Journal of Environmental Accounting and Management 10(1) (2022) 49-72

Journal of Environmental Accounting and Management

Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Sustainability with a Cost Perspective – Driving the Industry to Embrace Sustainable Thinking

Windmark Christina[1†], Anna Ericson Öberg[2], Mats Winroth[3], Peter Almström[3], Martin Kurdve[3], Carin Andersson[1]

[1] Lund University, Faculty of Engineering, Department of Production and Materials Engineering, Lund, Sweden

[2] Volvo Construction Equipment AB, Sweden

[3] Chalmers University of Technology, Department of Technology Management and Economics, Gothenburg, Sweden

Submission Info

Communicated by Feni Agostinho
Received 12 September 2020
Accepted 30 March 2021
Available online 1 April 2022

Keywords

Sustainable production
Performance
Cost simulation
Case study
Sustainability driver
Survey

Abstract

Previous research has shown that sustainable improvements need incentives to carry them through. An assumption is that it may be easier to incorporate sustainable thinking in an organization if the organization understands which actions it is that are having a positive effect on sustainability and on tangible costs. This paper aims to highlight the synergy effects that occur in the intersection between production costs, performance and sustainable improvements and to present a possible way of modelling these effects. The study has used three methods of analysis: literature review, a web survey sent to representatives in the Swedish manufacturing industry, and economic simulations using a case study. The literature review and the survey are used to identify important costs and incentives for sustainable improvements. The study is limited to the production shop floor level, incorporating only aspects directly affecting, and affected by manufacturing operations.

This paper takes a holistic approach to sustainability drivers, cost drivers in industry, and economic simulations, creating an overall insight. From the literature review and the survey, intersections between sustainability measures and cost drivers could be found in the areas of site-occupancy area/floor space, resource consumption, and efficiency. Apart from laws and regulations, economic aspects and management attention are perceived as the most important drivers, but also obstacles for sustainability improvements. The study aims to support industry to embrace sustainable thinking, presenting a quantitative method to visualize the synergy effects of sustainability and measurable improvements from production development, using performance measurements when estimating manufacturing costs. The possibility to connect manufacturing cost with environmental impact, through use of performance parameters is demonstrated in a case study; where the significant environmental and economic impact of rejections is analyzed for the machining of steel frames.

†Corresponding author.
Email address: Christina.windmark@iprod.lth.se

ISSN 2325-6192, eISSN 2325-6206/$-see front materials © 2022 The Authors. Published by L&H Scientific Publishing, LLC. This is an open access article under the CC BY license, (https://creativecommons.org/licenses/by/4.0/). DOI:10.5890/JEAM.2022.03.006

1 Introduction

The list of reasons for contributing to a more sustainable way of living, consuming and producing, is long, but may be hard to incentivize the needed changes into operational management. As agreed at the Paris summit 2015, followed by the agreements at the Marrakech Climate Change Conference 2016, more must be done to stop global warming. The UN sustainable development goals (SDGs) (United Nations, 2020) is a global spread way of quantifying how our nations and companies can reach to reach sustainability. The pressure from the society on manufacturing companies to be more sustainable is high especially since the manufacturing sector consume about half of the yearly global consumption of energy (EIA, 2019).

The primary goal for corporations is to make profit and to satisfy shareholders, leading to varying (sometimes little) concern and attention to sustainability. However, laws and regulations, as well as market pressure on sustainability, are pushing companies towards an increased awareness of specific sustainability aspects (Garg, 2015). Such external incentives are often dependent on region and country, placing a significant part of the responsibility on corporations to reach beyond regional legal provisions. Organizations, such as WWF, are also challenging companies to contribute to increased sustainability by establishing voluntary agreements about, for example, reducing their environmental footprint by reducing energy consumption (WWF, 2017). Laws and regulations at larger corporations are however handled at a higher hierarchical level, quite far away from the day-to-day operation. To attain sustainability awareness throughout an entire organization, operational incentives and drivers need to be identified. A first step could be to identify measures for improvement that are already in use, with connections to sustainability. Previous research (Zackrisson et al., 2017) has shown that about 90% of the indicators used in seven case companies have some kind of connection to sustainability. An assumption is that it is easier to incorporate sustainable thinking into an organization if measures with positive effects on both sustainability and tangible cost parameters are clearly understood. This field has been covered by many researchers, especially in connection to lean and green assessments (Léon & Calvo-Amodio, 2017). The motivation, however, for this study is to identify and investigate sustainable measures connected with the shop floor level that significantly influence production costs, using a cost-model incorporating performance. This to facilitate tangible connection between technology, economy and sustainability through shared measures. Previous research and reports have presented how performance parameters can be related to sustainability (Amrina & Yusof, 2011; Global Reporting Initiative, 2017; Hon, 2005) and to manufacturing cost (Ittner et al., 2002; Ståhl et al., 2007). However, there are very few publications on how measured operational manufacturing performance are used on product or batch level to connect sustainability and manufacturing costs. The objective of this study is to present a possible way to find the intersection between measurable improvements on manufacturing performance and manufacturing sustainability and the synergy effect on manufacturing costs on product level in a manufacturing system. A further motivation is to provide decision makers in the manufacturing industries with the insights and a method on how performance, cost and sustainability explicitly can be connected, with the aim to support the industry to embrace sustainable thinking. The paper presents a method on which companies can assess their system and processes from a sustainable point of view, combining economic measures with environmental and social measures.

The incentives for increased sustainability can depend on in which regions and countries the companies operate, where their customers are located, and what type of products they produce. Yale University and Columbia University, together with World Economic Forum presented in 2018 the Environmental Performance Index (EPI), which is a worldwide yearly recurrent index, ranking 180 countries using 24 indicators for sustainability. Sweden has a history of good ranking and in 2018 the country was ranked as number five (EPI, 2018). This is a motivation for looking at Sweden at a national level and this paper will investigate the perceived common drivers and obstacles for sustainability from representatives from Swedish manufacturing industry, to support the assumption that alignment between tangible costs with sustainability would drive sustainability improvements.

The study is limited to measures connected to decisions, actions, and developments in production operation. Sustainability, in this article, refers to the aspect of the triple bottom line, social, environmental, and economic

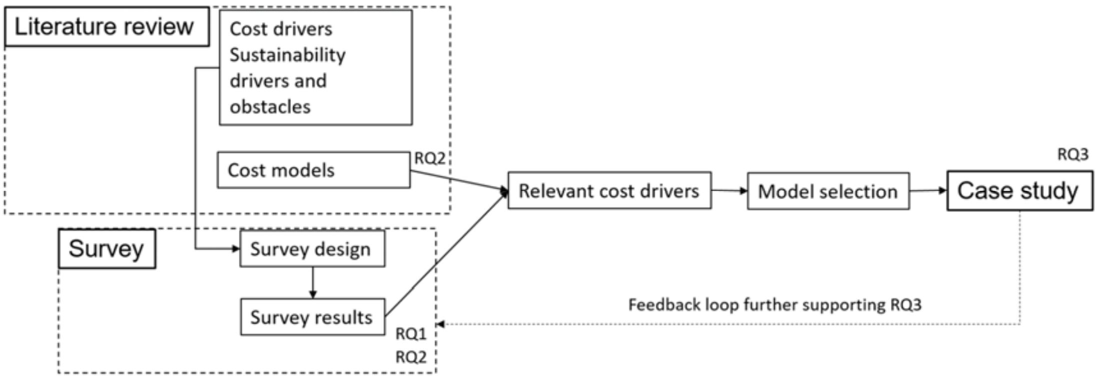


Fig. 1 The research design.

sustainability (Elkington, 1994; United Nations, 1987). To clarify the objectives in this paper, three research-questions are stipulated:

RQ1: What cost drivers are perceived as important in Swedish manufacturing industries?

RQ2: Which sustainability improvement drivers and obstacles are perceived as important in Swedish manufacturing industries?

RQ3: Is it possible to find measurable correlation between important cost drivers and sustainability indicators and what level of impact can selected sustainability measures have on manufacturing costs?

2 Research design and methods

This study has employed a web-survey method and literature reviews to gather data and information. The aim was to identify positive economic impact of sustainability measures by connecting them to operational cost drivers. An industrial case was used to demonstrate a method of how to simulate cost sceneries from sustainable improvements. First sustainability drivers and obstacles, cost drivers, and cost-models in literature were identified. Based on the findings in literature about cost drivers, sustainability drivers, and obstacles, a survey was used both to identify perceived cost drivers in Swedish manufacturing industries and to verify the impact of costs and economic aspects on sustainability improvements. The research design is presented in Figure 1, where the correlation between the three methods used in the research are presented together with what method that is used to answer each of the three research-questions.

A literature review to find cost-models for production operations incorporating sustainability aspects was performed. Frequent cost parameters from these models, together with cost drivers from the survey results, gave a list of relevant cost drivers. A cost-model was selected and used to analyze synergy effects between sustainable measures and essential cost drivers. The selection of cost-model was based on its ability to include manufacturing performance and capability. Finally, the model was applied to a case study at a Swedish manufacturing company within the heavy vehicle industry, producing earth-moving equipment. The cost simulations are based on a case involving machining of steel frames that are the main structure of earth moving equipment. The cycle times are approximately 1.5h in an Innse milling machine. The simulations were performed in the mathematical software Mathcad; and present a scenario analysis giving the possible cost outcome for different levels of improvements. Mathcad is a mathematical program that can handle numeric and symbolic computations in an easy readable way.

The survey was sent to 23 Swedish manufacturing companies within the authors' networks. The aim of the survey was to receive the perceived view from decision-makers working with production system developments. There were no limitations on the number of answers per company as production managers and sustainability managers could have different views on what they considered important. The importance of individual concerns and drives is among others emphasized in Bansal (2003). The total number of responses was 18. The response time for the survey was between February 2017 and September 2017. The survey was anonymous, not linking answers to a specific company. The respondents were asked to tell how they perceived the view of cost and sustainability at their company. This to better understand the mind set of employees and companies in the Swedish manufacturing industries.

The respondents to the survey could voluntarily state their position at the company. In the accompanying e-mail, the authors asked for respondents that work with production development or sustainability. The respondents' roles are either CEO/board member (three), process/production manager (five), quality manager (one), sustainability manager (four), process developer (one), or unspecified (four). Since different types of production operations have different levels of impact on energy consumption, costs, and environment, the respondents were asked to state what type of operations were performed at the company. To make the comparison between companies easier the different operations are divided into three company levels:

- Level 1: low energy-cost; usage of chemicals almost non-existent e.g. assembly.
- Level 2: medium level of energy use; moderate use of chemicals e.g. machining, sheet forming, cold forming, extrusion, injection molding, welding, and logistics.
- Level 3: high usage of energy and chemicals e.g. hot forging, heat treatment, casting, varnishing/coating, and chemical treatment.

Level 2 and Level 3 can involve operations included at lower levels.

All respondents work for companies with production sites in Sweden. To grasp the global presence of the companies, questions about market and production sites were asked. The respondents were also asked about company size in relation to number of employees, whether it was a micro (Mi) (<50 employees), small (S) (50-250 employees), medium (M) (250-500 employees) or large (L) (>500 employees) company. A summary of the respondents and their companies is presented in Table 3 in Section 4.

The survey design had four main parts. The first, involving a respondent's position at the company and company information regarding type of production, size, and global spread. The second, stating the cost drivers from literature, asking the respondents to mark the five most important cost drivers. (To ensure that the cost drivers considered as most important were included, the respondents had to state the three most important cost drivers in free text answers independently of those presented). The third part of the survey relates to sustainability assessment of the companies. A Likert scale is used for the evaluation of sustainability. In the fourth part, the respondents answered what they considered as drivers, obstacles, and catalysts for future sustainability improvements.

The answers to RQ1 and RQ2 are available from the survey results. RQ2 is used to find the drivers and obstacles for sustainability in production corporations, substantiating the actions concerning RQ3, whereas RQ1 relates to the cost-model selection. RQ3, finding measurable correlations between cost and sustainability and possible cost-impact is achieved by using the economic simulations based on the case study, which is illustrated in Figure 1.The case study is focusing on relating how changes in manufacturing performance affect manufacturing costs and carbon dioxide (CO_2) emissions. Carbon emissions (carbon emission equivalents) was chosen both because of its importance as a sustainability indicator but also because data availability and the possibility to connect the indicator to both cycle time, equipment availability and material waste, which all three are important manufacturing performance measures.

3 Literature review on sustainability and production costs

3.1 Drivers and obstacles for sustainability

The idea of finding synergy effects between profitability and sustainability in a corporation is not new and has received a lot of attention e.g. Dummett (2006), Hart, et al. (2003), Hauschild et al (2005), Thollander and Ottosson (2008), Ocampo et al. (2014), Le Roux and Pretorius (2016), and Eashwar and Geetha (2017). A model for investigating the trade-offs between quality, costs, green manufacturing, safety, and time is presented in Eashwar & Geetha, (2017). Drivers for initiating the reduction of green impact are not only forced by government-led programs and regulatory standards, but also from the view of meeting market needs, making money, and capitalizing on opportunities (Oxborrow & Brindley, 2012). In Ocampo et al. (2014) the importance of shareholder pressure is raised, stating that companies are having a hard time initiating this transition themselves. Although internal drivers and motivations, such as corporate culture, top management support, and the development of sustainable manufacturing are essential, they need to align with external motivations. Therefore, companies must develop or select a strategy that addresses both external and internal drivers. In Hauschild et al. (2005) the authors argue for not only including eco-efficiency in Life Cycle Assessments (LCA), but also company ethics and a product's environmental justification. The focus of the paper is the translation from LCA to sustainable production. In Dummett (2006) a list of drivers for sustainability is presented giving reasons for companies to embrace sustainability such as government legislation or threat of legislation, cost savings, market advantage, protection or enhancement of reputation and brands, avoiding risk, or responding to accident or environmental threat, a 'champion' within the organization, pressure from shareholders, pressure from consumers, pressure from non-government organizations, and societal expectation. A framework for sustainable value is presented in Hart et al. (2003), giving the drivers for sustainability in the context of the four dimensions of shareholder value. The dimensions are defined in relation to whether the activity is internal or external and whether the impact is today or in the future. Internal drivers for immediate sustainable values are given as the minimization of waste and emissions reducing costs and risks, and drivers for future values, such as the development of competence to strengthening innovations and technical agility. In Lee (2015) energy management for sustainable development is divided into the three bottom line aspects, economic, environmental, and social, providing examples of barriers for energy efficiency in: market, financial factors, information and awareness, institutional regulations, and technical factors. The paper also presents the results from a survey, answered by the Korean steel industry, stating cost savings as the prominent factor for energy efficiency. Pressure from owners and top management commitment are also ranked as important drivers. The same survey identified technical risk, adherence to capital budget, lack of influences from energy managers, cost of identifying opportunities, analyzing cost effectiveness and tendering, and lack of staff awareness as the top barriers for energy efficiency. In the study presented in Mittal and Sangwan (2011), the aim is to identify obstacles for sustainable production in India. The paper presents a literature review providing eleven factors of obstacles for production sustainability: lack of information, high cost, fear of success, lack of alternative technology, lack of human resources, no/weak legal structure, lack of public demand, lack of government support, pressure for low prices, slow rate of return, and lack of performance measures. Drivers and barriers for energy efficiency improvements in the Swedish pulp-and paper industry are investigated in Thollander and Ottosson (2008). The top barriers were reported as risk of production disruptions, cost of production disruptions, inappropriate technology, lack of time, lack of access to capital, slim organizations, and possible poor performance of equipment. The top drivers were reported as cost reduction, people with real ambitions, long-term energy strategy, and the threat of rising energy prices. In a literature study finding barriers for sustainability and material waste reduction in manufacturing industry presented in Shahbazi et al. (2016) seven barriers were found to be the most cited. The seven barriers were limited financial capability for environmental investments, lack of information, uncertainty of potential results, market benefits and environmental benefits, low commitment and support from top management, unclear/ weak strategic and business goals, employees' attitudes, motivation and awareness, and lack or scarcity of advanced technology and equipment with lower environmental impact. According to Le Roux and Pretorius (2016), one

Table 1 Compiled list of cost drivers for production operations found in literature

Number of started orders	Production volume	Energy consumption
Adjustments	Man-hours direct/indirect labor	Material handling time and complexity
The complexity of the equipment	Floor space	Number of unique products
Equipment hours	Quality control	Number of customers
Equipment efficiency	Direct material	Cycle time
Production efficiency	Material efficiency	Improvement work
Maintenance	Storage	Complexity of product design
Tools	Rework	

common obstacle for practitioners in the industry to improving sustainability is that authority levels hamper implementation. Decisions are made at a high level, interrupting or stopping the process at the level where the improvements are needed. In Alayón et al. (2017) cost savings, legalizations, market dependency, pressure from stakeholders, and employee retention are mentioned as drivers for sustainability improvements from interviewed respondents working for twelve companies in the Swedish manufacturing industry within plastics, metal-machining, foundry, engine manufacturing, hydraulic systems, and furniture manufacturing.

Conclusions to be drawn from the reviewed literature are that cost savings, pressure from higher levels, and champions within an organization are the internal drivers for production sustainability on the manufacturing shop floor. Lack of information, high cost, lack of alternative technology, lack of human resources, lack of performance measures, and lack of commitment from management are factors directly connected to the shop floor, acting as obstacles for sustainability development.

In the survey, the list of drivers for sustainability is based on the drivers presented in Dummett (2006), with modifications. The list is short, when compared to other studies, but comprehensive, as it includes most aspects, which is beneficial for this survey. The list has been modified as follows: Risk of accidents is divided between environmental accidents and work injuries. Shareholders are limited to board decisions, as it is the members of the board that stipulate company strategy, listed as one of the top drivers in Thollander and Ottosson (2008). The list is supplemented with efficiency improvements, directives from higher levels, reduced personnel absence, and reduction of personnel turnover, the last two related to employee retention which was one of the drivers suggested in Alayón et al. (2017). Decisions at higher levels are important for sustainability improvements to occur, as discussed in Le Roux and Pretorius (2016).

3.2 Cost drivers and cost affecting factors

Traditional cost estimation based on direct material, labor and overhead costs has been recognized as not containing enough detail necessary to estimate production costs in modern production systems (Mehra et al., 2005). One reason is the importance of considering manufacturing capability, which is a necessary aspect for competitiveness (Hayes et al., 1988). Kaplan and Cooper (1998) together with Johnson and Kaplan (1987), suggest that costs in production are driven by the complexity of the plant's operations. Furthermore, Hayes and Clark (1985), connect production complexity with the number of product lines, the variety of flow patterns, and number of inventory locations. The evolvement from the traditional economic system where overhead costs are divided into several different cost drivers is presented e.g. in Foster and Gupta (1990), Datar et al. (1993), Banker et al. (1995), Asiedu and Gu (1998), Tseng and Jiang (2000), and Ben-Arieh and Qian (2003).

Based on the findings in the literature above, a list of cost drivers was compiled, see below in Table 1. In the survey, the list was presented to the respondents with the intention of finding the cost drivers considered most significant. As the list mainly consists of cost drivers/cost affecting factors found in literature targeting economic aspects, there are overlaps between factors as e.g. equipment efficiency and production efficiency.

Table 2 Result in number of responses from the multiple-choice questions for each cost driver in the survey, in order of importance according to the respondents (limited to five factors per respondent).

Cost drivers	Responses	Cost Drivers	Responses
Man-hours direct/indirect labor	9	Rework	4
Production efficiency	8	The complexity of the equipment	3
Adjustments	7	Equipment hours	3
Direct material	6	Tools	3
Number of unique products	6	Storage	3
Complexity of product design	6	Material handling time and complexity	2
Equipment efficiency	5	Number of started orders	1
Quality control	5	Number of customers	1
Material efficiency	5	Floor space	0
Energy consumption	5	Improvement work	0
Production volume	4	Maintenance	0
Cycle time	4		

4 Survey results

This section presents the results from the survey, responded by representatives from Swedish manufacturing industries. The survey starts with questions about company attributes, followed by cost drivers and cost affecting factors. The cost drivers and factors relate to measures and occurrences at manufacturing shop floor level and are deliberately presented in a general manner. For example, waste management is not mentioned as it can relate both to material efficiency, and material handling-time and complexity. Another reason for this was to try to get the respondents to be as objective as possible, and not relate things to sustainability in this phase of the survey. The respondents were given a list of in total 23 cost drivers/cost affecting factors, based on findings in literature (presented in Section 3.2), in a multiple-choice question, and were asked to mark what they perceived to be the five most important factors. The result is displayed in Table 2. To investigate if there were cost drivers/cost affecting factors not presented in the list but perceived as important for the respondents, the respondents were asked to state the three most important cost drivers in free text answers. When comparing the answers, it was possible to draw the following conclusions: Most of the top ten cost drivers are the same in both answers, but in a different order. The free text answers had a greater representation of material handling and logistic costs, while labor costs, product complexity and number of orders were reported as more important in the multiple-choice question. However, three of the respondents added shipping as an important cost driver, making it one of the top three drivers perceived as important in the free text answers. When comparing the answers it is possible to draw the conclusions that the cost drivers reported in the literature are relevant to Swedish industry. However, the results are not used with the intention to draw any statistical or generalized conclusions, but the aim is to find what cost drivers that are perceived as important by the respondents.

4.1 Sustainability assessment

The respondents evaluated the sustainability work at their companies in relation to their views on perceived potential, using a Likert scale. In the scale, number 1 represents “not performing well” in relation to company potential, and number 5 represents “performing very well”. The answers are divided depending on the company level. The respondents also stated if they felt there were any differences concerning sustainability due to production location within the company, and if so what the reason for that was. The results can be seen in Figure 2 and Table 3. Respondents 3, 7, 14, 15, and 17 stated that there is only one production site within the company.

Almost 85%, 11 out of 13 respondents, felt that there were differences between production sites concerning

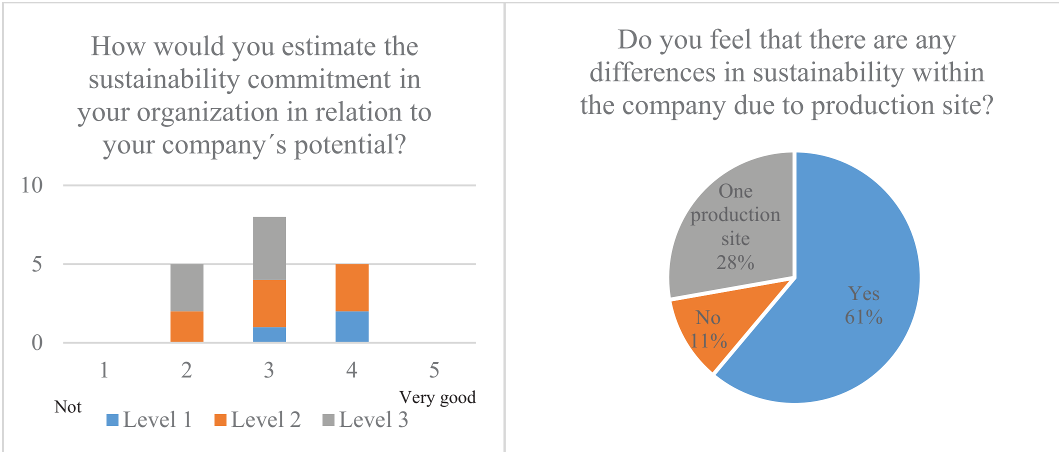


Fig. 2 Evaluation of sustainability in the organization.

sustainability. The main reasons are given to be laws and regulations (7 responses) followed by commitment and cultural differences (5 responses). The two respondents, answering that there are no differences in sustainability due to production site, either have all their production sites in Sweden or are employed at a Level 1 company only having assembly in their operations.

The respondents were also asked to evaluate the work on sustainability improvements conducted at their company. They were given 14 different types of sustainability improvements areas on which they ranked the commitment in their company from 1 to 5, where 1 stands for not at all and 5 very dedicated work with high targets. Based on the answers Table 4 is designed. The table provides three different results, the total score for each improvements area when multiplying number of answers for each of the five levels with the level number, the average, and number of high ranks from the respondents, giving number of responses on level four and five.

The result is not statistically significant but provides an indication that waste disposal, productivity, production efficiency, and energy efficiency are perceived by the respondents to be improved to a higher degree than sustainable material, sustainable energy sources, reduction of additives and transportation efficiency, at the respondents' companies.

4.2 Drivers and obstacles for sustainability improvement

The respondents were asked about the drivers for and obstacles to sustainability that they felt existed in their organization. A list, based on the findings in literature, was provided with the option to add aspects not included. There was no limitation on the number of selected drivers and obstacles, the respondents were able to mark none or all, see Figure 3 and Figure 4. After selecting drivers for sustainability within the organization, the respondents were asked to state the main driver for sustainability. In addition, the 18 respondents stated 10 different main drivers (one per respondent): profitability (four responses), board decisions (three responses), laws and regulations (two responses), cost savings (two responses), commitment (two responses), business marketing and brand (two responses), equipment recycling (one response), and customer demands (one response). This can also be seen in Figure 3, where these are the highest number of reported drivers for sustainability. The two most reported obstacles for sustainability reported in the survey and showed in Figure 4 are economic aspects and no clear directives or goals.

In Figure 4, two respondents added one aspect each related to system integration and lack of resources as obstacles for sustainability. Finally, the respondents were asked what they thought could facilitate future implementation of sustainability, see Figure 5. The top factor reported was clearer directives from management and superiors, in line with Le Roux and Pretorius (2016).

Table 3 Company presentation, classification and perceived global differences in sustainability.

Respondent	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Size	M	L	S	S	L	L	S	L	L	L	L	L	L	Mi	S	M	Mi	L
Market																		
Global market		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x
Smaller market	x																x	
Level of Energy Consumption and Environmental Impact																		
Level	3	2	3	2	2	3	1	3	3	3	3	2	1	2	2	2	2	1
Production Site Location																		
Sweden			x	x			x							x	x		x	
Scandinavia	x	x										x						x
Europe					x	x		x	x	x	x		x			x		
South America						x		x		x			x			x		
North America		x				x		x	x	x	x	x	x			x		x
Asia		x			x	x		x	x	x		x	x			x		x
Africa						x		x					x					
Oceania						x		x					x					
Perceived Differences in Sustainability at Different Sites																		
Yes/No	Y	Y	-	N	Y	Y	-	Y	Y	Y	Y	Y	Y	-	-	Y	-	N
Perceived Reason for Differences in Sustainability due to Different Sites																		
Competes	x								x		x					x		
Lack of resources	x								x	x								
Laws and regulations					x			x	x	x	x	x	x					
Maturity								x										
Business focus										x								
Commitment						x				x	x	x				x		
Culture differences		x				x		x				x				x		

5 Sustainability measures and estimations of manufacturing costs

Previous research indicates that a large number of the measures used for production evaluations and monitoring have a direct or implicit connection to sustainability (Zackrisson et al., 2017). In this paper, only sustainable measures, directly connected to production operations, are considered. A vast amount of research on sustainability indicators and frameworks has been performed e.g. Global Reporting Initiative (2000, 2005, 2017), Veleva and Ellenbecker (2001), Azapagic (2004), Fan, et al. (2010), Krajnc and Glavic (2003) and Nordheim and Barrasso (2007). From the literature, it is possible to find that prominent sustainability indicators are related to energy use, emissions, material use, use of chemicals and hazard substances, waste management, profitability, customer satisfaction, employee satisfaction, and sustainable choice of suppliers. In Winroth et al. (2016), a literature review on sustainable indicators at the manufacturing shop floor level was conducted, to design a survey for Swedish industry based on the findings. The survey was used to identify sustainability indicators relevant for production managers in the Swedish manufacturing industries. Among the 27 indicators, perceived as most important, five had a significance level of 0.00025: energy use, number of customers, rate of customer complaints, number of new customers per year, and employee satisfaction rate, giving the five indicators considered as most important. From the presented survey result, it is possible to assume that the economic aspects of sustainability are of high priority at production manager level in Swedish manufacturing industries.

There is a considerable number of cost-models for product-costs and production operations reported in the

Table 4 Results from evaluation of sustainability improvements at the companies.

Type of improvement work	Total score	Average	No. of high ranks
Waste disposal	74	4.1	15
Productivity	65	3.6	11
Production efficiency	65	3.6	11
Energy efficiency	62	3.8	11
Personnel satisfaction	62	3.7	10
Reduction and elimination of hazard waste	61	3.6	10
Sick leave reduction	61	3.4	9
Ergonomics of assembly	60	3.3	7
Material efficiency	55	3.1	6
Floor space efficiency	53	3.3	8
Sustainable energy sources	52	2.9	7
Sustainable material	52	3.0	5
Reduction of additives	50	2.8	3
Transport efficiency/reduced impact on environment from fuel	47	2.6	4

Fig. 3 Reported drivers for sustainability.

literature. Reviews summarizing the field can be found in Niazi et al. (2006), Xu et al. (2012), Jönsson (2012), Ståhl (2017), Salmi et al. (2016) and Windmark (2018). Depending on the model application and concept, cost-models can be classified into different categories. The cost-model selected for case simulation is a comprehensive performance-based manufactured cost-model for part manufacturing, capturing multiple improvement opportunities, such as quality, speed and availability losses, and material efficiency aspects described by Ståhl et al. (2007). The model was evaluated based on sustainability representation in Windmark and Andersson (2016), where sustainability indicators from 12 selected papers were matched with the cost-model parameters. The cost-model used for simulation is:

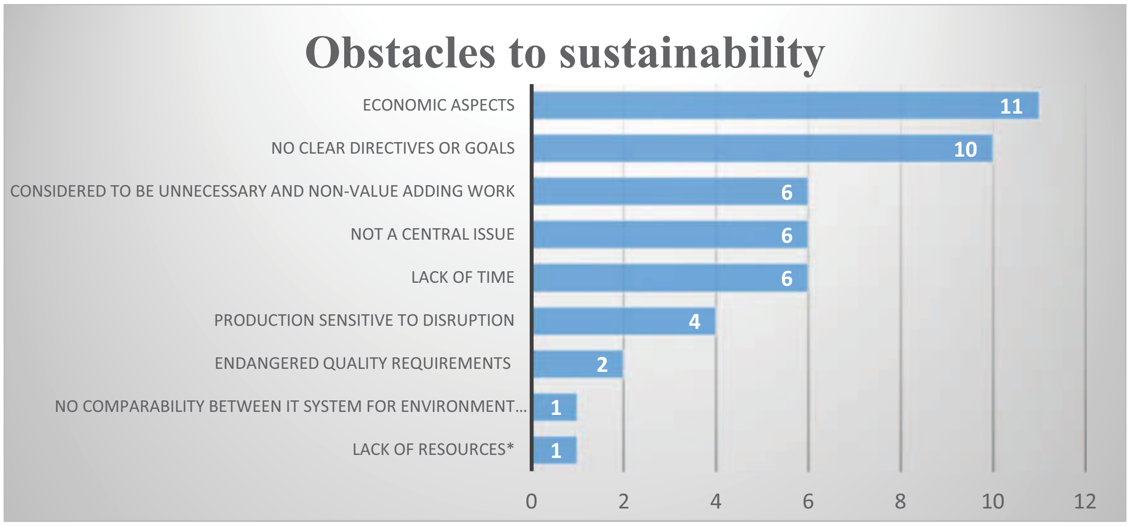


Fig. 4 Perceived obstacles to sustainability in the organization, * added by respondents.

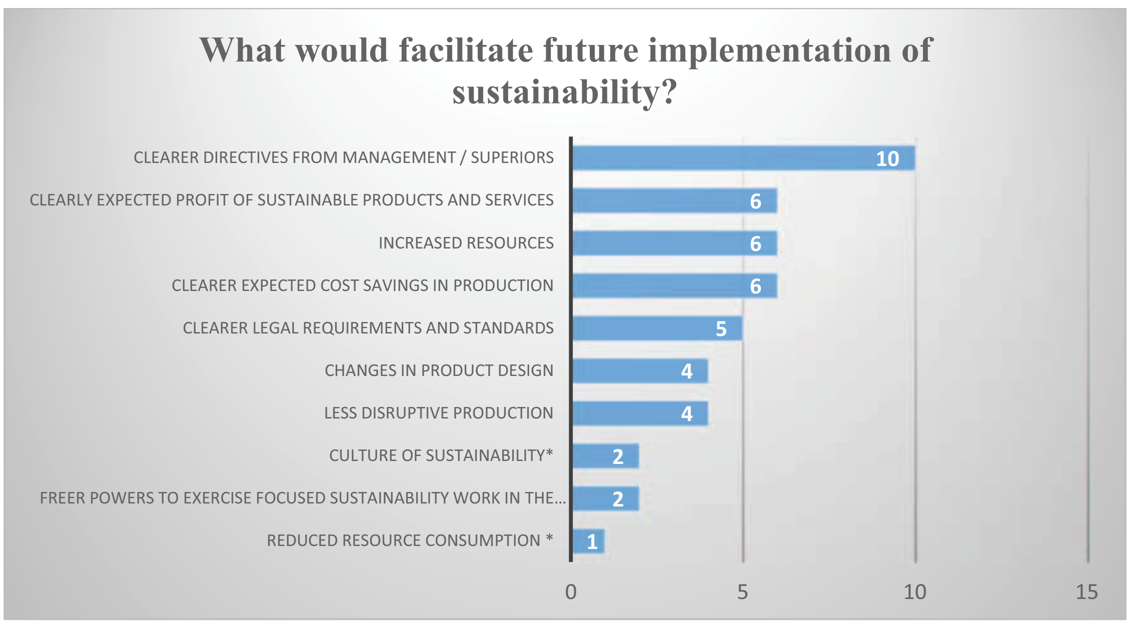


Fig. 5 Effects that would facilitate future implementation of sustainability, * added by respondents.

- Generic, with the option to incorporate different types of production operation
- High level of detail to capture changes made on the factory shop floor
- Including resource efficiency and utilization
- Incorporating several sustainability aspects, such as quality, availability, utilization and efficiency as well as many of the stated important cost drivers from literature and the survey
- Including the reported important cost drivers/factors: labor costs, production efficiency, adjustments/number of unique products, material costs, quality, and equipment costs. The cost driver/factor "the complexity of

product design" is not explicitly included in the model, but the model captures quality problems, production speed, adjustment needed and availability losses in general connected to complex design are included.

In Stål et al. (2012) the model is used to estimate the cost of different causes of availability losses, making it possible to connect specific problems/phenomena to an estimated cost. Hence, the model can be used to capture cost changes due to sustainability improvements. In Schultheiss et al. (2018), the model is used for assessing the cost impact of reducing the lead content in brass machining. In their article, the model is compared with other economic models concerning which and how many parameters included. It is found to be the model that uses the highest number of parameters out of the 13 models investigated.

5.1 The cost model

The model used is a performance-based cost model for discrete part production for assessment on batch level (Ståhl et al. 2007). The performance factors used, thus affecting the final part cost, are presented in the list below. The cost equation and all ingoing parameters are stated in Table 5. In addition, the cost model is complemented with equations describing the relation between (1) process time and carbon dioxide emission per timeframe based on energy consumption in equipment, (2) availability losses and carbon dioxide emission based on idling equipment, and (3) rejection rate and material carbon dioxide emission based on rejection rate, including process emissions for processed material. The relations are used for mathematical simulations in the case study.

- rejection rate
- material scrap rate in process
- downtime rate
- set-up time
- utilization based on reduced production
- speed loss rate
- cycle time

The cost model is based on four main cost items, material (k_B), running machine (k_{CP}), idling machine (k_{CS}) and personnel. To adapt the model to measure different energy consuming activities in the processes, the running machine costs have been divided into two different entities, running during engaging of tool, with high energy consumption due to the high forces and loads on the tools (k_{CPe}) and running during tool handling (movement of tool into correct positions and for changing tools) (k_{CPh}). The difference in machine cost is related to the energy consumption per hour. The three different hourly equipment costs are stated in equation 1-3. The cycle time and production time configuration is presented in equation 4-5 and the adjusted cost model in equation 6.

Hourly machine costs during engagement in the process.

$$k_{CPe} = \frac{K_0 \cdot \frac{p(1-p)^n}{(1-p)^n-1} + A \cdot K_{AP} + K_{CUH}}{T_{\text{Plan}}} + k_{ee}. \tag{1}$$

Hourly machine cost during tool and material handling (transportation) in equipment

$$k_{CPh} = \frac{K_0 \cdot \frac{p(1-p)^n}{(1-p)^n-1} + A \cdot K_{AP} + K_{CUH}}{T_{\text{Plan}}} + k_{eh}. \tag{2}$$

Hourly machine cost during idling

$$k_{CS} = \frac{K_0 \cdot \frac{p(1-p)^n}{(1-p)^n-1} + A \cdot K_{AP}}{T_{\text{Plan}}} + k_{ei}. \tag{3}$$

Table 5 Presentation of the parameters in mathematical models used in the simulations

Nomenclature		
A	Area used in the production	m^2
CO_{2e}	Carbon dioxide emission	kg
CO_{2ei}	Carbon dioxide emission during idling equipment	kg
$CO_{2process}$	Carbon dioxide emissions from the manufacturing process investigated	kg
CO_{2w}	Material carbon dioxide emission	kg
E_c	Energy consumption of equipment	kWh
K_0	Total investment in equipment	EURO
k	Manufacturing cost per part	EURO/part
k_A	Tool costs	EURO
K_{AP}	Process area costs	EURO/m^2/year
k_B	Material cost per part	EURO/part
k_{CPe}	Hourly machine cost during production during tool engagement	EURO/part
k_{CPh}	Hourly machine cost during production during handling in equipment	EURO/hr
k_{CS}	Hourly machine cost during equipment idling	EURO/hr
K_{CUH}	Yearly maintenance cost	EURO
k_D	Personnel costs	EURO/hr
k_{ee}	Energy cost per hour during tool engagement	EURO/hr
k_{eh}	Energy cost per hour during handling in equipment	EURO/hr
k_{ei}	Energy cost per hour during equipment idling	EURO/hr
n	Technical lifetime	year
N_0	Batch size	unit
n_{op}	Number of operators per piece of equipment	unit
p	Internal rate of return	-
q_P	Speed loss rate	-
q_Q	Rejection rate	-
q_S	Downtime rate	-
$\overline{q_S}$	Average downtime rate	-
t	Time	min
t_0	Ideal cycle time	min
t_{0h}	Ideal time per product handled in the equipment	min
t_{0e}	Ideal time per product during tool engagement	min
t_f	Time factor for simulations	-
T_p	Production time for the batch	hr
T_{plan}	Paid and planned production time	hr
T_{su}	Set-up time	min
U	System utilization	-
W	Wight	kg
w_{CO2e}	Weight factor of CO_2 emission from energy	$kgCO_2$/kWh
w_{CO2m}	Weight factor of CO_2 emission from material	$kgCO_2$/kg

The total ideal cycle time involving engagement time and handling time in equipment.

$$t_0 = t_{0e} + t_{0h}. \tag{4}$$

Production time for the batch.

$$T_p = T_{su} + \frac{N_0}{1-q_Q} \cdot \frac{t_0}{1-q_S}. \tag{5}$$

Cost per part based on batch manufacturing, where adjustment from Ståhl et. al. 2007 has been adopted to handle two different operation times when the machine is running.

$$\begin{aligned} k =& \frac{1}{N_0}[\frac{k_B \cdot N_0}{(1-q_Q)(1-q_B)}]_B + \frac{k_{CPe}}{N_0 \cdot 60}[\frac{t_{0e} \cdot N_0}{(1-q_Q)(1-q_P)}]_{CPe} + + \frac{k_{CPh}}{N_0 \cdot 60}[\frac{t_{0h} \cdot N_0}{(1-q_Q)(1-q_P)}]_{CPh} \\ &+ \frac{k_{CS}}{N_0 \cdot 60}[\frac{t_0 \cdot N_0}{(1-q_Q)(1-q_P)} \cdot \frac{q_S}{(1-q_S)} + T_{su} + \frac{1-U}{U} T_p]_{CS} \\ &+ \frac{k_D}{N_0 \cdot 60}[\frac{t_0 \cdot N_0}{(1-q_Q)(1-q_P)(1-q_S)} + T_{su} + \frac{1-U}{U} T_p]_D \end{aligned} \tag{6}$$

5.2 Case design

From the survey and literature presented in Section 3, both internal and external drivers for sustainability were found as main drivers. To support the aim to support industry to embrace sustainable thinking, the case study involves a method to visualizing the synergy effects of sustainability and measurable improvements from production development through manufacturing costs. The focus in the case scenarios will therefore be on internal drivers. However, fulfilment of finding relevant internal drivers could facilitate reporting related to laws and regulations, which is a very predominate external driver. From the survey, the top internal drivers for sustainability improvements can be related to management commitment and improved economic results. It is possible to assume that quantifiable economic improvements from sustainability work would make it easier for managers to make decisions for sustainability. In the case study, CO_2 is used as sustainability measure, but other measures as emissions of other greenhouse gasses, water consumption, education/training level of employees, and consumption of additives and chemicals could be used if sufficient information are available.

The review of literature and the survey give labor costs, production efficiency, adjustments/number of unique products, material costs, quality, the complexity of product design, and equipment costs as important cost drivers. From the literature review and the survey, intersections between sustainability measures and cost drivers could be found in the areas of site occupancy area/floor space, resource consumption, and efficiency. Regarding floor space, it is not only an important cost driver, but also a commonly reported sustainability measure in literature. Resource consumption relates to e.g. energy, material, water, and equipment usage. Shorter cycle times give less usage per product in relation to equipment, manpower, and energy (if the effect usage does not increase per time-period). Improved utilization also contributes to increased economic performance and a more efficient use of resources, in this aspect material efficiency is one of the strongest indicators.

The case study design is based on the selected cost model and the parameters found in the literature as well as the opportunities revealed at the case company. In the case study, the cost effects of implementation of different sustainability improvements are considered, such as cycle time reduction, equipment efficiency (equipment idling), and material efficiency. The case study is performed as an example on how it is possible to connect manufacturing operation performance, manufacturing costs and sustainability improvements, giving the possibility of aligning sustainability improvements and cost reduction on part level and on process yearly level.

The case company produces 1,000 kg heavy steel frames used in the heavy vehicle industry for earth moving equipment. In this study only the part of the value chain involving machining is included. The machining operation is performed in a multidimensional milling machine. In the machining process, the set-up occurs during production, using the method of external set-up, thus not causing any production interruptions. The company has a very expensive and material intensive product, where quality defects are corrected by rework (welding) instead of rejection and scrapping, making final quality losses almost non-existing. The parts are first welded, then machined and if quality problems occur they are welded again and if needed machined again. To simulate the possible correlation between sustainability gains and cost reduction by reducing quality issues the simulation of quality losses is fictitious but otherwise based on information from the company. The annuity of investments in equipment is based on a 5% internal rate of return (p) and on the technical lifetime (n) of the equipment. Calculations of the machine hour costs are displayed in equation (1) – (3). The engagement-time (t_{0e}) amounts approximately to one hour and the handling time of equipment (t_{0h}) to approximately 30 minutes. The total cycle time (t_0) is therefore about 1.5 h per part in the machining operation. The electricity cost is €0.05 per kWh. For confidentiality reasons other input values are not displayed.

The iron and steel industries are among the world's largest energy consuming manufacturing industries, contributing to about 5% of all CO_2 emissions (Ho et al., 2013). In this simulation 1 kg of steel corresponds to 1.8 kg CO_2, which is the reported correlation from two different research articles (Hasanbeigi et al., 2014; Ho et al., 2013). The CO_2 emission of 1 kg steel is dependent on what type of energy source that is used at the mill, and Swedish steel contributes to less emissions than for example steel from the US. However, because of the international market, 1.8 kg CO_2/ kg steel is used in this simulation. The CO_2 emissions per kWh used in the simulation are based on the presentation of average emissions per consumption by country in the European Union presented in (Moro & Lonza, 2018). For Sweden, the CO_2 emission is 45 g/kWh and the average in the EU is 428 g/kWh. These figures are from 2013, and the actual emissions of today might be slightly different. The simulation will use both figures to illustrate the importance of considering the manufacturers energy source. Here, the investigation is in-house at the company but the energy sources of other manufacturing plants within the business group and sub-contractors are equally important. Plant within the company group when deciding where to locate production and subcontractors as about 60 % of the manufacturing industry's energy consumption can be related to material production (Ashby, 2012). The lower level of CO_2 emission in Sweden originates from the high use of CO_2 neutral energy sources. About 50 % of the electrical power is from hydro and wind power, adding nuclear power, 90 % of the total electrical production is covered (Swedish Energy Agency, 2021).

In the model, the energy cost within the hourly machine cost is separated into energy cost during equipment running and during idling. Idling can occur both during production and non-productive times, e.g. nights and weekends. The cost of energy during "no production" is divided into the yearly planned production time, thereby added to the cost of energy during operation and during idling. It will then be possible to simulate the cost savings of turning off equipment when it is not being used. In this simulation, there are three different types of energy consumption in the equipment used, (1) active processing (tool engagement), contributing to the highest amount of energy consumption (42 kW/h), (2) movements and tool handling in the equipment (33 kW/h), and (3) idling of the equipment (3kW/h). These three levels of energy consumption are related to the three levels of operation where engaging correspond to the mean energy consumption when the machine is in value-adding operation. The cost-model is altered accordingly to handle the three different types of hourly equipment costs corresponding to the above. The simulations only take into consideration energy consumption based on idling equipment, cycle time, and material rejection/waste. Other sustainability aspects to take into future consideration, but not included here are, for example, floor space in buildings, product material scrap (removed chips etc.), chemicals and additives usage in processes, and the training level of operators affecting production performance. These aspects will not be part of this actual investigation, primarily because of poor information/data accessibility. The cost for emission allowances will also be excluded from the estimations.

5.3 Scenario simulation

The simulations show how the changes in performance correspond to the part-cost in the manufacturing processes and the CO_2 emission. In Table 6, the in-data is summarized.

Carbon dioxide emission per timeframe based on energy consumption in equipment, where w_{CO2} is the weight factor for CO_2 emission per kWh, E_c is the energy consumption per hour, t is the processing time and t_f

Table 6 Non-confidential in-data used in the simulations.

Parameter	Value	Parameter	Value
Engagement time	1 h	Availability ratio	0 – 0.8
Handling time in equipment	0.5 h	Quality ratio	0 – 0.2
Total cycle time	1.5 h	Electricity cost	€0.05/kWh
Setup time	0	CO_2 emission/kg steel	1.8 kgCO_2
Energy consumption engaged machine	42 kW/h	Machine hour cost (tool handling) in relation to machine cost when engaging	99.4%
Energy consumption, tool handling in machine	33 kW/h	Machine hour cost idling in relation to machine cost when engaging	64%
Energy consumption, idling machine	3 kW/h	CO_2 emissions EU (electricity)	428 g / kWh
		CO_2 emissions Sweden (electricity)	45 g / kWh

a time factor to simulate the effect of changing the processing time.

$$CO_{2e} = w_{CO_{2e}} \cdot \frac{E_c}{60} \cdot t \cdot t_f \tag{7}$$

Equation 8 illustrate the carbon dioxide emission based on idling equipment during availability losses, where T_{plan} is the total annual planed production time, and $\overline{q_S}$ is the mean availability losses during the year.

$$\mathrm{CO}_{2ei} = w_{CO_{2e}} \cdot \frac{E_c}{60} \cdot T_{\text{plan}} \cdot \overline{q_S} \cdot 60 \tag{8}$$

Equation 9 calculates the carbon dioxide emission associated to the active process during machining. The carbon dioxide weight factor for energy use is multiplied with the energy consumption per hour times the time of the activity. Equation 10 is used to estimate the material carbon dioxide emission per part based on rejection rate including process emissions. In the equation the w_{CO2m} is the weight factor per kg steel, W the total weight of the product, q_Q the quality rejection ratio and CO_2 the total emission for producing one product in the machining process.

$$Co_{2process} = w_{CO_{2e}} \cdot \frac{E_{ec}}{60} \cdot t_{0e} + w_{CO_{2e}} \cdot \frac{E_{hc}}{60} \cdot t_{0h} \tag{9}$$

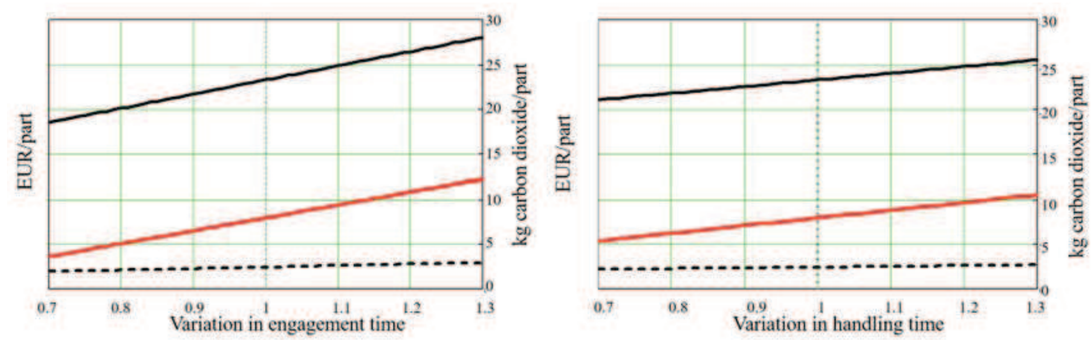
$$CO_{2w} = w_{Co_{2m}} \cdot W \cdot (1 + q_Q) + CO_{2process} \tag{10}$$

In Table 7, the processing part-cost (manufacturing part-cost subtracted from the material cost) and emitted CO_2 are related to changes in engagement time and handling time in the machining machine. If necessary data was available, it would also be possible to connect changes in engagement time with changes in used additives and cutting fluids. The result presented in Table 7 is also displayed in Figure 6, which shows the mathematical scenario simulation showing the possible CO_2 savings from reducing production time in the used equipment. The dotted vertical lines show the present state, the lower dashed black line corresponds to the CO_2 emission from Swedish consumption, the upper black line the average in the EU, and the red line the part-cost. The right and left diagrams in Figure 6 have the same scale both in costs and in carbon dioxide emissions, making it possible to compare the results. There is no simulation of cost with different energy cost dependent on production location due to the electric cost is not a significant part of the production cost in the manufacturing operation investigated. In addition, the factor between the most expensive region in Europe compare to Sweden have a factor two (Swedish Energy Agency, 2018), which would not make a notable difference in the simulations if Swedish and average European electrical prices were used.

The scenario simulation in Figure 7 shows how the total cost of downtime during equipment idling during active plant hours and total emission are affected by the total downtime rate during a year. The dashed line gives

Table 7 Energy carbon dioxide emissions based on production location and process cost not including the material cost in relation to changes in engagement time and handling time.

	Energy emissions – Sweden (CO_2/part)	Energy emissions – EU Average (CO_2/part)	Change in processing cost (€/part)
Current situation (t_0=1.5h)	2.5 kg	23.3 kg	-
Engagement time -20%	2.1 kg	20.1 kg	-14.0
Handling time -20%	2.3 kg	21.8 kg	-8.6
Engagement time +20%	2.8 kg	26.5 kg	+14.4
Handling time +20%	2.6 kg	24.8 kg	+8.5



(a) (b)

Fig. 6 The correlation between (a) processing engaging time and (b) handling time and part cost (red) and CO_2 emission per part (black) for EU average (line) and Sweden (dashed),where 1 on the x-scale represent the current state.

the current state, the lower black line corresponds to the CO_2 emission from Swedish consumption, the upper black line the average in the EU, and the red line cost relates to equipment and personnel availability losses. During downtime, the equipment is idling, using electricity, occupying floor space and the operator still has to be available. CO_2 emissions can be reduced if the operator can turn off the equipment during longer planned standstills, and if availability losses are improved, higher utilization of both energy, equipment and personnel can be achieved.

In Figure 8, the carbon emission per product as function of the rejection rate is showed. The more rejections, the more the final products need to carry of the carbon emissions of the rejected parts. The figures are based on virgin materials. The red line also shows the cost function based on the rejection ratio. In this case study, one product of virgin steel corresponds to about 1800 kg CO_2 emissions. Assuming that recycled steel material resemble to about 30 % energy use (Chen et al., 2001) of manufacturing of new raw material, the environmental impact of scraping one product correspond to about 360 hours active rework (in the same production process) (see calculations below).

(1800 (from material) + 2.5 (from process)) kg CO_2 / 0.045g CO_2 / kWh*33kW)*0.3 = 364 h

The scenario simulation shows how the part-cost and emission are affected by quality rejections based on rejection rate. The CO_2 rate is 1.8 kg per 1 kg steel, based on a 1,000 kg steel frame. As can be seen in Figure 8, the part-cost does not have a linear relationship to the final rejection rate, due to the performance parameters being in the denominators in the equation. The secondary y-axis shows the total CO_2 emissions that each part must bear due to the rejection rate. Having a rejection rate of 1.5 % on 1000 kg steel frames would correspond to an addition of about 27 kg CO_2/part whereas 30 % reduced engagement time would correspond to a reduction of about 4.75 kg CO_2/part and the same reduction in machine handling time to 2.3 kg CO_2/part based on energy consumed in an EU average country. In the case of a total reduction of availability losses, a total of about 4300

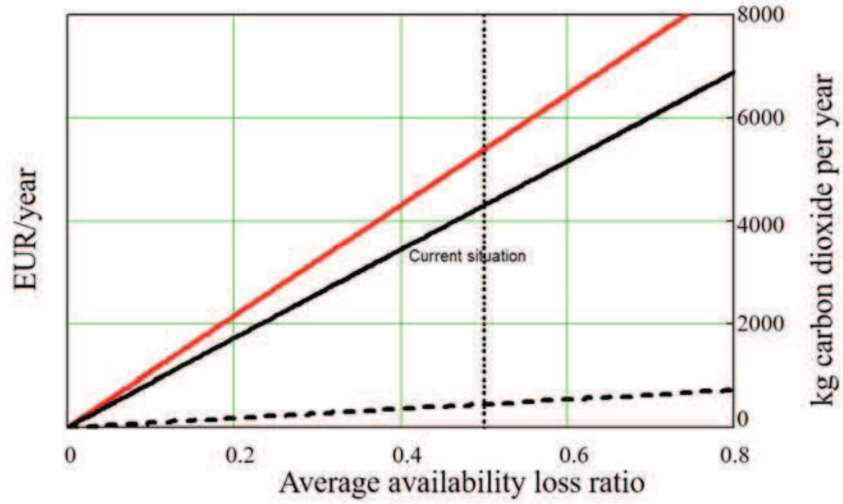


Fig. 7 Correlation between availability losses in idling equipment and cost (red) respectively CO_2 emissions (black) for EU average (upper line) and Sweden (lower dashed line).

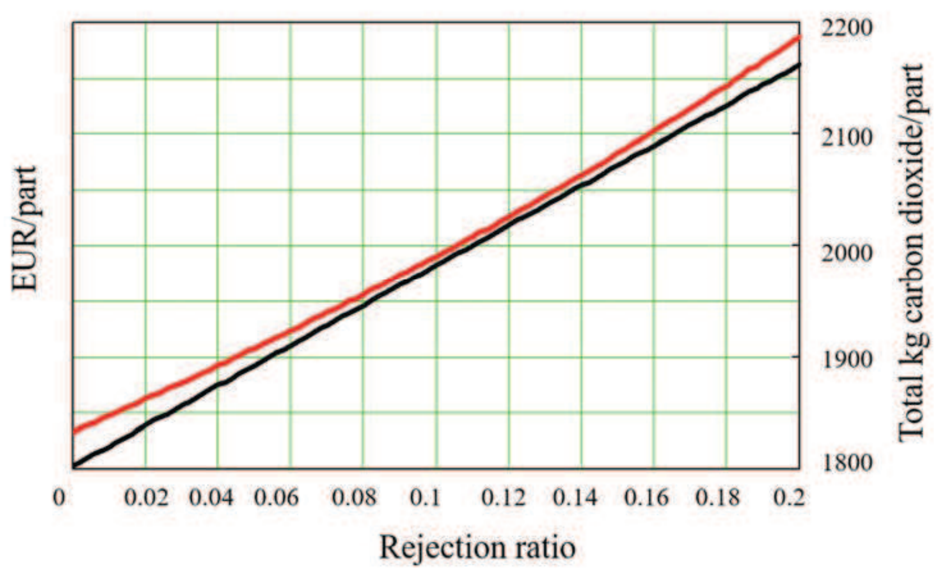


Fig. 8 Cost (red) and CO_2 (black) emission of virgin steel as functions of the rejection ratio. All other parameters in the cost equation are fixed, downtime = 30 %.

kg of unnecessary CO_2 emissions could be saved, corresponding to 1.8 kg CO_2/part if the production volume is 2400 parts per year. In a Swedish average company this would entail about 0.5 kg CO_2/part and 0.24 kg CO_2/part for 30 % reduced engagement time and handling time, and if all downtime and equipment idling was reduced 0.18 kg CO_2/part per part could be saved. For the company investigated, improvements reducing all idling of equipment and reduction of engagement time and handling time with 30 % would mean in total correspond to about 0.9 kg CO_2/part and cost saving on 50 %. Where most of the cost savings can be made from minimizing availability losses. An interesting observation is that it requires less than one rejected product to reach the level of CO_2 emissions as during all reported idling time in the equipment.

6 Discussions

Sweden has historically had good results in the Environmental Performance Index (EPI) making it an interesting country to analyze concerning the incentive for sustainable improvements at manufacturing companies. The survey gives insight into how representatives in Swedish industry perceive the importance of cost drivers and sustainability in their organization. The number of respondents is not high enough to make any general conclusions and a higher number of responses from a larger number of firms is needed for a statistically sound result for the whole manufacturing industry. However, the answers could be used as indicators of the perception in Swedish manufacturing industries.

As revealed in Figure 2, the respondents from the survey companies with the lower levels of energy consumption and environmental impact are those perceiving to be realizing their full company potential regarding sustainability. The companies facing the biggest sustainability challenges are those having furthest away from reaching their potential. Either the Level 3 companies have a harder time surveying and distinguishing between which improvements to make or they have a too steep uphill struggle to start making adequate sustainability improvements. The Level 1 companies are possibly able to pick low-hanging fruits and have no need to make dramatic changes in their production to achieve increased sustainability, when compared to Level 3 companies. From the survey, it was also possible to see that the sustainability areas the companies were working with the least were in improving sustainable material, sustainable energy sources, reduction of additives and transport efficiency/reduced impact on environment from fuels. The reason for this result can be several. In the survey, individuals working with the manufacturing operations were targeted and that could be an explanation for a perceived low commitment for more sustainable transportations. One reason for low commitment for more sustainable energy sources could be the overall low environmental impact from energy sources in Sweden. Comparing the average CO_2 emission in Sweden to an average EU country, the emissions are about ten times lower per kWh (Moro & Lonza, 2018). However, the result indicates that the respondents perceive that commitment for increased sustainability at the companies is more about improving in-house sustainability impact than the sustainability impact from the whole supply chain.

Raw material of a product often entails more costs and energy than what is possible to save by improvements in the manufacturing processes, making the sourcing of material highly important both from an economic and an environmental perspective. This is particularly when the material is scrapped further up in the value chain. This issue is also raised in Isaksson (Isaksson, 2005), concerning the concrete industry, showing the importance of both viewing the production performance as well as product quality. Another possible way of improving the sustainability of product is to change to a material with more environmental friendly compounds. A change in material could affect the producibility of the product and hence can be related to change in manufacturing performance and thereby changes in manufacturing costs (Schultheiss et al., 2018). The scenario simulation shows that it is possible to connect performance parameters, such as, availability losses, cycle time and rejection ratio to the sustainability measure of CO_2 emission, simultaneously showing the corresponding cost impact. Figure 6 to Figure 8 show how cost and CO_2 emissions relate to each other in this specific case. Understanding on how design of a product and of how to change the process to minimize process scrap rate and waste related to design is also a possible way to reduce the total material waste (Shahbazi et al., 2018). Changes in product design and process design are not taken into consideration here, but is very interesting for future investigations.

Drivers and obstacles/barriers identified in the literature are mainly from case studies of different specific industry sectors and locations. In the survey, the most frequently reported driver for sustainability improvements is laws, regulations and standards, which is also one of the top reasons stated in literature. The respondents also mention this as one of the main reasons for differences in sustainability improvements between different production sites, suggesting that the location of the operation has an impact on the level of sustainability commitment. In addition, board and management directives, and resource distribution have central roles in initiating sustainability improvements. Other top factors are expected financial gains, such as clear expected costs savings, and expected profit. However, in many cases, this suggested approach would require measurements that are more detailed and more comprehensive assessment of KPIs and manufacturing costs.

Various laws and regulations prevail in different parts of the world and depending on where a plant is located there are different levels of demand and political incentives for sustainability improvements. Even though Swedish companies are considered to have high sustainability ambitions, laws and regulations are still the main driving force for becoming more sustainable. From the survey, it was found that 11 out of 13 respondents at companies with more than one production site perceived that there were differences in level of sustainability at different locations. One of the two that did not perceive any differences only have assembly as production method and the other have only Swedish production sites. Increasing the awareness of how economical and sustainability improvements explicitly correlate, can motivate companies to have global improvement strategies and thus reduce the importance of law and regulation in favor for board and management directions and financial gains, which both are top factors found in the survey facilitating future sustainability improvements.

When comparing cost drivers to obstacles for sustainability found in the literature and from the survey, it is possible to make the conclusion that there needs to be a pressure for sustainability improvements. It is also important to realize that many of the obstacles reported in the literature are the actual lack of triggers/drivers. For example, board decisions are found to be one of the perceived most important drivers for sustainability, but no clear directives and goals from management is also one of the perceived most prominent obstacles. The results from the survey indicate that the respondents consider social sustainability to be of lesser importance, since only two respondents chose “reduced personnel absence” as important, and no one picked “reduction of staff turnover” as drivers for sustainability. When making decisions on manufacturing development, it is important to know how the decision will improve the system. By using performance parameters at equipment level, such as speed losses, availability losses, and quality rejections, the knowledge level at both operator level and management level can be increased, thereby facilitating increased sustainability awareness. Increased knowledge and skill level of employees could upturn the importance of minimizing staff turnover and personnel absence, as knowledgeable employees could be more valuable in both economic and sustainability aspects. This could be an incentive for increased well-being at work, and thus increase the company sustainability. Sustainability will not happen by itself but needs incentives. Increased system knowledge could facilitate decision making, which is beneficial for both economy, occupational health and the environment.

The economic analysis conducted here is similar to the assessment made by Diaz-Elsayed et al. (Diaz-Elsayed et al., 2013) where lean improvements and sustainability are connected by cost simulations. However, the simulation here has a clearer correlation between performance measures and sustainability improvements as the cost-model is presented with more detail. This method, linking measurable operational key performance measures from a manufacturing process with both costs and other sustainability factors, could provide usable and transparent information when connected data is available. This is especially true if companies further implement the strategy of Industry 4.0 and big data. The analysis does not involve cutting fluids and other additives or the tool material, which in a sustainability perspective can be considered as important. The arguments for not involving additives in the study are partly because of the large variances in cutting fluid system as described in Kurdve and Daghini (Kurdve & Daghini, 2012), some of the information is on a too high aggregated level for useful analyses and because of a low economic impact on manufacturing cost in this particular case. However, the insight of not having detailed information about the consumption of additives may catalyze future knowledge on the matter at the case study company. Another important aspect not taken into consideration is the knowledge level of operators. With more advanced equipment, the skill level in terms of handcraft operation is reduced, but expertise in problem solving, programming and planning is often needed. Performance in the manufacturing operations would be possible to connect to total hours, amount of and type of training, or work experience. More studies would have to be performed together with more detailed performance measures.

7 Conclusions

The outset of this study is the assumption that tangible cost connected to specific improvements could facilitate sustainability improvements. It was not possible to find any clear most important cost driver, but production efficiency, material costs, direct/indirect labor costs, adjustments, number of unique products, complexity of product design, equipment efficiency, material efficiency, energy consumption, quality control, production volume, and cycle time where the top ranked cost drivers in the survey, answering RQ1. To answer RQ2, there are no clear main drivers or obstacles. The respondents perceive laws and regulations as one of the main drivers for sustainability improvements, but clearer directives from boards and managements were also perceived as an important factor for increasing sustainability focus in manufacturing. Economic aspects were perceived as both drivers, but also as obstacles for sustainability improvements.

The paper shows that an existing performance-based cost-model can be used for aligning sustainability and cost assessment. However, the cost-model needed to be complemented with calculations for CO_2 emissions in this case. Some adjustments were also made in the cost-model to capture two different types of equipment process-modes, with higher and lower energy consumptions. In that regard, the model used here shows promise for future usage of specific and generic evaluations of production systems. The scenario simulation shows the possible monetary and CO_2 savings of a steel product in a machining operation. The simulation provides the information on what improvement in production efficiency (stated important cost driver) that provides the most reduction in production costs and CO_2 emissions (RQ3). In the simulations, we can see the low impact on the environmental load when increasing the efficiency of the production processing time, but the greater impact from reducing scrapped or rejected material. This is not novel in itself, but by integrating manufacturing monitoring measures with environmental measures, the option to monitor environmental and sustainability measures on a daily basis can be facilitated. By daily monitoring and relating measurements to activities on the manufacturing floor, the understanding of which action matters the most can support employees to be "champions" in their organization to contribute to more sustainable activities. It could also be easier for the manufacturing management to set measurable goals and support their employees' awareness of the impact of their actions and choices.

The presented model shows the relation between manufacturing cost and sustainability, using performance parameters important for the manufacturing industry. In the simulations, it is easy to see the impact from manufacturing losses, both on manufacturing costs and carbon emission and visualize the actual impact. Simple calculations, using measurable performance measurements from manufacturing activities such as quality rejections and availability ratio can be used to assess the environmental load from such manufacturing losses.

Both the survey results and the scenario simulations indicate that sustainability awareness and improvements could gain from a clearer alignment between sustainability and financial gain. However, the result from the survey is not statistically significant for the manufacturing industry in general due to the low number of respondents. The results from this study indicate that there could be a considerable gain, both financially and in sustainability, if performance is included in the estimation of the production cost. The option to see the alignment between the two could promote decisions on sustainable improvement. The findings from both literature and in the survey indicate that if the correlation between financial gain and sustainability were clearer, the probability for directives and initiatives from board and management would be higher, facilitating future sustainability improvements. Future research would be to further test the analyzing method, using in-depth data such as presented in (Orji & Wei, 2016) where cutting data and more detailed information are complemented with performance measures used here to calculate the cost and sustainability factors corresponding to more than CO_2 emissions. In addition, further analyses is necessary to find the economic impact from the social dimension such as education hours and skill level of personnel.

Acknowledgments

The project SuRe-BPMS is granted by the Swedish Strategic Innovation program Production 2030, financed by Vinnova, Formas and Swedish Energy Agency. The research is also a part of the Sustainable Production Initiative, SPI, with is a cooperation between Lund University, Lund and Chalmers University, Gothenburg, Sweden

References

Alayón, C., Säfsten, K.S., and Johansson, G. (2017), Conceptual sustainable production principles in practice: Do they reflect what companies do? *Journal of Cleaner Production*, **141**, 693-701. https://doi.org/10.1016/j.jclepro.2016.09.079.

Amrina, E. and Yusof, S.M. (2011), Key performance indicators for sustainable manufacturing evaluation in automotive companies. 2011 *IEEE International Conference on Industrial Engineering and Engineering Management*, 1093-1097. https://doi.org/10.1109/IEEM.2011.6118084.

Ashby, M.F. (2012), Materials and the environment? eco-informed material choice (2nd ed.), Butterworth-Heinemann.

Asiedu, Y. and Gu, P. (1998), Product life cycle cost analysis: State of the art review, *International Journal of Production Research*, **36**(4), 883-908. https://doi.org/10.1080/002075498193444.

Azapagic, A. (2004), Developing a framework for sustainable development indicators for the mining and minerals industry, *Journal of Cleaner Production*, **12**(6), 639-662. https://doi.org/10.1016/S0959-6526(03)00075-1.

Banker, R.D., Potter, G., and Schroeder, R.G. (1995), An empirical analysis of manufacturing overhead cost drivers. *Journal of Accounting and Economics*, **19**(1), 115-137. https://doi.org/10.1016/0165-4101(94)00372-C.

Bansal, P. (2003), From Issues to Actions: The Importance of Individual Concerns and Organizational Values in Responding to Natural Environmental Issues, *Organization Science*, **14**(5), 510-527. https://doi.org/10.1287/orsc.14.5.510.16765.

Ben-Arieh, D. and Qian, L. (2003), Activity-based cost management for design and development stage, *International Journal of Production Economics*, **83**(2), 169-183. https://doi.org/10.1016/S0925-5273(02)00323-7.

Chen, T.Y., Burnett, J., and Chau, C.K. (2001), Analysis of embodied energy use in the residential building of Hong Kong, *Energy*, 26, 323-340. https://ac.els-cdn.com/S0360544201000068/1-s2.0-S0360544201000068-main.pdf?_tid=c80592d3-9820-4756-b629-8e7d7fb2fd89&acdnat=1543401417_b3ee3606f8e7d7e0d57ca20fc3a58a25

Datar, S.M., Kekre, S., Mukhopadhyay, T., and Srinivasan, K. (1993), Simultaneous Estimation of Cost Drivers, *The Accounting Review*, 68(3), 602-614. http://www.jstor.org/stable/248203.

Diaz-Elsayed, N., Jondral, A., Greinacher, S., Dornfeld, D., and Lanza, G. (2013), Assessment of lean and green strategies by simulation of manufacturing systems in discrete production environments, *CIRP Annals - Manufacturing Technology*, **62**(1), 475-478. https://doi.org/10.1016/J.CIRP.2013.03.066.

Dummett, K. (2006), Drivers for corporate environmental responsability (CER), *Environment, Development and Sustainability*, **8**, 375-389. https://doi.org/10.1007/s10668-005-7900-3.

Eashwar, S. and Geetha, G. (2017), Trade-off between time, cost, quality, safety, environment - star optimization model, *International Journal of Control Theory and Applications*, **9**(11), 5467-5486.

EIA. (2019), International Energy Outlook 2019, https://www.eia.gov/outlooks/ieo/.

Elkington, J. (1994), Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development, *California Management Review*, **36**(2), 90-100. https://doi.org/10.2307/41165746.

EPI. (2018), Environmental Performance Index. https://epi.envirocenter.yale.edu/epi-country-report/SWE.

Fan, C., Carrell, J.D., and Hong-Chao, Z. (2010), An investigation of indicators for measuring sustainable manufacturing, *Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology*, 1-5. https://doi.org/10.1109/ISSST.2010.5507764.

Foster, G. and Gupta, M. (1990), Manufacturing overhead cost driver analysis, *Journal of Accounting and Economics*, **12**(1), 309-337. https://doi.org/10.1016/0165-4101(90)90052-6.

Garg, A. (2015), Green Marketing for Sustainable Development: an Industry Perspective, *Sustainable Development*, **23**(5), 301-316. https://doi.org/10.1002/sd.1592.

Global Reporting Initiative. (2000), Sustainability Reporting Guidlines on economic, *Environmental and Social Performance*, (Issue June).

Global Reporting Initiative. (2005), GRI Boundary Protocol. https://www2.globalreporting.org/resourcelibrary/GRI-Boundary-Protocol.pdf

Global Reporting Initiative. (2017), Linking the SDGs and GRI. https://www.globalreporting.org/resourcelibrary/SDG_GRI_LInkage.pdf.

Hart, S.L., Milstein, M.B., and Caggiano, J. (2003), Creating Sustainable Value, *The Academy of Management*, **17**(2), 56-69. http://www.jstor.org/stable/4165956.

Hasanbeigi, A., Arens, M., and Price, L. (2014), Alternative emerging ironmaking technologies for energy-efficiency and carbon dioxide emissions reduction: A technical review, *Renewable and Sustainable Energy Reviews*, **33**, 645-658. https://doi.org/10.1016/j.rser.2014.02.031.

Hauschild, M., Jeswiet, J., and Alting, L. (2005), From Life Cycle Assessment to Sustainable Production: Status and Perspectives, *CIRP Annals - Manufacturing Technology*, **54**(2), 1-21. https://doi.org/10.1016/S0007-8506(07)60017-1.

Hayes, R.H. and Clark, K.B. (1985), Explaining Observed Productivity Differentials between Plants: Implications for Operations Research, *Interfaces*, **15**(6), 3-14. http://eds.b.ebscohost.com/eds/pdfviewer/pdfviewer?vid=10&sid=744aa544-ebbc-4f70-a067-8d5b42040003%40sessionmgr102.

Hayes, R.H., Wheelwright, S.C., and Clark, K.B. (1988), Dynamic Manufacturing: Creating the Learning Organisation. The free press.

Ho, M.T., Bustamante, A., and Wiley, D.E. (2013), Comparison of CO 2 capture economics for iron and steel mills, *International Journal of Greenhouse Gas Control*, **19**, 145-159. https://doi.org/10.1016/j.ijggc.2013.08.003.

Hon, K.K.B. (2005), Performance and Evaluation of Manufacturing Systems, *CIRP Annals*, **54**(2), 139-154. https://doi.org/https://doi.org/10.1016/S0007-8506(07)60023-7.

Isaksson, R. (2005), Economic sustainability and the cost of poor quality, *Corporate Social Responsibility and Environmental Management*, **12**(4), 197-209. https://doi.org/10.1002/csr.85.

Ittner, C.D., Lanen, W.N., and Larcker, D.F. (2002), The Association Between Activity-Based Costing and Manufacturing Performance, *Journal of Accounting Research*, **40**(3), 711-726. https://doi.org/10.1111/1475-679X.00068.

Johnson, T.H. and Kaplan, R.S. (1987), Relevance lost: the rise and fall of management accounting, Harvard Business school press.

Jönsson, M. (2012), Cost-conscious manufacturing - Models and methods for analyzing present and future performance from a cost perspective, Lund University.

Kaplan, R.S. and Cooper, R. (1998), Cost and Effect - Using Integrated Cost Systems to Drive Profitability and Performance. Harvard Business Press.

Krajnc, D. and Glavic, P. (2003), Indicators of sustainable production, *Clean Technologies and Environmental Policy*, **5**(3-4), 279-288. https://doi.org/10.1007/s10098-003-0221-z.

Kurdve, M. and Daghini, L. (2012), Sustainable metal working fluid systems: best and common practices for metal working fluid maintenance and system design in Swedish industry, *Int. J. Sustainable Manufacturing*, **2**(4), 276-292. https://www.inderscienceonline.com/doi/pdf/10.1504/IJSM.2012.048582.

Le Roux, C. and Pretorius, M. (2016), Navigating Sustainability Embeddedness in Management Decision-Making, *Sustainability*, **8**(5), 444. https://doi.org/10.3390/su8050444.

Lee, K.H. (2015), Drivers and Barriers to Energy Efficiency Management for Sustainable Development, *Sustainable Development*, **23**(1), 16-25. https://doi.org/10.1002/sd.1567.

Léon, H.C.M. and Calvo-Amodio, J. (2017), Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective, *Journal of Cleaner Production*, **142**, 4384-4402. https://doi.org/10.1016/j.jclepro.2016.11.132.

Mehra, S., Inman, R.A., and Tuite, G. (2005), A simulation-based comparison of TOC and traditional accounting performance measures in a process industry, *Journal of Manufacturing Technology Management*, **16**(3), 328-342. https://doi.org/10.1108/17410380510583635.

Mittal, V.K. and Sangwan, K.S. (2011), Development of an interpretive structural model of obstacles to environmentally conscious technology adoption in Indian industry. *Glocalized Solutions for Sustainability in Manufacturing - Proceedings of the 18th CIRP International Conference on Life Cycle Engineering*, 383-388. https://doi.org/10.1007/978-3-642-19692-8-66.

Moro, A. and Lonza, L. (2018), Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles, *Transportation Research Part D*, **64**, 5-14. https://doi.org/10.1016/j.trd.2017.07.012.

Niazi, A., Dai, J.S., Balabani, S., and Seneviratne, L. (2006), Product Cost Estimation: Technique Classification and Methodology Review, *Journal of Manufacturing Science and Engineering*, **128**(2), 563-575. https://doi.org/10.1115/1.2137750.

Nordheim, E. and Barrasso, G. (2007), Sustainable development indicators of the European aluminium industry, *Journal of Cleaner Production*, **15**(3), 275-279. https://doi.org/10.1016/j.jclepro.2006.02.004.

Ocampo, L.A. and Clark, E.E. (2014), Developing a Framework for Sustainable Manufacturing Strategies Selection, *DLSU Business & Economics Review*, **23**(2), 115-131.

Orji, I. and Wei, S. (2016), A detailed calculation model for costing of green manufacturing, *Industrial Management & Data Systems*, **116**(1), 65-86. https://doi.org/10.1108/IMDS-04-2015-0140.

Oxborrow, L. and Brindley, C. (2012), Adoption of "eco-advantage" by SMEs: emerging opportunities and constraints, *Eu-*

ropean Journal of Innovation Management, **16**(7), 355-375. http://www.emeraldinsight.com/doi/pdfplus/10.1108/EJIM-09-2011-0079.

Salmi, A., David, P., Blanco, E., and Summers, J.D. (2016), A review of cost estimation models for determining assembly automation level, *Computers & Industrial Engineering*, **98**, 246-259. https://doi.org/10.1016/j.cie.2016.06.007.

Schultheiss, F., Windmark, C., Sjöstrand, S., Rasmusson, M., and Ståhl, J. (2018), Machinability and manufacturing cost in low-lead brass, *International Journal of Advanced Manufacturing Technology*, **99**(9-12), 2101-2110.

Shahbazi, S., Jönsson, C., Wiktorsson, M., Kurdve, M., and Bjelkemyr, M. (2018), Material efficiency measurements in manufacturing: Swedish case studies, *Journal of Cleaner Production*, **181**, 17-32. https://doi.org/10.1016/j.jclepro.2018.01.215.

Shahbazi, S., Wiktorsson, M., Kurdve, M., Jönsson, C., and Bjelkemyr, M. (2016), Material efficiency in manufacturing: swedish evidence on potential, barriers and strategies, *Journal of Cleaner Production*, **127**, 438-450. https://doi.org/10.1016/j.jclepro.2016.03.143.

Ståhl, J.E. (2017), An integrated cost model for metal cutting operations based on engagement time and a cost breakdown approach, *International Journal of Manufacturing Research*, **12**(4), 379-404. https://doi.org/10.1504/IJMR.2017.088397.

Ståhl, J.E., Andersson, C., and Jönsson, M. (2007), A basic economic model for judging production development, 1th Swedish Production Symposium.

Stål, C., Ståhl, J.E., Gabrielson, P., and Andersson, C. (2012), A production performance analysis regarding downtime and downtime pattern, *Presented at the 22nd International Conference on Flexible Automation and Intelligent Manufacturing*, FAIM., 809-820.

Swedish Energy Agency. (2018), Fördjupning Den europeiska elmarknaden-elpriser och slutkundspriser [Swedish].

Swedish Energy Agency. (2021). https://www.energimyndigheten.se/en/.

Thollander, P. and Ottosson, M. (2008), An energy efficient Swedish pulp and paper industry - exploring barriers to and driving forces for cost-effective energy efficiency investments, *Energy Efficiency*, **1**(21), 21-34. https://doi.org/10.1007/s12053-007-9001-7.

Tseng, Y.J. and Jiang, B.C. (2000), Evaluating Multiple Feature-Based Machining Methods Using an Activity-Based Cost Analysis Model, *Int J Adv Manuf Technol*, **16**, 617-623. https://link.springer.com/content/pdf/10.1007%2Fs001700070031.pdf.

United Nations. (1987), Our Common Future - Brundtland Report. In Oxford University Press.

United Nations. (2020), About the Sustainable Development Goals - United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/sustainable-development-goals//.

Veleva, V. and Ellenbecker, M. (2001), Indicators of sustainable production: Framework and methodology, *Journal of Cleaner Production*, **9**(6), 519-549. https://doi.org/10.1016/S0959-6526(01)00010-5.

Windmark, C. (2018), Performance-based costing as decision support for development of discrete part production - Linking performance, production costs, and sustainability [Lund University]. http://lup.lub.lu.se/search/ws/files/48190697/Windmark_C.pdf.

Windmark, C. and Andersson, C. (2016), Analysis of the potential of assessing sustainable production with a cost model, *7th International Swedish Production Symposium.*

Winroth, M., Almström, P., and Andersson, C. (2016), Sustainable production indicators at factory level, *Journal of Manufacturing Technology Management*, **27**(6), 842-873. https://doi.org/10.1108/JMTM-04-2016-0054.

WWF. (2017), Harnessing Forces for Conservation Initiatives WWF. http://www.worldwildlife.org/initiatives/harnessing-forces-for-conservation.

Xu, Y., Elgh, F., Erkoyuncu, J.A., Bankole, O., Goh, Y., Cheung, W.M., Baguley, P., Wang, Q., Arundachawat, P., Shehab, E., Newnes, L., and Roy, R. (2012), Cost Engineering for manufacturing: Current and future research, *International Journal of Computer Integrated Manufacturing*, **25**(4-5), 300-314. https://doi.org/10.1080/0951192X.2010.542183.

Zackrisson, M., Kurdve, M., Shahbazi, S., Wiktorsson, M., Winroth, M., Landström, A., Almström, P., Andersson, C., Windmark, C., Öberg, A.E., and Myrelid, A. (2017), Sustainability performance indicators at shop floor level in large manufacturing companies, *Procedia CIRP*, **61**, 457-462. https://doi.org/10.1016/j.procir.2016.11.199.