Sustainability Performance Indicators for Supporting the Realization of Sustainable and Energy-Efficient Manufacturing

Tapaninaho Mikko, Koho Mikko, Nylund Hasse, Heilala Juhani and Torvinen Seppo

Abstract The importance of performance measurement and indicators in realizing energy-efficient and, in broader perspective, sustainable manufacturing has been noticed and realized by the industry and academia. Although several frameworks for sustainability performance measurement and reporting exist, those focus mainly on corporate level and hence fail to provide adequate support for factory planning and management. This paper and the related research projects are motivated by this need to provide manufacturing companies with sustainability performance indicators that better support the realization of sustainable and energy-efficient manufacturing. The proposed paper aims to set the stage and to present the initial steps for identifying or developing sustainability key performance indicators that cover the three aspects of sustainability, economic, social, and environmental, and are linked to the improvement possibilities and measures at shop-floor level. The proposed paper contributes to the conference and the workshop by discussing performance indicators for planning and management of sustainable and energy-efficient factories. The paper presents guidelines and research needs for academia, while the related research projects intend to provide the industry with useful sustainability performance indicators for factory planning and management.

1 Introduction

Meeting the needs of the present without compromising the ability of future generations to meet their own needs is the often presented definition of sustainable development [1]. Achieving this objective and finding the balance between the

T. Mikko (✉) · N. Hasse · T. Seppo
Department of Production Engineering, Tampere University of Technology, Tampere, Finland
e-mail: mikko.tapaninaho@tut.fi

K. Mikko · H. Juhani
VTT Technical Research Centre of Finland, Tampere, Finland

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continuously increasing consumption and the limited resources of our planet have proven to be difficult tasks. This is demonstrated by the observation that at present, industrial systems are not sustainable in the long term due to their growing demand and use of non-renewable resources, demonstrates that [2]. Hence, more work and information on how to achieve and realize sustainability and sustainable development is needed.

This paper and related "Visualization of Sustainability Key Performance Indicators" (VS-KPI) research project build on previous sustainability and sustainable manufacturing related research projects carried out by the authors' organizations. The state of art and the state of practice in sustainability and sustainable development as well as challenges of and needs for realizing sustainability in industry were reviewed in a national research project "Competitive and sustainable production systems and networks" and in a EU-projects "SustainValue" and "Eco-Process Engineering System for Composition of Services to Optimize Product Life-Cycle". In these projects, the need for creating new sustainability criteria and indicators and means to measure sustainability performance and success was highlighted. These were seen as the key enablers toward sustainability and sustainable manufacturing [3–5]. Then, two national research projects "Framework and toolset for developing, analyzing, and controlling sustainable and competitive production networks" and "Eco-Efficient Production" focused on methods and tools for assessing sustainability or products, processes, and production systems. Although a wide variety of such tools and methods are available, a clear need for performance indicators that assist in designing, operating, and improving production systems and processes was identified.

The current research project (VS-KPI) aims to correct the identified gaps and shortcomings in sustainability performance measurement. The research project is based on observation that currently sustainability measurement and reporting is mainly carried out by large companies in annual CSR (Corporate Social Responsibility) or Sustainability reporting. Such reports provide high level, aggregated data, but the link to improvement possibilities and efforts is missing or, at best, weak. Thus, there is a disconnection between sustainability data and reports and those capable of influencing sustainability in manufacturing and product design (e.g., product and production engineers, operators, and managers at different levels of organization). To bridge this gap, sustainability key performance indicators covering the three aspects of sustainability, economic, social, and environmental, need to be identified or developed for manufacturing and product design and for different levels within an organization. In more detail, VS-KPI project seeks to:

- Identify and/or develop set of sustainability performance indicators focusing mainly on product design and manufacturing
- Group the participating companies based on their sustainability measurement practices and needs in order to propose relevant and useful sustainability key performance indicators for the company groups.

The theoretical background covers sustainable development, sustainable manufacturing, factory planning, and management. Based on these, the role of performance measurement and indicators in realizing sustainable manufacturing is clarified. Then, the available sustainability performance indicators and frameworks are reviewed, and their usefulness in planning and managing sustainable and energy-efficient factories is considered. Finally, the need for further research and development and initial steps aiming to develop sustainability performance indicators for realizing sustainable and energy-efficient manufacturing are presented.

2 Theoretical Background: Sustainable Manufacturing, Factory Planning and Performance Measurement

2.1 Sustainable Development Definitions and Approaches

Sustainable development has been defined in many ways, but the most frequently cited definition is “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1].” The definition highlights two aspects, first the needs and consumption, and secondly our environment’s and planet’s ability to meet and fulfil the needs now and in the future [1].

As the above definition indicates, sustainable development is dependent on both the consumers and the producers. This can be clearly seen in the definitions of sustainable production and sustainable consumption. The Lowell Centre for Sustainable Production [6] has defined sustainable production as “the creation of goods and services using processes and systems which are non-polluting, conserving of energy and natural resources, economically viable, safe and healthful for employees, communities, consumers and socially and creatively rewarding for all working people.” Additionally, sustainable consumption is “the use of goods and services that respond to basic needs and bring a better quality of life, while minimizing the use of natural resources, toxic materials and emissions of waste and pollutants over the life cycle, so as not jeopardize the needs of future generations [7].” These definitions also demonstrate that the actions of both individuals and companies have an effect on sustainability.

Sustainable development is typically further divided into three pillars, economical, social, and environmental sustainability. These three aspects are also referred to as “the triple bottom line” or “the 3 P’s”: planet, people, and profit (e.g., [1, 8, 9]). In this paper and research project, two additional aspects, technological and political, are also included and so called STEEP-framework or approach for sustainability is used [10]. The aspect of economical sustainability focuses on securing economic viability in short and long range. According to Jovane et al. [11] social sustainability can be achieved as people feel that they can have a fair share of wealth, safety, and influence. Environmental sustainability,

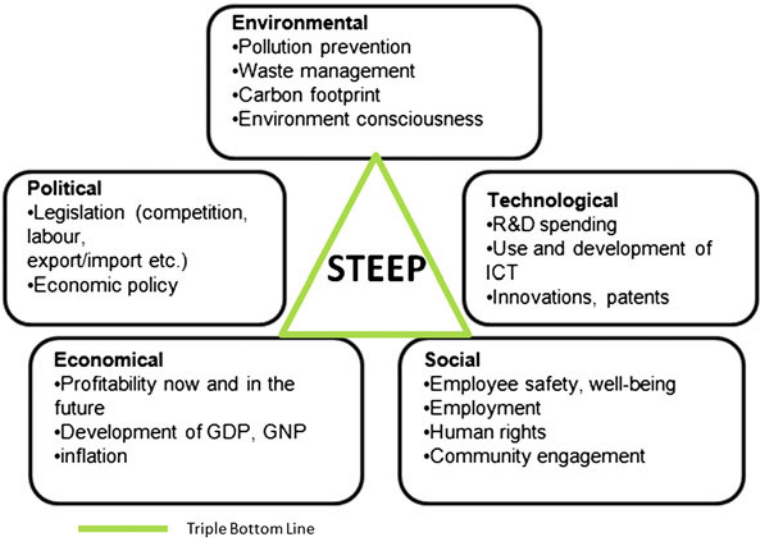

Fig. 1 Steep framework and the triple bottom line

"seeks to improve human welfare by protecting the sources of raw material used for human needs and ensuring that the sink for human wastes are not exceeded, in order to prevent any harm caused to human beings" [12]. In addition to those three also political and technological aspects are considered. Technology can offer significant potential in sustainable development and it can be seen as an enabling and empowering aspect (e.g., [11]). Finally, the political aspect is related, for example to national or international regulations and legislation. Figure 1 summarizes the STEEP-framework and presents examples for the five aspects as well as the triple bottom line.

2.2 *Required Changes and Potential Advantages of Sustainable Development*

Realizing sustainable development at company level requires changes within the company and its operations, but it also offers a number of benefits and advantages. The Ad-hoc Industrial Advisory group states that pursuing and achieving the objectives of sustainable development implies changes to different areas such as technology, processes, organizational culture, and management [13]. New technologies in products and processes are needed and these can reduce the environmental effects such as material and energy consumption, and emissions generated. In terms of processes, the current trend of utilizing end-of-pipe technology for decreasing the company's environmental impact needs to be changed and the sustainability and environmental issues must be considered and improved in every phase of the production process [14]. Such improvements could focus for example on process efficiency or on increasing recycling and reuse of waste materials. Finally, from the perspective of organizational culture and management, sustainability should be regarded as a way of increasing company's competitiveness rather than as a source of additional costs. It should have a central role in company's strategy, vision and, decision making [15, 16]. One way of increasing the role and importance of sustainability and sustainable development both within a company and in relation to its stakeholders, is measuring and reporting sustainability-related initiatives, results, and performance. For this, comprehensive metrics to measure sustainability are available, for example, the Organisation for Economic Co-operation and Development (OECD) and Global Reporting Initiative (GRI) has formed a set of key metrics for companies to use. [17, 18]. Also National Institute of Standards and Technology (NIST) has examples of indicators in the Sustainable Manufacturing Indicator Repository [19].

2.3 Factory Planning

Performance measurement and indicators have a key role in designing, operating, and improving factories, production systems and production processes. Several process models for planning and designing factories and production systems have been presented and all these include performance measurement as an integral part. For example, Lapinleimu et al. [20] (Fig. 2) and Vaughn et al. [21] present production system design frameworks that proceed from strategic level, i.e., corporate and business strategy, via manufacturing strategy to design decisions including layout, control systems, resources, skills, technologies, and equipment. Both frameworks and processes include performance measurement, which is relevant in piloting and implementation phase as well as in operation of the designed manufacturing system. Müller and Löfler [22] present a factory planning process that starts from analysis and project definition and includes basic and detailed engineering before implementation and usage of the factory. In this model, performance measurement is necessary in analysis phase as well as in implementation and usage phases in which the actual operation and performance of the factory is monitored and compared to the set targets.

Performance measurement and indicators are very important also in improving performance of factories, production systems, and production processes. The well-known performance improvement models PDCA and DMAIC demonstrate this. The PDCA-model consists of Plan, Do, Check, and Act phases, while the DMAIC-model includes Define, Measure, Analyze, Improve, and Control phases. In both models, performance measurement and indicators are needed in the beginning (Plan, Define and Measure phases) where the initial situation and performance as well as the improvement need and potential are evaluated and identified. Then, in the Check and Control phases, the conducted improvement efforts and changes and

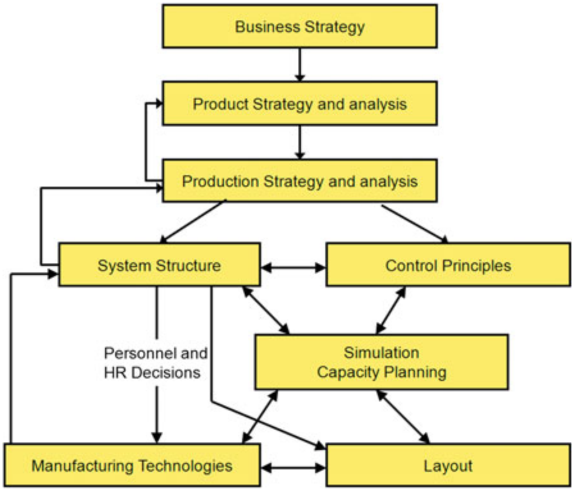

Fig. 2 Key steps to production system design (adapted from Lapinleimu et al. [31])

the performance of the new system or process are measured and compared to the targets set at the beginning. The Check and Control phases of these models are also related to the operation and usage of production systems and processes, where constant monitoring or system and process performance and comparison to targets is necessary in order to identify need to make changes in managing and controlling the system or process. It is also important to bring both traditional productivity indicators and sustainability indicators to the decision making process. Simulation and modelling can be used to analyze the performance of the product and production system, using traditional production performance measures and also taking into account environmental sustainability-related performance measures. Integration of sustainability and environmental aspects to simulations is one of the ongoing development efforts in many research projects, e.g., Eco-Process Engineering System for Composition of Services to Optimize Product Life Cycle [23].

2.4 Review of Sustainability Performance Measurement and Reporting

Individual manufacturing processes and the chain of processes they form together can be seen as an input–output system transforming the inputs to outputs. Hubka and Eder [24], in their theory of technical systems (TTS), classify the inputs and outputs into three types; material, energy, and information. In this paper, the study of environmental performance metrics is studied as an aggregated approach from machine level to corporate level.

In the category of material, material that flows thru the system and is realized as outputs is considered. Machines, tools, devices, humans, and the facilities are seen as the manufacturing resources that enable the transformation processes and therefore are not included in the category of material.

The viewpoints presented in this section are intended as the theoretical basis for structuring and developing a set of performance metrics. Behn [25] lists several important aspects of metrics which should be recognized:

- Evaluate the outcomes which are combined with the inputs and the expectations of exogenous factors
- To control the inputs which can be regulated
- Efficiency measures e.g., budgeting
- Metrics should provide almost real time data comparable with the production outputs
- Metrics should also provide easily understandable aspects of the current state of performance
- Metrics should provide the personnel significant and periodic achievement targets which give the personnel sense of collective and individual accomplishment
- Metrics should be a tool for learning as disaggregated data reveal deviances from the expected
- Metrics helps the company to improve their performance which connects changes in operations to changes in outputs and outcomes.

Additionally, performance metrics should be comparative rather than absolute assessments and it should be possible to quantify improvements [26]. Also, the ISO 14045:2012 standard takes a stance in choosing environmental indicators. ISO 14045:2012 states that indicators should present a quantitative statement. Furthermore, the standard describes the requirements for choosing indicators as follows, the increase in the production system value should represent an improved environment and decrease in environmental impact should represent improvements in production system [27].

Currently, a number of sources provide a large set of metrics. In the following is listed some of the generally accepted set of metrics. The most widely referred set of metrics are the Global Reporting Initiative (GRI G3 guidelines (80 indicators), OECD Sustainable Manufacturing Indicators (18 indicators) and EUROSTAT Sustainable Consumption and Production Indicators (15 indicators) [17, 18, 28].

Companies in general struggle to find standardized metrics and the amount of different metrics generally distract the companies from the ones which are essential for the company to measure. A review on sustainable metrics provided 41 different sets of metrics in this domain [29]. Additionally in terms of sustainable development, companies need metrics which takes a stance in terms of all the aspects of sustainable development. Typical examples of environmental performance indicators, related to the focus companies of this paper i.e., mechanical engineering industry, based on the GRI G3 guidelines, are [17]:

- Materials used by weight or volume
- Percentage of materials used that are recycled input materials

- Direct and indirect energy consumption by primary source
- Total weight of waste by type and disposal method
- Total direct and indirect greenhouse gas emissions by weight
- Significant environmental impacts of transporting products and other goods and materials used for the organization's operations.

3 Aggregated Sustainable Key Performance Indicator Design

Different levels of organization are responsible for different areas of manufacturing activities and therefore are interested in different performance measures. Figure 3 presents a basic view of the strategic, tactical, and operational levels of a manufacturing company.

The operational level consists of the process and production domains. The main responsibility of the people working on the shop-floor is to keep the manufacturing processes running and to create right quality at right time. Hence, metrics are needed to control the manufacturing processes to keep the behavior and characteristics of the activities within accepted limits.

The tactical level can be roughly divided into production planning and production system development. The main difference is the temporal focus. The production planning focuses on controlling and evaluating the daily manufacturing activities on the shop-floor. Production system development focuses more on how the system will manage with the changing requirements and constraints in the future. At the tactical level, the interest is on the metrics concerning on manufacturing performance and the timely flow on material and information.

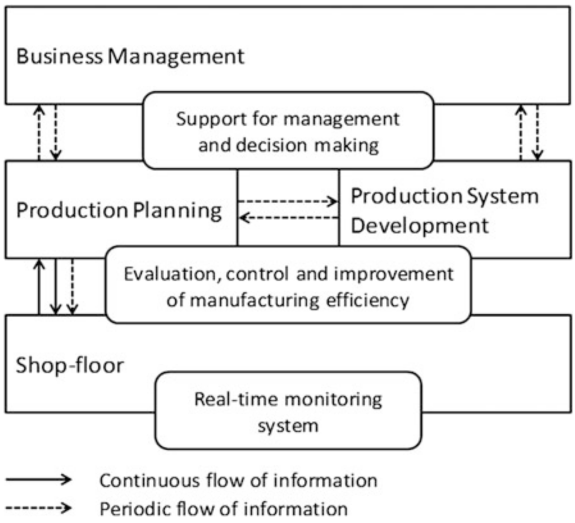

Fig. 3 Information transfer between strategic, tactical, and operational levels

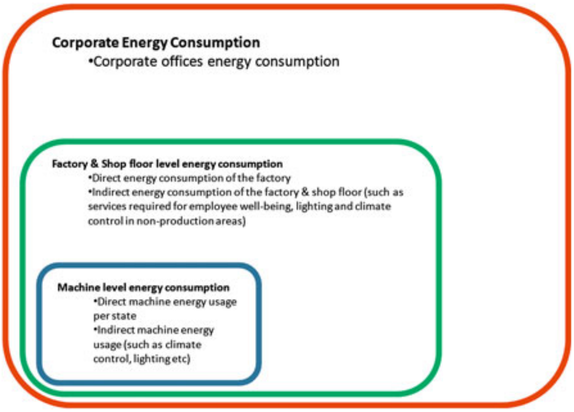

Fig. 4 Aggregated sustainable key performance indicator design

Business management focuses is on keeping up the competence of a company on a desired level. This requires key performance indicators to ensure that the entire company follows and commits to the competitive and sustainable goals and objectives of the business strategy.

Therefore, this study suggests dividing the selected metrics to different levels throughout the company to identify the accurate measurement levels of each layer of the aggregated company metric. The presented aggregation framework in Fig. 4 identifies energy consumption as an example metric for closer inspection. The current reporting guidelines presented by Global Reporting Initiative G3 suggest companies to report the annual energy consumption. This metric itself gives very little information on actual shop-floor or machine level improvements. Therefore, the company should measure the actual consumption where and when it happens. The aggregation framework divides both shop-floor and machine level to direct and indirect energy consumptions according to the OECD metrics. It is important to divide the direct and indirect energy used to manufacture the component as part of the energy used is not required to manufacture the component rather than increasing comfort of work for the workers.

In the academic research environment we are able to measure the energy consumption of a single turning machine in real time. This paper does not itself include a case study but an example of the setup to measure machine level energy consumption is presented. The academic research environment consists of several manufacturing resources and work pieces. Each of the entities has their corresponding computer models and simulation environments. The information and knowledge of the environment is stored in local databases and in a common knowledge base. With this setup we are able to extract real time information of the setup for the case studies conducted in our laboratory. An example of a setup which a case study of energy consumption monitoring was conducted with [30],

- Gildemeister CTX alpha 500 turning machine
- Carlo Gavazzi EM21 energy meter
- Siemens 840D SL controller.

4 Need and Plans for Further Research

Future research in this domain focuses on visualizing the metrics to each level of the company. Our research group's intention is to make these metrics easily accessible for all personnel working in the company to gain better management of the production system in terms of its sustainability. Exact measurements in each of these levels can provide the company an in depth view of the state of sustainability within the company at any given time or interval. Thus the companies gain a better understanding where they should focus on improving efficiency in the operations as well as managing the indirect effects of their operations.

Next step in this project is to develop means to visualize each of the metrics in every stage of the presented metrics framework. Visualization is an important aspect for companies to adapt these metrics. Through the visualization the company personnel should be able to tell with more ease whether the objectives for increasing the sustainability of the company are being achieved. Additionally visualization of the metrics should yield better understanding of possibilities of improvement within the factory or process.

Finally, this goal of this research project is to conduct case studies within the Finnish manufacturing industry and support companies to adapt the use of visualized sustainability key performance indicators and enhance sustainability in their operations. The case studies are expected to take place during the last quarter of 2013 and the first quarter of 2014.

5 Summary

This study discussed sustainable development from the point of view of production systems. The study reviewed the general aspects of sustainable development and sustainable production, factory planning, and sustainable performance measures. This study discussed the shortcomings of the current dominant sustainable performance guidelines such as GRI and suggested an alternative approach to conduct the measurements within a company. The study suggested an aggregated framework for metrics to be adapted in different entities within the company. The entities suggested were the machine level, factory and shop-floor level and corporate level. Additionally this study suggested in dividing the entities to direct and indirect measures according to the OECD guidelines. The results of this study are not considered generic for all industries. Hence, the results cannot be directly used outside manufacturing industry. Further case studies will provide the feasibility of this approach.

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