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13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use

A collection of tools for factory eco-efficiency

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Abstract

co-efficiency is generally defined as doing more with less, aiming to decouple environmental impact from economic and social value creation. This paper presents three tools to guide the implementation of eco-efficiency in factories: (1) definition and patterns of good practices for sustainable manufacturing, (2) a self-assessment tool and maturity grid, and (3) a factory modelling framework.

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1. Introduction

1.1. Background

The way factories are operating is a key determinant of the efficiency with which resources are converted into economic and social value (products and services). They hold great potential to support the transformation of our society toward sustainability [1]. However, performance between factories producing similar products with similar technology can vary greatly [2][3]. Such variation can be observed at different levels, from variation in the efficiency of similar utility systems across industry sector, to variation over time or between compressed air systems within a single factory. Fig. 1 illustrates performance variation at those various levels.

According to the WBCSD, "eco-efficiency is a management philosophy that encourages business to search for environmental improvements which yield parallel economic benefits" [4]. Critical aspects of eco-efficiency are reduced material and energy intensity, and increased intensity of goods and services, reduced dispersion of toxic materials, improved recyclability, renewables and extended product life.

Although eco-efficiency is a relatively new approach, the basic concept was developed 45 years ago by Ehrlich and Holdren with the *I=PAT equation* which describes the environmental impact (I) of human activity by the product of three factors: population (P), affluence (A) and technology (T) [5]. Eco-efficiency was further popularised by the BCSD report *Changing Course* [6] which advocates a radical change in perception of the role of industry from being the cause of environmental degradation to becoming a driver for sustainability. This research adopts the same positive view of industry. We define eco-efficiency as the concept of doing more with less, applied at factory level; in other words, creating goods and services while preserving natural resources and reducing waste and pollution during manufacturing.

1.2. Objectives

This paper presents the interim results of the Eco-Efficiency Grand Challenge – Environmental Performance Variation conducted with the EPSRC Centre for Innovative Manufacturing in Industrial Sustainability [7]. This project aims to improve the overall sustainability of manufacturing by addressing performance variation. The tools presented in this paper promotes eco-efficiency using five elements:

1. **Learn to see waste: What is your waste worth?**
   Identify and value waste.
2. **Find solutions: How can you remedy it?**
   Good practices for resource efficiency.
3. **The size of the prize: What are the benefits?**
   Understand potential savings and set targets.
4. **Self-assessment: Where are you now?**
   Evaluate current performance and benchmarking.
5. **Systematic improvements: Where to from here?**
   Systematise eco-efficiency activities.

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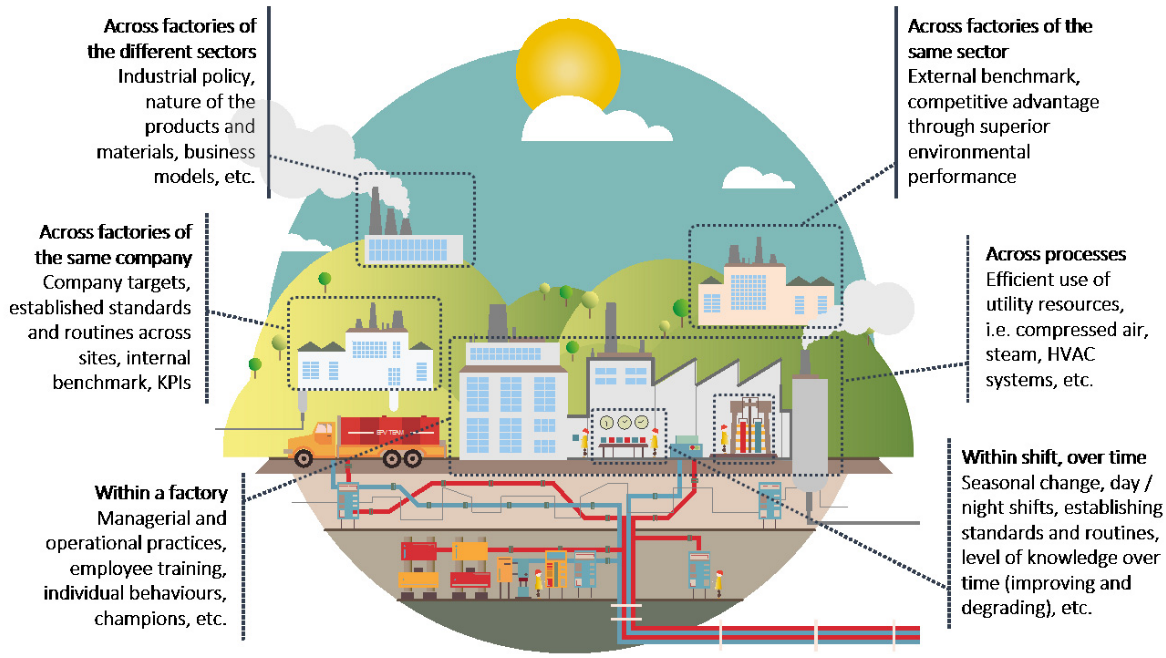

Fig. 1. Environmental performance variation at various levels and examples of causes.

2. A Collection of Tools

This section presents three tools: (1) definition and patterns of sustainable manufacturing practices, (2) a self-assessment tool, and (3) a framework for factory modelling and simulation.

2.1. Good practices for sustainable manufacturing

The technical knowledge for eco-efficiency is largely available, however the difficulty is to put it into practice. Most eco-efficiency practices are talked about in terms of some idealised change of equipment, e.g. replace old compressor; but there are more elements to consider when looking at different sites, shutdowns or improvement teams and investigating environmental performance.

There are numerous source of examples of good practices which can analysed to inspire new, specific solutions adapted to the inefficiency problem at hand. Such good practices can be found on open-source databases such as the Industrial Assessment Center's Database, which contains energy efficiency recommendations and company cases [8]. This type of information sources however may be overwhelming due to the size of the database and thus it may challenging to find specific, relevant information for a given company.

Here we define practices as patterns of unique actions [9]. They consist of physical and mental activities, equipment and its use, know-how, motivation and shared background understanding. New practices are rarely completely novel; usually there are pre-existing elements that need to form new links in order to be adopted. Those links are connecting three types of patterns:

- *Competences* include technical expertise, knowledge of production systems and operating constraints, data analysis techniques, and understanding of environmental performance metrics and evaluation.
- *Equipment* encompasses utilities and factory infrastructure, building fabric, environmental metering, data acquisition and monitoring.
- Finally, *engagement* covers environmental performance targets, meeting or exceeding those targets, working towards redefining the minimum non-labour resource requirements for an activity, accountability and motivation of different groups.

Following this practice pattern structure, the list of prompts and questions in Table 1 can guide the description of practices.

Table 1. Practice pattern structure and prompts.

Practice *patterns of unique actions*	• What is the activity? • What is the purpose of it? • How frequent is it? • What is the problem addressed? • What is the cause of the problem?
Competences *know-how, specialisation*	• What are the skills of the people involved? • What is their level of experience? • What data analysis techniques are available?
Equipment *materials, technology*	• What do you need to do the activity? • What production processes are involved? • What is the infrastructure? • How is data collected?
Engagement *targets, norms, responsibilities, accountability*	• Is the resource visible? • What are people's attitudes towards it? • Are people accountable? • Are people motivated to change? • Do people understand of the size of the prize? • How do you measure success and benefits?

2.2. Eco-efficiency maturity assessment grid

The Capability Assessment Grid for Eco-efficiency (CAGE) framework [10] provides a basis for qualitative assessment of the maturity of practices in various dimensions of eco-efficiency. The development of the maturity grid is grounded on the assumption that manufacturing practices mature over time and the resource-based theory [11]. The CAGE framework and maturity grid were tested in various settings (interview, workshops, etc.).

The grid consists of three maturity sub-grids, each one representing a different layer in eco-efficiency practices: process, facility and business unit. Each layer is further detailed to assess the maturity in the various dimensions of eco-efficiency as shown in Table 2.
Environmental performance dimensions in each layer follow the same evolutionary hypothesis:

- Maturity Level 1: business-as-usual type of practices
- Maturity Level 2: measurement and monitoring based on the improvement rule of: Plan-Do-Check-Act [12]
- Maturity Level 3: consistency and repetition of practices leading to standardization of environmental output. Aiming for continuous improvement attitude.
- Maturity Level 4: inclusive and bottom-up initiatives of improvement supported by a robust management system
- Maturity Level 5: deep understanding of environmental performance limits in product and processes (thermodynamic limits). Product and process life-cycle thinking and waste prevention attitude (extended system boundaries).

By keeping the evolutionary pathway in practices constant, the researchers can further make assumptions about alignment of practice maturity across the organizational layers. For example, companies that may excel at process level may not have well-developed management capabilities and miss opportunities for further improvement or set the basis for inclusive strategic planning.

Table 2. Layers and dimensions of eco-efficiency performance [10].

Layers	Dimensions
Process	Energy consumption Materials consumption Water consumption Process waste /pollution Human factor/operators Process equipment
Facility	Energy management Resource management Waste management People management Suppliers management
Business unit	Information systems & knowledge management Company norms/values Supply chain configuration Process and Product development

2.3. Factory eco-efficiency modelling framework

Reductions in resource use and associated cost is driving factory eco-efficiency improvements [13]. Early interventions seek to reduce energy and materials used in localised areas, such as manufacturing cells [14]. However, there needs to be understanding of the combined impact of manufacturing, utility and facility models. In particular there is little consideration for the relationship between model assets, data granularity and eco-efficiency performance indicators.

Data granularity refers to the extent to which a factory's data can be isolated into distinguishable pieces. Therefore, it is logical to subdivide resource pulse and magnitude data by linking to factory technical assets.

As progress is made in eco-efficiency, advances become more challenging. Resources across functional boundaries of manufacturing, utilities and facilities assets need to be integrated to accommodate further resource reduction opportunities an expansion of scope as shown in the framework in Fig. 2.

Examining factories as an integration of manufacturing, utilities and facilities is necessary to consider the distribution of resources, and how these relate to technical assets within a factory site [15]. This scale of analysis brings with it the complexity of composing a variety of discrete data pulses and magnitudes across asset subdivisions [16].

For example a facility may have a combination of manufacturing cells, sourcing different energies from utilities, which additionally supply other core and auxiliary zones. Therefore the framework must correlate subdivisions with other data granularity factors, whilst linking with relevant eco-efficiency indicators.

Data composition is a crucial pre-requisite for building representative asset models, which turns often-disparate raw data into information on asset eco-efficiency performance. Presently in eco-efficiency and modelling literature, there is a lack of understanding of data composition and asset modelling with appropriate indicators using data granularity factors.

The framework aims to develop knowledge in this area through data composition within and across subdivisions, by linking assets with relevant performance indicators. Framework models can be assembled at selected subdivisions appropriate to organisations eco-efficiency objectives. It has been designed to satisfy versatile user requirements, essential in developing representational factory models, with the ability to measure asset eco-efficiency [17].

The framework performance indicators include: power factor, water footprint, energy mix, material yield, energy per unit and thermodynamic minimums. Many performance indicators are applicable at multiple subdivisions. One the one hand, some are more applicable at manufacturing cells and single machine subdivisions, such as thermodynamics minimum and energy per unit. On the other hand, energy mix and power factor are more applicable at facilities and facility zones, when a number of assets are required to be eco-efficient.

Framework performance indicators are linked with resources magnitudes across asset subdivisions. Facility assets (e.g. air conditioning) operate in relation to manufacturing asset requirements (e.g. paint shop temperature and humidity). Utility assets may also share resources with building and manufacturing assets (e.g. hot/cold water circuits, steam pumps etc.). Therefore, attention in the framework is given to relationship and scale resource magnitudes across subdivisions.

Once data granularities are accurately composed, they are coupled with performance indicators in the modelling environment.

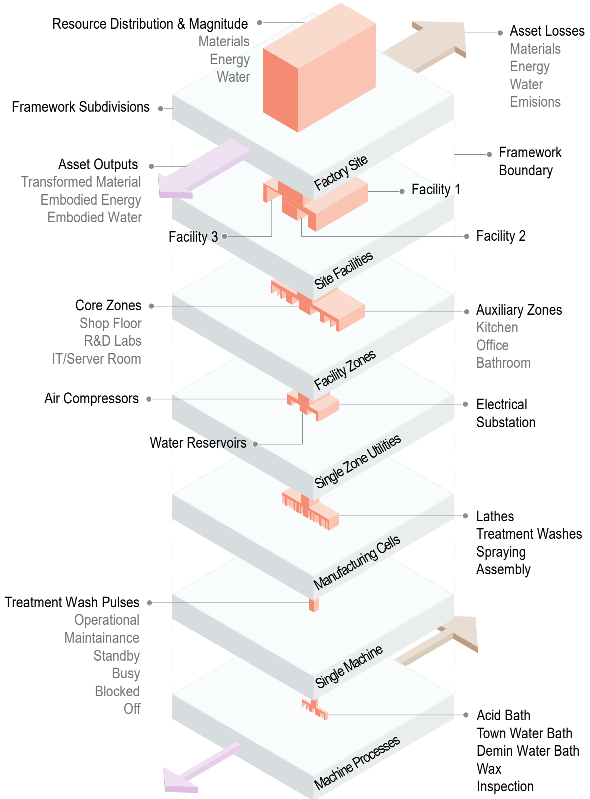

Fig. 2. Framework schema integrates factory resource subdivisions, pulse and magnitudes.
*Specified assets/resources are non-exhaustive and for framework demonstration purposes only

Modelling is a recognised tool for providing the necessary dynamic environment to measure eco-efficiency within different ranges of pulses. However, more guidance on the applicability of specific pulse granularities to accurately compose, model and indicate eco-efficiency is still required. The framework contributes to this area by consolidating subdivisions with resource data at given pulses. Quantifying eco-efficiency through models to produce a comprehensive understanding of the factory system, in which the modelled assets operate [18].

To develop knowledge in the area of data granularity the factory eco-efficiency modelling framework uses a structured data composition and modelling approach. This helps modellers move beyond current tendencies of developing localised point-solutions. Framework modelling results can be used to measure and determine improvement opportunities at single or multiple data granularities, based on the application of best practices from specific industries [19]. Framework models incorporate the evaluation of energy distributions and material transformations within technical assets [20]. Allowing eco-efficiency indicators, to systematically measure and improve factory performance [21][22].

3. Conclusions

In this paper, we have presented an extract of the eco-efficiency toolkit and covers the five elements of factory efficiency:

1. Learn to see waste
2. Find solutions
3. The size of the prize
4. Self-assessment
5. Systematic improvements

The first tool introduced enables a structured formulation and description of sustainable manufacturing practices. It can help identify wastes and ways to remedy them. This is achieved by defining and structuring eco-efficiency practices using three types of patterns: competences, equipment and engagement. In turn it can help turning good practices into good habits to systematise eco-efficiency activities.

Establishing good practices can be further supported by conducting a self-assessment using the maturity grid to assess current levels of performance according to various dimensions. This assessment can reveal where strengths and weaknesses are, i.e. where improvements can be made. In addition, the maturity grid can also be used for benchmarking purposes and enable the transfer of knowledge and practices from low- to high-performing areas.

Finally, the factory modelling framework enables a more integrated understanding of resource use throughout the factory. It is highly complementary to the two previous tools. The quantitative methods can support the identification of the biggest resource consumers in the factory, i.e. areas with the largest potential of improvements. The framework also addresses the issue of data granularity and how to make the best use of the data available. This is helpful to estimate the potential savings and benefits of improvement and thus focus the analysis and guide further data collection in the most promising areas. Thus this tool assist both performance assessment using KPIs and improvements identification through factory data analysis.

The eco-efficiency toolkit aims to provide an actionable guide to reduce resource use in manufacturing while delivering economic and social value through the products and services. It is clear that eco-efficiency can make a significant contribution to reduce industry's impact on the environment. However radical rethinking and redesign of industrial systems is needed to ensure that efficiency benefits are not fully offset by increased demand for goods and services. Therefore eco-efficiency needs to be combined with other approaches, such as industrial symbiosis and slow consumption, to ensure that society effectively moves towards sustainability.

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References

[1] Evans, S., Bergendahl, M.N., Gregory, M., Ryan, C., 2009. Towards a Sustainable Industrial System, with Recommendations for Education, Research, Industry and Policy. University of Cambridge, Institute for Manufacturing, Cambridge.

[2] Bocken, N., Morgan, D., Evans, S., 2013. Understanding environmental performance variation in manufacturing companies. Journal of Productivity and Performance Management 62(8), p. 856–870.

[3] Tomas Dahlman, T., 2012. Electrolux way toSustainability Leadership Case: Green Spirit. European Council for an Energy Efficient Economy (eceee) Industrial Summer Study, Solutions workshops 2012. http://www.eceee.org/industry/programme/solutions_workshops/Electrolux.pdf [accessed 06/05/2015]

[4] Lehni, M., Pepper, J., 200. Eco-efficiency: Creating more value with less impact. World Business Council for Sustainable Development: North Yorkshire, UK. http://www.wbcsd.org/web/publications/eco_efficiency_creating_more_value.pdf [accessed 13/04/2015]

[5] Ehrlich, P. R., Holdren, J. P., 1971. Impact of population growth. Science 171(3977), p. 1212–1217.

[6] Schmidheiny, S., 1992. Changing course: A global business perspective on development and the environment. Cambridge, MA: MIT Press.

[7] EPSRC Centre for Innovative Manufacturing in Industrial Sustainability. http://www.industrialsustainability.org/ [accessed 10/04/2015]

[8] Industrial Assessment Centers Database. http://iac.rutgers.edu/database/ [accessed 05/05/2015]

[9] Roberts, S.J.F., Ball, P.D., 2014. Developing a Library of Sustainable Manufacturing Practices. Procedia CIRP Conference on Life Cycle Engineering 2014, p. 159–164.

[10] Litos, L., Evans, S., 2015. Maturity grid development for energy and resource efficiency management in factories and early findings from its application. Journal of Industrial and Production Engineering 32(1), p. 37–54.

[11] Grant, R.M., 1991. The Resource-Based Theory of Competitive Advantage: Implications for Strategy Formulation. California Management Review 33, p. 114–135.

[12] Deming, W.E., 1986. Out of the Crisis. Cambridge, MA: MIT Press.

[13] Seliger, G., Kim, H. J., Kernbaum, S., Zettl, M., 2008. Approaches to sustainable manufacturing. International Journal of Sustainable Manufacturing 1(1), p. 58–77.

[14] Oates, M., Wright, A., Greenough, R., Shao, L., 2011. Understanding Resource Flows In A Factory Environment – A Graphical Approach. Proceedings of the 2011 1st International Conference On Sustainable Intelligent Manufacturing, Portugal: Institute of Energy and Sustainable Development.

[15] Salonitis, K., Ball, P., 2013. Energy efficient manufacturing from machine tools to manufacturing systems. Procedia CIRP 7, p. 634–639.

[16] Davé, A., Ball, P.D., 2013. Factory modelling: data guidance for analysing manufacturing, utility and building architecture systems. Proceedings of 11th international conference on Manufacturing Research, p. 115–121.

[17] Huppes, G., Ishikawa, M., 2005. A Framework for Quantified Eco-efficiency Analysis. Journal of Industrial Ecology 9(4), p. 25–41.

[18] Chuang, S. P., Yang, C. L., 2013. Key success factors when implementing a green-manufacturing system. Production Planning & Control 1(15) p. –.

[19] Abdul Rashid, S. H., Evans, S., Longhurst, P., 2008. A comparison of four sustainable manufacturing strategies. International Journal of Sustainable Engineering 1(3), p. 214–229.

[20] Herrmann, C., Thiede, S., Kara, S., Hesselbach, J., 2011. Energy oriented simulation of manufacturing systems—concept and application. CIRP Annals-Manufacturing Technology 60(1), p. 45–48.

[21] Gould, O., James Colwill, J., 2015. A framework for material flow assessment in manufacturing systems. Journal of Industrial and Production Engineering 32(1), p. 55–66.

[22] Patterson, M. G., 1996. What is energy efficiency? Concepts, indicators and methodological issues. Energy policy 24(5), p. 377–390.

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