory, 1998).

What makes the alignment even more challenging, is the particular configuration of this outsourced production system where brand headquarters and product developers are in different and geographically remote locations. Various improvement strategies have been used so far within the overall apparel industry with a broad range of objectives. These initiatives span from transparency of financial transactions to product life cycle analysis (LCA). The latter practice has been central to the sustainability work of the apparel industry. Leading brands and retailers have also experimented with a number of other strategies, driven by intense non-governmental organizations and consumer pressures, including initiatives

around traceability, impact assessment, and score-cards. Recently, a number of brands have come together within the Sustainable Apparel Coalition to develop the “Higg” sustainability index. These efforts can be integrated into tools for product design, material selection, sourcing, manufacturing, use-phase interventions, and end-of-life management. (O’Rourke, 2014)

#### 8.4.2 PMGEM application steps

The first two steps of PMGEM are documented in the following paragraphs as prescribed in chapter 7. The outcome of the first two steps and additional limitations did not activate the workshop process. Instead a discussion process substituted the workshop in order to examine some of the PMGEM assumptions.

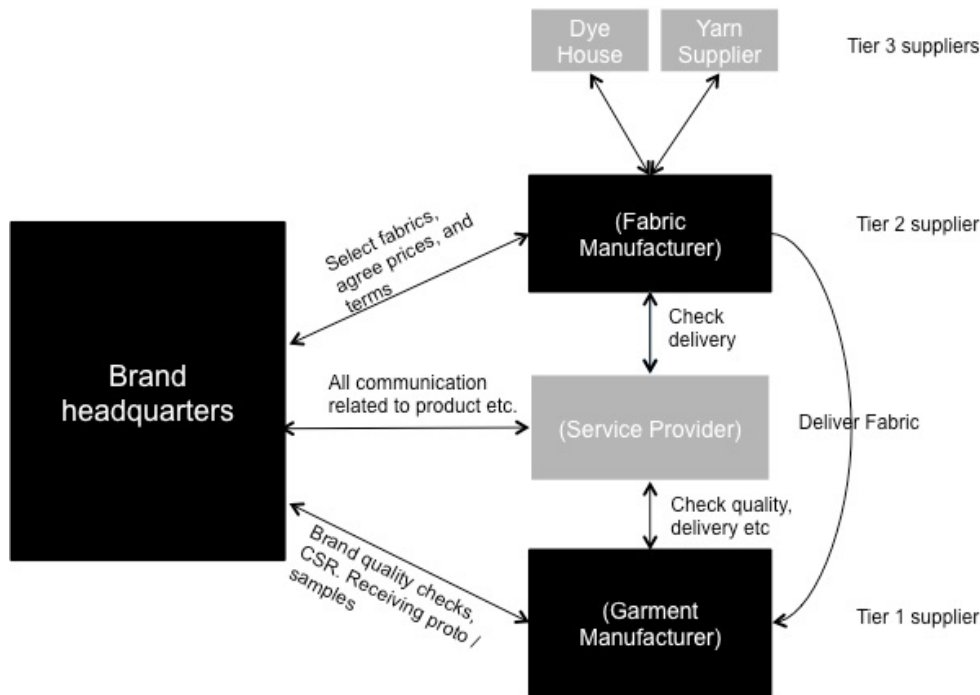
##### 8.4.2.1 Step 1- Industrial challenge and maturity assessment

This case study is part of a wider improvement plan that the brand has initiated in recent years. The aim was to enhance environmental management capabilities within the supply chain and internally. Other efforts include product life cycle analysis and sharing of best practice across supplying factories. Figure 8.4 demonstrates a simplified version of the supply chain configuration and the participating links of this chain. Tier 3 suppliers provide dyes and yarn to the fabric manufacturer. This is then supplied to the garment manufacturer. This process is regulated by a service provider which is an independent authority and has an open communication channel for all matters with the brand headquarters. The service provider mediates for matters like pricing or product specifications and customer demands in a close loop between tier 1 and tier 2 suppliers with the brand headquarters.

Preliminary interviews were held with the brand managers to gain a better understanding of the issues within their supply chain. They provided a list of contact emails for tier 1 and tier 2 managers. An introduction email was sent out by the brand manager to all parties, that outlined the scope of the project. Overall, the people who participated in this case study were:

Two environmental managers from the brand headquarters (Email exchange and 4 hours of interviews transcribed), 4 managers from manufacturing from the Tier 2 supplier (email exchange – 3 emails), 2 managers from manufacturing from the Tier 1 supplier (email exchange – 3 emails)

**Figure 8.4 A simplified version of this sportswear supply chain. The participants in this study are represented in black boxes. The service provider has a mediating role between the tier 1 and 2 suppliers.**



As in the previous case study, the first step was to apply the maturity self-assessment independently between the participant companies. This process was remotely run, compared to the previous case. Kerr et al., propose that the use of these tools (i.e. PMGEM) should contain some degrees of freedom to adapt to changing conditions by not being too prescriptive in the application process (Kerr et al., 2013). It was observed that in order to execute PMGEM across such a diverse audience, some flexibility in the way that PMGEM can be applied was given to the participants. For example, visiting the practitioners in their companies was not an option at this stage, mainly due to time limitations.

The maturity grid as template and instructions of use were sent out via email, to 8 practitioners (see Appendix D). The email contained a template of the maturity grid and an example of an assessment. The email script can be found in Appendix C. No objections or questions from practitioners were recorded regarding the instructions given and replies with attached maturity profiles were received promptly. The maturity profiles are presented in Table 8-4.

The representation of the maturity levels in numerical format (i.e. from 1 to 5) was avoided in this application, as this could relate more to a benchmarking exercise or audit. Environmental

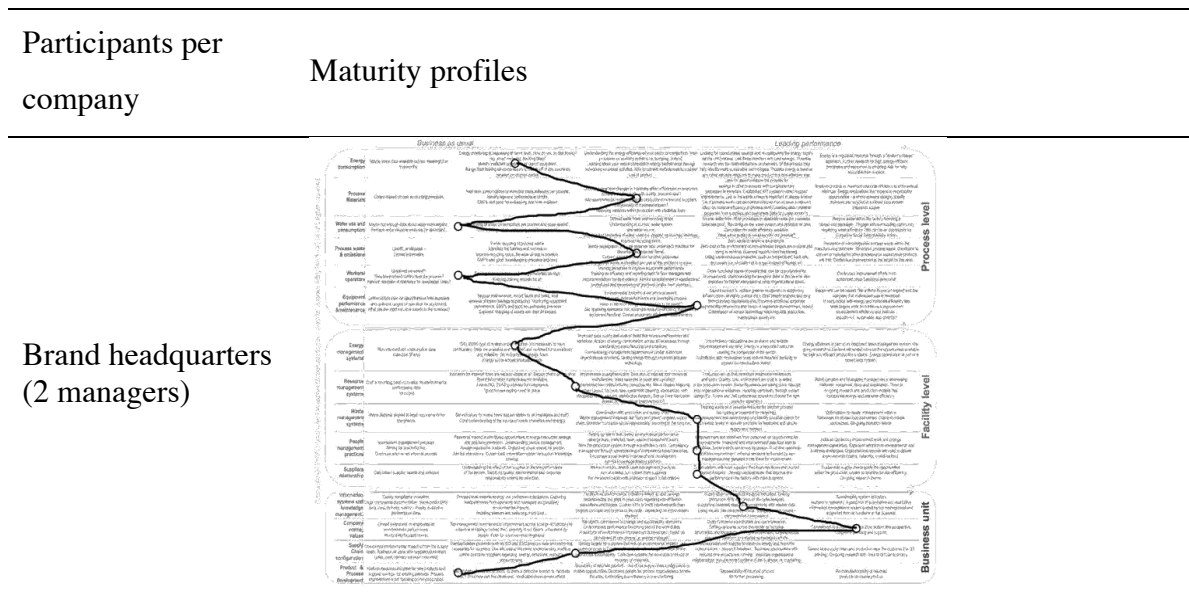


and social audits were already a practice within the supply chain and followed a five-level scoring structure. One of the managers from the headquarters commented:

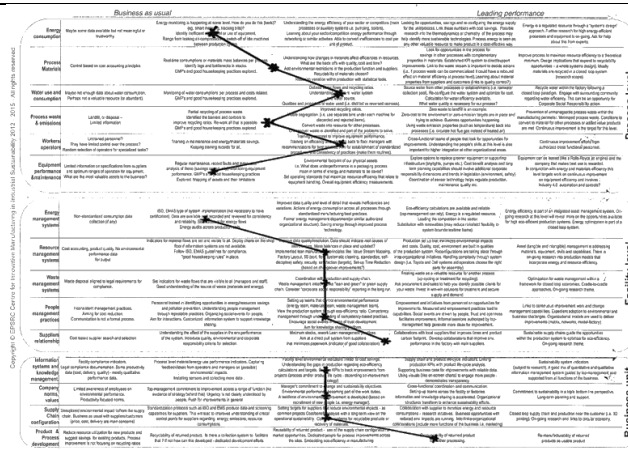
“I think the logic (of the maturity grid) is very similar (to our audits) and the content of each block (grid cell) describes the visual things or evidence that you can recognize to get a hold on that maturity level, the level of best practices...but at the end you do sense that they do really looking for...and also during the assessment...for the 4 suppliers in Indonesia it was the first time to really go through our rating in a more detailed level...

...but it's like school they are really looking for a grade: Oh how did I do? I'm not necessarily looking for all those fail things (during audits). I'm really trying to get a grasp of the maturity level. When it comes to practices and you are actually doing it because it is in my code of conduct or are the different subjects connected because you do see that there is a common link which is sustainability.” The manager made this comment as the ISO14000 auditor for the tier factories. From her experience, using assessment forms creates a sense of scoring and competition between factories. Instead it was see more appropriate to use a non-numerical scale from “business-as-usual” to “leading performance”.

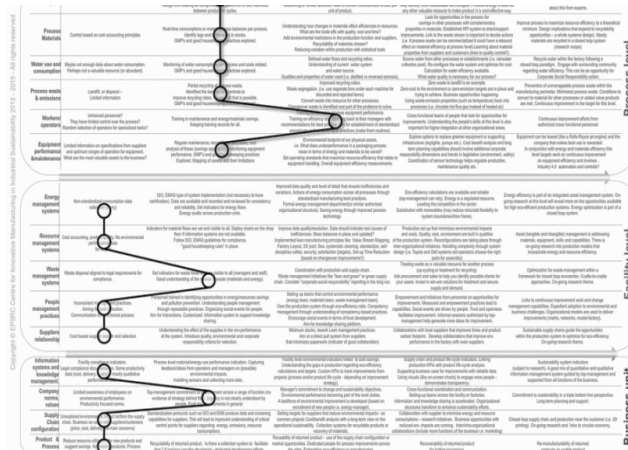
**Table 8-4 The maturity profiles from the three companies in the supply chain (the original copies as received via email). All three profiles have been developed after common agreement from practitioners in each company.**



Tier 2 supplier  
(4 manufacturing  
managers)



Tier 1 supplier  
(2 production  
managers)



8.4.2.2 Step 2 - Maturity analysis

Direct observations include and comments by the researcher (in italics):

- There is little evidence of practice maturity agreement between these companies.
  - Practitioner’s perception can be based on performance figures, managers’ experience and judgment or industrial performance benchmarks.
- Tier 1 supplier exhibits higher practice maturity at process level but low maturity is observed at management systems level.
  - Tier 1 supplier signals that eco-efficiency is not an urgency improvement area. The maturity assessment may have been an opportunity for them to express their interest or ask for help to improve from the brand.
- At a brand headquarters there seems to be strong variation in practice maturity across most organizational areas and particularly processes.
  - This has been also highlighted by one of managers and this may influence the engagement with their suppliers in pursuit of a collaborative eco-efficiency improvement scheme. As he observed:

- “A part of the reason for this variation is due to sustainability strategy e.g. focus on energy, and less attention to water use (given it is driven more by the number of employees). But this does not explain the whole difference...?”
- Tier 2 supplier exhibits better consistency between the three companies in terms of maturity levels (little colour variation).

#### 8.4.2.2.1 Follow-up discussion with participants

Running a workshop with this audience was deemed impossible due to time and geographic limitations. In order to better understand more about the shape of these maturity profiles, three contextual questions were emailed to all participants. This was not part of the PMGEM process. More contextual data about this manufacturing system were needed to gain deeper insights in the way that each company affects eco-efficiency in this supply chain. These were aligned to the theoretical framework in chapter 4 (section 4.6). The questions and responses were shared with all participants of the case study in order to keep everyone informed about the study course. The questions were:

- 1) What do you feel is the link or relationship in your factory between manufacturing practice maturity and environmental efficiency?

The first question aimed at learning how practice maturity was perceived by practitioners. In the discussion (via email) that followed, initial findings indicate that not all practices (i.e. ISO14000 system audits) are capable of connecting improvements at process level with business interests. Practices should be aligned to a vision and clear objectives (see chapter 7). For example, one of the headquarter managers mentioned that: *“We have built our maturity level from these two elements (ISO14000 and life-cycle assessment), however 'environmental efficiency' comes from having knowledge + targets + clear actions to help achieve the targets”*. At the factory level, one of the managers in the tier 2 factory pointed out that *“the same tools may not be appropriate to bridge the gap in maturity on environmental management. Different priorities may create obstructions when building a common eco-efficiency roadmap”*. This observation indicates that there is a deeper need within the supply chain to develop a common language in practices and ways of describing eco-efficiency.

- 2) How would you pursue environmental performance improvements for your factory individually?

The second question relates to the strengths of each particular link in the supply chain. As one of the tier 2 factory managers mentions in response to the brand sustainability manager: *“As you (the brand manager) emphasized, the brand uses ISO14001 system to plan, check and focus on improvement process to one environmental - related target per year. That means that fabric suppliers can contribute their efforts by focusing on reducing water consumption per year”*. The tier 2 factory had implemented water and waste-water efficiency projects and suggested that this is a good way to contribute to water efficiency at process level (a low priority dimension for the brand headquarters).

- 3) How would you pursue environmental performance improvements for the overall supply chain (your recommendations based on the other profiles)?

The third question makes a more specific reference to the role of each link in the supply chain and the overall contribution to eco-efficiency. In general, there was a consensus that a common approach for energy and resource efficiency across the supply chain is required, where different actors are using their strengths to achieve improvements.

From a brand sustainability perspective, the efficiency gains should be a strong selling point to improve the factory’s customer portfolio as they usually supply more than one apparel brands: *“...we want to encourage our suppliers and it is important that the suppliers can see the value of this approach in terms of both operational efficiency and environmental performance improvement..Also, material suppliers are providing their materials e.g. fabrics, to many different garment manufacturers, and even to suppliers in different industries... It is important that their approach to environmental performance takes their broad customer base into account”*.

The brand’s sustainability manager made an indirect point about the gains that operational and environmental efficiency may have on the business’ profitability. This observation is in alignment with Srari et al., (2013) that suggests that a mature organization will be driven by a mutual understanding of customer requirements and a strategy to inform and co-develop these requirements (Srari et al., 2013).

#### 8.4.2.2.2 Recommendations to the Apparel Headquarters

The apparel brand is the driving force in this supply-chain eco-efficiency initiative. The selling point of driving efficiency improvements is cost reduction and improved environmental performance (as in section 4.4, natural-RBV by Hart, 1995). However, the sense of urgency from other companies in the chain to improve and change is not strong

(Kotter, 1995, 2012). The managers at the brand headquarters collect all necessary information related to the supply chain eco-efficiency and seem to be the key stakeholders. However, a local resource (person or group) liaising with their suppliers is missing. Such resource could help accelerate improvement initiatives and reduce overall system friction (system being the supply chain). It was observed that remote communications such as emails and call meetings can be counter-productive at this stage. Until an agreed improvement strategy is set within this supply chain, a local human resource needs to be dedicated from the brand to facilitate necessary changes. This was the first recommendation made to the brand managers. The recommendation follows the practice of networking and knowledge sharing, discussed in chapter 6.

Another recommendation that seemed appropriate is another type of resource allocation from the brand. A technical improvement project, that is of common interest with their suppliers, could be found (i.e. water management project at process level) and co-funded by the brand. The funding would enable the suppliers to undertake brand driven improvements of mutual interest and reduce some of the financial risk involved. Even though financing was not mentioned in the case study, one of the brand's sustainability managers commented on this study:

“It is probably a good idea to ask our suppliers who would like to volunteer for this type of research and listen to their concerns and ideas, which I'm sure vary a lot from region to region, country to country and perhaps type of product to type of product. More of a bottom up approach rather than a top down approach where we analyse from atop and draw conclusions from our viewpoint. I think that trying to be on their shoes is a good approach to get a totally different perspective. I feel that the financial and economic driver was not highlighted enough, and let's be clear, money does make the world go round sort of speak. I think that our role has to be that of a brand that makes it easy for our partners to be sustainable”. This person was not involved in the case study at any stage but his opinion was asked by the involved brand managers. His views as an external observer compliment the observations that the application of PMGEM generated.

## 8.5 Chapter summary

The chapter described the application of a novel method that aims to help practitioners better assess their manufacturing system and develop improvements for eco-efficiency. In this chapter it was used in two very different manufacturing systems. The lessons learned

regarding the application process will be discussed in the following chapter as part of the evaluation process. The key points for the reader from this chapter would be:

#### Case study 1

- 1) A company with relatively low to medium self-perception of practice maturity in manufacturing. The alignment of practices to manufacturing strategy and organizational resources and capabilities was found to be weak and system exhibited a reactive character. Performance areas of high agreements as well as high variability were observed in the self-assessments.
- 2) Development of existing capabilities such as measurement and data accuracy is necessary if the company wishes to advance in eco-efficiency. A lack of guidance and support by top-management was pointed out by all participants during the self-assessments and it is probably something that requires more work.

#### Case study 2

PMGEM application in this case study did not go beyond the maturity self-assessments as it was not fully supported by the conditions of the application (very remote industrial settings). Nevertheless, the process was slightly modified to gain some more contextual information about the profiles:

- 1) PMGEM was able to generate combined maturity profiles from a group of practitioners from three companies of the supply chain. This implies agreement between a range of practitioners within the company about the common maturity profile. The collected profiles demonstrated variability of maturity between these three companies. This observation was verified by the difficulties that the brand had in a product life-cycle analysis for environmental impacts (another supply-chain wide activity) and advancing eco-efficiency as a target within the supply-chain.
- 2) A short email exchange between the most active stakeholders of the supply chain demonstrated the difficulty in setting common priorities. At the same time different priorities in each company could become complementary in a supply-chain-wide improvement plan for eco-efficiency. This confirms the rationale behind RBV theory for this system. Companies would be contributing to the supply chain eco-efficiency through what they are good at. The boundaries of this

system would need to be re-defined to acknowledge this contribution. This observation has implications for the use of RBV theory (see 10.2.2).

# 9 EVALUATION OF PMGEM APPLICATIONS

## 9.1 Introduction to the chapter

This chapter presents the evaluation of the PMGEM as applied in the case studies chapter 8. Blessing and Chakrabarti propose two types of evaluation in the second descriptive study (Blessing and Chakrabarti, 2009a):

- 1) Application Evaluation (AE): Aims to identify whether PMGEM can be used for the task for which it is intended and that it does address the key factors that are directly influenced, in the way they are supposed to be addressed, i.e., the focus is on usability and applicability.
- 2) Success evaluation (SE): aims to identify whether the support had the expected impact i.e., whether the desired situation has been realised, taking into account that unexpected side-effects may occur. The focus is on usefulness of the PMGEM.

The type of this descriptive study is initial-type (Figure 3.1). Time constraints limited the potential to explore the full impact of PMGEM. This would be necessary to perform a comprehensive SE according to DRM requirements. This chapter evaluates the usability and applicability of PMGEM based on feedback and observations and further discuss on its strengths and limitations.



## 9.2 Application Evaluation

According to Blessing and Chakrabarti (2009), evaluating success is far more difficult than evaluating applicability and usability and the research findings are not easy to generalise. They suggest that success can only be truly measured in the intended situation, i.e., in practice, and in many instances only in the long term. In chapter 7, two success criteria were described when applying PMGEM. To recap, the method was intended to:

1. Assess the levels of practitioner's understanding about the influence of current practices on eco-efficiency and help them identify what they need to achieve in the future to reach higher maturity levels in practice.
2. The support needs to be timely and require as little facilitation as possible. This criterion indicates how likely it is for practitioners to use the support on their own and with peers. Platts refers to this dimension of assessment as “How easily can the process be followed?” (Platts, 1993b)

The AE will be presented in two sections. The first section demonstrates evidence of applicability of PMGEM. Platts refers to this attribute as feasibility, by answering the question of “Can the process be followed?” (Platts, 1993b). The second section of the AE will discuss on the usability of PMGEM. Within the AE process, usability refers to the means of application that facilitate the interaction with participants. Platts refers to this attribute with the question of “How easily can the process be followed?” (Platts, 1993b). The researcher used the questions by Platts to guide the AE. DRM for initial type of descriptive studies does not offer a comprehensive set of tools to perform the AE.

Each of the two AE sections consists of three types of evaluation evidence: for the self-assessments, the workshop and the overall PMGEM. Initial signs of applicability and usability for the self-assessment and the workshop modules (as standalone tools) were described in chapter 5 (sections, 5.6, 5.7, 5.8). Upon that initial feedback, the researcher synthesised PMGEM (chapter 7). However, the applications in chapter 5 were not focused in solving real-life problem (the nature of the first descriptive study is non-interventional). The difference between AE here and the assessment in chapter 5 is that PMGEM was used to address certain real-life problems. In this chapter, the evaluation is informed by practitioners’ feedback and aims at verifying its intended use. As the self-assessments and the workshop can be used as standalone tools, the evaluation was performed separately for each tool, as well as for PMGEM overall. Some practitioners, in the first case study in chapter 8, were

introduced only to the self-assessment whereas others only took part in the workshop. Very few participants had the chance to participate in both modules. This observation is also a limitation to the evaluation process overall but further reflects the difficulty in securing people's availability.

### 9.2.1 Applicability of PMGEM

Applicability assessment answers the question of whether PMGEM can be followed. It asks the researcher to reflect on whether the process was appropriate for use in the applied conditions. From the researcher's perspective PMGEM was applicable in both cases in chapter 8 as:

- Both companies had done very little progress to-date on eco-efficiency even though both carried environmental standard ISO14000 accreditations. This means that a level of understanding about their EP existed but that was disconnected from their manufacturing practices or business strategy (see **Figure 3.4**).
- Eco-efficiency improvement was perceived as a desirable target for both companies. By decomposing eco-efficiency in 15 dimensions, practitioners were in a position to better understand how they can improve on eco-efficiency. Decomposition and simplification were perceived by the researcher as useful concepts to describe PGMEM. Nevertheless, this was not expressed explicitly by the practitioners and remains a personal observation from the researcher's perspective. Thus, the decomposition of eco-efficiency remains open for further investigation.

As the main tools of PMGEM were assessed in DSI separately the researcher wanted to retain a level of evaluation consistency across the two research phases. For that reason, a questionnaire based on the questionnaire used in the first workshop in chapter 5 was sent out to participants requesting feedback in a more structured way (see section 5.8.1). Only two participants filled in the questionnaire from the building products company and one of them sent a separate response. One of the participants was the sustainability manager and can be considered an expert in this industry (thus more biased than others on the application's evaluation). The responses are shown in Table 9-1 in 2 columns per question for direct comparison. For each of the five questions, the underlying rationale and motivation is described. All feedback comments are numbered for further reference.

**Table 9-1. The responses received from the practitioners in the building products company (answers in bold). The sustainability manager can be considered an expert in this feedback and therefore a certain level of bias is expected.**

Sustainability manager (participated in both modules of the method)	Health and safety manager (took part only in the workshop)
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1. What were the expectations that you wanted to fulfil prior to the workshop (name a few)?

**Question rationale:** Information to better describe/verify the scope of the application. Some practitioners may have had un-resolved expectations which would help broaden the scope of PMGEM.

**Received answers:**

“To give some clarity to future direction for the sustainability program and confirm our thoughts going forward. Also to get people from other areas of the business to talk about sustainability.” [comment 1]

“Increased awareness of both future and previous achievements with reasoning behind decisions”.  
[comment 2]

2. How would you rate the effectiveness of the process (maturity assessment and workshop) in meeting your expectations (rate from 1=very bad to 7=very good):

**Question rationale:** Connect the scope and the output of the application. A 7-scale rating was used to make this easy for practitioners to answer quickly.

**Received answers:**

“5”

“7”

3. How would you rate the quality of the workshop - rate from 1 to 7 for

- a) content quality:
- b) content clarity:
- c) educational value:
- d) overall:

**Question rationale:** A question specific to the workshop. As this workshop version evolved from the application in DSI this question can indicate areas for further improvement (i.e. content, clarity).

**Received answers:**

content “5”  
content clarity “5”  
educational value “4”  
overall “5”

content quality: “7”  
content clarity: “7”  
educational value: “7”  
overall: “7”

4. To what extent was the outcome of the process useful in improving your eco-efficiency in the future (and would you recommend this to other practitioners)?

**Question rationale:** A direct question about usefulness to facilitate evaluation of the workshop and the overall process. The sub-question about recommendation to others helps the researcher understand the level of applicability of PMGEM.

**Received answers:**

“Would recommend it but I don't think we learnt anything new, however it did back up what we already knew and what we needed to do and gives some credibility to the message we need to give to the Board on the future direction of our company sustainability program.” [comment 3]

“Highlights concentrated periods of change, which could be explained by both internal and external influences, increased awareness of future challenges and possible implications. Yes, definitely recommend to other practitioners.” [comment 4]

5. Are there other things that we need to be better at in meeting your expectations?

**Question rationale:** Connect the scope and the output of the application. A 7-scale rating was used to make this easy for practitioners to answer quickly.

**Received answers:**

“Can't think of at the moment - maybe a case study which goes into the specifics of what was identified, and actions taken etc.” [comment 5]

“Would imagine this to be very group dependent, Lampros was very knowledgeable in the subject, but perhaps not very experienced in presenting to a group. Although this was fine for us, another group may have prepared a more controlling guide. All that said it was very good.” [comment 6]

A different aspect of the PMGEM was uncovered by one of the managers in the first case study in chapter 8. **The continuous improvement manager** commented after having participated in both modules of PMGEM:

“It was a benefit for us all to have an open and honest discussion with ourselves regarding eco-efficiency. We now just need to do the work internally to understand where we need to be going with sustainability and what steps will add value most.” [comment 7] The manager acknowledges the lack of direction and lack of capabilities that were uncovered through PMGEM. In this case, a specific roadmap for improvement was not defined and it is a dimension that PMGEM was found to be weak.

**One of the apparel sustainability managers commented** (participated in the self-assessments and facilitated the conversations post-application): “Our industry seems overrun with sustainability assessments at the moment and this is an issue for suppliers. I really like how the tool is trying to identify root causes of performance differences and to show a path to improve. That is valuable for suppliers, and the assessment is much easier to fill in than the Higgs Index. Also, looking at the different characteristics across the supply chain has been

insightful. I hope we can define an effective way of working with these supply chain partners using this as a starting point.” [comment 8]

The manager acknowledges the value of tools such as the PMGE and understands the function of the tool (to show improvement pathways). It is also noticeable that PMGE is being compared to a commercial and quantitative tool which is being developed specifically for this industry (the Higgs Index). Ease of application is being verified as a desirable property of PMGE. From the apparel industry one of the brand’s sustainability managers sent his feedback about the usefulness of the overall process. The apparel case was also presented to two external practitioners who were not involved in the PMGEM application at any stage. The first one was a sustainability consultant from the American region and the other one was a sustainability consultant with background in logistics and supply chain. The process and findings of the apparel case study were presented to them as third parties for triangulation and feedback was received (unstructured).

**Sustainability manager for the apparel brand for American branch:**

“It is probably a good idea to ask our suppliers who would like to volunteer for this type of research and listen to their concerns and ideas, which I’m sure vary a lot from region to region, country to country and perhaps type of product to type of product. More of a bottom up approach rather than a top down approach where we analyse from atop and draw conclusions from our viewpoint”. [comment 9]

**Sustainability consultant (independent observer to the apparel industry):**

“It was a 'light-bulb' moment for me when you made your observations about how the players in the supply chain have different perspectives on maturity. I think, that is going to be really useful to have in mind, as companies look to develop greater circularity in their processes - realizing that not only within their organizations but also outside, there are different views on where the opportunities are.” [comment 10]

Overall, the feedback on the applicability of the PMGEM has been positive but some limitations were also presented. In section 9.3. the researcher discusses upon the overall applicability of PMGEM. The following section evaluates the PMGEM usability.

### 9.2.2 Usability of PMGEM

Usability refers to the degree to which users understand the language and concepts used (Maier et al., 2012). A usable process would be easy to follow according to Platts (1993). The

researcher has to examine how well both modules (self-assessment and workshop) interact with people and assess the overall usability of PMGEM as a process. For example, in the case of the apparel sportswear company, the maturity framework was found to be familiar to the practitioners to an existing audit tool for social assessments in supplying factories. This familiarity helped the practitioners support the case study better as it was seen compatible to existing auditing tools. It was easier to explain the nature of the maturity grid and engage with them. Such an indication of familiarity with such tools was not evident in the building products company and therefore the maturity approach may seem less familiar in that context.

#### 9.2.2.1 Usability of the maturity grid as a self-assessment tool

Two theoretical frameworks have been used to describe usability for the self-assessment module and for the workshop. The frameworks by Maier et al., (20012) and Kerr et al., (2013) provide a substrate to analyse the PMGEM procedures. Frameworks that can help design and assess the quality of theoretical models (such as the PMGE) have been found to be rare but also very helpful in this study. The first part of the usability assessment is directly related to the design of the maturity grid. Table 9-2 completes the second part of the design assessment table introduced in chapter 5 (**Table 5-2**), as the intended use of the PMGE is better defined.

**Table 9-2 Maier et al., propose two more phases in the design of maturity grids: An evaluation phase and a Maintenance phase. The evaluation phase is in alignment with this chapter, whereas the dimensions of the maintenance phase would be more applicable once a comprehensive success evaluation is produced. The text in left hand column is derived from the paper by Maier et al., 2012. Phases I and II remain as described in section 5.4.**

Phase III Evaluation	
1. Validate: evidence needs to be given for correspondence between the researcher’s findings and the understandings of participants.	So far, two instances of validation were observed. A practitioner using the PMGE in section 5.6.1.3 acknowledged that: “I have used the maturity grid to help me to shape some ideas as part of the planning for future Environmental Programs. I hope to build this into our plans for the future as a way of measuring our progress.” This validation point was received without having established what the intended use was for the PGMEM. It did help the researcher however to clarify what the intended use can be (see chapter 7). The second type of validation of intended use comes from the apparel sustainability manager: <i>[comment 8]</i> .

		Additional validation points are comments: [4], [7] and [10]. Comment [4] also refers to the underlying rationale of PMGEM in regards to maturity. This point strengthens the theoretical proposition of using a maturity model to simulate eco-efficiency in manufacturing.
2. Verify: In terms of verification, through application, the method developed needs to be evaluated against the success criteria.		According to the words of the sustainability manager in the first case study: “It did back up what we already knew and what we needed to do and gives some credibility to the message we need to give to the Board on the future direction of our company’s sustainability program.”  Additional verification points can be: comments [5] and [6]. The limited number of applications in chapter 8 is also an inhibiting factor to make more efficient verification of the intended use.
Phase IV - Maintenance		
1. Check benchmark (and adjust description in cells):	(if applicable)	An updated version of the PMGE is presented in Appendix E.
2. Maintain results database:	(if applicable)	Not applicable but could be considered for future work.
3. Document and communicate development process and results:	(audience specific)	The development of the maturity grid as well as the way to apply this has been published in Litos and Evans (Litos and Evans, 2015a).

### 9.2.2.2 Usability of the workshop

The second area is related to the workshop. It is discussed separately as it focuses more on the interactions between the practitioners and the method. This task was guided by work from Kerr et al. As described in chapter 7, Kerr et al., propose that processes like PMGEM can generally follow 7 principles. These are used in this section as an assessment template in Table 9-3 and comments are made post-application in the case of the building products company. The researcher re-populates the assessment table by Kerr et al., (2013) to reflect mainly upon the workshop process. The workshop design principles are reviewed post application in chapter 8. The intended use of the workshop is described in section 7.4.3.

**Table 9-3 Workshop assessment based on criteria set by Kerr et al. (2013)**

Assessment principles	Researcher’s comments post-application
<i>Being human-centric</i>	<p>PMGEM focuses on managers’ perceptions to characterize and assess the maturity of manufacturing practices. It is human centric as it involves people in both main components. Human input is essential to inform research. At the same time participants act as educators for their peers as they go through the process and perform peer-to-peer communications. These communications are hard to record and can be missed by the researcher. As some of the participants pointed out, it is key to acknowledge what other people think about eco-efficiency and what needs they want to fulfil (see comments 1,7,9,10)</p>
<i>Workshop based:</i>	<p>Without the workshop, as in case of the apparel company, the study remains subjective to the interpretation of the maturity profiles by the researcher. The follow up workshop from that step would provide context to build better understanding about manufacturing capabilities and practice maturity.</p> <p>Without the workshop, the researcher had to take initiative and follow up from the self-assessment process to gain deeper insights about the case study context and the relationships between various stakeholders. In the building products company, the workshop was received well by practitioners with medium to very-high ratings (see question 3 in table 9.1).</p>
<i>Neutrally facilitated:</i>	<p>The level of the researcher’s interference, particularly in the workshop, needs to focus on pacing the process rather than directing content (Kerr et al., 2013). Facilitation was acknowledged as an important element of the overall process (see comment 7).</p> <p>The researcher’s personal input would bias the workshop output and remained as neutral as possible. It was necessary to answer participants’ questions (i.e. definitions) but the main objective was to keep track of time. In occasions he would urge some practitioners to write their thoughts on the post-it notes and/or expand their notes so that others can read these and make additional comments.</p>



*Lightly processed:* Both modules of the process can quickly generate results in a structured format as they follow the grid structure. The structure and use of colour post-it notes can provide quick feedback to the researcher about the most active areas in the company. In addition, the data transcription was greatly facilitated by the coloured notes and the grid structure.

*Modular:* The workshop can be seen as modular in two ways. It is the second part of the maturity-based method and it consists of three maturity grids. In the case of the building products company, both modules of PMGEM were used. In the apparel supply chain only the self-assessments were used. If a workshop was performed, there would be the option of different practitioners choosing different set of maturity sub-grids to focus on.

The workshop can look into the eco-efficiency of the manufacturing system rather than a single manufacturing site. The case of the supply chain helped the researcher make that distinction more visible.

In addition to customisation of the process, not all dimensions of the grid are relevant to every case study. For example, the dimension or “process water” was not important in the case of the building products company as very little water is used overall in their processes. Practitioners may choose to disregard a dimension of the grid as irrelevant or not material to the business.

*Scalable:* As one of the practitioners in the apparel company mentioned “*the use of scalable sustainability tools is a priority for the brand*”. The process is available to practitioners to run themselves with little or no facilitation by the researcher. Scalability was found difficult to assess at this stage. The only promising evidence of scalability came in the apparel case study as the self-assessment process (PMGE) was perceived positively when compared to an industry wide tool (see comment 8).

*Visual:* A few comments about visual attributes have already been made such as the colour of the post-it notes and their density once the process is complete. Visual enhancement of the process certainly helps the participants review the process output faster. This dimension drove the rationale behind Figure 7.1 and Table 8-4). However, the efficient use of such visuals was not adequately

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assessed in this work mainly due to the limited number of cases applied. Sharing of maturity profiles in Table 8-4 amongst participants did generate discussions but it is not clear how the visual element works in detail. The researcher assumes that the misalignment of maturity profiles did trigger a benchmarking process between tier factories and the brand but yet this remains an assumption for further elaboration.

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### 9.2.2.3 Overall usability of PMGEM

One of the key parameters that enabled PMGEM to take place, was the facilitation offered by some of the participants. Achieving the levels of engagement as in chapter 8, would have been impossible for the researcher to deliver in a timely fashion. It was critical to achieve commitment from the companies before this process could start. It was also observed that PMGEM has to become more intuitive for practitioners to use themselves independently (i.e. with a supplier). The self-assessments required little facilitation but the same cannot be claimed for the workshop. Having discussions about eco-efficiency improvements between practitioners and/or suppliers is the stage where the researcher sees more value for practice. It is also the stage where theoretical assumptions from RBV can be translated into actionable recommendations.

### 9.2.2.4 PMGEM and success criteria

Based on the analysis, the researcher argues that the success criteria set for PMGEM have been addressed adequately. There is evidence in both case studies that practitioners were better informed about the current levels of the system's eco-efficiency and about the challenges that the variability of perceptions generates. The researcher needs to further acknowledge that certain conditions of the application did inhibit the overall success. In the first case study, top-management commitment for eco-efficiency improvements was found to be weak as an incentive for practitioners but further weakened the motivation for people's participation in the process. Similarly, the distance between practitioners in the second case study prevented the full application of PMGEM.

Positive comments about future use of PMGEM and integration to existing assessment tools was evident but it is difficult to generalise such statement at this point due to limited feedback.

### 9.3 Discussion and limitations

The researcher sees the two main parts of the process (self-assessment and workshop) as complimentary to each other. The maturity grid in the self-assessment tool was developed mainly with literature data and users are given a populated grid (PMGE). On the other hand, the workshop is developed to help practitioners design their own eco-efficiency improvement pathway by focusing on practices that can be supported with existing capabilities. The grid structure and rational (RBV theory) of the PMGE are the properties that are being held constant between these two application steps. This observation became apparent to the researcher after the applications in chapter 8.

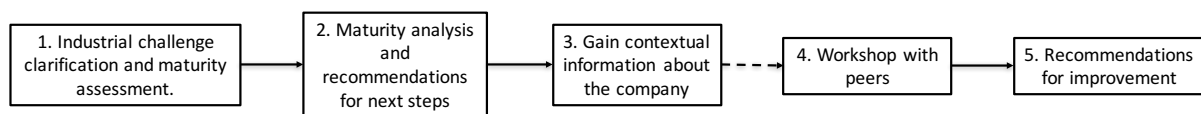
Overall, as a complete method, PMGEM did achieve some positive feedback. One of the process strengths was perceived to be the maturity profiles (i.e. as in Table 8-4). Collecting maturity profiles, as expected, produced results of fair quality but with little impact to the organizations. The follow up process of peer-to-peer discussions (see section 8.6.3) or the workshop was found to be the most valuable part of PMGEM for research and practice. This participatory process provides context to the maturity profiles and helps the user of the method understand what the improvement recommendations can be. In the building products company, the ground for improvements was not found to be fertile yet. As the continuous improvement manager commented: *“We now just need to do the work internally to understand where we need to be going with sustainability and what steps will add value most”*. This comment is aligned to the maturity self-assessment output where all participants agreed that *“there was a top-management commitment to improve across a range of functions that lacked strategic intent, the urge was generic and not clearly understood by people”*. For PMGEM this indicates internal consistency as the process does not seem to generate conflicting results (subject to more applications). Nevertheless, the improvement options for the building products company were not clear or straightforward. Potentially, more work is required for PMGEM to be able to produce actionable recommendations. Certain implications for theory are discussed in the following chapter.

One of the problems with maturity-based empirical research has been in operationalizing the attributes of interest and synthesizing appropriate measures (Mullaly, 2014; Thomas and Mullaly, 2007). Indeed, it was found to be challenging to create actionable and valuable recommendations in the applications in chapter 8. The researcher sees this issue depending on context and facilitator’s experience. In the apparel company it seemed easier to make suggestions for improvement as there was a higher drive to improve the supply chain. A

similar urgency in the building products company was not observed. Potentially, PMGEM is limited as a design process by the urgency levels that the corporate environment experiences. The researcher’s experience in facilitating PMGEM was highlighted by one of the participants (see comment 6). Some further practice is required to deliver PMGEM effectively to meet the success criteria in the long run. It was not very clear what precisely was missing from the facilitation but it is a point that came up and cannot be ignored.

The PMGEM process can be revised to incorporate the questions used in the apparel case to gain a level of contextual information (Figure 9.1). The questions enabled the clarification of some of challenges that the system faced.

**Figure 9.1 The revised PMGEM**



## 9.4 Review of contributions to practice post-application

In chapter 7, certain aspects of this work were brought forward to the reader as tentative contributions to theory and practice. In this chapter, in table 9.4, the researcher clarifies what the contributions to practice are. In the following chapter the researcher reflects on the theoretical grounds of this work and reviews the tentative contributions to theory.

**Table 9-4 - Revised contributions to practice post-application**

Tentative contributions	Revised contributions to practice
<p>1. PMGE application needs to be timely and produce contextual information about eco-efficiency improvements. The users need to have clear expectations from the application and a specified goal.</p>	<div style="border: 2px solid #0056b3; border-radius: 15px; padding: 10px;"> <p>1. PMGEM application is dependant to the context of the application. PMGEM users need to acknowledge contextual factors that may influence the results of the application.</p> </div> <p>Therefore, participants (users) that are familiar with the context of the application are in a more advantageous position to interpret the PMGEM results.</p>

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2. At high maturity levels the variation of practitioners' perceptions is reduced significantly as internal information flows improve. At high maturity levels, perceptions about practices are aligned and converge. At lower maturity levels, perceptions can be scattered across various maturity levels or converge strongly to either side of the chart (indicating an imbalance between environmental and economic performance).

Improved information flows may accelerate the improvement process but there is not enough evidence to strongly support the argument about reduction of variability due to improved information flows.

2. Practitioners' perceptions may vary and converge in various dimensions of performance. The use of PMGE enables this observation and provides a basis for further investigation. Acquiring contextual information can help interpret some of the variation in maturity profiles.

3. Maturity levels 3 and 4 are crucial for a company's transition from business-as-usual to leading performance. Gaining more contextual information is critical to help clarify what improvements can be proposed.

Both case studies in chapter 8 did not exhibit strong evidence of high practice maturity, as in the case studies in chapter 6. However, it was found that strong support from top-management is key to help practitioners advance the maturity of their systems and sustain improvements at maturity level 3 and 4. The proposition can be refined as:

3. Top-management support is critical for the design of eco-efficient manufacturing systems and to advance

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The second descriptive study further helped the researcher clarify a practice contribution to design research methodology. The steps followed in this study can be seen as an 8<sup>th</sup> type of DRM project which researchers may use to design improvement methods similar to

PMGEM. The contribution is reflected in the introduction of two descriptive studies after the research clarification phase. The first one is an inductive study where the researcher intends to learn more about the situation and the problem as in the 5<sup>th</sup> type of project. A second descriptive study at this phase of the research is initiated to model the situation. As this can be a novel model (like PMGE) an inductive-deductive study can be performed to build and to understand how the model interacts with the real world (practitioners in this case, see section 5B). The composition of the model can be inductive with data from literature and the first descriptive study. The application of the model is deductive as it is a test of the model in various conditions to check for usability/applicability. This type of DRM project is presented in table 9-5 and contrasted to the 5<sup>th</sup> project type that this research plan was based upon (see figure 3.2)

**Table 9-5. The 5<sup>th</sup> and the new 8<sup>th</sup> proposed type of DRM project**

Type of DRM project	Research phases	Research Clarification	Descriptive study		Prescriptive study	Descriptive study
	5 <sup>th</sup> type	Review-based	DS I (Comprehensive)		PS (Comprehensive)	DSII (Initial)
8 <sup>th</sup> type (proposed)	Review-based	DSI Initial or Comprehensive	DSII Comprehen sive	PS Comprehensive	DSIII Descriptive study (initial)	
	Literature review	Inductive study (i.e. open or semi-structured interviews) Literature review to relate to theory that may explain patterns in data.	Modelling of data and model testing through a deductive study (see chapter 5B).	Inductive study. Method development – the method is based on the model. This is how the method finds its way into being practiced.	A deductive study where the researcher seeks evidence to shape the model and connect it back to theory.I	

### 9.5 Chapter summary

The researcher analysed the feedback from the application of PMGEM in two case studies from chapter 8. The evaluation process followed two main dimensions of analysis: applicability (can the process be followed?) and usability (how easily can the process be followed?). Overall, the method received several positive comments that validate its intended

use to a satisfactory level for this (initial type) descriptive study 2. This chapter addresses the second research objective with the development, testing and revision of the PMGEM.

More applications and testing are seen as necessary to learn more about the organizational context that enables actionable recommendations to emerge through PMGEM. The user's ability to facilitate the applications was also seen as an important factor to achieve higher impact in practice.

# 10 CONCLUSIONS AND FUTURE WORK

## 10.1 Introduction to this chapter

The final chapter of this thesis overviews the research activities carried out and reflects upon the research tasks set in chapter 3. The researcher reviews and clarifies the theoretical contributions of this work. Future research goals based on this work are also proposed.

## 10.2 Main knowledge areas

This inquiry is connected to certain knowledge domains. From a context perspective, it is addressing challenges within the sustainable manufacturing literature (section 3.3). The researcher's overall intention has been to help manufacturers make products in a more sustainable way. This inquiry is also connected to environmental management and assessment literature as it offers tools that can be used to assess and manage eco-efficiency targets. As the researcher demonstrated the development and application of these tools, this work offers additional support to researchers and practitioners that want to develop and apply interventional tools. Therefore, the inquiry is connected to the body of literature that focuses on the design and use of tools for business research and practice.

Overall, the theoretical contributions of this study advance knowledge in three domains:

1. The researcher confirms and extends the theoretical work on organizational maturity by Baumgartner and Ebner (2010) in the specific domain of eco-efficiency with additional empirical evidence. (see further discussion in 10.2.1). The researcher found



a way to practice the maturity profiling by Baumgartner and Ebner (2010) in real life situations and offer applicable and usable information to practitioners to plan and action eco-efficiency improvements.

2. The resourced-based view theory has been found to have transferable implications for eco-efficiency in manufacturing systems. This work confirms the applicability of RBV theory for manufacturing systems at high-maturity levels (based on PMGE). At lower maturity levels RBV was not equally supported in this work and further research is required to understand the improvement mechanisms at lower maturity levels. (see further discussion in 10.2.2)
3. The maturity-model body of literature (theory and application) as addressed by Maier et al., (2012). This knowledge discipline is also connected to the research plan rational (based on DRM), as there are common design similarities between the two disciplines. (see further discussion in 10.2.3)

In the following paragraphs the researcher discusses in more detail how this inquiry has advanced and contributed to the fields of these knowledge domains. Tentative contributions to knowledge from chapter 7 are finalised here by also acknowledging the use of PMGE/PMGEM that helped to surface the contributions. Comments are also made on future research activities in each area.

### 10.2.1 Organizational maturity and eco-efficiency

This inquiry is positioned within the field of sustainable manufacturing. Aligned to the researcher's philosophical stance, this work is oriented to help practitioners in manufacturing improve on eco-efficiency. The maturity profiles work by Baumgartner and Ebner inspired the researcher to use the concept of maturity profiles in real-life and demonstrate how it can be used for eco-efficiency. The researcher found a way to observe and record the variability of practitioners' perceptions about eco-efficiency practices and how variability may be linked to underperformance.

The first tentative contribution to theory is finalised now as:

1. PMGEM users can observe variations of perceptions between practitioners. At high-maturity levels, practitioners' perceptions converge and vertically align on the maturity grid, while the system exhibits high eco-efficiency levels (economic and environmental performance are balanced). At low maturity levels practitioners' perceptions may converge to certain dimensions of performance but do not show overall alignment thus predicting imbalance between environmental and economic performance.

The self-assessment process that has been developed in chapter 5, operationalises the theoretical work of Baumgartner and Ebner. Practitioners are now equipped with a tool that can generate rapid insights about a system's eco-efficiency. The tool is structured and it has proven its applicability and usability. Additional work is required through real-life applications to create behavioural system patterns as Baumgartner and Ebner predict (see figure 5.1).

A conference paper was written by the researcher on this subject in the second Sustainable Design and Manufacturing conference in 2015 (Litos and Evans, 2015b). The researcher proposes that sustainable manufacturing strategies can be characterised by the maturity of practices at different dimensions of performance. The PMGE is adjusted to facilitate this type of work.

### 10.2.2 The resource-based view theory and eco-efficiency

In chapter 4, the researcher found that the resource-based view theory, and its extension from Hart (1995) for the natural environment, could serve the research objectives. RBV predicts that companies may choose to exploit existing internal capabilities to tackle environmental challenges. Hart proposed that cost advantages can be achieved through pollution prevention initiatives. In chapter 6, the researcher observed how mature companies may leverage internal capabilities to support eco-efficiency improvement projects. The observations justified the RBV approach for the companies in the automotive and aerospace sectors. As these are sectors where high practice maturity is expected, the observations are difficult to generalise to other types of industries. Therefore, additional descriptive work in other industries (i.e. process industries) is necessary to demonstrate to the academic and industrial communities

how existing capabilities can be leveraged to achieve cost advantages. Specifically, within the field of sustainable manufacturing the examples were found to be rare.

Through the case studies in chapter 6 and 8 another observation emerged. The way that one defines the manufacturing system influences the areas where system strengths can be found and applied for eco-efficiency. Especially in the cases of the aircraft and apparel companies, the manufacturing system extends to more than one factories and can incorporate suppliers. Improvement options can be found in across the wider supply chain.

The second tentative contribution to theory is finalised now as:

2. Mature eco-efficiency practitioners have largely relied on their core strengths to shape programs of action (thus confirming the grounds of RBV theory). The concept of using existing system strengths to support eco-efficiency improvements has been confirmed for manufacturing systems that employ mature manufacturing practices, through the PMGEM application.

The above statement is subject to the condition that: it is important to define the boundaries of the manufacturing system where transferable system strengths may be applicable for eco-efficiency improvements.

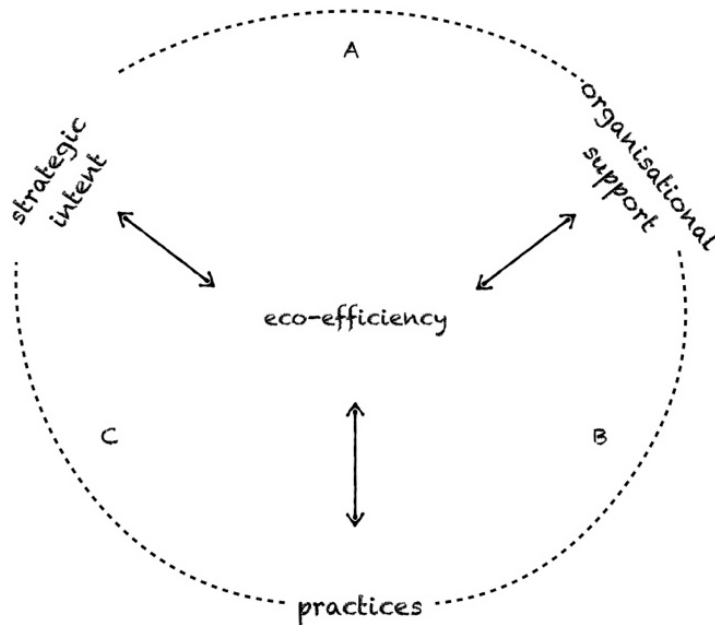
Within the RBV theoretical grounds one more tentative theoretical contribution was presented in chapter 7:

Tentative contribution to theory 4: At high maturity levels, key enablers for improvements are aligned to core system capabilities and business objectives.

As both cases in chapter 8 were at low to medium maturity levels, the above statement remains tentative subject to critical review. This tentative conclusion has implications about the theoretical framework in chapter 4. The links between strategy, practices and eco-efficiency (area C in figure 10.1), were not well-explored in this work and can be a considered for further elaboration. The argument that alignment between practices, strategy and organizational capabilities may enable or accelerate eco-efficiency improvements sounds logical and there are studies that may support similar statements in other knowledge

disciplines (see section 4.7). Top-management commitment may be one of the influencing factors (as absence of commitment and clear strategy was a problem for the first case study in chapter 8). Nevertheless, evidence so far do not support the forth tentative conclusion further.

**Figure 10.1 - Review of the theoretical framework from chapter 4.**



### 10.2.3 PMGEM design principles

In chapter 5, the researcher demonstrated how the concept of maturity was operationalised for research activities following the design principles offered by Maier et al., (2012) and Kerr et al., (2013). This thesis offers an example of how maturity grids such as the PMGE can be designed and applied for research. This work has been published in Litos and Evans (2015). The researcher found the design guidelines by Maier et al., (2012) very helpful to design the interface (the maturity grid) between the concept of maturity and real-life situations.

The feedback received in chapters 5 and 9 was aligned to the intended use of the PMGEM (see sections 5.3 and 9.2) and further proves the utility of the design guidelines by Maier et al., (2012). In addition, the workshop was found to be a valuable tool for collecting contextual information about system capabilities and help develop recommendations. The modularity (Kerr et al., 2013) between the self-assessment and the workshop enabled the complementarity of information within the application (internal consistency). In table 9.3 the

researcher clarified the practical contributions of the PMGEM. In this chapter, the third tentative contribution to theory is finalised as:

3) PMGEM was found to be applicable and usable. It confirms the utility of the maturity grid design principles by Maier et al., (2012) and the utility of the workshop design principles by Kerr et al., (2013).

The PMGEM design process can be used by other researchers and practitioners to further the development of PMGEM or other similar methods. The element of modularity within the two main modules of PMGEM (self-assessment and workshop) made the overall method more robust and consistent therefore these are necessary components to the method. Additional future efforts to improve PMGE is to refine and enrich the description of practices in the grid cells as well as to experiment within a more positivistic methodology (i.e. a survey). Ultimately, the researcher envisages that PMGEM can become a benchmarking platform for eco-efficiency

### 10.3 Limitations and future work

The researcher designed and tested a method (PMGEM) that has been positively commented by practitioners in manufacturing companies. The research activities followed the methodological principles that Blessing and Chakrabarti set in their design research methodology (DRM) framework. The alignment of this work to DRM has been intentional as the researcher needed a rigorous methodological research plan to develop design support for practitioners. DRM offered a rigorous platform to conduct research. Nevertheless, limitations do exist within this work and need to be acknowledged and considered for future research endeavours. The identified limitations are contextual, methodological, and theoretical and content-related.

- a) Contextual limitations originate from the environment where this work is applied. The researcher observed that practitioners' perceptions can be biased for a number of reasons like job roles, educational background or type of industry they work in. Therefore, participants' understanding and perception of eco-efficiency may vary. This limitation was found to be countered by the level of facilitation offered (being as

neutral as possible). The more the researcher would facilitate the interaction between the participants and the tools (i.e. maturity grid or workshop), the easier it was for people to engage with these. Neutral facilitation nevertheless is important for an unbiased outcome and users of PMGEM need to be aware of this requirement.

- b) A level of variation between practitioners can be attributed to the practice descriptions in the cells of PMGE. The researcher estimates that this should not be more than 1 level between two practitioners. It is expected that future applications of the maturity grid by other users may contribute to more clear and singular descriptions in PMGE cells to avoid this type of variation. For that respect a library of revisions should be established that keeps records of such changes in the grid.
- c) Methodological limitations also exist. DRM was selected in chapter 2 as the preferred framework to plan research activities. Other frameworks could have offered a different route to answer the research question and objectives. DRM offered the angle of “intended use” in the development of the PMGEM whereas other methodologies may had offered an alternative investigation route such as more attention to the influencing factors of eco-efficiency or more attention to the theoretical links to RBV.
- d) In addition to methodological limitation, the researcher acknowledges that this work could have had a different outcome within other theoretical perspectives such as the theory of planned behaviour (Ajzen, 1991). The researcher considers that the behavioural element of management practices can further enhance the applicability and usability of this work. By taking into account the impact of maturity profiles on people's psychology and behaviour, PMGEM can become even more effective in the design of eco-efficiency solutions.
- e) Content-related limitations were observed with the PMGEM's capability to deal with different types of inputs about practices and generate valuable recommendations. Relying on RBV as a theory to generate improvement options may work well for some cases but more work is required to be at a level where the method can deal with both low and high levels of input data quality.

## 10.4 Additional discussion points and future work

Three additional points can be brought forward that could be used as a basis to further extend this work:19

a) In chapter 7, an observation about the effectiveness of execution of practices at various maturity levels was excluded from the PMGEM development. For example, within one cell of the maturity grid the researcher can apply a traffic light system to indicate how a practice performs (work in progress, delays or satisfactory execution). It is proposed that this type of work can add more detail in PMGE and make it more comprehensive. In addition, a combination with quantitative data could add another dimension to the PMGEM and link the grid to eco-efficiency performance figures. There is significant amount of research on quantitative maturity grids that this work could be linked to and improve robustness and reliability. The research challenge would be to make the PMGE more comprehensive and still usable as the researcher predicts a trade-off with usability.

b) Another concept that the researcher introduces in the design of PMGE is its three-layered structure. As PMGE consists of three sub-grids and therefore the user needs to reflect on the maturity of practices across three important organizational layers: processes, systems and top-management (leadership). Unfortunately, there was not enough time to explore the cascade of practice maturity across these layers. The thinking is embedded in the proposition about alignment of perceptions but the researcher now refers more to the actual practice itself. There are very few qualitative studies on sustainable manufacturing that embed this type of thinking in the research tools. There was only one paper found that discusses the mechanism of practice diffusion within the organization (Ansari et al., 2010). This thesis can be an opportunity to further explore how maturity can be diffused through the organizational layers and practices within each layer.

c) On a more personal note, the researcher also finds that PMGEM was applicable and useful by practitioners as a method of simplifying and decomposing eco-efficiency. This was not explicitly mentioned by practitioners and therefore it was not included as a contribution to knowledge and practice. Nevertheless, as a practitioner, the researcher can see that the maturity grid decomposes eco-efficiency in manageable tasks for improvement and this is probably why it was used for planning purposes (see section 5.6.1.3). Future work could also involve the investigation of the planning capabilities of PMGEM.

# 11 PUBLICATIONS

## Journals

Litos, L., Evans, S., 2015. Maturity grid development for energy and resource efficiency management in factories and early findings from its application. *Journal of Industrial and Production Engineering*, 1 - 18

## Conferences

Litos L., Gray D., Johnston B., Morgan D., Evans, S., 2016. A maturity-based improvement method for eco-efficiency in manufacturing systems. 14th Global Conference on Sustainable Manufacturing, GCSM 2016; Cape Town; South Africa; 3-5 October 2016

Litos L., Lunt P., Hope S., Evans S., 2015. Empirical approaches to development and sharing of environmental best-practice within multi-site manufacturing configurations, Global Cleaner Production & Sustainable Consumption Conference, Sitges, Barcelona, Spain, 1 - 4 November 2015

Litos L., Morgan D., Johnston B., Romy Miltenburg R., Evans S., 2015. Eco-efficiency maturity assessment and improvement methodology in the apparel industry, Global Cleaner Production & Sustainable Consumption Conference, Sitges, Barcelona, Spain, 1 - 4 November 2015

M. Despeisse, A. Davé, L. Litos, S. Roberts, P. Ball, S. Evans, 2015. A Collection of Tools for Factory Eco-Efficiency, 13th Global Conference on Sustainable Manufacturing Ho Chi Minh City & Binh Duong Vietnam September 17th 2015



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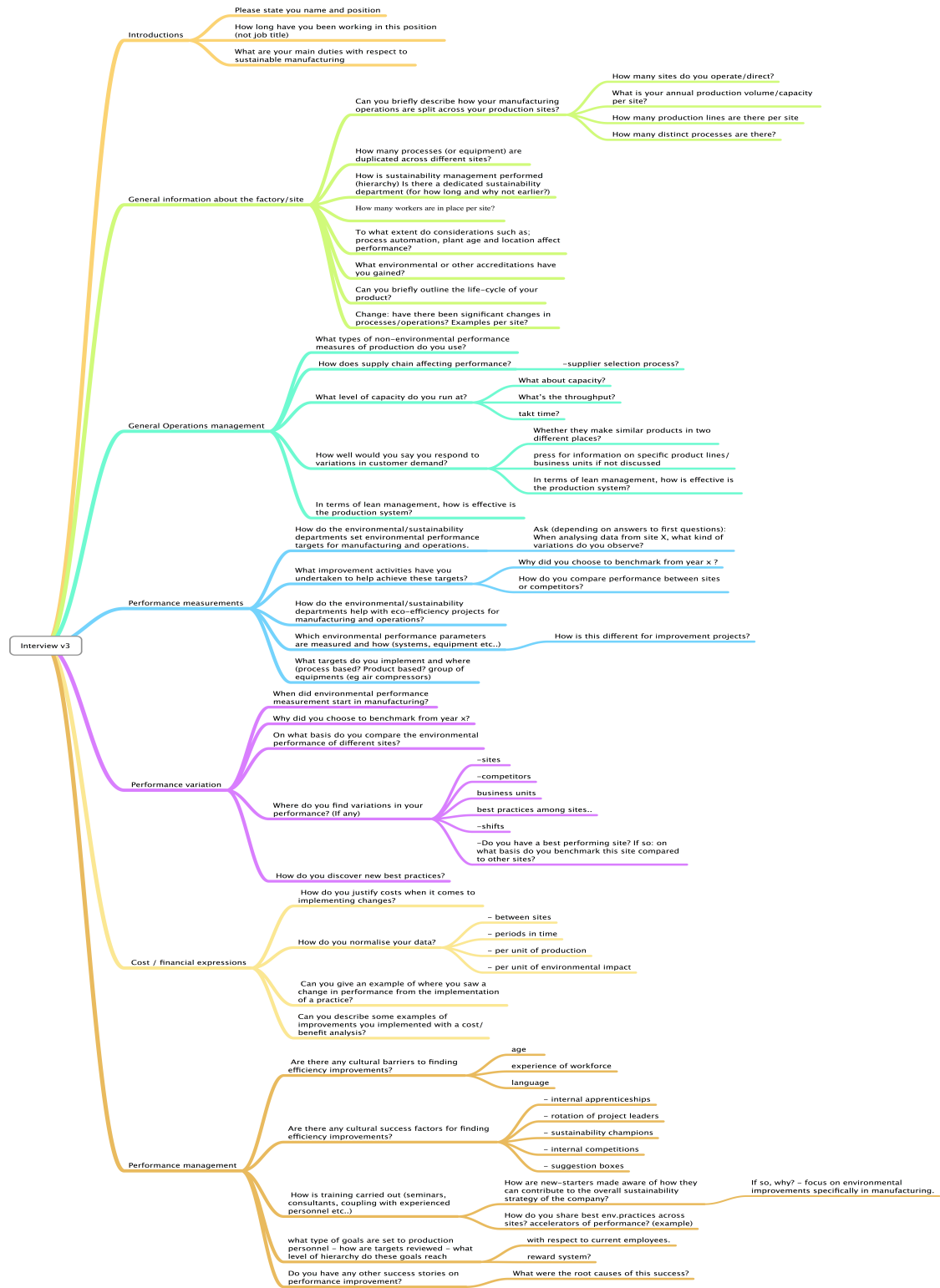
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# APPENDIX A

Semi-structured interview guide used in chapter 4 to collect information from practitioners about energy and resource efficiency improvements.





## APPENDIX B

The data from the workshop were transcribed and sorted in five maturity levels. As the audience was quite diverse, the researcher focused more in characteristics of each maturity level regardless of the practice dimension. This approach helped the researcher validate the reactive to proactive sequence of practices on the maturity grid - as developed through literature. The researcher focused on the key words that participants used. The table below is the reduced version. A blend of practices and goals is evident. The useful information is the wording that changes from left to right and validates the PMGE approach.

Business as usual----->	----->	-----towards----->	----->	Leading Performance
start measuring	recycling	define	living process	generate
reaction	recycled	sorting	leading	design
awareness	reuse	targets	innovative	close loop
cost	measure	leadership	optimise	no water
individual practices	document	understand	generate/source	cross-functional
price	standards	just in time	philosophy	collective intelligence
low quality	measure	procure local	bio-degradable	design for optimisation
"don't care about culture"	KPIs	recycled materials	footprint	KPIs
no-values	technology	match demand	KPIs	continuous improvement
permits	skills	suggestions	symbiosis	constant
hazardous	record data usage	kaizen	think systematically	ecology
record information	lean	concrete issues (well defined)	job naration	close loop
market based decisions	segregate waste	monitor asset	ISO50000	eco-friendly culture
little measurement	training	flow	ethically	LCC buying
no benchmarking	rewards	asset value	localy	supplier integration
remote materials	pre-scored	measure	collaborate	systematically
bad accounting systems	pre-approved	setting targets	culture	proactive management
time inefficiencies	fast mover	innovate/brainstorm	awareness	centralised opportunity
linear process	partners	<-quality management	proactive	global collaboration
lack of management	value	monitor	buying groups	right corporate culture
introduce principles	ask questions	<-coaching/training	coalitions	values
requirements & specifications	share knowledge	integration of systems	env. Performance tenders	transperancy
open market		partners/behave	disclosure	procurement and transperancy
static		common SCAs/KPIs	tracking	ethical
silos		create a game	involvement	LCA
cost focus		target data collection	eco-strategy	smart technology
lack of investment		lessons learned	optimise network	
policy legislation		use metrics to drive	changing behavior	
cost		culture	joint responsibility	
price		collaboration	broad community	
		customers with env.concerns	shared value	
			incorporating	

## APPENDIX C

### Chapter 8. Example emails to practitioners to describe the aims of the workshop.

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#### *Email 1*

*The aims of this workshop will be to raise awareness on eco-efficiency in manufacturing and draft the company's roadmap towards energy and resource efficiency.*

*The output of this effort could indicate what the company is good at in manufacturing and how current capabilities can reduce energy and resource consumptions without further expenses.*

*The participants would be requested to reflect on past efficiency achievements in manufacturing and also bring forward improvement ideas that they wish to explore.*

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A second email followed a few days before the workshop with details about the process as well as a preparation request.

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#### *Email 2 -Workshop outline (3hrs)*

*A) Introduction to eco-efficiency (example slide attached) and expression of expectations by the workshop participants.*

*There will be two exercises that will be focused on manufacturing capabilities and practices:*

*B) The first exercise will focus on past events or practices that have shaped manufacturing processes and/or products. Therefore, I would like to ask participants individually to bring a few notes along with memorable events or practices (at least 2 or 3) that they felt these had an important impact in your way of making products. We would encourage contributions from a range of roles and perspectives and we shall try to assign an environmental dimension to them during the workshop.*

- *An example of such an event could be: “introducing quality checks in the curing process”*
  - *such a practice may have reduced process variability and may have reduced raw material consumptions*
- *another example could be “redesign factory layout to improve product flow”*
  - *such an event could have improved lead times and energy consumption per shift*

*C) The second exercise will be looking at building a mid-term eco-efficiency plan for the future (5-10yrs).*

*This will be a group exercise and participants will be divided in groups to discuss with each other and suggest improvements on energy and resource efficiency targets.*

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## APPENDIX D

Invitation to the apparel supply chain. Example of instructions for the self-assessment communicated via email to participants to reduce facilitation by the researchers. To be used with a printed copy of PMGE.

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Instructions to participants.

The slides attached are best print in colour, in A3 size paper.

*The first slide is an example of how a complete maturity profile looks like.*

The second slide is an empty template for people to produce their own maturity profiles.

The maturity grid consists of 3 areas (purple, green and blue). Each area represents an organisational layer in manufacturing.

The title for each dimension within those areas is in the left-hand column. The text in the grid describes manufacturing practices related to energy and resource efficiency from left to right (left being business-as-usual and right being leading performance).

The purple area or process area is where you can observe your environmental performance. It could be a paint-shop in the automotive or a picking process in logistics. It also relates to the way an operator may be using the assigned equipment (boiler, forklift, mill).

- The green area relates more to management systems and management practices across a range of processes (or the sum of processes above) – facility level.
- The blue area represents higher-level functions of the business that are more related to manufacturing (i.e. product development or supply chain configuration – top management area).

The practitioners using this matrix can read the text in each row of the grid and decide what type of practices describe their system best in each area. The first slide demonstrates a way to do this with dots or checks, which can be then connected. There is also the option to highlight the things that may occur in your system and may be found in multiple positions in the same row.

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# APPENDIX E

A printable final version of PMGE as it can be delivered to practitioners.

## Eco-efficiency maturity grid of practice

	Business as usual	Leading performance
<b>Energy consumption</b>	Energy monitoring is happening at some level. How do you do this (boots)? (eg. smart metering, tracking utility) for the plant. Learning from leading air-compressors to switch-off of idle machines between production cycles.	Looking for opportunities, savings and re-configuring the energy supply for the unimproved. Link these numbers with cost savings. Possible research approach: Further research for high energy-efficient processes and equipment is on-going. Ask for help about this from experts.
<b>Process Materials</b>	Real-time consumptions or materials mass balances per process. Identify gaps and anomalies in the data. GMP's and good housekeeping practices explored.	Improve process to maximize resource efficiency to a theoretical minimum. Design implications that expand to recyclability (eg. waste to energy design). Ideally materials are recycled (ie. a closed loop system (research scope)).
<b>Water use and consumption</b>	Monitoring of water consumptions per process and costs related. GMP's and good housekeeping practices explored.	Recycle water within the factory following a closed loop paradigm. Engage with surrounding community regarding water efficiency. This can be an opportunity for resource to make product (ie. a cost-effective way).
<b>Process waste &amp; emissions</b>	Partial recycling of process waste. Identify the hot and cold streams. Improve process to maximize resource efficiency to a theoretical minimum. Design implications that expand to recyclability (eg. waste to energy design). Ideally materials are recycled (ie. a closed loop system (research scope)).	Prevention of non-separable process waste within the manufacturing perimeter. Minimized process waste. Conditions to convert to material for other processes or added value to products.
<b>Workers/operators</b>	Training in maintenance and energy/materials savings. Keeping training records for all.	Continuous improvement efforts from authorized cross functional personnel.
<b>Equipment performance &amp; maintenance</b>	Regular maintenance, record faults and leaks, cost analysis of these (savings opportunity). Monitoring equipment performance. Explored: Mapping of assets and their limitations.	Equipment can be leased (like a Rolls-Royce jet engine) and the company that makes best use is rewarded. In conjunction with energy and materials efficiency this leads to a more efficient and robust plant (ie. equipment efficiency and robustness). Industry 4.0 automation and controls?
<b>Energy management systems</b>	ISO, EMAS type of system implementation (not necessary to have certification). Data are available and reviewed for consistency and reliability. Set indicators for energy flows. Energy audits across production units.	Energy efficiency is part of an integrated asset management system. Ongoing research at this level will reveal more on the opportunities available for high eco-efficient production systems. Energy optimization is part of a closed loop system.
<b>Resource management systems</b>	Indicators for material flows are set and visible to all. Deploy charts on the shop floor if information systems are not available. Follow ISO, EMAS guidelines for consistency. Good housekeeping rules in place.	Asset (tangible and intangible) management is addressing materials, equipment and capital. There is ongoing research at this level to reveal more on the opportunities available to incorporate energy and resource efficiency.
<b>Waste management systems</b>	Waste disposal aligned to legal requirements for compliance.	Optimization for waste management within a framework for closed loop economies. Cradle-to-cradle approaches. Ongoing research theme.
<b>People management practices</b>	Personnel trained in identifying opportunities in energy/resources savings through repeatable practices. Organizing social events for people. Aim for interactions. Customized information system to support knowledge sharing.	Links to continuous improvement work and change management capabilities. Expertise adoption to environmental and business challenges. Organizational models are used to deliver improvements (train, networks, model-factory).
<b>Suppliers relationship</b>	Understanding the effect of the suppliers in the environmental performance of the system. Introduce quality, environmental and corporate responsibility criteria for selection.	Sustainable supply chains guide the opportunities within the production system to optimize for eco-efficiency. Ongoing research theme.
<b>Information systems and knowledge management</b>	Facility compliance indicators. Legal compliance documentation. Some productivity data (cost, delivery) are available. Quality performance data.	Sustainability system indicators (subject to research). A good mix of quantitative and qualitative information is available. Management and supported from all functions of the business.
<b>Company norms, values</b>	Limited awareness of employees on environmental performance. Productivity focused norms.	Commitment to sustainability is a high bottom line perspective. Long-term planning and support.
<b>Supply Chain</b>	Unexplored environmental impact to/from the supply chain. Business as usual with suppliers/customers (price, cost, delivery are main concerns).	Closed loop supply chain and production near the customer (ie. 3D printing). On-going research and links to circular economy.
<b>Product &amp; Process development</b>	Reduce resource utilization for new products and suggest savings for existing products. Process improvement is not focusing on recycling ratio.	Re-manufacturability of returned products as usable product.