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

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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 CO₂; 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, make-sell business models, more radical reductions in energy use can be achieved through innovative business 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 is 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].

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.

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.

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).

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

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

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
perspective). 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 3 – Establishing the Energy Demand: The final
stage involves ensuring that the energy demand should
be measured and established for the complete
business strategy. This stage requires the
organisation to prioritize and balance the
environmental decisions made. This can
involve trade-offs between various
environmental and business
objectives.
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, $E_{\text{Proc}}$, 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, $E_{\text{Plan}}$, 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, $E_{\text{Corp}}$, 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 $E_{\text{Proc}}$ should be replaced with the terms $E_{\text{Proc},1}$, $E_{\text{Proc},2}$, … $E_{\text{Proc},n}$ for $n$ production processes. This also applies to $E_{\text{Prod}}$, $E_{\text{Plan}}$, and $E_{\text{Corp}}$, and therefore, for the manufacturing stage of the life cycle, the predicted energy demand is:

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

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

$$E_{\text{BS}} = \sum_{i=1}^{n} \left( \sum_{j=1}^{M} (E_{\text{Prod},i,j} + E_{\text{Proc},i,j} + E_{\text{Plan},i,j} + E_{\text{Corp}}) \right).$$  \hspace{1cm} (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.
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.

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 \( \sum (E_{\text{Proc}} + E_{\text{Plan}}) \)) 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/m² over 25 years) is almost entirely recuperated by the energy off-set from reusing/repurposing 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 \( E_{\text{es}} \) from \( E_{\text{Proc}} + E_{\text{Plan}} \) 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.

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

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