

# Energy efficiency improvements and carbon emission abatement in European manufacturing: a strategic decision framework in response to climate change

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## Abstract

Addressed are the topics of energy efficiency improvements and carbon emission abatement in European manufacturing. The primary issues of concern are energy consumption and carbon emissions as they relate to manufacturing enterprise activities. The focus of the paper is on development of a strategic decision framework that serves the purpose of both visualising the scope of improvement areas and well as identifying strategic options and priorities. This decision framework is presented in the form of a grid, which is being developed to represent, in a graphical form, some underlying foundational principles. These principles are briefly reviewed, and reflect the complexity of addressing energy efficiency improvements and carbon abatement measures in modern advanced manufacturing environments. Given this complexity there is an urgent need to develop a strategic decision framework to support both development of research policy and strategy in government circles, and strategy development in manufacturing enterprises. The proposed strategic decision framework is offered as a first attempt to provide such a supporting tool.

**Keywords:** Sustainable manufacturing; energy efficiency in manufacturing, carbon abatement in manufacturing; operational energy efficiency; embodied energy, climate change, greenhouse gas emissions.

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## 1. Introduction

European Manufacturing research and practice will, over the next 20 years and more, be shaped by the need to respond to global warming. The challenges posed by climate change are significant and urgent. To make a large impact it will be necessary to address many fundamental and taken-for-granted assumptions concerning the practices of modern advanced manufacturing enterprises. Moreover, given the scale of the problems and the limitations on available resources, a strategy that targets these resources at high impact areas is essential. This is the case for both government agencies when it comes to identifying areas for research support, and for enterprises, with

respect to targeting their own resources on improvement projects.

However the problem of energy efficiency improvements and carbon emission abatement in advanced manufacturing is not an easy issue to address. The whole topic domain is extremely complex by virtue of several factors such as interactions between system components, supply chain relationships, energy embodiment, off-shoring of production, inherent process limits on energy efficiency, lifecycle issues, and so forth. For further discussion of these complications see Kidd [1], who in response to these complexities has proposed six foundational principles upon which actions in manufacturing enterprises to improve energy efficiency

in response to global warming, need to be based.

This paper briefly introduces these proposed foundational principles, and then focuses in on the key issue of energy embodiment, a factor of energy efficiency that if overlooked leads to misunderstanding and erroneous results about the true energy consumption in manufacturing. The paper then provides an overview of a visual method that is being designed to provide a decision framework. This framework will support both government agencies and manufacturing enterprises in their efforts to target resources at the most important high impact areas that require urgent attention if energy efficiency, energy reduction measures, and carbon emission abatement are going to have the degree of impact that are required by the demanding political targets that have been set in the European Union.

## **2. Foundational principles for energy efficiency in manufacturing enterprises**

The world faces the challenge of reducing the emission of greenhouse gases, primarily Carbon Dioxide. In addition, energy consumption also needs to be cut, not just as a means of lowering Carbon Dioxide emissions that result from the burning of fossil fuels in power stations, but also to respond to increasing concerns over energy scarcity and security of supply, as dwindling fossil fuel resources raise the specter of future black-outs and energy shortages. Further discussions about these issues can be found in [2,3].

Manufacturing industries will need therefore to invest considerable resources over the next few decades, in reducing both energy consumption and Carbon Dioxide emissions. However, there are many complexities associated with manufacturing, which transforms what might at first inspection seem a straightforward issue, into one of considerable complexity. In essence the belief that all that is necessary is to start cutting energy consumption by investing in new, more energy efficient components, machines etc. is a suspect assumption. The International Energy Agency [4], for example, have described the example of a motor driven pumping system, where replacing the motor with one that is more energy efficient is not necessarily the right thing to do to achieve an optimal system in terms of energy efficiency. The reason for this is that the motor is only one component of the system. The overall efficiency of the pumping system is dependent upon the efficiency of the various components in the system. Thus the

reasons for energy inefficiencies do not just lie with one component of the system, but with several. Moreover, the way that these components interact, could in general terms, also be important for overall system performance. Furthermore, the matching of the pumping system with the demand is also a crucial design issue. This simple example highlights the importance of a systems-based approach to energy efficiency improvements. And there are many other issues which taken together add to the complexity of addressing energy efficiency in manufacturing.

Consequently a set of foundational principles have been proposed [1], which are intended to provide a guiding framework for addressing energy efficiency in manufacturing, in response to climate change related drivers. These foundational principles are as follows:

### *Principle 1. The principle of multiple levels*

Energy savings and carbon emission reductions can in principle be made by taking actions at individual machine level, at sub-system level, at process level, at factory (plant) level, at enterprise level, or at inter-enterprise level.

### *Principle 2. The principle of systems and lifecycle perspectives*

Crucial to determining whether an overall reduction in energy use or Carbon Dioxide emissions is achieved, regardless of what level the energy saving or carbon emission reduction action is taken, will be system wide and a lifecycle analysis, that factors in all the elements including supply, use, and disposal.

### *Principle 3. The principle of potentially competing objectives*

Energy savings and reductions in Carbon Dioxide emissions are not necessarily mutually supportive. There may be circumstances where pursuit of one, results in the increase in another, and vice versa. For example, the implementation of carbon abatement measures could potentially involve greater use of energy.

### *Principle 4. The principle of energy embodiment*

Energy and Carbon Dioxide emissions used in the manufacture of a product can be considered as being embodied in the product. This applies whether the product is an item sold to a consumer, or some component purchased for use within a manufacturing plant, etc. Embodied energy and carbon emissions should be factored into calculations of the energy saving and Carbon Dioxide emission reduction

potential of any energy efficiency or carbon emission abatement projects.

*Principle 5. The principle of direct and indirect energy use and Carbon Dioxide emissions*

A distinction needs to be made between direct and indirect energy use and Carbon Dioxide emissions. Direct energy use and Carbon Dioxide emissions are those that take place within the boundaries of an enterprise, and which potentially the enterprise has direct control over. Indirect energy use and Carbon Dioxide emissions are those that take place outside the boundaries of an individual enterprise. Typically suppliers control indirect energy use and Carbon Dioxide emissions, or indirect energy use occurs during the life of the product (while in use), or at the point of disposal.

*Principle 6. The principle of energy efficiency versus energy use elimination/reduction*

A distinction needs to be made between energy efficiency and energy use elimination (or reduction). The two things are very different. Energy efficiency is primarily a measure of the conversion of the energy that enters the system, into useful work, that is to say a measure of system losses. Energy use elimination seeks to avoid the use of energy by finding non-energy consuming solutions, or by simply doing away with energy consuming devices, or by lowering the rating of energy consuming devices to better match actual demand.

### **3. A strategic decision framework grid**

Embodied energy is that energy which is used in the production of some item or product. Likewise embodied carbon is the Carbon Dioxide emitted in the manufacture of an item or product. This embodied energy perspective is often used in economy-wide analysis of the impacts of manufacturing activities, for example the lifecycle impacts of consumer goods [5].

There are several formal definitions of embodied energy [6]. Some of these limit the scope to the energy used in the manufacture and supply to the point of use, of a product, material or service. Others consider embodied energy to be the energy used during the entire lifecycle of a commodity, that is to say, from extraction of raw materials, through manufacture and transportation, to disposal.

In the construction sector there is an extensive body of literature on embodied energy. One of the

reasons for this is that with increasing efficiencies in operational energy use, the relative significance of embodied energy is becoming more important as this embodied energy forms a greater proportion of the total energy used over the life time of a building [7].

Both embodied energy and embodied carbon are crucially important with respect to manufacturing industry's response to global warming. Ignore embodied energy and carbon, and one is reduced to making local decisions about current operational energy consumption or carbon emissions, without any regard for the energy that already been consumed or the carbon emitted in the construction of a plant, or the energy that will be consumed and the carbon that will be emitted, in the disposal of an item or product. And the aim is to achieve a global reduction in both, not a local minimization.

For manufacturers there are two distinct types of embodied energy and carbon:

- The embodied energy and carbon in the products they manufacture; and
- The embodied energy and carbon in the equipment used to manufacture these products.

Clearly the first is a function of the second. But the first is also a function of the non-tangible, that is to say, the policies, practices and procedures implemented within the manufacturing enterprise. An example of these would be frequent just-in-time delivery of components to a plant, which results in energy used in transportation becoming embodied in products.

An approach to reducing energy consumption and carbon emissions needs therefore to be founded upon the understanding that it is necessary to have in place, or to collect data concerning the energy and carbon emissions embodied in the plant as well as that which results from the operation of the plant and the policies, procedures, etc. in use. This of course is a major undertaking, and one where support is clearly needed at Government level to ensure that such data is preserved and stored and made available to those who need it.

	Direct				Indirect			
	Energy		Carbon		Energy		Carbon	
	Embodied	Operational	Embodied	Operational	Embodied	Operational	Embodied	Operational
Intra-enterprise								
Enterprise								
Factory								
Process								
Sub-system								
Machine								

**Figure 1: Energy and Carbon Emissions Strategic Decision Grid**

	Direct				Indirect			
	Energy		Carbon		Energy		Carbon	
	Embodied	Operational	Embodied	Operational	Embodied	Operational	Embodied	Operational
Intra-enterprise					H	H	H	L
Enterprise								
Factory	H	L	H	L				
Process								
Sub-system								
Machine								

**Figure 2: Fictitious Illustrative Example of a Partially Completed (As-Is) Energy and Carbon Emissions Strategic Decision Grid (H = High, M = Medium, L = Low)**

The relevance of the above is that, in what follows, embodied energy and carbon form an integral part of the approach. For this, the foundational principles have been used to shape the development of an analysis grid, which has the form shown in Figure 1.

Included in this grid are all the key foundational principles. In the left column there are all the different levels at which energy efficiency and carbon emissions can be considered (Principle 1). These also encompass the systems perspective (Principle 2). The remaining part of the Grid is divided into two parts, dealing with direct and indirect energy use and carbon emissions (Principle 5). Each of these two columns is further sub-divided into two sub-divisions: energy and carbon emissions (Principle 3). These are then further sub divided in operational energy use (carbon emissions) and embodied energy (embodied carbon) (Principle 4). Ideally to complete the process, there should be a final further sub-division of columns into

energy efficiency and energy use elimination (Principle 6). However, this has not been done since Principle 6 refers solely to energy, and there is no link with carbon abatement. It would therefore make no sense to include this under the columns headed “carbon”. Alternative means of visualizing this principle need to be identified.

The intention is that the Grid will provide a high-level view of energy and carbon emissions, which would be designated simply as high, medium or low in various parts of the diagram (see Figure 2 for a fictitious illustrative example of a partially completed Grid). It should be noted that there are potentially two different versions of the Grid. One representation could highlight actual energy efficiency (carbon emissions) as high, medium or low, while the second could identify potential for improvements (high, medium or low). Both versions of the Grid are useful. The first would illustrate the “as-is” circumstance, while the second would convey information about

potential areas where improvements can be made. This difference is important, as it may be the case, as an example, that energy efficiency is low as a result of some inherent limitation of a process, but no alternative process is available.

It should also be noted that not all parts of the Grid would be relevant. For example, some companies may not own manufacturing facilities, but instead may wholly sub-contract manufacturing to a contract manufacturer. In such a case the energy efficiency and carbon emissions of the subcontractors would be included in the right-hand side of the Grid. In this way manufacturers that outsource manufacturing would have to account for the energy and carbon emissions of their subcontractors, which is an important requirement in the globalised world of manufacturing.

Underlying these energy and carbon emission designations (high, medium, and low) would be “quantification”, which would be the first step in the process of applying this Grid. This is acknowledge to be a major exercise, since it not only involves undertaking a significant amount of data collection and analysis, but also carbon footprint modeling, for example using the PAS2050 Carbon Footprint Modeling tool [8,9].

However, once such an exercise has been undertaken, the tool will help to provide a visual overview of energy use and carbon emission issues and problem areas, both within the enterprise and beyond it in supply chain partners, as well as in terms of operational energy use and operational carbon emissions, and those which are embodied within the plant (factory) itself.

Clearly the whole process needs to be supported with appropriate ICT tools, but these do not yet exist, which suggests in itself a topic of research. This is a matter for future consideration. Moreover, as with the construction sector, there is a need to ensure that data is collected at the level of national economies and regional economic groupings so that embodied energy (and carbon) analysis can be undertaken.

What this visual representation will provide, is a guide for targeting resources in areas where most energy is consumed, or where most carbon is emitted, or both. It also highlights the difference between operational energy use (carbon emissions) and embodied energy (carbon), and should, with dynamic links (via computer-aided tools), show how improvements in operational energy use and carbon emissions, lead to increases in embodied energy, which is an inevitable result of expending energy and

carbon emissions on improvement projects. What the Grid does not fully do however is highlight ways in which carbon abatement projects might clash with the desire to reduce energy consumption (Principle 5). For this a more dynamic Grid is needed, which necessitates linking the grid to a model which captures the dynamics of the specific circumstances. A spreadsheet model could deliver this functionality, but this again is a matter for future consideration.

#### **4. Conclusions**

What this paper has attempted to do, is provide a response to an urgent need for better understanding among government policymakers and senior executives with regard to adopting a holistic approach to the issue of reducing energy consumption and carbon emissions.

At the present time there is a limited understanding of the implications for manufacturing of reducing both energy consumption and carbon emissions. This is partly due to a lack of systems understanding [4], but also partly because past efforts in the area of energy efficiency have been primarily driven by energy cost concerns, for example as a result of the energy price shocks of the 1970s [10].

Currently the thinking with respect to improving energy efficiency in manufacturing is very much dominated by component level improvement in energy efficiency [11], with a tacit focus on minimizing energy use at the level of the individual enterprise, or at lower levels within the enterprise. The focus is also entirely upon reducing operational energy use, and the matter of embodied energy has not been adequately considered, if at all.

Yet there is no guarantee that this rather limited approach will lead to lower energy use and carbon emissions at the level of national economies, as it effectively assumes that optimization at a micro level will lead to optimization at macro economic level. And it is at this macro level of the global economic system, where efforts need to be directed. The same aim also applies to carbon emissions. With these objectives in mind, those that set research agendas within government bodies need to begin to address the problem of economy-level improvements. This involves looking beyond micro level considerations and examining the problem of energy consumption and carbon emissions at a macro level and then working downwards to the micro, rather than working from the micro level up towards the macro level as is

the case at present. This is not an easy task and goes well beyond what is both accepted thinking and normal practice. However, with the use of Information and Communications Technologies (ICT) this approach should be feasible, but will be challenging. And this in fact, is one of the major application areas for ICT used for energy efficiency in the manufacturing enterprise. The benefits of ICT for energy efficiency in the manufacturing enterprise lie, not just with low level improvements (which may not deliver any real benefits as a result of failure to take into account system level issues), but with high-level intra-enterprise and macro level applications focused on delivery of large reductions in energy use and carbon emissions.

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