KES Transactions on Sustainable Design and Manufacturing I
Sustainable Design and Manufacturing 2014 : pp.362-373 : Paper sdm14-023

Understanding eco-efficiency through environmental performance benchmarking – a qualitative approach

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Abstract

A lack of consensus on the definition of eco-efficiency and consecutively the way to calculate eco-efficiency in production activities has provided space for various quantifying efforts in the literature. Based on cases of environmental performance benchmarking the authors describe an approach to capture eco-efficiency as a systemic quality with transferable properties across manufacturers. A review of the benchmarking literature is performed on environmental performance measurement and management practices with special focus on case study comparisons between industrial processes and production activities. The authors identify cases studies that demonstrate environmental performance variations in production's environmental output and, following a resource-based view of the production system, design a framework that qualitatively addresses eco-efficiency in terms of capabilities and practices currently implemented in manufacturing. Initial research data from the framework use, suggest that there is a need for companies to understand their strengths and weaknesses and develop their practices for eco-efficiency further. Examples of self-assessment on the suggested framework are provided from two companies. Manufacturers are interested in identifying gaps in efficiency and developing new capabilities. The proposed framework is designed to facilitate horizontal dissemination of practices that are found to improve eco-efficiency.

Keywords: Eco-efficiency, capabilities, maturity, assessment, sustainable manufacturing

1. Introduction

A collection of open interviews with practitioners in various companies [1] indicates an emerging issue of variation in environmental performance between production sites. The metrics of variation are usually in the form of normalised data or key performance indicators (KPIs) that a company is interested in monitoring or benchmarking such as energy consumption per production unit or time unit [2]. This comparison is consistent with the benchmarking that [3] refers to as an applied way of using eco-efficiency calculations.

However, comparability of cases between different companies can be an issue, as companies tend to modify indicators to suit their individual needs [4]. Cases where the authors constructed KPI's for research purposes can also be identified [5], whereas in parallel, numerical methodologies such as Data Envelopment Analysis have been used to evaluate a system's environmental performance [6]. This study discusses on the cases on environmental benchmarking and the potential for research and improvements that it unveils. Moreover, by taking a qualitative approach, the authors try to understand the pathway for improved eco-efficiency in production and suggest a theoretical framework testing in case study research.

2. Background and related work

The cases on environmental performance variation presented here have been divided into three clusters with respect to the scope of the research undertaken or the potential impact. The first cluster comments more on the technical improvements and product design impacts on environmental output as well as the relative benchmarking traced in the literature. The second cluster is driven by variations that are more relevant to the intangible agents of environmental performance. Finally, the third cluster discusses on the possibilities to improve the system's environmental output by considering re-configurations. These three clusters will guide the development of a research tool (next section) for case study and action research.

2.1 Cleaner production projects

Kliopova and Staniskis, make a cross-sectorial analysis of the Lithuanian industries on the savings potential from implemented Cleaner Production (CP) projects [7]. This is a benchmarking opportunity on eco-efficiency from a savings view that acknowledges the effect (however small) of good housekeeping rules on the savings potential (no-investment or technological improvement required).

A case study in a beer brewery demonstrates the production manager's alarm for underperformance after reviewing international benchmarking figures on energy and water demand (twice as high) for beer breweries worldwide. Additionally, the authors highlight the momentum and motivation that the indicators' benchmarking generated which led improvement actions to take place with a long-lasting effect [8].

2.2 Extended improvement mechanisms and capabilities

The dissemination of improvements potential and achievements is highly desirable for every company and consortiums such as the Carbon Disclosure Project can facilitate such actions. Within this scope, Dell reported a 436% improvement in two years via the Carbon Disclosure Project by sourcing 26% of electricity from renewable sources worldwide [9]. Geffen and Rothenberg provide insight through interviews on the beneficial collaboration in environmental performance with the company suppliers. Variation in normalised data of emissions is up to 300% for a particular process within 3 car manufacturers that has been attributed to the different suppliers [10].

Furthermore, evidence of variations in waste produced has been significantly correlated to the process knowledge and amount of time spent on improvement by managers and team leaders [11]. This is a signal for improvements at process level that are not obvious to managers with limited knowledge of the production processes.

In parallel, Xerox draws attention by benchmarking the environmental performance in the factory between similar products with different design principles (modular vs non-modular). Modularity and re-manufacturing design improve consumptions by almost a factor of 2 to 3 [12].

2.3 Wider re-configurations and long-term planning

Interviews with CEOs on the use of indicators for decision-making, performed on behalf of IISD, as a management option, reveal the lack of consistency in this practice [4]. This has particular implications when trying to benchmark environmental performance in a sector. On the other end, Holton et al., discusses on four case studies of industrial sustainability management in the concrete industry where management systems and continuous improvement culture (rather than measurement and indicators) are found to be very important in moving towards sustainable industrial systems [13]. This is lifting some burden from the indicators based management since these companies have found that cultural driven performance improvements have much wider (e.g. building stakeholder's confidence) and long-lasting effects.

Systems reconfiguration as mean of delivering environmental improvements is the case for OneSteel as well [14]. The company makes a stepwise improvement in energy consumption through system reconfiguration, introducing a new energy service department in the production plant that regulates energy demands. In this case, the new energy department regulates the energy flows between other processes or business units in the facility.

2.4 Eco-efficiency drivers

More than working on improvements on environmental performance with measurable results (i.e. reduced CO2 emissions) the authors explore the case of improvements on eco-efficiency (taking into account financial improvements achievable). Kuosmanen and Kortenlainen perform eco-efficiency benchmarking and define eco-efficiency as "economic value added per environmental damage incurred". This definition emphasizes the trade-off between economic and environmental aspects of production activities, giving equal emphasis to both [6]. Both financial and environmental impacts have to be quantified in one term respectively [15] and furthermore, Figge and Hann discuss on the implications that this concept brings on prioritization of actions to improve performance [16].

The analysis so far, demonstrates that there is considerable interest amongst practitioners in case studies to benchmark their environmental output and justify their improvement actions in financial terms. In this section, the authors discuss main drivers for eco-efficiency and the types of assessment that other authors have applied in order to appraise production systems. Building up on that information, the authors present in the following section a qualitative approach for eco-efficiency assessment.

2.4.1. Inter-organizational collaborations

Inter-organizational collaborations boost environmental performance [17]. This is a systems' evaluation that suggests benefits from an open collaboration platform to improve on sustainability. This point has also been addressed with measurable effects in the automotive industry [10].

2.4.2 Pro-activity

Findings indicate that environmental proactivity is positively related to operational performance, organizational learning, environmental performance, stakeholder satisfaction and financial performance. Moreover, the mediating role of stakeholder satisfaction is also supported by the data even though the mediating role of environmental performance and the moderating role of types of technologies are not supported with findings [18]. Additionally, early timing in adopting environmental practices is contributing to eco-efficiency by lowering costs of compliance and minimizes disruption of the production process. The firm also gains competitive advantage in production costs through the learning curve effect. The hypothesis however of early timing in environmental actions has been found to have a significant effect on cost savings only at high-level complementary assets [19].

2.4.3 Lean practices and tactics

Lean manufacturing has been referenced as an accelerator of environmental performance in manufacturing [20]. The model of lean manufacturing that Toyota introduced to the industry has gained the respect of the manufacturing community and is regarded one of the most valuable approaches in resources and systems optimization. In terms of eco-efficiency it would be difficult to separate the contribution of lean management on environmental performance, even though studies on lean manufacturing and environmental performance exist and show a positive correlation [21].

Other specialised techniques like Kaizen events [22] or 6R [23], have been implemented in many cases to enhance productivity and firm performance. Material or energy efficiency as an outcome of quality and production improvements is a win-win for environmental targets therefore these practices cannot be ignored. The authors assume that more environmental benefits could be reaped when environmental targets become inseparable from the production targets [24].

2.5 Assessment options for eco-efficiency

This section identifies benchmarking cases of eco-efficiency assessment in a two-fold approach: quantitatively and qualitatively. Examples of appraisal on environmental output and eco-efficiency in production systems that are based on measurements are presented and are followed by cases of qualitative assessments. The authors consider that these two pathways for eco-efficiency assessment should converge in findings when applied in the same system.

a) Quantitative approach and indicators based assessment

Following the reasoning described above, Van Passel et al., make a distinction, based on their panel data calculations on opportunity costs and sustainable value, between front-runners and laggards in the dairy sector and relate the differences with financial and non-financial factors [25]. Within this sector, the estimated savings on energy, water and acid have been calculated as 30/%, 20% and 90% respectively with implementations that are generally neither advanced nor particularly high-tech when seen from an engineering perspective [26].

Nagel benchmarks the energy and material flow indices of 25 printed board production facilities and proposes that insight in the energy and mass balances can result to improved environmental impact as well as a straightforward business case [27]. Most of the companies are unaware of their resource flows and speculatively underperform on environmental aspects. Variations in energy, mass and emissions are presented but not in a straightforward way. More light in that area is provided by Saidur et al., that try to identify savings potential by mapping the energy flows in paper industry and relative examples of calculations are also provided [28].

b) Qualitative approaches

Labuschagne et al., discussed on the possible assessment methods and concluded that a qualitative route for assessment could be an option when incorporating sustainability performance aspects into decision-making and propose a 5 level cascading framework with arising issues on sustainability and operations in production [29].

Sardinha et al., present results from a benchmarking study on the environmental or sustainability reports of 23 companies of the real estate sector in the UK. The comparison is divided in 4 main themes: External results (indicator for the formal recognition of the company's peers), internal results (indicator of disclosure on the company activities), Management processes (indicator of management processes to improve CSR), Learning and innovation (indicator for learning and innovation processes). The variation the authors describe is drawn on a 1-8 scale with information drawn from the sustainability reports [30].

Similarly, Baumgartner and Ebner introduce a framework for benchmarking CSR strategies with a clear orientation to environmental performance activities. The theoretical framework is generic but the idea of qualitative comparisons is evident in this study as well [31].

The authors have chosen to follow a qualitative methodology to approach eco-efficiency. This approach is represented in this study by a theoretical framework that is meant to simulate basic flows within a production or operations facility (i.e. energy, materials, waste). Qualitative research into eco-efficiency is relatively limited in the literature as different authors within this field view the production facility in various angles and methods (i.e. surveys, interviews, etc) while quantitative models are more specific in methods available.

3. Framework development: Capability Assessment Grid for Eco-efficiency (C.A.G.E)

The authors have developed a theoretical model to capture the behavior of practices that control basic flows (dimensions) within the production facilities. In the following sections the authors dissect this framework and provide evidence to support its structure.

3.1 Scales and dimensions of application

This study presents the development of a maturity grid, that intents to interpret the variations observed in terms of actions that occurred and capabilities that various companies have developed in order to improve on environmental performance and eco-efficiency. In figure 1 the authors present the CAGE framework. Three different colors represent the 3 scales of operations and management and the color contours represent the maturity level (light color = level 1, dark color = level 5). The grid is initially populated with examples drawn from literature (examples are provided in table 1) in order to demonstrate the type of information that is expected to populate this grid from research.

The first scale focuses in the resources (dimensions of performance: of energy, materials, water, waste, equipment and human factor input) in a single process within a production facility. An example can be the paint-shop in automotive production [10] or a batch reactor [32].

The second scale is the production floor, alternatively the sum of all production processes [33, 34] and the dimensions from the previous level (flows or process areas for improvement) are represented by the management systems for energy, materials etc. Figure 2, represents the resource management dimension in this scale as an example of the available options in practices that are found in literature. The logic behind the allocation of practices in maturity levels is described in the following section 3.2.

Similarly, the third scale represents the view of the production facility as a business unit from a top management perspective. Environmental accounting [24, 35] and decisions on product design affecting rework or remanufacturing [12] are issues usually guided by top-management decisions.

For each scale of management, five maturity levels have been introduced. The capability levels qualitatively measure how well a company performs on eco-efficiency. The capability levels were adapted from CMMI literature [36] (figure 3, left).

Figure 1. Overview of the Capability assessment grid for eco-efficiency (CAGE). The reader can distinguish the 3 scales of management and the color gradients representing the 5 maturity levels' progression.

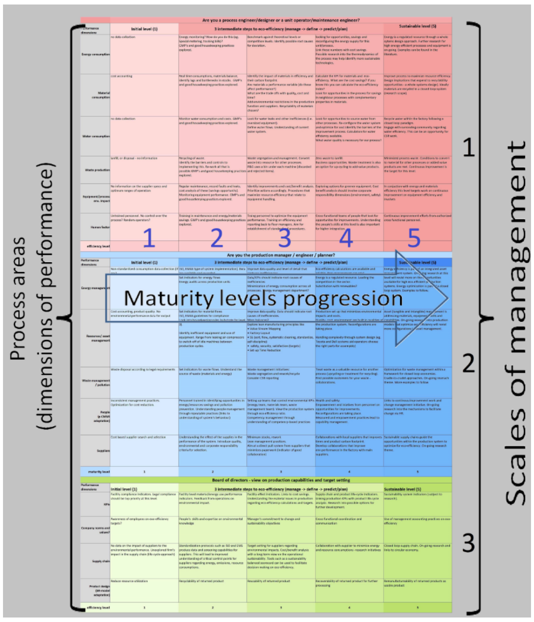


Figure 2. Magnification on the grid's resource dimension on 2nd scale of management (levels 1 to 5, from left to right) for readability

Resources	Cost accounting, product quality. No environmnetal performance data for output	Set indicators for material flows ISO, EMAS guidelines for compliance Look into housekeeping rules (substrate for level 3). Identify inefficient equipment and use of equipment. Range from leaking air-compressors to switch-off of idle machines between production cycles.	Improve data quality. Data should indicate root causes of inefficiencies. Mass balances? Explore lean manufacturing principles like • Value Stream Mapping • Factory Layout • 5S (sort, flow, systematic cleaning, standardize, self-discipline) • safety, security, satisfaction (targets) • Set-up Time Reduction	Production set up that minimizes environmental impacts and costs. Quality, cost, environment are built in qualities of the production system. Reconfigurations are taking place. Handling complexity through system design (eg. Toyota and Dell systems aid operators choose the right parts for assempbly)	Asset (tangible and intangible) management is addressing materials, equipment, skills and capabilities. On-going research into production models that optimize eco-efficiency will reviel more configurations in asset management.

Having set the framework approach and basic structure, the authors have a more targeted audience for applying this maturity grid in case study research with manufacturers. The process scale can be populated with information of practices from maintenance engineers, operators and shift supervisors. The production floor scale can be populated from interviews with production managers and planners, whereas the third scale on top-management can be addressed to CEOs or board members. This segregation of management levels helps identify basic dimensions or interview questions. This design property (dimensions) addresses key environmental attributes for eco-efficiency at process level (i.e. energy consumption, material consumption, process waste, etc.) and based on literature tries to escalate these dimensions on the production floor and manufacturing strategy level. The authors provide samples of literature that informs the CAGE dimensions in table 1.

Table 1. Content contributions for the maturity grid

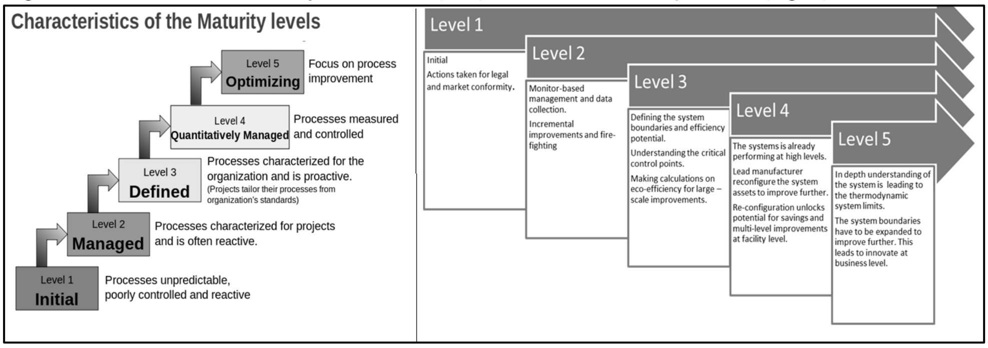
Relative dimension and contribution in CAGE
Process level, material efficiency: Proposed set of 3D metrics. Selecting the more-sustainable process by comparing process alternatives [37]
Process level, energy efficiency: Identifying more sustainable technologies [38]
Process level, water efficiency: Methodology to compare alternative options [39]
Process level, equipment efficiency: Implementing good practices according to competence [26]
Process level to production level scaling. Use for calculations: Calculating process eco-efficiency and scaling to production floor [32]
Production level, type of approach: Qualitative benchmarking of capabilities [38]
Production/top-management level, type of approach: Link the production level to top-management initiatives [39]
Production level, type of approach: Qualitative benchmarking of capabilities [40]
Top-management level: Ideas for implementation at corporate level, motivation for change [41]
Production/top-management KPI level: Learning on the indicators used [42]
Production level: Examples for best practices (qualitative approach) [43]
Top-management level for designers: Implications for strategy on product design and production eco-efficiency [40]

3.2 Adaptation of maturity levels for eco-efficiency research

The concept of growing maturity, as described by Maier et al., [41], underpins the potential for growing capabilities and improvements on eco-efficiency. From levels 1 to 3, the authors assumes that, manufactures are trying to improve their system within a first loop learning approach [42]. Improvements require monitoring of various processes and can involve a level of technological intervention that could range from 10 to 70% (more is possible depending on the particular dimension i.e. energy, water, materials etc.).

In order to move to maturity levels 4 and 5 the manufacturers would have to work within a second loop thinking and questioning of their current strategy and practices, and seek for opportunities through collaborations and wider system thinking. The interaction of the processes has to be explored further and more attention is given to cross-functionality of operations [43] and horizontal involvement of personnel in improvement initiatives.

Figure 3. Levels of maturity in CMMI (left) and CAGE adaptation (right)



4. Research application to-date and discussion

4.1 Research approach

The design principles, presented in the previous section, are related to the research methodology and the type of data that will be collected (not numerical). The authors are taking a resource-based view of the production [44] and focus in the tangible and intangible resources and firm's capabilities in order to explain variability in environmental performance. This view adds value to the originality of the study, as the literature on eco-efficiency is mainly concentrated in assessment through measurable key performance indicators and performance calculations [43, 44].

4.2 Application in research

a) Self-assessment methodology and case study research

Interested industrial practitioners are approached initially with a pre-assessment form (scaled 1-5) and a short description of the project and they are asked to provide a rapid assessment of their maturity level in environmental management. An example of this pre-assessment is presented in figure 3. The researcher can use this information to understand the environmental performance profile of the manufacturer and relate this information to company details (size, revenue, etc). This approach facilitates a faster engagement of the researcher with the interviewee and can generate more discussion on the areas that the interviewee thinks require attention.

The interviewees are then presented with the grid in large-scale print out to create focus on the types of practices of interest and they are asked to discuss about their operational practices to improve on environmental performance. The data collected populate the grid; they are assessed by the authors and are allocated in maturity levels. The allocation is performed according to the sophistication and understanding of the system demonstrated by the interviewees in respect to the behavior discussed earlier on double loop learning (figure 2).

The CAGE has been designed to facilitate empirical investigation of current practices and capabilities that industry can adopt in order to improve on eco-efficiency. In figure 6 the authors demonstrate evidence of its early use from two initial case study interviews with the production manager from a leading optics manufacturer in the UK and the quality manager from a leading food production company in Greece. The practitioners filled the forms (1-5 scale) and will be involved in case study research in this project. The data from these case studies have been anonymised as requested from the participants, as they contain sensitive information for the manufacturing operations.

The interview data are assessed by the authors and allocated on the maturity grid and further related to practices demonstrated in literature in terms of the underlying capabilities that promote and support eco-efficiency practices. This allocation is subject to continuous improvement as more cases are collected and studied. In the following example of applying the framework the allocation of practices along the maturity levels is provided by the practitioners.

b) Industrial workshop with practitioners

C.A.G.E. has been also designed and is soon being tested in a workshop environment. The self-assessment form is presented to the workshop delegates and is meant to create focus on the practices currently running in the factory. At the day of the workshop, the researchers are performing two exercises. The first one is

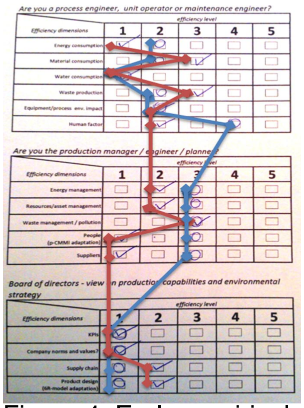


Figure 4. Early empirical evidence of the CAGE applicability between two manufacturers (blue for optics, red for food manufacturer)

a collection of practices exercise in two columns for current or scheduled and future or stretch practices that they implement in their factories along the dimensions of C.A.G.E. The delegates are writing down this information in repositionable notes. The second exercise is about allocating these notes into a gradient of five levels of performance (business as usual to leading performance). This is an interactive process where the delegates are free to discuss with each other on the best sequence that the practices follow along the framework dimensions. At the same time they are requested to keep notes of the organizational capabilities that they think are important in each level to help the system move forward in terms of performance. At the end of the session the delegates are presenting their notes of recorded capabilities to each other and the researcher is responsible for collecting all this data as well as the key messages of the discussion in the end about organizational capabilities. The goal is, having repeated the workshop a few times, to populate the maturity grid with a gradient of practices and a list of capabilities that promote eco-efficiency.

5. Conclusions and future work

The authors have demonstrated a conceptual self-assessment framework for qualitative benchmarking of production facilities on eco-efficiency. The framework is designed to managers understand how high their system performs in terms of environmental output and from that point on, identify improvement steps for eco-efficiency with respect to a set of capabilities that promote eco-efficiency. The framework is designed and populated with data drawn from the literature on capabilities and practices that have been found to improve the eco-efficiency ratio.

In the authors view, eco-efficiency can become a systemic property rather than a production target. It can be an internal function or a specific set of capabilities that continually improve the system's environmental performance. On that note, the authors argue that these systemic capabilities can be grouped in levels of maturity and account for the system's behaviour and capabilities in driving improvements. The potential for improvement in terms of eco-efficiency by definition grows as the production capabilities mature. A five level maturity grid to represent the basic dimensions of eco-efficiency in factories is presented. One of the key concepts in this representation is that, as production capabilities grow in terms of controlling environmental output, system improvements are not being driven by externalities (such as legal obligations and market pressures). There is a turning point in this framework, where system re-configuration is internally driven and eco-efficiency is peaking while the foundations for continuous improvement are starting setting in place (maturity level 3 to 4 and onwards).

Moreover, the framework is designed as a maturity grid to be applied for research across three scales of management (process, production floor and manufacturing strategy) and can easily be converted into a qualitative benchmarking platform for operational purposes in factories. The logic for this conversion is:

- To facilitate application for research into the maturity profiles across various cases studies
- Help managers apply and study the gaps and opportunities in their system either between their own production sites or within a sector.
- Examine the alignment of maturity along three scales of management.

The potential uses of this framework extend from empirical data collection on eco-efficiency capabilities and practices to a benchmarking platform for production facilities. The research goals that the authors will be covering along this agenda have been identified as:

i) Empirically and qualitatively assess the eco-efficiency profiles of various types of industries and populate the CAGE with data on practices and capabilities (case studies and workshops)
ii) Refine the framework as a tool for action research and help production managers make informed decisions on eco-efficiency and improvements in the factory and prioritise actions.

6. References

1. N. Bocken, D. Morgan, and S. Evans, “Understanding environmental performance variation in manufacturing companies,” *International Journal of Productivity and Performance Management*, vol. 62, no. 8, pp. 856–870, Oct. 2013.
2. A. Azapagic and S. Perdan, “Indicators of Sustainable Development for Industry: A General Framework,” *Process Safety and Environmental Protection*, vol. 78, no. 4, pp. 243–261, Jul. 2000.
3. J. R. Ehrenfeld, “Eco-efficiency: Philosophy, Theory, and Tools,” *Journal of Industrial Ecology*, vol. 9, no. 4, pp. 6–8, 2005.
4. C. Searcy, “The role of sustainable development indicators in corporate decision-making,” International Institute for Sustainable Development, 2009.
5. R. K. Singh, H. R. Murty, S. K. Gupta, and A. K. Dikshit, “Development of composite sustainability performance index for steel industry,” *Ecological Indicators*, vol. 7, no. 3, pp. 565–588, Jul. 2007.
6 T. Kuosmanen and M. Kortelainen, “Measuring Eco-efficiency of Production with Data Envelopment Analysis,” *Journal of Industrial Ecology*, vol. 9, no. 4, pp. 59–72, 2005.
7. I. Kliopova and J. K. Staniskis, “The evaluation of Cleaner Production performance in Lithuanian industries,” *Journal of Cleaner Production*, vol. 14, no. 18, pp. 1561–1575, 2006.
8. S. Schaltegger, T. Viere, and D. Zvezdov, “Tapping environmental accounting potentials of beer brewing: Information needs for successful cleaner production,” *Journal of Cleaner Production*, vol. 29–30, pp. 1–10, 2012.
9. “Case Study: Dell.” [Online]. Available: https://www.cdproject.net/en-US/WhatWeDo/Pages/Case-Study-Dell.aspx. [Accessed: 04-Feb-2013].
10. C. A. Geffen and S. Rothenberg, “Suppliers and environmental innovation The automotive paint process,” *International Journal of Operations & Production Management*, vol. 20, no. 2, pp. 166–186, 2000.

11. D. Lu and A. Betts, “Why process improvement training fails,” *Journal of Workplace Learning*, vol. 23, no. 2, pp. 117–132, 2011.
12. W. Kerr and C. Ryan, “Eco-efficiency gains from remanufacturing: A case study of photocopier remanufacturing at Fuji Xerox Australia,” *Journal of Cleaner Production*, vol. 9, no. 1, pp. 75–81, Feb. 2001.
13. I. Holton, J. Glass, and A. D. F. Price, “Managing for sustainability: findings from four company case studies in the UK precast concrete industry,” *Journal of Cleaner Production*, vol. 18, no. 2, pp. 152–160, Jan. 2010.
14. Energy Efficiency Opportunities Department of Resources, Energy and Tourism, “Iron and Steel,” Jun-2010. [Online]. Available: http://ietd.iipnetwork.org/content/iron-and-steel#enms. [Accessed: 06-Feb-2013].
15. G. Huppes and M. Ishikawa, “A Framework for Quantified Eco-efficiency Analysis,” *Journal of Industrial Ecology*, vol. 9, no. 4, pp. 25–41, 2005.
16. F. Figge and T. Hahn, “The Cost of Sustainability Capital and the Creation of Sustainable Value by Companies,” *Journal of Industrial Ecology*, vol. 9, no. 4, pp. 47–58, 2005.
17. V. Albino, R. M. Dangelico, and P. Pontrandolfo, “Do inter-organizational collaborations enhance a firm’s environmental performance? a study of the largest U.S. companies,” *Journal of Cleaner Production*, vol. 37, pp. 304–315, Dec. 2012.
18. M. Sambasivan, S. M. Bah, and H. Jo-Ann, “Making the case for operating ‘Green’: impact of environmental proactivity on multiple performance outcomes of Malaysian firms,” *Journal of Cleaner Production*, vol. 42, pp. 69–82, Mar. 2013.
19. P. Christmann, “Effects of ‘best practices’ of environmental management on cost advantage: The role of complementary assets,” *Academy of Management Journal*, vol. 43, no. 4, pp. 663–680, Aug. 2000.
20. M. G. (Mark) Yang, P. Hong, and S. B. Modi, “Impact of lean manufacturing and environmental management on business performance: An empirical study of manufacturing firms,” *International Journal of Production Economics*, vol. 129, no. 2, pp. 251–261, Feb. 2011.
21. S. Hajmohammad, S. Vachon, R. D. Klassen, and I. Gavronski, “Lean management and supply management: their role in green practices and performance,” *Journal of Cleaner Production*, vol. 39, pp. 312–320, Jan. 2013.
22. W. J. Glover, J. A. Farris, E. M. Van Aken, and T. L. Doolen, “Critical success factors for the sustainability of Kaizen event human resource outcomes: An empirical study,” *International Journal of Production Economics*, vol. 132, no. 2, pp. 197–213, Aug. 2011.
23. S. S. Kuik, S. V. Nagalingam, and Y. Amer, “Sustainable supply chain for collaborative manufacturing,” *Journal of Manufacturing Technology Management*, vol. 22, no. 8, pp. 984–1001, 2011.
24. A. Mayyas, A. Qattawi, M. Omar, and D. Shan, “Design for sustainability in automotive industry: A comprehensive review,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 4, pp. 1845–1862, May 2012.
25. S. Van Passel, F. Nevens, E. Mathijs, and G. Van Huylenbroeck, “Measuring farm sustainability and explaining differences in sustainable efficiency,” *Ecological Economics*, vol. 62, no. 1, pp. 149–161, Apr. 2007.
26. N. Honkasalo, H. Rodhe, and C. Dalhammar, “Environmental permitting as a driver for eco-efficiency in the dairy industry: A closer look at the IPPC directive,” *Journal of Cleaner Production*, vol. 13, no. 10–11, pp. 1049–1060, Aug. 2005.
27. M. H. Nagel, “Managing the environmental performance of production facilities in the electronics industry: more than application of the concept of cleaner production,” *Journal of Cleaner Production*, vol. 11, no. 1, pp. 11–26, Feb. 2003.
28. R. Saidur, N. A. Rahim, H. H. Masjuki, S. Mekhilef, H. W. Ping, and M. F. Jamaluddin, “End-use energy analysis in the Malaysian industrial sector,” *Energy*, vol. 34, no. 2, pp. 153–158, Feb. 2009.

29. C. Labuschagne, A. C. Brent, and R. P. G. van Erck, "Assessing the sustainability performances of industries," *Journal of Cleaner Production*, vol. 13, no. 4, pp. 373–385, Mar. 2005.
30. I. D. Sardinha, L. Reijnders, and P. Antunes, "Using corporate social responsibility benchmarking framework to identify and assess corporate social responsibility trends of real estate companies owning and developing shopping centres," *Journal of Cleaner Production*, vol. 19, no. 13, pp. 1486–1493, 2011.
31. R. J. Baumgartner and D. Ebner, "Corporate sustainability strategies: sustainability profiles and maturity levels," *Sustainable Development*, vol. 18, no. 2, pp. 76–89, 2010.
32. A. Levente L., U. Fischera, and K. Hungerbühlera, "Systematic Retrofit Method for Chemical Batch Processes Using Indicators, Heuristics, and Process Models," *Industrial & Engineering Chemistry Research - IND ENG CHEM RES*, vol. 47, no. 1, 2007.
33. J. R. Duflou, J. W. Sutherland, D. Dornfeld, C. Herrmann, J. Jeswiet, S. Kara, M. Hauschild, and K. Kellens, "Towards energy and resource efficient manufacturing: A processes and systems approach," *CIRP Annals - Manufacturing Technology*, vol. 61, no. 2, pp. 587–609, 2012.
34. W. C. Lucato, M. V. Júnior, and J. C. da S. Santos, "Measuring the ecoefficiency of a manufacturing process: a conceptual proposal," *Management of Environmental Quality*, vol. 24, no. 6, pp. 755–770, 2013.
35. C. A. Adams and P. McNicholas, "Making a difference: Sustainability reporting, accountability and organisational change," *Accounting, Auditing & Accountability Journal*, vol. 20, no. 3, pp. 382–402, 2007.
36. M. B. Chrissis, M. Konrad, S. Shrum, and M. B. Chrissis, *CMMI for development guidelines for process integration and product improvement*, 2nd ed. Upper Saddle River, NJ: Addison-Wesley, 2007.
37. A. A. Martins, T. M. Mata, C. A. V. Costa, and S. K. Sikdar, "Framework for Sustainability Metrics," *Ind. Eng. Chem. Res.*, vol. 46, no. 10, pp. 2962–2973, May 2007.
38. M. Herva, A. Franco, E. F. Carrasco, and E. Roca, "Review of corporate environmental indicators," *Journal of Cleaner Production*, vol. 19, no. 15, pp. 1687–1699, Oct. 2011.
39. A. Ingaramo, H. Heluane, M. Colombo, and M. Cesca, "Water and wastewater eco-efficiency indicators for the sugar cane industry," *Journal of Cleaner Production*, vol. 17, no. 4, pp. 487–495, Mar. 2009.
40. H. Sugiyama, U. Fischer, K. Hungerbühler, and M. Hirao, "Decision framework for chemical process design including different stages of environmental, health, and safety assessment," *AIChE Journal*, vol. 54, no. 4, pp. 1037–1053, 2008.
41. A. M. Maier, J. Moultrie, and P. J. Clarkson, "Assessing Organizational Capabilities: Reviewing and Guiding the Development of Maturity Grids," *IEEE Transactions on Engineering Management*, vol. 59, no. 1, pp. 138–159, 2012.
42. C. Argyris, "Double loop learning in organizations," *Harvard Business Review*, vol. 55, no. 5, pp. 115–125, Sep. 1977.
43. M. Despeisse, M. R. Oates, and P. D. Ball, "Sustainable manufacturing tactics and cross-functional factory modelling," *Journal of Cleaner Production*, vol. 42, pp. 31–41, Mar. 2013.
44. E. Claver, M. D. López, J. F. Molina, and J. J. Tarí, "Environmental management and firm performance: A case study," *Journal of Environmental Management*, vol. 84, no. 4, pp. 606–619, Sep. 2007.