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Conceptual sustainable production principles in practice: do they reflect what companies do?

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Abstract

A common understanding of sustainable production principles and the identification of sustainable manufacturing practices among practitioners are key starting points in studying how manufacturers are making their operations more sustainable. However, there is a lack of insight in the literature connecting conceptual sustainable production principles, and the practices reflecting these principles. Using semi-structured interviews founded on the sustainable production principles posed by the Lowell Center for Sustainable Production, this paper presents an outlook of how companies in different industries carry out manufacturing practices related to the sustainability production principles. Results showed that the majority of sustainable manufacturing practices remain strongly centered on the environmental dimension of sustainability, with the greatest number of practices emanating from principles concerning energy and material conservation, and waste management. Similarly, reactive sustainable manufacturing practices prevailed over proactive sustainable manufacturing practices, as most of the practices aimed to comply with regulatory and market pressures. Quality and environmental management systems were acknowledged as important tools for putting sustainable production principles into practice; while Swedish environmental and social regulations were found to drive sustainable manufacturing practices. This study connects sustainable production principles with sustainable manufacturing practices and opens the way for further studies on a global or sector-specific scale.

Keywords: Sustainable production principles; Sustainable manufacturing practices; Manufacturing companies

1. Introduction

Manufacturers have become progressively more aware of their operations' impacts on the triple bottom line (people, planet and profit), with increasing pressure to account for their resource consumption and environmental footprint (Kleindorfer et al., 2005). Therefore, it is crucial to clarify sustainability from an operational perspective, and to understand the way in which it might be attained within manufacturing organizations.

Based on the understanding that principles constitute values that guide actions, conducts and organizational practices (Glavič and Lukman, 2007; Shrivastava and Berger, 2010), sustainable production principles provide a common understanding of sustainable operations among practitioners. In the literature, sustainable production principles have been defined mainly from a broad and conceptual perspective, and have addressed mostly environmental concerns (e.g. Al-Yousfi, 2004; Tsoulfas and Pappis, 2006; Lindsey, 2011). A better understanding of the empirical reality surrounding the adoption of sustainability principles among organizations is required (Shrivastava and Berger, 2010); given this, further studies regarding sustainability principles are necessary.

Sustainable manufacturing practices have yet to be extensively documented by scholars (Despeisse et al., 2012; Roberts and Ball, 2014), and rectifying this paucity of studies is needed to help companies achieve sustainability objectives (Roberts and Ball, 2014). Literature on sustainable manufacturing practices has predominantly centered on the environmental dimension of sustainability (e.g. Montabon et al., 2007; Yüksel, 2008; Despeisse et al., 2012; Schoenherr and Talluri, 2013; Singh et al., 2014; Roberts and Ball, 2014), and has mostly studied settings within large-sized manufacturing. It is a bit surprising that, despite the cumulative environmental and social impacts small and medium sized enterprises (SMEs) have on global sustainability, research on sustainable manufacturing practices of SMEs has received little attention among scholars and practitioners (e.g. Kurapatskie and Darnall, 2013). Given this, further studies addressing sustainable manufacturing practices from a triple bottom line perspective that involve both SMEs and large organizations are needed, to gain a comprehensive understanding of how the manufacturing industry is adapting its operations to be more sustainable responsive.

Thus, it is evident that there is a lack of insight in the literature connecting conceptual sustainable production principles (considering the three dimensions of sustainability) with the practices reflecting these principles that, at the same time, considers both large manufacturers and SMEs. To address this, this study aims to transcend the literature on sustainability principles to show how sustainable production principles are adhered to in current manufacturing practices. Therefore, the following research question is posed:

How are sustainable production principles being adhered to in current manufacturing practices?

This paper constitutes a rare effort to address adherence to sustainable production principles of manufacturing practices. Not only does it highlight sustainability principles from an operative perspective, filling the gaps in current literature regarding how manufacturing companies translate sustainability into operative actions and on sustainable manufacturing practices. It also adds to the general discourse on how industry adopts principles of sustainability and applies them in practice. Furthermore, it provides a foundation for future in-depth studies that examine conceptual sustainable production principles and their implementation within a particular context (e.g. within specific sectors, or on a national or global scale).

The paper is organized as follows: section 2 presents the frame of reference introducing definitions on sustainable production, sustainable production principles, and sustainable manufacturing practices. Section 3 introduces the methodology used. Section 4 presents the results from the interviews. Section 5 discusses the empirical findings. Section 6 presents the theoretical and practical implications of the study. Finally, conclusions and suggestions for further research are presented.

2. Theoretical framework

There is limited consensus among researchers on the definition of sustainability (Berns et al., 2009) nor on the definition of sustainable production (Figge, 2005). The Lowell Center for Sustainable Production (LCSP) (1998) defines sustainable production as “the creation of goods and services using processes and systems that are non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for employees, communities and consumers; and socially and creatively rewarding for all working people”. As this definition is broader than alternative approaches which focus only on environmental concerns, the LCSP definition was chosen to frame this study.

2.1 Sustainable production principles

Sustainability principles have been associated with moving companies closer to a sustainable production state by addressing aspects such as resource use, energy practice, product and waste management, and therefore making companies more sustainable responsive (Shrivastava and Berger, 2010).

Several studies discuss sustainability principles from an operative perspective (e.g. Gladwin et al., 1995; Al-Yousfi, 2004; Tsoulfas and Pappis, 2006; Lindsey, 2011; Despeisse et al., 2012). However only the LCSP principles in Veleza and Ellenbecker (2001) tackle the three dimensions of sustainability. The LCSP

principles encompass the main aspects of sustainable production: energy and material use, the natural environment, social justice and community development, economic performance, workers and products (Veleva and Ellenbecker, 2001). To address the complexities of sustainability, both a triple bottom line and a product life-cycle approach are needed, which is why the LCSP principles were selected to frame this study. Table 1 presents the LCSP sustainable production principles.

Table 1
LCSP principles of sustainable production

1	Products and packaging are designed to be safe and ecologically sound through their life cycles; services are designed to be safe and ecologically sound.
2	Wastes and ecologically incompatible by-products are reduced, eliminated or recycled.
3	Energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends.
4	Chemical substances or physical agents and conditions that present hazards to human health or the environment are eliminated.
5	Work places and technologies are designed to minimize or eliminate chemical, ergonomic and physical hazards.
6	Management is committed to an open, participatory process of continuous evaluation and improvement, focused on the long-term economic performance of the firm.
7	Work is organized to conserve and enhance the efficiency and creativity of employees.
8	The security and wellbeing of all employees is a priority, as is the continuous development of their talents and capacities.
9	The communities around workplaces are respected and enhanced economically, socially, culturally and physically; equity and fairness are promoted.

LCSP principles reflect the main aspects of sustainable production. For products, principle 1 concerns practices such as product design, product efficiency, durability and ease of recycling, and environmental and user-friendly product characteristics. Regarding energy and materials, principle 3 involves energy reduction, non-renewable resources, water and material consumption, and material usage that is safe for the environment, workers and customers.

Effects on the natural environment are addressed by principle 2, which focuses on the reduction or elimination of waste, and by principle 4, focusing on hazardous emissions into air and water, and hazardous physical agents, technologies or work practices.

Principles 5, 7 and 8 address different aspects impacting workers. Principle 5 tackles reduction of the risks workers are exposed to, while principle 7 concerns practices aiming to increase employee efficiency, promote employee participation, creativity, and reward systems. Principle 8 concerns practices seeking to provide opportunities for employee advancement, job satisfaction, training, gender equality, and reduction of turnover rate.

Regarding economic performance, principle 6 comprises practices aimed at reducing environmental health and safety compliance costs, improving participatory management style, promoting stakeholder involvement in decision making, and increasing customer satisfaction; all of which enable company profitability over time. Referring to community development, principle 9 deals with employment opportunities for locals, developing community-company partnerships, and community spending.

2.2 Sustainable manufacturing practices

The growing importance of sustainable production over the years has led to a heightened interest in the study of sustainability practices. A number of researchers (e.g. Millar and Russell, 2011; Hurreeram et al., 2014; Habidin et al., 2015) have approached sustainability practices from the perspective of different industry

sectors and countries. The majority of studies on sustainability practices have tackled mainly environmental practices, effects of sustainability practices on firm performance, and sustainability practices among countries and sectors (e.g. Montabon et al., 2007; Despeisse et al., 2012; Schoenherr and Talluri, 2013).

Previous studies have indicated that recycling, proactive waste reduction, remanufacturing, environmental design, and market surveillance for environmental issues are the environmental sustainability practices that most strongly affect company performance (Montabon et al., 2007). Similarly, Hurreeram et al. (2014) determined that the most common environmental sustainability practices among large companies were eco-design, renewable energy usage, energy and material optimization, recycling, product life cycle and end of life-cycle management, and waste minimization.

Sustainable manufacturing practices have been defined mostly from an environmental perspective, aiming at minimizing the impacts of manufacturing operations on the environment while optimizing the production efficiency of the company (Nordin et al., 2014). Thus, in this paper *sustainable manufacturing practices* is understood as the actions, initiatives and techniques that positively affect the environmental, social or economic performance of a firm; helping to control or mitigate the impacts of the firm's operations in the triple bottom line.

Finally, although literature often uses interchangeable the terms manufacturing and production it is relevant to introduce some terminology considerations. Although the authors of this study are aware of the distinction between these terms, this paper refers to *Production*, in sustainable production principles, only for citation purposes of the LCSP production principles in Veleva and Ellenbecker (2001). Likewise, *manufacturing*, in sustainable manufacturing practices, refers to the sustainable practices carried out within the manufacturing industry (i.e. sustainable manufacturing practices).

3. Methodology

Data collection was primarily conducted using semi-structured interviews with open-ended questions. The LCSP sustainable production principles and the indicators for sustainable production (Veleva and Ellenbecker, 2001) were used for designing the interview guide. Great care was taken with wording of questions to ensure complete understanding from respondents. The interview-guide was pilot tested among fellow researchers, looking not only for clarity, but also, to verify the measurement properties of the data collection instrument. Open-ended questions allowed to gather richer insights regarding the adherence to sustainable production principles.

The exploratory nature of the study, made appropriate the use of a non-probabilistic purposive sample. Thus, this paper did not attempted to draw statistical generalization from the results, but to present empirical evidence of adherence to the LCSP sustainable production principles through practices in the manufacturing sector. The study included twelve companies from the following sectors: plastics, metal-machining, foundry, engine manufacturers, hydraulic systems and furniture (Table 2). These manufacturing sectors differ from the usual sectors explored in sustainability literature; indeed foundry, wood furniture and machining (metal-mechanic) sectors are underrepresented within the literature on environmentally sustainable manufacturing practices (Despeisse et al., 2012).

Other underrepresented sectors include plastics, engine manufacturers, and hydraulic-systems, the latter which supply the automotive and transport industries.

It was of particular interest to include Swedish companies within the sample since Sweden has been acknowledged as one of the most environmentally progressive countries (Short et al., 2012) and is ranked second within the social progress index (Porter et al., 2014). The sample's inclusion criteria comprised: companies from any of the six manufacturing sectors of interest, carrying out what they considered to be sustainable manufacturing practices, and located in Sweden.

Table 2

Sample overview

Company abbreviations

	F1	F2	E1	E2	M1	M2	M3	H1	H2	P1	P2	FD
Industry	Foundry		Engines		Metal-mechanic			Hydraulics		Plastics		Furniture
SME	X						X	X		X		X
Large		X	X	X	X	X			X		X	
No. employees	50	500	1400	1595	590	500	9	150	430	200	350	50
Interviewee role	CEO	EM, EC	PM, EM	PM, EM	EM	CEO	CEO	QSE	EM	CEO	QSE	QSE

*EM: environmental manager, EC: environmental coordinator, PM: production manager, QSE: quality safety and environment manager

The key respondents were environmental managers and managing directors. Triangulation was sought by using other data collection sources: factory visit insights, direct observations and company website information.

4. Results

This section presents the empirical findings where the sustainable manufacturing practices are connected to the LCSP principles. A detailed list of practices is presented at the end of this section.

Principle 1: Products and packaging are designed to be safe and ecologically sound through their life cycles; services are designed to be safe and ecologically sound.

Regarding design for the environment, all the respondents cited the recyclability of the materials used in their products and processes. Product safety was associated with using materials approved by the European Union legislation REACH (registration, evaluation, authorization and restriction of chemicals) and ROHS (Restriction of Hazardous Substances Directive). Life-cycle approaches during product design were highlighted as a way to design safe and ecologically sound products only in large companies. In this sense, the large metal-mechanic company has life-cycle considerations early in the design phase, which allows the company to have an operational phase with lower environmental impacts, to use safe materials and to produce highly fuel-efficient products.

Seven companies mentioned that producing safe and environmentally sustainable products is dictated by their product design process. However, the remaining companies considered this principle not applicable to them as product design was predetermined by customers.

Most of the companies associated safe and ecologically sound packaging with having environmental and quality considerations in packaging decisions. All respondents recycle or reuse the packaging from incoming materials and final products. SMEs highlighted their role as followers of the demands imposed by their customers concerning product design specifications, packaging, and delivery frequency. The majority of companies minimize outgoing product packaging.

Regarding sustainability on services, one large engine manufacturer ties up products to supporting services, such as premium maintenance, upgrading services, and product training. Thus, the company promotes reduced fuel consumption and emissions during their product's usage phase.

Principle 2: Wastes and incompatible by-products are continuously reduced, eliminated or recycled.

In light of the solid waste management hierarchy of the environmental protection agency (EPA), waste prevention practices such as the reduction of waste before recycling (source reduction) is preferred over recycling, energy recovery and disposal. Source reduction practices involve prevention, minimization and reuse of waste. Core casting design optimization to reduce material usage at the large foundry is an example of a source reduction practice. Product redesign and material reuse also constituted common source reduction practices (e.g. the hydraulic system SME sources specifically shaped raw material to prevent solid waste).

Companies usually kept operational performance indicators (OPIs) (ISO, 2013) to monitor the environmental performance of operational processes. OPIs were used by the companies to quantify waste,

quality assurance, and reduction of non-conforming products. Likewise, most companies sought to reduce solid waste sent to landfills through recycling and waste reuse. Exemplifying this, the SME foundry reused the sand waste from the core casting as raw material for producing sand cores.

In terms of by-products, the furniture SME donates the majority of its textile by-product to schools, with the remaining material being used internally as filling for certain products. Regarding waste recycling, the plastic companies and foundries conserve resources by re-grinding and re-melting waste, by-products, and nonconforming products. Thus, waste material is used as internal raw material within their processes.

Considering the EPA's waste management hierarchy, more environmentally proactive management practices on sand waste were found in the large foundry than in the SME foundry. Apart from recycling sand waste internally and externally (i.e. using it as a raw material for the concrete industry) the large foundry reduces sand usage before recycling by optimizing the core design. A high recyclability rate of waste sand has been possible thanks to a patented method for pressing and hardening the sand without using additives. This technology reduces waste at source, and eliminates a risk factor for workers.

Continuous waste reduction is part of all companies' strategic objectives mainly due to waste is perceived by companies as a burden with high economic impact. Regarding the role of employees on waste management, most of the respondents stressed the importance of training on waste sorting, as employees are vital for succeeding in such initiatives. The role of environmental management systems (EMS) – specifically ISO 14001 – was highlighted by the companies, who consider ISO 14001 as an enabler to continuously reduce waste, set environmental goals, and keep track of safe materials, chemical and oils. Similarly, and with respect to the ISO 9001 quality management system, the continuous improvement process was associated with the reduction of nonconforming products and solid waste.

Principle 3: Energy and materials are conserved, and the forms of energy and materials are most appropriate for the desired ends.

All companies reported to measure and track energy consumption, contributing to energy saving goals, supported in most cases by their environmental management systems. Employees were acknowledged as critical in saving energy, e.g. by influencing the amount of power required to run equipments, lighting spaces, and avoiding energy losses. Therefore, employee training to increase awareness on energy saving constituted a common practice. Other common practices included: energy metering, LED and motion sensor lighting, heat exchangers, mapping energy consumption for identification of energy savings, updating ventilation systems, and energy-efficient building automation systems for controlling heating, cooling and lighting during working hours. Heat exchangers were frequently mentioned in heat recovery; resulting in economic savings and also environmental benefits by decreasing waste heat discharges into the atmosphere. Such within-process energy or heat waste can be captured by heat exchangers and used, for example, to generate different temperature fluids for use in other processes, and for facility heating.

For renewably sourced energy, most companies use district heating from waste incineration. Eight out of twelve companies indicated electricity use from renewable sources. Exemplifying this, the large foundry replaced fossil fuel-based heating centrals, for bio-oil-based. Referring to energy efficiency, LED lighting, heat recovery and acquiring energy-efficient machines constituted common practices. Regarding energy-related job positions while all large organizations have both energy managers and environmental managers, most SMEs shared environmental and quality responsibilities within one job demonination.

For the majority of companies, the conservation and reduction of materials were associated with R&D responsibility. Common practices were: material substitution for less weight and better efficiency, re-design of products, scrap minimization, material usage and process optimization, and material recycling and reuse. Illustrating this, the hydraulic system SME reduces material consumption by re-designing components which, in turn, reduces solid waste generation.

Most of the companies monitor fresh water use and installed closed-loop water systems to reduce fresh water consumption, allowing for multi-purpose water usage within processes, and reduced wastewater generation. Other practices for reducing fresh water consumption were: recirculating water for cooling, storm water use for cooling processes, and closed-loop water systems.

Lastly, energy and materials conservation, and waste management, were the sustainable production principles with the greatest number of sustainable manufacturing practices.

Principle 4: Chemical substances, physical agents, technologies, and work practices that represent hazards to human health or to the environment are continuously reduced or eliminated.

All companies tracked chemical use in products and processes in conformity with the European Union legislation REACH, which requires declaring and finding alternative chemicals with lower impacts on human health and the environment. Examples of these practices are the substitution of chromium 6 for chromium 3, the replacement of mineral oil for biodegradable vegetable-oil based fluids within machining processes, and reduction of chemicals. Standard safety procedures on work practices were also common. Although chemical substitutions are mainly driven by regulations, most large companies acted proactively, anticipating potential legal chemical restrictions, and identifying chemicals substitutes.

Regarding emissions, hazardous airborne emissions were mostly produced by burning fossil fuels for generating power or heat, smelting heavy metals, greenhouse gases, some hazardous chemicals, or equipment leaks. The large companies studied have long experience in reducing volatile organic compounds (VOCs) and carbon dioxide (CO₂). Five out of twelve companies commented on VOCs emission reduction via the substitution of solvent-based paints for water-soluble paints. For other hazardous emissions, foundries use cleaning systems for harmful pollutants (e.g. sulphur oxides – SO_x – and heavy metal fumes).

Heat exchanger equipment represents an environmental concern because of resulting emissions of sensitive fluid into air, ground or water. Some practices for reducing hazardous emissions into water included: heavy metal filtration in waste water streams, closed-loop process water systems, oil leakage prevention, biologically based wastewater treatment for removing paint from closed water systems in paint shops, and oil leak prevention training.

Principle 5: Workplaces are designed to minimize or eliminate physical, chemical, biological and ergonomic hazards.

All companies keep statistics to assess the extent to which employees are protected from work-related hazards, and to corroborate whether preventive actions against identified hazards are effective. Safety inspection audits to identify situations that might lead to exposure to risks or hazards were common practice. Companies received inspections from the Swedish Work Environment Authority to verify how systematically the work environment is managed. Respondents stressed the importance of internal workstation risk assessment on health and safety.

Robotic automation was also very common for eliminating ergonomic and safety risks; as in the metal-mechanic SME where manual welding was replaced with robotic welding. Practices for improving ergonomics included reducing the heights of pallets for storing material, installing mechanical lifting aid, and rotating employees among the work stations.

With respect to physical risks, companies perform internal inspections and control of noise, vibration, and lighting conditions. Noise levels were measured internally and in the surroundings. Vibrations have been reduced within the metal-mechanic companies by modifying the raw material shape. Employees were continuously trained on hazardous risk identification, and on reporting of accidents and incidents. Most companies expressed that practices oriented towards ensuring safe workplaces were undertaken to fulfill the requirements set by the Work Environment Authority.

Principle 6: Management is committed to an open, participatory process of continuous evaluation and improvement, focused on the long-term economic performance of the firm.

All companies keep financial key performance indicators (KPIs) for measuring, monitoring and assessing how effectively key business objectives are being met by the company. All companies mentioned have integrated sustainability elements into their strategic planning, as well as integrated sustainability considerations within company public statements (e.g. missions and values). Hence, companies have an strategic plan, which is generally constituted by goals at department and section level. Companies stated that continuous goal and action plan monitoring is critical for their consecution. Management reviews, within ISO

9001, support continuous evaluation by the company to tackle economic, environmental, quality and safety aspects.

The large foundry acknowledged the importance of prioritizing investments considering environmental, safety, and quality aspects. Respondents emphasized their continuous sharing of information with operators and employees at all company levels about strategic plans, goals, targets and performance. Visualization of strategic and functional plans, goals, targets and results was used to increase employee commitment towards its consecution.

Most of the companies associated long-term economic viability with follow-up of financial indicators and provision of high quality products, which satisfy customer specifications while decreasing company costs.

Principle 7: Work is organized to conserve and enhance the efficiency and creativity of the employees.

Companies linked employee efficiency with work standardization; highlighting the importance of formalizing processes, and creating accountability for increasing employee efficiency.

The majority of companies focus on practices that enhance employee creativity, such as encouraging, quantifying and setting goals on number of employee improvement suggestions. Collection methods for employee's ideas vary from installing a suggestion box, to raising new ideas during morning meetings, quality and environment meetings, or improvement meetings. Companies value highly the operator's knowledge and experience; therefore improvement suggestions per employee over a time period is a common KPI. Initiatives that reward creativity include monetary incentives, awards to the best idea of the month, and publicizing employee successes in the company. Finally, team work is perceived as a way of making the most of employee skills, and as a tool to promote individual and collectively creativity.

Principle 8: The security and wellbeing of all employees is a priority, as is the continuous development of their talents and capacities.

A health and safety management system that assesses and monitors risks is a way of ensuring employee security. Preventive actions for controlling, mitigating or eliminating risks was commonly mentioned. In relation to the continuous development of talents and capacities, all respondents highlighted the importance of training plans.

Organizations offer career development programs, and promote job rotation. Education plans aim to further develop employee skills at work. Likewise, companies associate employee training with highly competent workers, high quality products, and competitiveness. Another key point on employee development is performance evaluation. Annually, individual performance evaluations address aspects such as job satisfaction, educational needs and additional competencies. For many respondents ISO 9001 serves as a tool for systematically working on training and competence. The management review meetings in ISO 9001 support this principle as the meeting agenda tackles aspects such as safety, work environment, training planning and environmental issues.

Principle 9: The communities around workplaces are respected and enhanced economically, socially, culturally and physically; equity and fairness are promoted.

Community development aims to provide equality and a good quality of life for the surrounding communities.

Commonly, both large companies and SMEs enhanced their communities by providing job opportunities, collaborating with educational institutions, providing fair wages and good working conditions. The companies were interested in participating in research projects with universities, and providing summer jobs, internships or thesis possibilities. Similarly, most of the companies invited students from local high schools for factory visits, in order to attract potential future employees. Regarding communication with communities, periodical meetings with municipality authorities informed on infrastructural modifications, significant production changes, and its potential environmental impacts. The large companies took this principle a step further by contributing economically through volunteer work with locals, and by having a stronger presence in local associations.

Table 3 summarizes how the sustainable production principles are being adhered to in manufacturing practices. Since interrelations occur not only between environmental impacts and social impacts, but also between different principles within the same sustainability dimension (e.g. principles 2 and 3), practices do sometimes overlap and thus address more than one principle at a time.

Table 3

List of sustainable manufacturing practices mentioned

Principles	Sustainable manufacturing practices
1. Products and packaging are designed to be safe and ecologically sound through their life cycles; services are designed to be safe and ecologically sound.	Material usage according to REACH and ROHS in processes and products Hazardous substances substitution or elimination in products and processes Considerations regarding disassembly, reuse and recycling during product design Eco-design assisted by customers Recyclability and reuse of incoming materials packaging Design of energy efficient products Packaging minimization Design for the environment (DfE) Extra services to reduce fuel consumption and emissions during product use.
2. Wastes and ecologically incompatible by-products are reduced, eliminated or recycled.	Component and product design optimization Substitution of hazardous materials Redesigning of components to reduce solid waste Non-conforming products reduction Reuse and recycle of direct and indirect waste Employee training on sorting and waste reduction Process water and emulsions close loop systems External and on-site recycling Biological process for processing waste waters Donation of waste and by-products to other industries or institutions OPIs ISO 14001
3. Energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends.	Employee training on energy savings Mapping energy consumption for identifying energy savings Renewable energy Bio-oil based heating centrals Heat recovery and recycle using heat exchangers Ventilation systems upgrade Equipment upgrades for improving efficiency Preventive equipment maintenance Energy-efficient building automation systems Energy audits Prevention and correction of leakages in air compressed systems Energy metering High efficient lamps and motion sensors Material recycle and reuse Material substitution for better efficiency Material usage optimization Process optimization Monitor fresh water use Recirculating water for cooling Close loop water systems Storm water usage for cooling processes OPIs ISO 14001
4. Chemical substances or	Hazardous substances substitution or elimination in processes

physical agents and conditions that present hazards to human health or the environment are eliminated.	Tracking chemicals in processes and products Materials usage according to REACH and ROHS in processes and products Training on hazardous substances Solvents substitution Air filtration and cleaning systems Heavy metals filtration Closed-loop process water systems Biological based wastewater treatment Oil leakage prevention Standard safety procedures OPIs
5. Work places and technologies are designed to minimize or eliminate chemical, ergonomic and physical hazards.	Robotic automation in hazardous activities Internal safety inspections External work environment audits Mechanical lifting aids Employees rotation among work stations Process modifications to reduce noise and vibrations Employee training on hazardous risks Key performance indicators
6. Management is committed to an open, participatory process of continuous evaluation and improvement, focused on the long-term economic performance of the firm.	Strategic sustainability and functional goals display throughout the plant Technology investments prioritization considering environment, safety, quality and economic aspects Communicating employees about strategic plans, targets and results ISO 9001 for managerial continuously evaluation Financial key performance indicators
7. Work is organized to conserve and enhance the efficiency and creativity of employees.	Work standardization Work accountability Employee improvement suggestions goals Rewards for applicable improvement suggestions from employees Team work Improvement meetings Key performance indicators
8. The security and wellbeing of employees is a priority, as is the continuous development of their talents and capacities.	Health and safety management system Training plans Career development programs Employee rotation Scholarships Subsidies for health and wellbeing purposes Job satisfaction assessment Performance appraisal ISO 9001 supporting training and competence Key performance indicators
9. The communities around workplaces are respected and enhanced economically, socially, culturally and physically.	Job opportunities for locals Collaborations with educational institutions Periodical meetings with local authorities Volunteering work within local communities Sponsoring local associations

5. Discussion

The research question raised in this paper was how sustainable production principles are being adhered to in current manufacturing practices. To answer this question, the results were discussed initially under the environmental, social and economic sustainability dimensions.

The environmental dimension comprises product, resources, and the natural environment; it is often the dimension attracting the most attention in the literature on sustainable manufacturing practices (e.g. Montabon et al., 2007; Despeisse et al., 2012; Schoenherr and Talluri, 2013), a situation mirrored among the companies studied. The most common practices associated with providing sustainable products could be grouped under the concept of design for the environment (Kurk and Eagan, 2008; Johansson and Sundin, 2014) as follows: product design for disassembly, recyclability of some final products, energy savings considerations in products, and considerations for greater product durability. Nevertheless, in our sample only large companies implemented life-cycle approaches on product design. And only one company commented on designing of sustainable services which might be due to the companies involved in this study were product focused, and belong to the manufacturing industry.

Energy management (principle 3) and waste management (principle 4) comprised the majority of practices in the study. Examples of energy and material management-related practices include: training on energy savings, energy audits, heat recovery, material substitutions for improving efficiency, and renewable energy usage. The likely explanation for the uptake of energy-related practices is that improved energy efficiency entails economic savings, increased competitiveness and higher productivity (Yüksel, 2007; Thollander et al., 2013). Regarding waste, most of the companies reuse and recycle (internally or externally) solid waste. Waste management practices were mainly characterized by reactive approaches: waste reuse and recycling. The high frequency of waste management-related practices in the sample could be rooted in economic motivations, as usually waste generation is associated with production process inefficiency. Waste management practices were found to be associated with pursuit of the highest resource efficiency and reduction of emissions in order to benefit from the related economic savings. This popularity of waste management practices is consistent with Montabon et al., (2007), stating that recycling and waste reduction is acknowledged as one of the practices with the strongest effects on firm performance. In addition, the emphasis on energy, material and waste minimization also could be influenced by the implementation of lean production and EMS. Lean production and sustainable development are often associated as compatible initiatives based on their common waste reduction objective (Mollenkopf et al., 2010). Thus, our results agree also with previous findings (Yüksel, 2008; Alshuwaikhat and Abubakar, 2008), identifying ISO 14001 EMS as a driver for sustainability, and therefore encouraging the firms to implement more environmental production practices.

Further, it was found that a common mechanism by which these environmentally-related principles were adhered to by the companies was compliance with the Swedish environmental and social regulations. This could imply that a company's adherence to the principles is caused by a reactive posture to meet regulatory pressure. Reactive behaviors comply only with regulations or customer requirements, while proactive behaviors go beyond regulation or anticipate competitors' actions (Azzone and Noci, 1998). This might imply that the company's adherence to the principles might be caused by a reactive posture to meet regulatory pressure. Reactive behaviours whereby firms intent to only comply with regulations or customer requirements, and proactive behaviours aiming to go beyond regulation or anticipate competitors (Azzone and Noci, 1998).

Another motivation for adoption of environmentally sustainable manufacturing practices was pressure from customers and stakeholders (González-Benito and González-Benito, 2005; Mollenkopf et al., 2010). SMEs stressed the role played by the requirements of large customers in improving environmental sustainability; a factor related to market dependency and fear of losing market share.

Regarding social sustainability, specifically about workers (principles 5, 7, 8) internal safety inspections, external work environment audits, employee training on hazardous risks, health and safety management systems, training plans, career development programs, and employee rotation constituted some common practices. The Swedish Work Environment Authority represents an external driving force for complying with the minimization of workplace hazards and improving the work environment. Employee training was seen as a critically important practice by the respondents, which might be rooted in the perception of training as a critical factor in success while implementing sustainability practices. Trained employees are more aware of the impact their tasks have on resource minimization, cost reduction, and hence, economic savings. These results are

aligned with earlier studies highlighting the importance of employee training. For Sarkis et al. (2010), employee training efforts facilitate the adoption of environmental practices motivated by stakeholder pressures.

Respondents raised the positive effect open organizational culture has on employee creativity. This could be related to the inherent Swedish team-oriented organizational culture, which is more open to discussion and less hierarchical than in many other countries (Gustavsson, 1995; Holmberg and Åkerblom, 2006).

The high standard of working conditions and job security are not only a result of legislation compliance; also labor unions have great power and collective bargaining coverage in Sweden (Helfen et al., 2016), and the country has inherent equalitarian values and strong social democratic traditions (Gustavsson, 1995; Holmberg and Åkerblom, 2006). These implications of national culture have been highlighted previously (Pagell et al., 2005; Diabat et al., 2014), firstly as national culture could affect some operational management decisions, and secondly, as the adoption of sustainable production systems is strongly determined by culture and a country's regulations.

Similar to the environmentally-related practices, the social-sustainability practices within all companies were perceived to be driven by the environmental and social regulations established by the Swedish government, the Swedish Environmental Agency (naturvardsverket), and the Swedish Work Environment Authority (Arbetsmiljöverket). This is consistent with previous research (Zhu and Sarkis, 2006; Jones, 2010) emphasizing the role of national regulation as an important driver influencing a firm's environmental responsiveness, as well as the acknowledgement of national regulation as the sustainability component with the strongest impact on business (Berns et al., 2009).

With regard to economic sustainability (principle 9), financial KPI measurement, monitoring and assessing the business objectives, and technology investment prioritization were among some common sustainability practices. While economic sustainability also considers the way companies influence and manage social and environmental impacts, a deficiency in practices concerning the reduction of compliance costs related to environment, health, and safety when addressing the managerial commitment towards long-term financial viability in the company was noticed.

Large companies were seen to carry out greater investments within their environmental and social sustainability practices compared to SMEs in the same sector, a result aligned to Hettige et al. (1996) and Yüksel (2008) stating that often large firms have more proactive behaviors, allocating more resources towards pollution prevention technologies. Motivations behind our finding could range from greater human and financial resource availability, to the greater company visibility and tougher scrutiny that large organizations often receive from external stakeholders (Brower and Mahajan, 2013).

The adherence to LCSP principles might have been also influenced by organizational size. Most SMEs implemented sustainable reactive practices to barely comply with the principles, in contrast to the large enterprises that often exhibited more sustainable proactive practices. Our findings support previous research posing that a firm's organizational size explains proactive behaviors, as large enterprises are more proactively engaged in environmental management initiatives (Singh et al., 2014), and usually exhibit a greater number of sustainability practices compared to SMEs (Brower and Mahajan, 2011).

During investment decision-making, environmental and social considerations were found to be common. This aligned with the sustainability investment notion of the United Nations Economic Commission for Europe (UNECE, 2009) in which investment not only involves a traditional increase in financial capital, but also includes investment in knowledge (by investment in research and development) and workers (by investment in education, training and health).

Corporate performance has been traditionally measured in terms of financial performance (traditional measures of profits, return on investment, and shareholder value); therefore economic performance is comprehensively addressed within the traditional financial reporting frameworks made within companies. Which might be a reason why economic sustainability-related practices were the least common practices mentioned.

Considering practices by sector, the foundry, metal-mechanic and engine manufacturer sectors were noted to undertake more proactive sustainability practices than the other sectors. The rationale here is that these sectors are suppliers within the automotive and transport industries with high environmental and social impacts along all stages of the product's life cycle (Koplin et al., 2007). Similarly, it was seen that reactive

sustainability practices overpowered proactive practices, where most practices were developed to meet the regulatory and market pressures.

6. Theoretical and practical implications

This paper has investigated whether conceptual sustainable production principles, represented by the LCSP principles reflect what companies do. The paper revealed that a number of the production principles are adhered to in current manufacturing practices. This indicates that the LCPS principles do reflect the sustainability efforts in practice which entails both, theoretical and practical implications. The theoretical implications refer to that the LCSP principles are of a conceptual nature and have not been tested whether they reflect manufacturing practices. This paper showed that the conceptual LCSP principles indeed reflect the sustainability endeavours carried out by practitioners. Thereby, the study provides empirical support that the principles seem to capture essential dimensions of the sustainability efforts carried out by companies. A number of practices were identified in practice reflecting the LCSP principles. Following this finding, it can be argued that the LCSP principles seem useful for deepen the understanding of sustainability efforts in industry. Similarly, the practical implications of this study lie in the identification of several sustainable manufacturing practices serving as examples of how the conceptual LCSP principles can be operationalized or put into practice by companies, and might be used as checklists of relevant manufacturing practices.

The practices identified are valuable to be used as benchmark of sustainable manufacturing practices for companies aiming at either implementing LCSP principles or having holistic sustainable operations. It can thus be argued that the LCSP principles constitute a relevant guiding aid for companies aiming to work towards sustainable production.

7. Conclusions

Building on the existing work on sustainable production principles and the limited studies on sustainable manufacturing practices that consider the triple bottom line, this paper presented empirical evidence of adherence to the LCSP sustainable production principles through practices in the manufacturing sector. More specifically, this is the first study to explore adherence to the LCSP sustainable production principles in practice, involving both large firms and SMEs, and addressing the three dimensions of sustainability.

The greatest number of practices were found in sustainable production principles concerning energy and material conservation, and waste management. It was also found that sustainable manufacturing practices are still predominantly centered on the environmental dimension of sustainability.

Most companies still engage in reactive sustainability practices driven by regulatory and market pressures. Nevertheless, the foundry, metal-mechanic and engine manufacturer sectors seemed to engage in more proactive sustainable practices. This might be because the industries supplied by these sectors (automotive and transport) have a longer trajectory of working on sustainability, along all stages of the product's life cycle.

The adherence to LCSP principles was seen to vary according to organizational size: while SMEs barely complied with principles, large companies engaged often with sustainable proactive practices, anticipating or going beyond regulation. Large customers requirements, market dependency, and employee retention were seen to drive sustainability practices in SMEs.

The compliance with Swedish environmental and social regulation constituted the most common mechanism by which the principles are being adhered to in practice. By complying with environmental- and social-related regulations, practices are being translated into sustainable operations and products.

Similarly, quality and environmental management systems, and some production systems (specifically in large organizations), constituted important tools for putting some sustainability principles into practice.

The fact that this study considered the three dimensions of sustainability enables its use as a benchmark of sustainable manufacturing practices for companies aiming at holistic sustainable operations. Similarly, it provides a point of reference for SMEs, in which current research on sustainable manufacturing practice is still

in its infancy. Furthermore, the paper contributes to increase the understanding of those sustainable production principles that underlie sustainable manufacturing practices.

Since there are relatively few studies on the implementation of sustainable production principles, or on the connection between these principles and sustainable manufacturing practices, the following lines of research are suggested: (i) In-depth studies connecting conceptual sustainable production principles and its implementation within different contexts of interest (e.g. specific industries, at the national or global scale). (ii) Studies on the critical factors influencing the level of maturity of sustainable manufacturing practices. And finally, (iii) studies on awareness and adoption of sustainability practices in SMEs.

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Highlights

- Adherence to the LCSP sustainable production principles in practice is explored.
- Most practices respond to principles tackling environmental sustainability.
- Energy conservation and waste management formed the majority of practices.
- Reactive practices driven by legislation predominate in the companies studied.
- Quality and environmental management systems support adherence to some principles.