Logistics and Integration in Small and Medium Enterprises

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Proposed integration of small and medium enterprises (SME) aims the improvement of their individual production efficiency through better resources integration with an emphasis on environmental sustainability. The main resource in question is energy, but water, transport, waste, services, IT, inventories, etc. are also considered. Three methodologies are proposed for direct implementation: The first one explores integration between areas of integrity, the second utilises the marginal value concept and the third - amalgamates two successful systems integration tools such as Pinch analysis and eMergy analysis entering the domain of multiple resources management.

Keywords: Integration, Pinch, SME, resources management

Currently, process integration can be seen as a holistic approach to process design, retrofitting, and operation, which emphasizes the unity of the process. It can be seen as a common term for the application of methodologies developed for system-oriented process plant design. The three major features of process integration methods are: The use of heuristics; the use of thermodynamics (e.g. pinch analysis, exergy analysis) and the use of optimisation techniques. The core element of such integration remains at the system approach to energy and material flows, where the effluent’s flows and waste management becomes a whole new dimension of it.

Experimental Part (The Eco-industrial Network)
The drive for integration leading to possible economic and environmental benefits has turned our focus onto local small and medium enterprises (SMEs) located in the Mid-West region of Ireland. The Mid-West region of Ireland comprises County Limerick, County Clare and County Tipperary and includes approximately 10% of the national land area and population of Ireland. The industrial base is dominated by light industry such as electronics, instruments, pharmaceutical and healthcare, metals and engineering. The attractiveness of the Mid-West as a location for industry is demonstrated by the large number of foreign-owned plants established in the region. It is estimated that there are approximately 400 SMEs in the Mid-West region.

While SMEs contribute to growth, employment and rural development they also exert quite significant impacts on the environment. It is estimated that in total SMEs are responsible for 70% of all industrial pollution across the EU [1].

The announcement of our research in the area of industrial integration has attracted significant interest in the region and already 22 SMEs from the Mid West region formally expressed commitment to this project. Many of these companies already work together in areas other than sustainability and this basis has established such crucial advantages as mutual trust.

There are many successful international examples of SMEs integration to form Eco-Industrial networks and these have been successful in terms of the reduction of environmental impacts, e.g. waste reduction, resource use reduction, improved transport management, etc. and improved competitiveness for the companies involved. Such are: Kalundborg - Denmark and Styra - Austria; the INES project in Rotterdam Harbour and the UK National Industrial Symbiosis Programme. But there is still significant work to be done in terms of integration methodology development and methodology generalisation.

Results
Eco-Industrial development is characterised by closely co-operating manufacturing and service industries working together to improve their environmental and socio-economic performance by improving their energy resource use and waste disposal efficiency through identification of options for reuse recycling or regenerative reuse of resources across areas of integrity. This may be as simple as identifying one SME’s waste which could be used as a raw material by another business, or as complex as rethinking the transport and supply logistics for the entire cluster or maximising economic and environmental performance using grass-root multi-objective optimisation methodology.

The attraction in the concept of Eco-Industrial development lies in its application of the natural ecosystem metaphor to “industrial ecosystems”. The ideal of the metaphor is that industrial ecosystems function according to the system development principles of natural ecosystems, i.e. closed loops and waste utilisation between industrial actors [2]. A local or regional industrial system is encouraged to move towards an interactive system through cooperative waste material and waste energy utilisation (recycling of matter, cascading of energy) and sustainable use of local renewable natural resources of matter and energy between the industrial actors. By reducing the waste management costs, emission control costs, raw material and energy costs, transportation costs, costs resulting from the implementation of measures required in environmental legislation and by improving the environmental image as well as the “green market situation” of the network, economic gains are possible.

The goal of Eco-Industrial development is, at the minimum, to generate the least damage in industrial and ecological systems through the optimal circulation of materials and energy.

All companies participating in this project confidently expect that by improving their performance with respect to sustainability they will gain economically through shared marketing initiatives, accessing green markets and gaining...
recognition as responsible stakeholders within the local community.

The system approach
System oriented methods provide practical way to find required minimums for energy, raw material and water based on process integration.

Heat recovery between areas of integrity
The energy integration concept introduced in [3] may very well match the undertaken task of beneficial integration within the Eco-Industrial Network. The concept utilises the natural division of process plants in logically identifiable regions (areas of integrity) and the potential for heat (energy) recovery between these areas. The optimisation task in the case is formulated as identification of schemes of energy recovery between areas of integrity, which offer maximum heat flow exchange with least number of interconnections between the regions (fig.1). This concept can be adapted without changes for the purposes of energy conservation within an Eco-Industrial Network. The areas of integrity in this case are the SMEs themselves and the integration of energy will be done with minimum re-piping or other type of interconnections between them.

Marginal value analysis
As shown in [4], this method evaluates the real value of utilities, such as steam, water, etc., which in the general case have different value when different production sites are concerned. It allows more transparent and convincing ground for decision-making when the integration of energy and other resources between industrial partners is an option.

To define the marginal value of any stream or utility, the evaluation of three marginal values is proposed. Those are the marginal profit, the production cost and the production value. The calculation of these three values can be done using so-called site model, which consists from material and energy balances and topology (structure) of the system in question.

We propose a new application of marginal values for integration decision-making and multi-site application. An important side of this analysis is the creation of an integrated site model. The proposed analysis in general case will include marginal values of utilities, services, inventories, transport, IT, treatment, etc. The final purpose of the analysis is the evaluation of eventual changes of marginal values as a result of proposed integration.

Emergy-Pinch analysis
The available solar energy used up directly or indirectly to make a service or product available, defined as emergy [3], was applied by number of authors to compare inputs of different origin, such as human labour, transportation, energy, fuels, chemicals, utilities, plant cost, etc. Solar emergy is the solar energy directly or indirectly necessary to obtain a product or a flux of energy in a process; it is an extensive quantity and its unit is the solar emergy joule [sej]. To convert inputs and other kind of flows into the solar equivalent, it is necessary to know the solar transformity, which is the emergy necessary to obtain one unit of product.

Unlike the emergy, transformity is an intensive quantity and usually measured in [sej/J]. Transformity calculation

Fig. 1. Horizontal and Vertical integration at an Eco-Industrial park

Fig. 2. Combined Emergy-Pinch analysis covers the Life Cycle of a process
is a difficult task stimulating researchers to exchange data and build databases establishing common ground for analysis. An interesting feature of Emergy analysis is the historical information about the resource or activity in question. The emergy value associated with a product is the memory (the sum) of the all energies that were used to produce it. Another great feature of emergy analysis is its ability of identify critical processes/stages/units. This makes it quite suitable for the purposes of environmental consideration in the Eco-Industrial Network.

In [6] it was promoted the interesting idea of combining emergy analysis with Pinch analysis [7] - a well-known tool for resources management in industry. These two methods give the missing link between the industrial resources management for economic benefits and the environmental impact assessment comparing alternative solutions (fig.2).

The treatment and reuse of wastes is the key to the evaluation of systems sustainability. The emergy loss is considered through the investment of waste treatment, but in the same time, this treatment may not only recover ecological acceptable level of the resource, but raise its potential for regenerated usage.

**Bottlenecks identification**

Combining Emergy and Pinch concepts makes possible to identify more precisely the combined influence of critical processes or phases through allocation of constrained processes (these touching the total emergy investment supply line and preventing its further lift up). The Pinch-type of targeting gives several important evaluation parameters: (1) The ultimate minimum emergy supply to run the entire process at any time (the slope). This is the flow of resources, services and work required to run the entire system; (2) The total emergy investment for the entire process for the entire period; (3) The maximum transformity (the “amplitude” of transformity, giving the total “power” of resources to run the process - another criteria to compare alternatives, identifying what process needs resources of highest quality) - the horizontal projection of the right end point of the emergy investment supply line; (4) Limiting stages/resources (restricting the emergy investment supply line to increase its slope). This one gives indication about processes and resources which utilisation is to be intensified in order to improve the efficiency of the entire process; (5) Pinch point - limiting point allocation. Details of these cases can be found in [6].

**Oxygen-water-Pinch**

The intent to design more cost attractive wastewater treatment systems was approached by extending Pinch principles towards so-called Oxygen Pinch analysis [8]. The idea is to target prior to design the idealistic minimum oxygen required by the micro-organisms to degrade organic waste and to suggest treatment flowsheet and design changes ensuring efficiency of operation close to the earlier stated target. In most of the cases the oxygen is supplied to the micro-organisms through agitation. Agitation and other forms of aeration require energy, so finally the analysis based on Oxygen Pinch principles leads again to their original application associated with energy conservation. Apart from this, Oxygen-Pinch concept allows for the first time targeting a quality characteristic - the growth (the reproduction rate, or health) of micro-organisms.

**Combined Water-Oxygen Pinch Analysis**

The aim of this methodology is to help decision making about the strategy and the organisation of wastewater treatment within an Eco-Industrial Network. Major factors contributing to the cost of wastewater treatment and pollution levels are the wastewater quantity and the wastewater quality. The wastewater quantity is directly linked to the amount of energy required for the wastewater treatment. The objective to minimise the wastewater quantity can be achieved using the Water-pinch analysis. Water Pinch helps to increase concentration levels of wastewater and decrease its quantity. In contrary, wastewater quality is inversely proportional to the energy required for wastewater treatment as well as pollution levels. There is no integration technique that would facilitate wastewater quality improvement. A mechanism to negate this effect is required. This objective can be achieved by the application of Oxygen Pinch Analysis. Thus the overall effect of increasing the cost effectiveness of wastewater treatment can be addressed through combination of Water and Oxygen Pinch Analysis. The expected result is a decision-making procedure suggesting within particular market circumstances what amount of wastewater to be taken for treatment within particular member factory of the Eco-Industrial network and what part of it to be sent to the servicing wastewater treatment plant.

The above methodology may very well serve particular Eco-Industrial network as a convincing argument for or against the idea for commissioning of a centralised wastewater treatment plant, its allocation, etc. It can serve as a firm ground for targeting the minimum electrical energy (respective cost) for treatment of different quantities and qualities wastewater – a tool for determination of servicing charges.

**Emergy-Water-Pinch**

An important feature of Water Pinch, inherited from the classical Pinch analysis is that it gives design guidelines - an important advantage to Emergy analysis. Water Pinch considers mainly streams’ contamination level, what in the general case is not enough. It is more than obvious that different contaminations and concentration levels would need different effort of water treatment depending on the nature of contamination, composition, chemical bounds, etc., not only concentration levels and limits. Here comes the help of Emergy analysis. The ability to assess the history and the effort associated with making water resource available (boring dept, pumping, pre-treatment (softening, filtration, chlorinating, etc.)) provides good ground to compare resource of equal quality.

Therefore, the Water-Emergy Pinch analysis can be used for decision making in the constrained cases of plant expansion, when the water resources are limiting the expansion decision.

**Discussion - Integration in Eco-industrial park**

We constrained the possible integration into four different vertical levels: (a) energy; (b) water; (c) waste treatment; (d) transportation. With the help of geographic data management system we first considered the possibility of horizontal integration between areas of integrity (fig.1). First, decomposition in clusters of member SMS was proposed accounting for their geographic allocation. Second level of decomposition was based on common landfill waste-disposal sites. The third level of decomposition accounted for potentials of inter-factories waste-reuse/waste and utilities utilisation options. The optimisation problem of maximum cost benefit can be formulated as a problem of finding the maximum of the “vertical sum” of “horizontal integration benefits”. The
proposed principle for redistribution of the achieved savings amongst the member enterprises was proportionality to the integration investments.

Other integration activities

These may include investigating possibility for integration of not only energy, water and waste recovery, but possible sharing of information and information technology investments. The diffusion of information and communication technologies (ICT) offers opportunities to transfer, collect and manage a great amount of information and to reduce the space and time barriers. Participating firms may reduce their ICT costs by forming a joint Management Information System (intranet) for the Cluster and this will identify further opportunities for sharing information and resources.

The next level of integration expansion will be common purchase of materials and shared transportation, shared commuting, shared inventories, shared shipping through integrating the transportation logistics of the participating SMEs. Each of these provides for a reduction in environmental impacts through reduced fuel cost, transport related emissions while also reducing the transportation costs of the companies and providing additional social benefits in reducing the number of vehicles on the roads.

Conclusions

This paper builds a set of appropriate methodologies and develops procedure suitable to identify synergies between collaborating SMEs targeting opportunities for socio-economic benefits. The idea behind the integration

of these methodologies is the merge between sustainability concerns at regional level with environmental concerns first at process level and second at SME level. The effort of such a project can demonstrate the practicality of the proposed framework providing a platform for the eventual set up of an Industrial Ecology Park.

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References

[1] EC Enterprise Directorate General, Public Policy Initiatives to Promote the Uptake of Environmental Management Systems in SMEs, 2004

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