11th Global Conference on Sustainable Manufacturing
Sponsored by the International Academy for Production Engineering (CIRP)

Proceedings

11th Global Conference on Sustainable Manufacturing

Innovative Solutions

Berlin, Germany
23rd–25th September, 2013

Günther Seliger
Editor

Technische Universität Berlin
Institute of Machine Tools and Factory Management
Fraunhofer IPK
Global Production Engineering
CRC 1026: Sustainable Manufacturing – Shaping Global Value Creation
Sponsored by the German National Science Foundation (DFG)

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.dnb.de.

Editor
Günther Seliger
Technische Universität Berlin, Germany
Department of Machine Tools and Factory Management
Pascalstr. 8–9, 10587 Berlin
Germany
seliger@mf.tu-berlin.de

Universitätsverlag der TU Berlin 2013
http://www.univerlag.tu-berlin.de

Fasanenstr. 88, 10623 Berlin
Tel.: +49 (0)30 314 76131 / Fax: -76133
E-Mail: publikationen@ub.tu-berlin.de

ISBN 978-3-7983-2609-5 (online)

Online published on the Digital Repository of the Technische Universität Berlin:
URL http://opus4.kobv.de/opus4-tuberlin/frontdoor/index/index/docId/4027
URN urn:nbn:de:kobv:83-opus4-40276
http://nbn-resolving.de/urn:nbn:de:kobv:83-opus4-40276

GCSM
11th Global Conference on Sustainable Manufacturing
2013
23rd - 25th September
Berlin - Germany

11.4 Extending the boundaries of energy management for assessing manufacturing business strategies

E. Woolley [1], L. Sheldrick [1], J. Arinez [2], S. Rahimifard [1]

[1] Centre for Sustainable Manufacturing and Recycling Technologies (SMART), Loughborough University, UK

[2] Manufacturing Systems Research Lab, General Motors R&D Center, Michigan, USA

Abstract

Manufacturers are responsible for about one third of global energy demand, and thus have a responsibility for reducing their reliance on rapidly depleting non-renewable energy sources. Consequently, a plethora of research has arisen to develop novel ways of improving energy efficiency in factories by focusing on changes to energy intensive production processes and other energy using systems that support manufacturing activities. However, the ultimate goal of manufacturing companies is to maximise profit by refining their business strategy, highlighting the importance of assessing the impact of different business strategies on energy demand. Therefore, one of the key research challenges is to assign anticipated energy demand to various decisions within a business. This paper presents a hierarchical approach to attribute the potential energy demand of manufacturing activities to alternative business decisions, thus informing selection of the most energy efficient business strategies.

Keywords:

Energy Management, Business Strategy, Manufacturing, Life Cycle Analysis, Sustainable Manufacturing

1 INTRODUCTION

It has been well documented and is widely agreed that the future global community will not have access to the same level of energy-rich fossil fuels that we enjoy today. This limitation may be of some environmental benefit as it will naturally limit our tendency to generate CO_2, however, it also creates a significant challenge for communities, governments, industries and end users who currently rely on inexpensive energy to sustain their activities. Broadly speaking, there are two options available for reducing our reliance on fossil fuels: significant and prolonged investment in renewable energy resources, or systematic and continuous efforts for reduction in primary energy demand. In terms of cost-effectiveness, the latter option appears to be the most attainable in the short to medium term. However, in order to meet the growing energy challenges ahead, future initiatives are likely to comprise a combination of both approaches.

Radical improvements in energy efficiency will be of particular importance to the manufacturing industry which currently represents approximately one third of global energy demand. In addition, many manufacturing companies are already struggling to remain profitable in poor economic climates, and will need to become more resilient to increases in the cost of energy and/or shortages in future energy availability. Even with these drivers it is recognised that a business is unlikely to change its profit model based on energy use alone, however, energy is likely to become an increasingly important consideration and will form a key decision factor for company managers in the not-too-distant future.

Historically, successful manufacturing businesses have been those that produce and sell more than their competitors, leading to widespread disregard for resource consumption and pollution levels. However, business strategies are beginning to change as companies seek new ways to remain competitive, and implement new approaches to win market-share whilst reducing operating costs. These emerging business models carry different energy foot-prints when compared to historical models. For instance, in the case of pay-per-use washing machines, the business owner, and not the end user, is responsible for the cost of the energy used during the use phase. Similarly, for cars sold in Europe and Japan, the manufacturer is responsible for processing and recycling of the vehicles at their end-of-life. Therefore, this additional energy demand (and its associated cost) needs to be accounted for during business planning.

This highlights the need for an approach to establish the energy demand implications of potential business decisions, enabling the manufacturing industry to intelligently identify and select the most energy efficient business strategies. A three stage method is proposed in this paper which attributes potential energy demand to business strategies, thus identifying radical energy efficiency opportunities. The broad applicability of this energy assessment for business strategies is then demonstrated through the consideration of an example product.

2 A BRIEF REVIEW OF ENVIRONMENTAL BUSINESS PLANNING AND ENERGY MANAGEMENT STRATEGIES

Over the last few decades, there has been a proliferation of research which has delivered a range of methodologies and tools for improving energy efficiency in manufacturing companies. These approaches have mainly focussed on technology or reactive end-of-pipe improvements to manufacturing activities. Although such approaches are suitable for incrementally improving energy efficiency in make-sell business models, more radical reductions in energy use can be achieved through innovative business models that meet consumer needs without the emphasis on selling large volumes of products.

As such, the appropriateness of existing business models are being challenged [1, 2], and many studies are suggesting a dramatic evolution such as those introducing new concepts of cradle-to-cradle [3], localised manufacturing [4], product service systems [5], and product compatibility and upgradeability [6].

G. Seliger (Ed.), Proceedings of the 11th Global Conference on Sustainable Manufacturing - Innovative Solutions

ISBN 978-3-7983-2609-5

To help companies systematically consider the inclusion of environmental factors in their business planning, a number of tools such as the ‘Sustainable Business Scorecard’ [7] have been developed. In relation to this, Boons *et al*. [8] have recently discussed a range of studies which explore the different ways that established companies have developed sustainable business models for their products. These studies have highlighted that current changes are predominantly driven by a reactionary approach to regulatory or social pressures and therefore deal mainly with business transition management and the adaptation of existing businesses to be retrofitted with relevant environmental considerations. It can also be seen that whilst a great deal is known about the drivers for more sustainable business models, very little is known about how to develop more sustainable businesses from the outset [8]. Existing studies do however offer useful insights into decision making and highlight a number of research gaps in both the planning of comprehensive sustainability in businesses [9] and in addressing strategic company objectives such as improving resource efficiency (e.g. energy, water or materials) to achieve specific sustainability goals [10].

Instead of approaching these objectives from the corporate level, sustainability improvements are often addressed directly at isolated levels within a manufacturing organisation. In particular, the current field of research on improving manufacturing energy efficiency is typically focused on physical energy using activities at various manufacturing levels. These levels can be described in terms of a hierarchical system similar to the ‘Shop Floor Production Model’ developed by the International Organisation for Standardisation (ISO) [11]. An adaptation of this model for describing energy use [12] (as shown in Figure 1), has five levels which include:

- **Turret**: energy considerations at the tool-chip interface have led to very process specific research in this area [13, 14], being largely defined by the materials used and products manufactured.
- **Machine**: includes the many energy using activities that make up a process, adding complexity. Research focusses on either the direct energy required to carry out the work, or auxiliary energy required to support manufacturing activities [15].
- **Machine cell**: energy use from the supply of material resources, transport systems, waste material processing, product maintenance, better planning and production engineering and management [16].
- **Facility:** energy use by the infrastructure and other indirect manufacturing requirements such as ventilation, lighting, heating and cooling [17].
- **Enterprise**: includes a range of activities from the supply chain of materials to the logistics of finished products [18]. At the enterprise level there is scope for efficiency improvement activities directly related to business strategy, for example Seliger *et al*. [19] made a comparison of energy required for remanufactured and make-use-dispose products.

In general, the processes developed for incorporating sustainability into business strategies are non-structured and based on the implementation of piece-meal approaches to improving certain aspects of company performance.

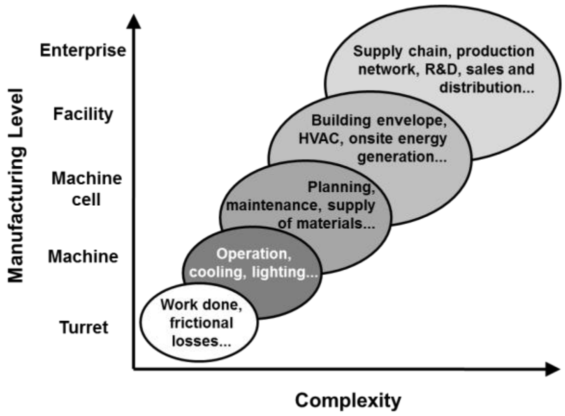

Figure 1. Energy considerations at different manufacturing levels. Adapted from [12].

Consequently, for a business manager, it is difficult to identify how decisions will impact the amount of energy required at each of these manufacturing levels, and even less so, what the full energy implications are for these decisions. This is due to a disconnect between the objectives of business strategies and the way in which current energy management systems operate. Hence, there is a need to develop a systematic process that allows a comprehensive evaluation of business strategy with respect to energy demand.

3 RESEARCH METHODOLOGY

Company planning activities can be targeted at two different strategic levels within any given organisation. The first is **corporate strategy** which applies to planning across the whole enterprise. The second is **business strategy** which applies more specifically to defining the choice of product, service, and market [20]. At the corporate strategy level, significant changes are rare and transitions typically occur on a more evolutionary basis due to heavy restrictions from inflexible factors such as company location or a mature supplier network. However, at the business strategy level, decisions can be more readily linked to energy consuming activities by defining the types of products to be manufactured, the nature of services to be provided, and other supporting activities required at the enterprise level. Therefore, this research is focussed on assessing business strategies to identify future energy demand for a manufacturing company.

In order to effectively assess potential energy demand at the business strategy level, it will be important to assign activities to different decisions using a systematic method. Therefore, instead of attributing energy use to the infrastructure of an enterprise (as can be done through the use of the ISO model), it is more appropriate to attribute energy to manufacturing activities required to deliver and support a particular product, thus allowing a comparison between different strategies that meet similar customer needs.

In this context, an extended version of the ‘3P perspective’ proposed by Seow and Rahimifard [21] can be used to assign components of energy use to either the **product**, the **processes** or the **plant**. In order to account for the entire range of the activities which can determine the energy footprint of a business strategy (in particular within medium to large manufacturing companies), an additional perspective needs to be included in this approach. This new perspective consists of activities at the '**corporation**' level, which accounts for all energy using activities outside the company's plants (e.g. logistics, sales and marketing offices). Together, the combination of these four holistic categories can be deemed the '**3PC perspective**'.

A number of new and emerging business models such as product service systems (PSS) require a company to have further interaction with a product beyond the point of sale, for example through maintenance or take-back activities. It is therefore important to consider the energy requirements of these additional life cycle stages within any energy assessment. In order to account for this, the 3PC perspective should be applied for each phase of the product life cycle as illustrated in Figure 2. Clearly, one of the key considerations in this new approach is to avoid the 'double accounting' of energy demand between the different energy perspectives. This approach can then be used to identify energy use hotspots within a business strategy, or used to compare different strategies that fulfil the same consumer need in the same market. This will ultimately enable manufacturers to reduce the overall energy input required for their business activities by enabling the selection of the most appropriate strategies, and identification of any inefficient areas.

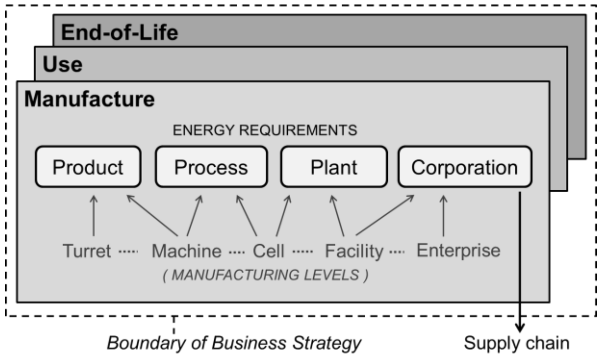

Figure 2. Defining the required energy considerations for business strategy energy modelling.

4 ATTRIBUTING ENERGY DEMAND TO BUSINESS STRATEGY

As with any business strategy, there should always be a focus on meeting the need or demand of the customer to ensure long-term success. Nowhere is this more true than in manufacturing where the most successful business strategies are those that remain focused on the product. In these cases, the processes, plant and corporate structure are then defined by the requirements of the product and consumer need. The method for establishing the potential energy demand of a business strategy should therefore assume the same approach, starting with the requirements for the product, and then adopting a bottom-up approach (from processes to plant and corporation levels) to identify the total energy requirements of the company. However, in order to be able to determine the appropriate energy consuming activities (i.e. those for which a company is economically accountable), it is necessary to first establish the boundaries for a company's energy considerations. In this context, a three stage approach is presented below to model and reduce the energy demand for a business strategy.

Stage 1 – Setting the Energy Demand Boundaries: These should include everything that a manufacturer is responsible for, or has direct control over during the entire product(s) life cycle(s). However, these should also be limited to exclude factors such as the extended supply chain which are outside the manufacturer's direct control and for which they are not responsible for the cost of energy use. The scope of energy using activities included will vary depending on the business strategy under consideration (e.g. reverse logistics required for remanufacturing) but should certainly include significant factors under the responsibility of the manufacturer (e.g. environmental control for spray booths).

In this context, there are two key dimensions in which a manufacturer should use to define the boundaries for their energy demand: a) the various product life cycle stages, and b) the entire manufacturing infrastructure (as defined by 3PC prospective). The relevant stages of the product life cycle that need to be considered are determined by the choice of business strategy. For example, in a make-sell approach, neither the 'use' nor 'end-of-life' stages will incur an energy demand from the manufacturer, whereas the implementation of a PSS may require energy expenditure during the use as well as end-of-life stages of the product, as illustrated in Figure 3. In terms of infrastructure, the energy using activities under consideration will depend upon the way a product is manufactured and provided to the customer. Using both the life cycle and manufacturing infrastructure dimensions to define the boundaries of energy consideration enables manufacturers to identify the complete range of key attributes which should be included in their energy assessment.

Stage 2 – Attributing Energy to Business Activities: This stage involves quantifying each energy requirement that the manufacturer is economically accountable for, as defined in Stage 1. Within any manufacturing business, there will be a vast number of energy using activities, and so a structured approach is required whereby each activity is clearly defined and assigned an energy value (e.g. in kJ or BTU). By using the proposed 3PC perspective, energy can then be attributed to a range of specific activities that are influenced by the business strategy. It should be noted that each of these four perspectives represent a number of activities across various product life cycle stages that should be included in the energy model, as outlined below:

Product – Transforming a quantity of material, or materials, into a product requires a minimum theoretical amount of energy as defined by physical laws [15]. The fundamental energy required to manufacture a product, E_{Prod}, can thus be deduced either by calculation from known principles, or by retrieving LCI data from one of the commercially available LCA databases.

Processes – Beyond the theoretical energy required to manufacture a product, the processes within a manufacturing facility require additional energy in order to power auxiliary units (e.g. coolant systems, tooling and fixturing systems, computer control). An amount of energy is also typically lost through inefficiencies within the process (e.g. heat generated through machining processes). All of these various factors must be taken into consideration when compiling the total process energy demand. The energy required to run the manufacturing processes, E_{Proc}, for a single product can be obtained or calculated from equipment data sheets or from empirical monitoring of existing processes.

Plant – The energy consuming activities not directly associated with production processes can be attributed to a manufacturing plant. These typically include systems that maintain a production environment and includes HVAC, lighting, internal transport, offices, security, etc. The energy requirements at plant level, E_{Plan}, can be deduced from its dimensions and environmental data, as well as the requirements for computing and other business support systems, or from measuring (metering) its current energy use. The total energy requirement for a plant over a set period needs to be amortised for each product produced at that plant.

Corporation – Extending beyond the walls of the plant, this level considers potential energy demand for transportation of materials and products, product warehousing, external sales and marketing offices, etc. The energy requirement for these enterprise level activities, E_{Corp}, can be estimated from readily available transport energy data, known distribution nodes, and through the use of a similar approach to the 'plant' perspective for non-manufacturing buildings.

Each of the above energy perspectives will likely include a number of energy using activities (e.g. one factory may have tens or hundreds of processes). In this respect, the energy level notation E_{Proc} should be replaced with the terms $E_{Proc,1}$, $E_{Proc,2}, \ldots E_{Proc,n}$ for *n* production processes. This also applies to E_{Prod}, E_{Plan}, and E_{Corp}, and therefore, for the manufacturing stage of the life cycle, the predicted energy demand is:

$$E_{Manuf} = \sum_{i=1}^{n} (E_{\mathrm{Prod},i} + E_{\mathrm{Proc},i} + E_{Plan,i} + E_{Corp,i}). \qquad (1)$$

Similarly, the total energy attributable to a business strategy, E_{BS}, can be defined as:

$$E_{BS} = \sum_{Manuf}^{EoL} \left[\sum_{i=1}^{n} (E_{\mathrm{Prod},i} + E_{\mathrm{Proc},i} + E_{Plan,i} + E_{Corp,i}) \right], \qquad (2)$$

where, the product life cycle stages consist of manufacturing (Manuf), use (Use) and end-of-life (EoL).

Figure 3 illustrates the total energy demand for three business strategies, namely make-sell, producer responsibility (in which manufacturer is responsible for take back and recycling of their product), and product service system. Clearly, in the cases where business strategies require the manufacturer to have an interaction with the product after the manufacturing stage (e.g. PSS), then the 'use' and 'end-of-life' stages of that product's life cycle becomes a significant consideration due to the additional energy demand during these stages.

It should also be noted that this assessment of energy demand has to be considered with respect to an expected 'functional unit' within an application which could be defined in terms of time, number of uses, unit cost, etc.

Stage 3 – Reducing the Energy Demand for a Business Strategy: Once the potential energy demand for a business strategy has been determined it is possible to then either analyse the data to highlight the energy hotspots and thus focus efforts for improvement in energy efficiency or to compare the strategy with other potential approaches to revenue generation. In terms of identifying and addressing energy hotspots, there are a number of methods of analysis as described in Rahimifard *et al.* [15]. By following the three stage approach presented above, manufacturers are able to plan and include all of the relevant energy requirements in their business models and thus use a single procedure to make suitable comparisons between different business strategies, or different energy using activities across a product's life cycle.

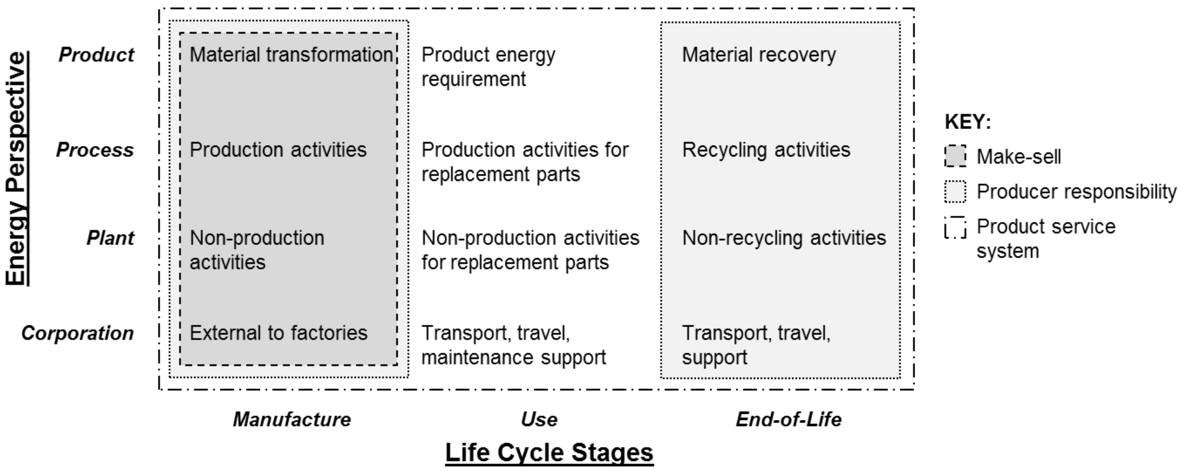

Figure 3. Mapping of boundaries for different business strategies.

5 COMPARING ENERGY DEMAND FOR A MAKE-SELL AND PSS BUSINESS STRATEGIES

The following example compares different business strategies for the manufacturing and provision of steel roofing using energy data from a study conducted by Kara and Manmek [18]. In this example two business strategies are compared in terms of their potential energy demand per product year, one supplying steel roofing panels via a traditional make-sell business strategy, the other supplying identical roof panels via a PSS business strategy. In the latter instance, the manufacturer is responsible for the panels' maintenance throughout their lifetime plus their end-of-life recovery. Therefore, in terms of energy consideration boundaries, the make-sell business strategy is concerned only with the manufacturing stage of the product life cycle, but the PSS business strategy needs also to consider the maintenance of the panels during 'use' phase plus energy required to recover the steel at its end-of-life. In this case study, since it is the same product supplied to the user based on different business strategies, the energy requirements for the manufacture of the panels has been assumed to be identical. It should be noted that in other applications, a manufacturer may choose to improve the quality of their product (to extend its use life) under PSS business strategy, and thus the manufacturing energy demand may significantly vary.

The energy data summarised in Table 1 are calculated for both business strategies based on information provided by Kara and Manmek [18] and from calculated theoretical requirements for known production processes and transportation methods. It has also been assumed that, if the manufacturer instigates the recovery of the material, they can off-set any energy benefit against their manufacturing energy requirements. In addition, the lifetime of the steel roofing for the make-sell and PSS business strategies has been assumed to be 15 and 25 years respectively; the PSS roofing having, on average, an extended lifetime due to a regular maintenance schedule.

Energy Contributor	Make-Sell	PSS
Manufacture		
E_{Prod}	33 MJ/m^2 *	33 MJ/m^2 *
$\Sigma(E_{Proc} + E_{Plan})$	145 MJ/m^2 #	145 MJ/m^2 #
ΣE_{Corp}	2 MJ/m^2 #	4 MJ/m^2 &
Use (maintenance)	N/A	
ΣE_{Corp}	N/A	2 MJ/m^2 yr &
EoL	N/A	
E_{Prod}	N/A	-48 MJ/m^2 #
ΣE_{Corp}	N/A	4 MJ/m^2 &
L_P	15 yr	25 yr
E_{BS}	12 MJ/m^2 yr	7.5 MJ/m^2 yr

** = data calculated from physical material properties*
 # = data taken or inferred from [18],
& = data simulated from company/customer location

Table 1. Energy requirements considered through product life cycle for comparison between make-sell and PSS business strategies for steel roofing.

Despite the additional energy requirements from the PSS business strategy during the 'use' and 'end-of-life' stages over that of the make-sell approach, that the energy requirement per square-metre per year of the roofing is less, as shown in Table 1. This is because the energy demand for the manufacturing stage of the product (mostly due to $\Sigma(E_{Proc} + E_{Plan})$) represents the largest energy outlay for the company, and so preserving this investment in energy (through the use of additional energy during use and EoL) by adopting a PSS business strategy becomes a worthwhile task. However, in other cases where the product in question did not require as much energy to manufacture, it might be less beneficial to use further energy for maintenance during its lifetime.

It should also be noted that in this example, the energy expenditure on maintenance (50MJ/m^2 over 25 years) is almost entirely recuperated by the energy off-set from reusing/reprocessing of the material at the end of its life. As a result, an extension to the product life by a further 67% yields a reduction in energy per functional unit of 38%, demonstrating a more energy efficient approach to meeting the customer need through the application of a different business strategy.

From the data in Table 1 it is possible to further investigate the specific energy contributions from various aspects of the business model in order to identify and address any energy demand hotspots. An analysis of the predicted energy demand per year for the above PSS business strategy is shown in Figure 4. In this example, the contribution to E_{BS} from $E_{Proc} + E_{Plan}$ is a dominating factor and requires further investigation in order to identify specific energy contributing activities. This analysis however is based on high level data, and a more detailed analysis would be required in practice (e.g. to include the energy requirement of individual manufacturing processes) in order to establish the true potential for energy demand reduction in the PSS strategy.

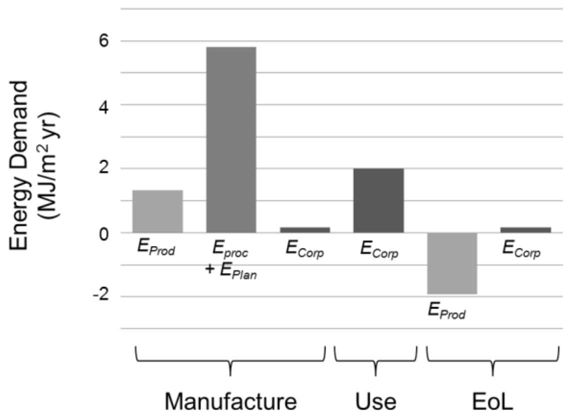

Figure 4. Comparison of the life cycle energy demand components, averaged per year, for the example PSS of steel roofing panels.

6 CONCLUSIONS

Despite the well-recognised need to better manage the way the manufacturing industry uses energy, demand continues to increase. The potential future problems faced by industry in terms of energy cost and availability could be catastrophic causing significant global shrinkage of manufacturing output. Correspondingly, much research has been published detailing tools and methods for addressing energy management, monitoring, and efficiency within the physical infrastructure of manufacturing enterprises. However, the research reported in this paper has argued that the energy demand of a manufacturing company is significantly influenced by its business strategies

A three stage approach to attributing and minimising the predicted energy demand for business models has been presented and its application has been demonstrated using an example product based on make-sell and PSS business strategies.

Ultimately, the management of energy at the business strategy level needs to integrate with existing business considerations (e.g. profit, resilience, established supply chains) to inform better decisions. At present, manufacturers' primary consideration in choosing a business strategy comes down to profit, and it is unlikely that manufacturing activities will be fully optimised solely for their energy efficiency. In this respect, assigning a cost to energy within the proposed energy modelling approach in this paper could allow manufacturers to assess not only the current financial implications of different energy requirements, but also factor into their decision making processes the likely rises and fluctuations in the cost of energy. It is envisaged that this approach for assessing energy demand for various business strategies is likely to become increasingly important in the next few decades.

REFERENCES

[1] Comes, S. and Berniker, L., 2008. Business model innovation. *From Strategy to Execution***,** 65-86.

[2] Lee, K. & Casalegno, F., 2010. An Explorative Study for Business Models for Sustainability. *PACIS 2010 Proceedings***,** 47.

[3] Braungart, M., Mcdonough, W. & Bollinger, A., 2007. Cradle-to-cradle design: creating healthy emissions-a strategy for eco-effective product and system design. *Journal of Cleaner Production,* **15,** 1337-1348.

[4] Kumar, K., 2004. *From post-industrial to post-modern society: New theories of the contemporary world.* 2nd ed. Wiley-Blackwell

[5] Tukker, A., 2004. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. *Business strategy and the environment*, **13**, (4), 246-260.

[6] Li, Y., Xue, D. and Peihua, G., 2008. Design for Product Adaptability, *Concurrent Engineering*, **16**, 221-232.

[7] Figge, F., & Hahn, T., 2002. The Sustainability Balanced Scorecard – linking sustainability management to business strategy. *Business strategy and the environment*, **11**, (5), 269-284.

[8] Boons, F., Montalvo, C., Quist, J., Wagner, M., 2013. Sustainable innovation, business models and economic performance: an overview, *Journal of Cleaner Production*, **45**, 1-8.

[9] Boons, F., and Lüdeke-Freund, F., 2013. Business models for sustainable innovation: state-of-the-art and a step towards research agenda, *Journal of Cleaner Production*, **45**, 9-19.

[10] Lambooy, T., 2011. Corporate Social Responsibility: sustainable water use, *Journal of Cleaner Production*, **19**, (8) 852-866.

[11] ISO, 1990. ISO TR 10314-1: Industrial Automation – Shop Floor Production, International Standards Organisation: Switzerland.

[12] Vijayaraghavan, A., and Dornfeld, D., 2010. Automated energy monitoring of machine tools, *CIRP Annals - Manufacturing Technology*, **59**, (1) 21-24.

[13] Kalpakjian, S. and Schmid, S. R., 2008. *Manufacutring Processes for Engineering Materials,* Prentice Hall, Singapore.

[14] Draganescu, F., Gheorghe, M. and Doicin, C. V., 2003. Models of machine tool efficiency and specific consumed energy, *Journal of Materials Processing Technology,* **141,** (1) 9-15.

[15] Rahimifard, S., Seow, Y. and Childs, T. (2010) Minimising Embodied Product Energy to support energy efficient manufacturing, CIRP Annals - Manufacturing Technology, 59, (1) 25-28.

[16] He, Y., Liu, F., Cao, H., 2005. Process Planning Support System for Green Manufacturing and its application. *Computer Integrated Manufacturing Systems* **11,** (7) 975-980.

[17] Boyd, G., Dutrow, E., and Tunnessen, W., 2008. The evolution of the ENERGY STAR® energy performance indicator for benchmarking industrial plant manufacturing energy use. *Journal of Cleaner Production* **16,** 709-715

[18] Kara, S., and Manmek, S., 2010. Impact of Manufacturing Supply Chains on the Embodied Energy of Products. Proceedings of the 43rd International Conference on Manufacturing Systems.

[19] Seliger G., Kernbaum, S., and Zettl, M., 2006. Remanufacturing approaches contributing to sustainable engineering., *Gestao & Producao,* **13,** 367-384.

[20] Andrews, K. R., 1997, The concept of corporate strategy, in Resources Firms and Strategies, Foss, N. J. (ed) Oxford University Press, Oxford, UK.

[21] Seow, Y. and Rahimifard, S. (2011) Improving Product Design Based on Energy Considerations, In *Glocalized Solutions for Sustainability in Manufacturing* (Eds, Hesselbach, J. r. and Herrmann, C.) Springer Berlin Heidelberg, pp. 154-159.