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Towards guidelines for selection of production performance indicators to measure sustainability performance

Babak Kianian[a,] *, Elaine Daly[b], Carin Andersson[a]

[a]*Department of Mechanical Engineering, Division of Production and Materials Engineering, Lund University, Box 118, 221 00, Lund, Sweden*
[b]*Department of Strategic Sustainable Development, Blekinge Institute of Technology, 371 79, Karlskrona, Sweden*

Abstract

This paper's main aim is to review and compare sustainability frameworks and models aiming to propose an overarching strategic planning process for selection of sustainable production (SP) indicators within the manufacturing sector, which point toward radical, systematic and goal-oriented changes. The Framework for Strategic Sustainable Development is selected as a conceptual model to guide strategic decision-making support for sustainability KPIs selection. The main outcome, the conceptual model, and its validity in a future study will be tested and used to offer decision-support to case organizations e.g. gear manufacturers and the results will be compared with other leading SP indicator sets.

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Keywords: Sustainability Challenges; Nested-interdependent System Analysis; Sustainable Production; Production Performance Indicators; Decision Making Support

1. Introduction

Individual actions either at the shop floor level or within the corporate level of a manufacturing organization may not actually bring about sustainable consequences [1]. Many studies have in fact shown that incremental change can have unintended consequences or rebound effects (see Jevons complex) which can outweigh the good that was intended from the original action [1,2,3,4]. This means that focusing solely on creating change at the shop floor level,

* Corresponding author. Tel.: +46-46-222-8134; fax: +46-46-222-8504.
E-mail address: babak.kianian@iprod.lth.se

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without a thorough understanding of the larger system and its challenges, can lead to both unintended consequences and less bad practices rather than the radical shifts needed to achieve sustainability and sustainable production (SP).

Sustainability is a well-established concept following its advancement over five decades of scientific literature [1]. Lubin el al [5] in their review illuminated that the majority of executives are aware of the immense effects of sustainability challenges on their organizations competitive advantage. However, a minority of them have a strategic and systematic perspective to enable them to lead their organizations through sustainability challenges [5].

The 1992 United Nations Conference on Environment and Development concluded that the major cause of continuous natural resources degradation is unsustainable consumption and production [6]. The manufacturing industry is a major contributor to unsustainable production but also has the potential to contribute to sustainable development (SD) and specifically SP [7]. In order to improve a manufacturing company toward sustainable operations, it is important to begin to monitor current practices and set key performance indicators (KPIs), which also take account of pertinent sustainability aspects. This paper suggests there is a major gap between current business practice and the academic consensus on the full aspects of the sustainability. Indicators form an important part in this process as they enable decision makers to make well-informed decisions. Thus, the strategic choice of which indicators to select and utilize becomes of great importance. There is also a risk when seeking to find a specific standardized list of indicators that one aims for incremental change. Indicator sets have been created for multiple scales of the system, e.g. there are indicators sets utilized at the global or Macro scale, the organizational or Micro scale, and also at a sector or Meso scale [8]. One key challenge is to be able to align and compare indicators between these scales [9].

Based on the drive to increase sustainability in manufacturing sector, this paper aims at providing guidance for strategic selection of sustainable production indicators (SPIs). These strategic guidelines will enable decision makers within the manufacturing sector to take a systems perspective to the global sustainability challenge, and relate that directly to their shop floor activities. Hence, this paper aims to answer the following research question. *What conceptual sustainability model is best suited to offer strategic advice to decision makers looking to operationalize sustainability KPIs into shop floor activities?*

2. Research design

As a method to answer the research question, sustainability frameworks and models are reviewed and reported in section 3 below. Their drivers and limitations to offer strategic advice to decision makers are argued and through a comparison, a framework is selected and described. Section 4 illustrates how the chosen framework can be implemented to design a conceptual model to support decision makers looking to operationalize sustainability KPIs into shop floor activities. A table consists of guiding questions for decision makers is provided, and in a related further case study, the validity of this proposed conceptual model will be tested with in-use data from companies.

3. Sustainability frameworks and models: literature review

Indicators present important information about the physical, social or economic system. They enable exploration of trends and cause-and-effect relationships. Indicators alone are insufficient; they must be standardized and interpreted correctly to gather their benefits [6,10]. Currently there are many generic sets of indicators in use within the manufacturing industry with respect to SP and particularly for the shop floor. Winroth et al 2016 [9] identified the most relevant sets of SPI frameworks where special attention was given to two most cited frameworks - Veleva et al 2001 [6] and Azapagic et al 2000 [10]. This paper argues that one key lack, in available sets of SPIs, is an absence of an overarching strategic planning approach. For example, [10] discussed multi-objective decision-making, but failed to propose a robust implementation method for organizations utilizing their framework. [6] proposes a clear process for indicator implementation, which could be helpful to the [10] framework or any new indicator implemented by an organization. These studies hinted at transformational practices such as closed loop and product service system offerings, but they failed to stretch an organization into a new paradigm of production. This will leave decision makers with evidence of less bad practices rather than radically redesigned completely closed loop sustainable operations.

When an overarching strategic planning approach does not exist, there is a weakness in either using sets of indicators alone, or seeking to find a specific standardized list of indicators. That could lead to small and slow incremental change e.g. less bad practices, when it has been shown that the industry needs transformational change to achieve SP [11]. However, the presence of a strategic approach can enable decision makers to make well-informed decisions to set a vision and long-term goals alongside mapping their current reality [12]. Recently there have been great improvements in science and industry's understanding of both the socio-ecological aspects of the sustainability challenge, and standardization of industry indicators. Examples are the international geosphere-biosphere program that produced the summary of the volume global change and the earth system [13]; the intergovernmental panel on climate change- synthesis report summary for policymakers [14]; sustainable consumption and production indicators for the future Sustainable Development Goals (SDGs) [15]; sustainable production indicators at factory level [9].

There is a strong need to strategically select and identify wise indicators sets that match both the global sustainability challenges, and the shop floor reality. Neely et al. [16] suggests some key elements that need to be considered when selecting wise indicator sets; measure the right variables; be correctly calculated; be comparable both to past results to access potential improvements; and to current competitors for benchmark purposes; and have long-term sustainability goals to assess if moving towards the goal at an acceptable pace. Sustainability frameworks and models relevant to sustainable production are described and compared below.

Sustainable Development (SD) was first defined by the United Nations Bruntland Commission report in 1987, which stated that SD means, "To ensure that [humanity] meets the needs of the present without compromising the ability of future generations to meet their own needs" [17]. This definition was a major breakthrough and decisive moment in the SD movement creating a normative value statement that many could align with and follow, this paper suggests however, that it is rather hard to quantify and is too vague to guide effective indicator selection.

The Triple Bottom Line (TBL) originated in the 1990's by John Elkington, as an accounting framework looking to measure "the total cost of doing business" in three areas: Economic, Social and Environmental [18]. The interconnectedness of the social, ecological and economic systems is however not conveyed in this model; therefore, feedback-loops and unforeseen consequences are likely to be missed. On its own, this framework does not help users to "get their priorities straight" between the 3 areas, nor to measure the socio-ecological performance [19]. Thus, this paper attests that using TBL alone is insufficient guidance to help decision makers decide on appropriate indicators.

The Planetary Boundaries (PB) was first developed in 2009, and updated in 2015 by Johan Rockström and Will Steffen et al. PB was designed to define a "safe operating space for humanity" where once human activity has passed certain thresholds or tipping points, defined as 9 "planetary boundaries", there is a risk of "irreversible and abrupt environmental change" [20]. The PBF highlighted the boundaries that was have already passed as a global society thus impressing on organizations and decision makers the urgency to act with respect to environmental sustainability.

The Doughnut Economics Model (DEM) seeks to improve the PB model to include social aspects into a definition of the safe operating space for humanity. The doughnut's outer environmental layer consists of 9 planetary boundaries and inner layer consists of twelve dimensions of a sustainable society. These social dimensions are derived from the SDGs. DEF declares that sustainability lies within this green space between the social and planetary boundaries. The DEF gives an appropriate depiction of how the social system is nested within the environmental system, and declares that this safe operating space should define the goal of our modern economic system [21]. The authors suggest that DEF has yet to be fully operationalized to be a robust framework for strategic decision making for wise indicator selection, though it does clearly point the way for companies to better understand the Brundtland definition.

The Sustainable Development Goals (SDGs) can be considered as a 'moral obligation' and were developed at the United Nations Conference on SD in 2015 [22]. As a general overview, there are 17 goals, 169 targets, 230 indicators (regional, national, global and thematic). These indicators can help companies decide what should be taken into account when monitoring their sustainability efforts [23]. The SDGs succeed to set global targets for SD, but their

formulation was not constructed to be an accord of scientific understanding of the social and environmental systems as seen in the PB and DEM, instead they were based on a consensus process at a political level [24].

Lowell Center for Sustainable Production Framework (LCSP) has broken down the key elements of sustainability related to the production industry and states that, *SP* "utilizes processes and systems, in their product and service creations, which do not pollute the ecosystem and preserve resources and energy. These processes and systems are economically feasible, harmless and healthy for a workforce, community, and clientele" [6]. This definition has six main aspects of 1) energy and material use, 2) natural environment, 3) social justice and community development, 4) economic performance, 5) workers, and 6) products. LCSP also developed nine guiding principles in order to endorse a comprehensive understanding of SP. However, LCSP does not propose a strategic planning process for long-term goal setting, so there is a high risk that when it is implemented alone could lead to small and slow incremental change when it has been shown that industry needs transformational change in order to achieve SP.

The Framework for Strategic Sustainable Development (FSSD) like the DEM seeks to define both socio-environmental sustainability from a scientific perspective. It also is designed to give operational advice to decision makers to make wise economic decisions on their sustainability practices. The FSSD has two main constructs, 1st is a conceptual model based on five levels illustrated in fig 1a, which helps structure a full understanding of the complexity of sustainability within both a global and organizational context. This conceptual model includes an operationalized definition of sustainability, which was derived from a nested system understanding. The 8SPs are broken down to the environmental sustainability principles (ESPs) and the social sustainability principles (SSPs), as defined below [12].

- In a sustainable society, nature is not subject to *systematically increasing:*
  - concentrations of substances extracted from the Earth's crust (ESP1),
  - concentrations of substances produced by society (ESP2),
  - degradation by physical means (ESP3).
- And in a socially sustainable society, people are not subject to *structural obstacles* to:
  - health (SSP4), influence (SSP5), competence (SSP6), impartiality (SSP7), meaning-making (SSP8).

Both categories were formulated from an upstream perspective to encapsulate through first principles the mechanisms of destruction of our environment and society. The 2nd core construct of the FSSD is a strategic planning process (ABCD) illustrated in fig 1b that enables organizations to create a strategic sustainability plan inclusive of justified indicators (e.g. SPIs) that organizations can use to monitor their path towards success [12].

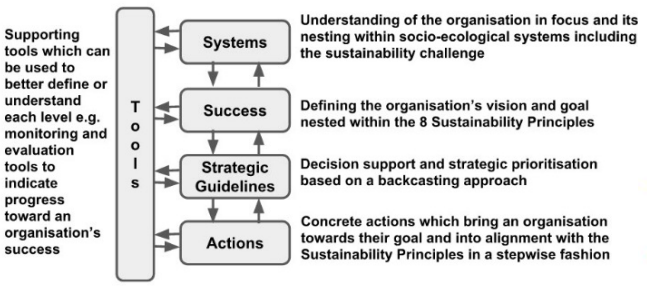
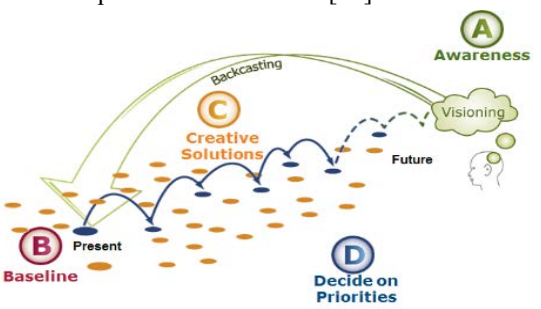


Fig. 1. (a) the 5 level model of the FSSD [12];



(b) the ABCD method for FSSD implementation [12].

4. Results and discussion

A comparison of the sustainability frameworks shows only a few frameworks offer processes, which enable decision makers within organizations to select SPIs. It is possible that organizations can select SPIs without a thorough understanding of the field of sustainability; this is visualized in Fig 2a where a stream metaphor is used to signify the system in question (e.g. the organization). If we think of the upstream area as the region of the first unsustainable harm done to the system and as the stream progresses these first order harms become mixed and compounded into 2nd and

3rd order effects in ever increasing levels of interconnected complexity. As the literature review showed, there have been a number of sustainability frameworks, which have looked to expand and operationalize a definition of sustainability. Fig 2b depicts how these constructs relate to this stream metaphor and the notion of the first harm done to the system. Within this visualization, the PBF can be seen as an ecological warning system closely linked to an upstream perspective whereas the SDGs are global targets constructed further downstream by comparison. The FSSD principles have been designed from an upstream perspective thus marking a filter across the full stream. If actions within the system are taken in line with these principles, the stream should be pure despite the increased complexity and mixing further downstream. It is clear that for decision makers, having a full understanding of the sustainability landscape and available constructs can lead to better indicator selection and the further upstream the construct the more likely the indicator set will offer a more complete perspective on the sustainability of the system.

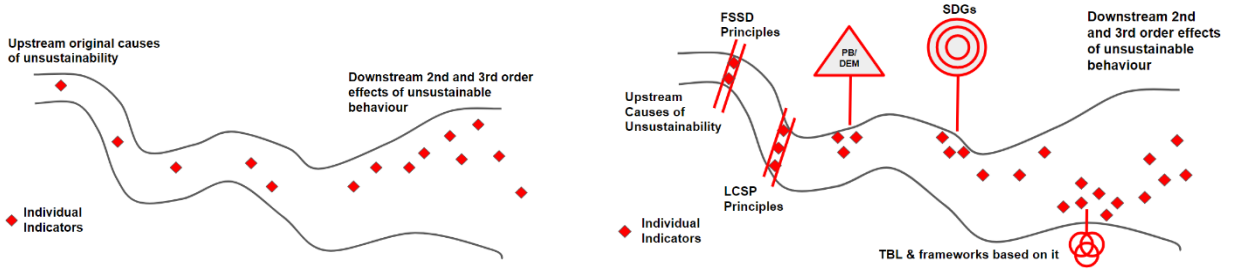


Fig. 2. (a) upstream versus downstream SPIs selection; (b) sample SPIs sets built off reviewed frameworks.

Through the comparisons above this paper suggests that an overarching sustainability framework designed with an upstream perspective and capable of being utilized at multi (sub micro to macro – see fig 3) scales of the system in question is best suited to offer decision support to shop floor management tasked with the design of appropriate indicator selection. Based on these criteria, we suggest that the FSSD and LCSP are best suited to this task. The FSSD is selected as it has been designed to offer organizations a stepwise way of decreasing their negative impacts on the nested socio-ecological system whilst improving the organizations own processes through "innovation opportunities, including new business models, exploration of new markets and winning of new market shares, and through reduced risks and operation costs". The FSSD also enables effective handling of system boundaries and trade-offs (both financial, ecological and social) when moving towards sustainability. As it is designed from a precautionary approach, it can assist decision makers to avoid possible damages from yet unknown problems [12]. Design of a conceptual model to guide strategic decision-making support for effective sustainability integrated KPIs selection was done by utilizing both constructs of the FSSD (5 level model – fig 1a, and ABCD method – fig 1b).

Developing a system understanding; systems thinking and a thorough understanding of the systems, which can impact the shop floor reality of a manufacturing company plants is paramount to achieving an aligned and robust indicator selection. The Systems Level of the FSSD proposes that organizations need to be aware of their own internal systems, and how they relate to the global socio-ecological system. This paper illustrates this in fig 3, which extends and improves the classifications of the multi scale models put forward by [8] and [9]. It outlines a model of the multi-scales of the related nested-interdependent systems, which can influence an organization and its capacity to undertake SP. Having a clear understanding of these different scales, within the nested-interdependent systems at play, can increase a decision maker's capacity to visualize their context and position their organization within a global transition towards SD. Overlaying this awareness with the understanding of the basic operations of each system, in turn gives decision makers more capacity to ensure that they make wise decisions that will take the full complexity of the system into account. This is in line with the suggestions of [1]. A brief description of each scale within this nested-interdependent system's model in fig 3 is as follows:

The *Macro system* covers the full global socio-ecological system. This gives an awareness, that as a society we are a fully own subsidiary of the environment and thus fully reliant on the earths ecosystem services and we have been systematically degrading these systems so that they are no longer able to provide for humanity in perpetuity.

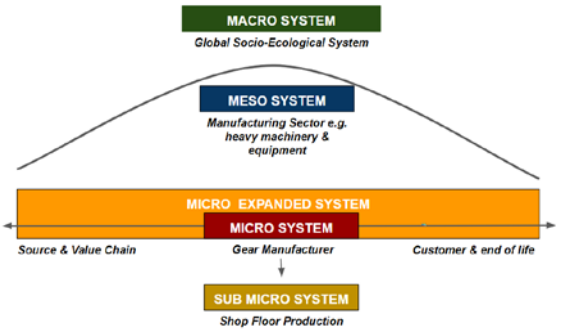


Fig. 3. Nested-interdependent systems

The *Meso System* can be made up of multiple systems. It is vital that an organization can choose the most pertinent meso system(s), which influences their organization. In the case of a manufacturing company, some possible meso systems might be the heavy equipment and machinery industry, the transportation sector, manufacturing industry within a given region. This meso system can give more specific examples of sustainability issues, having a direct influence on the organization, and also on some other organizations who are working towards the same goal. It can also highlight some possible pitfalls or rebound effects within the production and retail sector where incremental improvements can cause increased consumption and sustainability challenges [2].

Micro extended system covers the full value chain from source to end of life. It is vital within the SP industry to take a value chain perspective as many of the major negative contributions that a product may have to SD is located at either extreme of the value chain. For example, one of the biggest negative contributors towards SD is the extraction industry, both in terms of its CO_2 contributions, health and wellbeing of employees and ecological effects. Looking at a manufacturing company in isolation will mean that the shop floor is at risk of taking incremental steps to do less bad practices rather than looking for radical shifts to move away to net zero contributions to GHG etc.

Micro System covers a manufacturing company and its shop floor production as a sub system within the whole. This scale is very important as most of the sustainability reporting will be compiled and communicated at this scale to both stakeholders, and the public [25]. It is vital that any sustainability undertaking on the shop floor (sub micro) is nested within the manufacturing company as a whole and that all strategic plans cross over from high level policy into actual operations management. In this way, a full understanding of the organization as a system can better assist decision makers to align goals and indicator selection at both company and shop floor level.

Sub Micro system is the shop floor and the system of focus for this paper. It is also the key target of the decision support for indicator selection. A full understanding of this system is vital to any effective indicator selection. Often taking a narrow view of this system alone, gives decision maker's limited understanding of the systems the shop floor is nested within, thus leading to rebound effects and incremental shifts. An organization specific indicator design can often mean that the full understanding of actual shop floor operations is omitted and key savings and operational efficiencies could be overlooked. Thus, this paper suggests that it is in the visualizing and understanding of all of these nested-interdependent systems that decision makers are better informed to make wise strategic indicator selection.

Comparable sustainability definition at multi scales of the interdependent systems; understanding the relevant systems is insufficient on its own to generate strategic decision support for indicator selection. What is also required is a clear definition of sustainability that can be operationalized at all of the scales of fig 3. The 8SPs were designed to be applied at any of the above-mentioned scales of fig 3. Thus, indicator selection at any scale should nest within the 8SPs as a way of monitoring the ongoing trajectory towards increased sustainability.

As the 8SPs are designed to be operationalized into the ABCD strategic planning process, they can be utilized to help decision makers to decide on priorities and create strategic goals [12]. Once the key long-term strategic goals (fig 1a) are decided, the decision makers can ensure that their indicator selection is in line with both the organizations definition of success and their definition of sustainability. Thus, these two business drivers can be aligned to become a joint force to propel the organization towards continued economic viability and eco-social sustainability. Another important factor is that often indicator selection can aim for incremental change. When using the 8SPs as design constraints, it enables organizations to avoid blind alleys and unintended consequences, as indicator selection is done through an upstream perspective. This means that in the case of a manufacturing company, production managers can use the 8SPs and the indicators built on them to balance tradeoffs and progression towards long-term goals.

Decision method for shop floor management for strategic indicator selection; once different decision makers have a mutual understanding of the nested-interdependent systems involved and an agreed-upon definition of success, then a method to decide on priorities and choose the pertinent indicators to monitor their progress towards success is required. The Strategic Guidelines Level of the FSSD and in particular the D step of the ABCD planning model outlines the importance of taking a backcasting approach whereby decision makers first define success then undertake a robust baseline assessment of the status quo of their organization e.g. a manufacturing company [12]. KPIs selection then should be made based on this gap between the current reality and the desired future.

Table 1. Guiding questions for decision makers

SYSTEM LEVEL	- Do you fully understand the basic scientific laws and governing structures, which underpin the global socio-ecological system? - What are the global level sustainability issues that can affect your organization both now and in the future? - What are the possible Meso systems nested between your organization and the large global Marco system? - What are the Meso scale sustainability issues that can affect your organization both now and in the future? - Do you fully understand your organization as a system made up of both parts and the interrelationship between those parts? - What are the Micro level sustainability issues that are alive in your organization today? - Can you fully map and describe the full value chain in which your manufacturing organization operates within? - What are the sustainability issues within the value chain that either have a direct/indirect influence on your organization? - What are the ways in which your organization can affect change in the value chain, to collectively, move towards sustainability? - What are the sub micro scale shop floor production sustainability issues currently at play within your organization? - How can the other scales of the relevant systems at play, affect the capacity of the shop floor to move towards sustainability? - What are the current gaps of understanding held within your organization regarding each scale of the relevant systems? - How can your organization seek to address these gaps?
SUCCESS LEVEL	- How has your organization defined its own long-term business definition of success? - How does this relate to the strategic goals of the shop floor? - Can this definition of success, be bounded within the 8SPs ensuring long-term viability of the organization? - How can this combined definition of success be broken down into KPIs and SPIs to monitor progress towards these goals?
STRATEGIC GUIDELINES LEVEL	- What is the internal decision-making structure used by both your organization and shop floor management? - How can you, balance an understanding of the system scales whilst ensuring the long-term viability of your organization? - Which indicators are strategic to monitor improvements towards the defined definition of success? - How do they ensure reliable data is used to calculate the company's return on their sustainability investments? - Does the indicator set in use cover all aspects of the organization vision and the 8SPs definition of success? - Is there a decision structure in place to balance future changes to shop floor activities and long term financial gain? - How can this decision structure be better supported by strategic indicator selection and ongoing monitoring?

Based on the conceptual model and stepwise approach outlined above this paper proposes a preliminary checklist (table 1) of guiding questions for decision makers both at the shop floor and organizational level to operationalize a FSSD perspective into their indicator selection process.

5. Conclusion and outlook

It is important for decision makers to understand how the systems that surround their organization are influenced by their organization's actions. These systems can sometimes have a large influence on the organization and vice versa. Having knowledge of these influences can help insulate the organization from future shocks related to sustainability issues. E.g., an organization can have full control over its own sustainability practices and gateways (procurement

policy etc.) to best limit these issues, but still miss out on profound sustainability challenges found at the extreme edges of the value chain. Based on a literature review of holistic sustainability frameworks, we argue that awareness of advantages of upstream SPIs selection (see fig 2a, 2b) facilitated with implementation of the FSSD 5 level model (fig 1a), and ABCD model practices (fig 1b), can bring clarity on how to limit the organization's contributions to sustainability challenges. Table 1 above can facilitate these processes. In future case studies, the validity of this proposed conceptual model will be tested with in-use data from companies. This will help to ascertain the ability of the FSSD and its lens and guidelines, as a method, to select wise integrated indicators of ongoing progress toward increased sustainability.

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