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An investigation between the links of sustainable manufacturing practices and innovation

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Abstract

Without a clear sustainability agenda in place, manufacturing companies would typically aim for products with incremental improved performance for their customers or introducing novel and innovative products and services that appeal to their target audience. However, mounting pressures to improve environmental performance indicators (carbon emissions, waste) require companies to think about step change improvements in how they operate and manage energy and resources. Companies trying to make their products with less energy and materials (doing more with less) are likely to face, or must address, operational and systemic changes in order to achieve better outcomes for the environment or ESG targets. Part of the issue at hand is the complexity and effort required to design effective changes with positive environmental outcomes and minimal disruption for on-going operations and manufacturing performance. In this article the authors aim to extend and explore the utility of a novel maturity model for eco-efficiency into innovation processes and practices and better understand the implications for theory and practice.

Keywords: eco-efficiency; eco-effectiveness; sustainable manufacturing; practice maturity; improvement

Introduction

Manufacturing companies face increased urgency for change and compliance in recent years, since the 2015 Paris Agreement [1], the launch of the United Nations Sustainable Development Goals (SDGs) [2] as well as additional Environmental, Social and Governance (ESG) disclosure requirements by stakeholders and shareholders [3].

Nomenclature

SDGs	Sustainable Development Goals
PMGE	Practice Maturity Grid for Eco-efficiency
ESG	Environmental Social and Governance

Products and manufacturing processes need to become considerably more environmentally friendly, and many companies face difficulties in addressing required changes while remaining profitable within their markets. The extension of this requirement is also to account for the results these changes generate across the manufacturing system when one takes a cradle-to-cradle approach. For instance there is little information about production-wide level impacts when a new ingredient is introduced to the product composition in order to reduce water use during its life-cycle [4] and in some cases companies can observe positive as well as certain negative results in pursuing eco-efficiency and assessing the full product life-cycle [5]. It is unclear whether unwanted effects are generally accepted or go unnoticed when these occur.

Part of the literature review in this paper focuses on understanding the dual context around changes in either

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making the manufacturing processes more eco-efficient (producing more output with less input - doing more with less) or changes that make a product more environmentally friendly throughout its life-cycle and possibly enable reuse and recycling at the end-of-life (more environmentally effective changes). If the impacts of changes could be better defined and interdependencies could be acknowledged, the authors are then concerned with the efficient implementation of these changes and to what extent these rely on core capabilities or whether innovations and new capabilities need to be developed.

This study utilises a novel maturity model for eco-efficiency in the context of better understanding how companies develop and try to implement their sustainability plans. This study seeks to explore how practitioners can uncover the interdependencies between different types of changes in manufacturing systems starting from a rapid maturity assessment of practices.

2. Literature review

This literature review consists of articles found on Scopus in two rounds. The first round of articles was found using keywords: "eco-efficiency", "eco-effectiveness", "innovation", "manufacturing", "maturity" and "practice" in various combinations and published between 2015-2022. Abstracts and full articles with highest relevance and number of citations were reviewed. The second round of the review consisted of a snowballing technique from the articles from the first round with no time restriction. The purpose of the second round was to identify articles with empirical examples of environmental performance improvements that referred to the interdependencies between product and process changes.

2.1 The tension between innovation and efficiency in the context of sustainable manufacturing

There is a well-documented tension in manufacturing between creating process efficiency gains and product innovation gains [6,7]. In the context of environmental performance, efficiency gains can be represented by eco-efficiency strategies [8] while product/service gains can be represented by eco-innovation strategies [9].

In the context of sustainability, innovation is directly linked with the creation of circular business models and more environmentally sustainable products [9,11] and could be approximated by eco-effectiveness. However, Kuzma et al., observe that there is a lack of studies that assess the combined effects of the implications of innovation on sustainability performance, nor the size of the effect in the organizational contexts in which it occurs [12]. As an exemption, Ball and Lunt try to describe how incremental changes applied systematically through mature maintenance practices, led to a deeper understanding of the interdependencies between mature lean practices and eco-efficiency [13]. Therefore, there is possibly considerable opportunity for sustainability researchers in studying the interdependencies between practice maturity and sustainability improvements (size, life-cycle stages, product design, or process development).

Moreover, the concept of eco-effectiveness embodies the disciplines of eco-efficiency, product design and cradle-to-cradle life-cycle analysis [14]. Eco-effectiveness is seen as a more inclusive concept and challenges the shortcomings of eco-efficiency in "their inability to address the necessity for fundamental redesign of material flows, their inherent antagonism towards long-term economic growth and innovation, and their insufficiency in addressing toxicity issues" [14]. Eco-effectiveness is considered as a more advanced performance level for companies to reach, though it can be supported by eco-efficiency practices [15]. In conclusion, it appears that a more operational approach for eco-effectiveness in manufacturing has yet to fully emerge and life-cycle analysis is the dominant practice in addressing eco-effectiveness.

2.2 The theory and practice gap in for manufacturing

Research outputs on the topic of sustainable manufacturing operations remains limited in producing scalable ideas and approaches for companies [11]. A number of theoretical frameworks in the field of sustainable manufacturing and business was recently reviewed in the context of life-cycle engineering [16] and reviewed the benefits and opportunities of bottom-up as well as top-down approaches to addressing sustainability in companies. Hauschild, Kara, and Røpke conclude that "when the two perspectives meet, the efficiency improvements turn into a quest for effectiveness and life cycle engineering solutions can be judged on whether they have the potential to deliver the level of improvements that is needed to achieve future consumption and production patterns that are not just more sustainable but sustainable in absolute terms" [16].

Moreover, beyond theoretical and conceptual frameworks, clearly developed guidelines with empirical examples that can support industrial practitioners to improve, innovate and produce appropriate action plans are more difficult to encounter in the literature. In fact, research at the practice level can be inconclusive in regards to the contribution that changes and improvement plans could make towards higher environmental rewards [17,18]. There is however ongoing research on how to convert theoretical frameworks into operational reality and practice [19–21]. As a starting point to address changes, many authors suggest that an assessment of current practice against best-practice (or similar industry/sectoral benchmarks) can be performed to generate some inspiration and ideas for change and better estimate the level of required effort [22–24].

2.2 Using maturity models to assess capabilities and improvement changes

Maturity models have been used to analyze and define multi-dimensional options for improvement in manufacturing companies [28]. The use of stages to describe organizational development of capabilities and structures has been studied and used in research in the form of maturity grids [29–31]. A maturity grid can be used to help a business identify step changes in practices (with each step defining a type of

behavior e.g., "optimizing") and these practices can be linked to organizational performance. Some prescriptive analysis within the grid cells offers indications about the activities required to achieve expected performance at the practice level [30]. In addition to the analysis of key performance dimensions, some maturity grids have introduced higher-level groupings (sub-grids) that reflect a set of assumptions about organizational behavior or structure [21,32,33]. In other words, maturity grids can decompose and translate performance dimensions into behavioral profiles, and these can be used to test assumptions about how the business is organized and could perform.

2.3 The research opportunity

Drawing from this literature review, the authors hypothesize that the way that manufacturing companies address environmental performance requirements seems to be fragmented and at cases driven by life-cycle assessment for products or eco-efficiency improvements at process level. There seems to be a need for interoperability between bottom-up and top-down approaches and at the same time there is a requirement for better evaluation and attribution of impacts (gains and losses) when improvements are needed.

This study therefore aims to explore how eco-effectiveness and can be better connected to eco-efficiency practices through practice maturity assessment.

3. Methodology and data

3.1 Sample companies

This article gathers data from 3 companies trying to accelerate their journey towards sustainability and draws some motivation from the authors' previous work on eco-efficiency practice maturity modelling [8,34]. The companies that have been approached represent sectors as diverse as chemicals conversion (A), drinks bottling (B) and metallic frames fabrication (C). The companies have been anonymised in this work. All companies have been selected for the purposes of this piece of research as only recently having launched and executing a sustainability strategy since 2018.

All three companies have multinational operations and sales and multiple manufacturing sites across the world. Therefore these would be companies that would not typically qualify as small or medium size [35]. The size aspect of the profiles of these companies means that they would be expected to self-fund most improvements and changes in their organisations. In addition, all companies had similar levels of urgency to achieve higher environmental performance, driven by their shareholders and stakeholders and actively explore various opportunities at the process and product level.

3.2 Data collection process

The PMGE maturity grid has been used to profile the companies that participated in this piece of work [8,34]. The profiles of three companies visited are provided in Table 1 and indicate their eco-efficiency practice maturity as assessed by the authors in numerical format (1-5).

There are two reasons why this grid has been used in this piece of research. The first one is because the grid consists of 3 sub-grids that reflect process level, facility level and business-unit/product capabilities – therefore an interoperability proxy. The organisational pyramid that these sub-grids compose allows for better visibility of practice maturity when an assessment is performed. For example, if high-practice maturity is evidenced at process level for energy usage and low practice maturity for information systems at the business unit level, it can be assumed that the top-management may have a limited understanding about where energy savings could come from. The second reason this maturity grid has been used is because it refers to capabilities, taking a resource-based view of the firm [36] – therefore an improvement proxy. This means that when improvements are required the grid could be used to better understand where existing capabilities exist and how transferable these are to other areas to support required improvements. For example, if a company has developed strong product design capabilities, then a discussion can take place about using some of these capabilities to design more efficient processes to manage recycled material at process level – as long as a practice maturity assessment has taken place.

Table 1 – Maturity levels assessment (1-5) for companies A, B, C across PMGE's 3 sub-grids (layers). Some dimensions have been omitted for readability.

Layers	Performance Dimensions	A	B	C
Process	Energy use/consumption	1.5	4	2
	Process materials use	3	4	3
	Process waste & emissions	3	4	2.5
Facility	Energy management systems	1.5	2	1.5
	Waste management systems	3.5	3	2
	Information systems	2.5	3.5	2
Business	Company norms & values	3	3	2
	Product & process dev	2.5	3	1.5

Semi-structured group interviews were arranged, in the 3rd quarter of 2022, with all companies, represented by their sustainability manager, the factory manager, the supply chain manager as well as the technical director. To maximise time efficiencies and calendar availability, the format of the data collection process consisted of a corporate sustainability presentation around high-level corporate achievements and metrics, how these related to SDGs, a brief factory tour looking at core manufacturing processes and changes they have been making to improve environmental performance and a brief semi-structured interview with group participants to seek additional information or clarifications (also see limitations section). Key interview questions developed and the reasoning for these questions were:

1. How do you inform your key sustainability metrics with data from across the organisation?
2. How do you drive the implementation of your improvement strategies (bottom-up or top-down)?

3. What is the methodology you use in pursuing and implementing change and improvements?
4. How have your manufacturing processes or product designs been affected or changed as part of your sustainability journey and strategy for change?

The 1st question is related to how companies identify their materiality and performance indicators, as well as how they cascade or aggregate their various indicators across stakeholders (production floor operators, mid/senior managers, customers or suppliers, etc.). At high-maturity levels, these indicators are composite indicators that incorporate or are influenced by contributions from a range of core manufacturing activities including quality and health and safety. Responses allow for a deeper understanding of the rigour and robustness of the key performance indicators they follow and how well these address SDGs and ESGs.

The 2nd question is related to how practitioners learn and support activities that come from the shop-floor, process owners and operators (bottom-up). A top-down approach in implementing a sustainability strategy is driven by top-management first (e.g. following a business acquisition or market changes) and would require a methodology to secure buy in from all members of staff in securing delivery of targets. A more balanced and mature manufacturing management system utilises approaches from both ends of this spectrum. A company as such should be capable of enabling the free flow of as many ideas as possible from the shop-floor to the board room of directors and equally there would be a process that onboards people in the shop floor in trying to engage and train them in achieving desired benefits for the business and meeting core objectives.

The 3rd question is seeking to explore to what extend the company identifies and deploys its strengths and capabilities in pursuing certain improvements and changes. This question draws from the resource-based view of the firm [36] and sits at the basis of capability maturity models and how efficiently and effectively companies could leverage their core strengths in pursuing sustainability goals. This allows changes to be implanted through a familiar and methodical path that is being used time and again as the norm for continuous improvement.

The 4th question allowed the authors to better understand the links and connections between eco-efficiency and eco-effectiveness, assuming that product or process level changes are interdependent and can have multiple effects.

4. Discussion and key findings

This section reflects on the authors observations and how these observations link back to the literature search in section 2.

4.1 Sustainability assessment using PMGE maturity grid

The assessments were performed to help the authors to quickly assess and identify areas for improvement as well as to efficiently guide the interview process by focusing on maturity-level differences between different organisational layers.. For example, in company C, the idea that they can further improve on energy efficiency by implementing ISO 50001 in less than a year, didn't seem fitting with their profile and created additional discussion points. The wider socio-economical context was also interesting in this case, as the UK at the time of this work was heading for a serious energy cost crisis that threatened many companies. Therefore, the company was thinking of adding a new energy management system as an appropriate response to the energy cost crisis. In this context and considering how long it may take for a new management system to be operationally effective, energy saving practices at process level would be more beneficial, while either option could only have incremental effects to the environmental performance of their products.

Another interesting finding of this work was related to the PMGE dimension of "Norms and Values" at the business unit level. In two out of three companies in this study top management members' salaries had a sustainability reward set by shareholders to ensure that meeting sustainability objectives remains a priority throughout the financial year. This practice requires additional investigation because it suggests that sustainability objectives could be met or be driven if financial incentives are provided. However, neither of the two companies had considered what capabilities or resources they could leverage to reap these financial rewards and targets.

4.2 Eco-efficiency links to eco-effectiveness and innovation practices – a typology

All companies in this study appeared quite motivated to achieve higher sustainability credentials, be more commercially successful and exhibited strong appetite to innovate and bring new products to market. However, in assessing their sustainability trajectory and practice maturity, the authors observed that there could be a misalignment at the practice level and perceived outcomes and gains from driving certain improvements. It is suggested that companies find it difficult to appreciate how changes and improvements at the process and product level contribute to their sustainability metrics and there is a risk that companies will spend resources in developing action plans that have limited actual effect in sustainability terms. Four types of cases can be inductively proposed and examples from the interviews are offered to support each case:

a) Performing incremental changes at product level and/or incremental changes at process level. These can be typical or business-as usual changes performed over time as required. For example, working with a new supplier for a packaging material that has improved environmental credentials (product level intervention). This change may require only negligible changes at process level. Alternatively, a processing piece of equipment becomes obsolete, and it is naturally replaced with a more energy efficient option (i.e., LED lights, energy motors). One of the companies here opted for power supply from renewable sources thus making a significant change in their carbon emissions with very little effort (though at some additional premium).
b) Performing incremental changes at product level, but step-changes at process level. In the same spirit as in the first case for product level change, the company may decide on

a step-change intervention at process level i.e., by introducing a new production line with better environmental credentials or adopting lean manufacturing practices across the shopfloor or even facilities restorations for improved insulation in the winter. Step-change process interventions tend to require considerable resource, time for planning, design and development and could achieve multiple benefits for the business (legal compliance, capacity/new markets, sustainability, health and safety, etc). It is logical to expect that a change that has no serious impact at product level will need to achieve multiple and diverse set of objectives, as justifications for effort required.

c) Performing step-changes at product level, but incremental changes at process level. Adding or removing a chemical compound from a product composition can introduce/subtract a range of product capabilities and benefits to the user. If only incremental process level interventions apply, then the product change may be easily introduced from the business. Companies would typically pursue these types of interventions as part of their product innovation portfolio of activities. However, process level impacts from a change as such seem to be difficult to proactively identify and record. One of the companies had created a new product incorporating more recycled content, but the recycling system they used was not appropriately sized and designed to support this new product line. In parallel, a new recycling unit needed to be introduced and energy and material requirements were not captured at the product development stage.
d) Performing step-changes at product and process level. The final case in this set is about step changes performed both for products and processes. For instance, a new assembly line is introduced to enable the production of a new product, or a product level change requires process level interventions at considerable capital expense. In the context of sustainability and learning from the companies in this article, a new product was in development from the collection of post-consumer products at the end of their life cycle. This however required the introduction and operation of a nation-wide take-back scheme with additional introduction of processing equipment for the recovered material and making of the recycled product.

It can be proposed that for companies to plan more effective improvements, due attention may be necessary at the maturity and interdependencies of practices deployed between these two areas. Practice maturity is important for efficient implementation and execution of new developments and changes and requires a reflection from practitioners on the organisational strengths and capabilities. An appreciation of the interdependencies between products and process could also help companies develop more effective improvement portfolios (multiple changes), especially when driven by external factors (e.g., climate change).

4.3 From eco-efficiency to eco-effectiveness

Companies that have started to make environmental, social and governance disclosures (ESGs) need or are required to capture as much information as possible about positive environmental and social impacts that occur throughout the business. However, if a product roadmap is heavily focused on product innovation attributes (for example a novel packaging material), process level changes (positive or negative) can go unnoticed and thus not be recorded. In one of the companies here a planned change in the packaging material led to an accidental reduction of compressed air pressure (therefore energy) by 30%. However, the energy savings of that change was not part of their improvement strategy. In fact, it would be far less obvious that this change at the product level could be initiated by a requirement to save energy.

6. Summary and future work

In this article the authors propose that there is a way for a company to bridge the gap between eco-efficiency and eco-effectiveness. Starting from a practice maturity assessment with a tool like PMGE, the questions developed in this article and the four types of cases presented in section 4, researchers and practitioners could review improvement plans more systematically.

Nevertheless, a key challenge emerges in generalizing this proposition. The challenge of defining incremental and step changes in performing improvements, especially when working across different layers of the organization (process to business unit). “Incremental”, “radical” or “step” are commonly used in the literature to characterize changes [13,15,37]. However, the issue that the authors identify here is of how to better define changes (incremental vs step) in a way that is applicable across various industries, so that there is broad consensus about what qualifies as incremental changes or radical and step interventions.

Future work could include a larger sample survey that would quantify to what extend companies acknowledge or miss opportunities to capture or develop sustainability gains and offer some insight about how the size of different changes (incremental, radical, step).

7. Limitations

In this study the authors acknowledge certain limitations in generalizing their findings and conceptualizing the results. For instance, the size of the sample companies is very small and some of the findings were only made possible due the large size of the organization, but equally because they had sophisticated reporting systems. Thus, the propositions made about the typology of cases through the use of the practice maturity concept remain inductive.

Interview time was also limited due to the size of the groups and thus follow-up and in-depth interviews would be beneficial for a deeper understanding of the complexities that practitioners face. Some political dynamics during the group interviews could also be considered due to the seniority of the people involved and thus difficult to verify the quality of the data offered.

On a theoretical basis, a language triangle between eco-innovation, eco-efficiency and eco-effectiveness can be observed where these concepts overlap and are interchangeable in certain cases. This is a limitation for the development of more rigorous terminology and could hinder the efficient knowledge transfer of academic outputs to practitioners.

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