The Sustainable Process Index SPI as an engineer's tool for environmental impact assessment of processes: the sugar industry as a case study

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Abstract

The Sustainable Process Index (SPI), a member of the ecological footprint family, is an ISO 14000 compatible tool for the evaluation of environmental impacts of processes. It allows the calculation of the relevant ecological pressures of a process including prechain and product usage. The SPI focuses on aspects of environmental sustainability and is aimed at engineers and the factors they can influence most effectively: material and energy flows that processes exchange with their environments.

The data of these flows are roughly known early in process development. The corresponding data for natural systems are the sedimentation rate of carbon in oceans, the natural concentrations of substances in soil and water, the exchange rates per area unit of airborne pollutants between forests and air as well as the replenishment rates for soil and water. Most of the natural flow and quality data allow a certain "regionalization" of the SPI wherever that is needed.

For a fast calculation of the SPI a computer program based on MS Excel has been developed. This tool has proven its usefulness in comparing different engineering options in view of their ecological impact. The most recent case studies are the investigation of the ecological and economical feasibility of small-scale ethanol production facilities that use corn or wheat as a raw material and the analysis of alternate usages of (by)products of the European sugar industry. The results of these case studies will be discussed here
Keywords: Life Cycle Analysis, environmental impact assessment, sugar production, bio fuels, optimization.

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1 Life Cycle Assessment with the help of the Sustainable Process Index SPI

In recent years there has been a rising demand for ecological save or "green" products. But what is a green product? A product sold in a store or a service given have usually a long history of other products and/or services up to the moment of being handed to the consumer, and most products end up as waste after their time for use is over. So to discern the ecological impact of a product or service, one has to consider the total life cycle. The execution of such a Life Cycle Assessment has been codified in the ISO 14000 standardization series and different tools to facilitate such an assessment have been developed.

1.1 Life Cycle Assessment

Life Cycle Assessment LCA has been proven to be a successful tool in analyzing environmental pressures of products, services or processes. A complete LCA also includes the examination of all relevant products or services before and after the item under consideration. The procedure for an LCA has been defined in the ISO standard 14040 [1]. This standard defines four phases of a LCA analysis. Those phases are (Figure 1):

1. In the first phase a goal and scope definition has to be done. This includes the definition of system boundaries which clarifies the content of the life cycle assessment.
2. In the second phase data is collected and related to the process steps in question. Eco-inventories including all relevant input and output data of a process are assembled. If a process produces more than one product allocation methods have to be chosen.
3. In the following impact assessment phase the data is assessed according to the chosen methodology to obtain evaluation results. These results are then interpreted.
4. In this phase the results of the prior 3 phases have to be discussed and interpreted. During the life cycle assessment results may be obtained that may propose a revision of prior phases, e.g. sub processes for a process have been excluded that now seem to be important and so the system boundaries have to be adapted. Therefore, LCA must be conducted as an iterative process.

The ISO 14000 standards provide only a guide how to proceed in the evaluation; they do not prescribe a fixed evaluation method. The reason for this neutrality in relation to evaluation methods is the large number of possible applications for a LCA, and each of these applications has its own difficulties, boundary conditions and scopes.

In most production processes there is more than one product, and in this context waste has to be considered as a product as well. In this case the overall ecological pressure has to be allocated between the products. An often used way is the allocation of the whole ecological pressure on one primary product, another is to share according to the mass flows associated with the different products and a third possibility is the distribution following the economic values of the respective products. There are numerous other possible ways to allocate the ecological pressure, but to compare two services or products the allocation method must be the same.

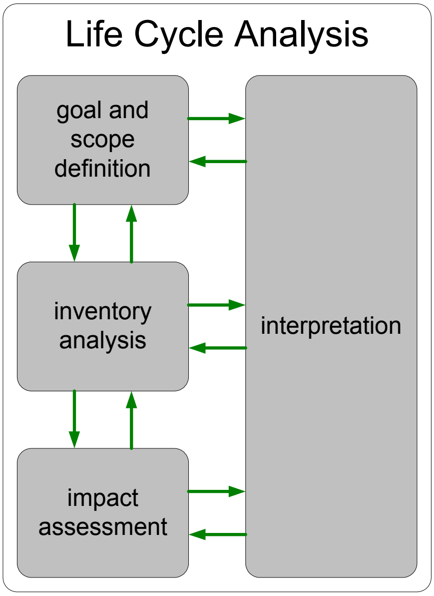

Figure 1: The 4 phases of a Life Cycle Assessment.

Most LCAs are based on the problem oriented approach to impact assessment (Centrum vor Milieukunde Leiden, CML-method) [2, 3] resulting in various impact categories. They provide a reasonable communication and discussion tool for questions like which environmental problems are caused to which extent over the life cycle of a product.

But for the problem of comparing the ecological impact of technologies and industrial processes a tool that leads to one highly aggregated number which can be compared easily is much more useable. Such an aggregated number will have to be based on sound scientific and engineering principles. The SPI is just the tool for comparing industrial processes.

1.2 The Sustainable Process Index SPI

The SPI uses a concept for environmental sustainability taking into account the limitation in the natural income for setting criteria for the exchange of material flows between anthroposphere and the environment. These criteria were developed by the Austrian research project SUSTAIN [4] and are written as follows:

1. Human activities must not alter long term storage compartments of global material cycles in quality as well as in quantity. If this principle is

not adhered to resources will be depleted and substances accumulated in ecosphere, overstraining the natural cycles.

2. Flows to local ecosphere have to be kept within the qualitative and quantitative range of natural variations in environmental compartments. If such flows exceed the amount a compartment can integrate the accumulating substances will alter the compartment. This alteration can lead to a local environment that is no longer able to sustain flora and fauna.
3. The variety of species, landscapes and habitats has to be preserved or increased. Variety is an important factor for flexible response of natural systems to pressures.

The SPI is a tool based on these criteria; it is a member of the ecological footprint family and is compatible to the modus operandi described in the ISO 14000 standard. It aggregates the different ecological pressures to one number; this single number is the area necessary to embed a process or service sustainable into the ecosphere. It allows for simple comparison between different technologies and especially assists in the comparison of processes based on fossil raw materials to those based on renewable resources. The SPI focuses on aspects of environmental sustainability for engineers and the factors they can influence most effectively. These factors are material and energy flows that processes exchange with their environments. The corresponding data for natural systems are the sedimentation rate of carbon in oceans, the natural concentrations of substances in soil and water, the exchange rates per area unit of airborne pollutants between forests and air as well as the replenishment rates for soil and water. Most of the natural flow and quality data allow a certain "regionalization" of the SPI wherever that is needed.

1.2.1 Calculation of the SPI

With some simple algorithms the Sustainable Process Index uses the criteria stated above to convert material and energy flows extracted from and dissipated to the ecosphere into area. This area is the surface required by nature to reintegrate the mass and energy flows into the global material cycles or it is the area needed for the regeneration of the compartments. This area is the "ecological footprint" of the process, the product or the service under consideration. The larger this footprint, the higher is the ecological "cost" for this product.

The total area A_{tot} is the sum of all partial areas (equation (1)) needed for the provision of the product or service.

$$A_{tot} = A_R + A_E + A_I + A_{st} + A_P \qquad [m^2] \qquad (1)$$

where A_R stands for the area necessary to produce raw materials, A_E represents the area requirement to provide process energy, A_I takes into account the area attached to physical installations, A_{st} is the area required for staff and A_P denotes the area to accommodate products and by-products in the ecosphere.

As the area A_{tot} corresponds to real technical processes, e.g. a bio-ethanol plant producing 10 000 t of ethanol per year, a_{tot} is the area for a single unit of product or a single unit of service n_s, like 1 kWh of process heat. It may be calculated as

$$a_{tot} = A_{tot}/n_s \qquad [m^2\ a\ unit^{-1}] \qquad (2)$$

The SPI is now calculated by relating this area a_{tot} to the area a_{in} that is statistically available to a person to provide all services and goods in a sustainable way. For Central Europe this area amounts to about 6 ha per person if the pertaining surface area of the seas is included.

$$SPI = a_{tot}/a_{in} \qquad (3)$$

More details about the calculation of the SPI and the sub areas can be found in the works of Niederl [5] and Sandholzer [6]

1.2.2 The program SPIonExcel

For the tedious task of calculating the different areas and the SPI a computer program has been developed. This program, SPIonExcel, calculates the ecological footprint of a process and the SPI of a product or service through the input that characterizes the process given by an eco inventory. The eco inventories used for the calculation of the overall footprint contain mass and energy flows of processes in terms of input and output flows. For calculating the SPI and the overall footprint the software is able to work with different Access databases that contain these eco inventories in a structure usable for this program. The databases can be easily expanded by the user.

With these data all partial footprints are calculated using the mass and energy inputs and outputs of all processes along the life cycle. This results in the overall ecological footprint a_{tot} for a unit of a desired product or service. Additional information can be gained by the amount the partial footprints contribute to the overall footprint. This identifies which intermediate or impact inflicts the largest pressure on the environment.

The program and a basic set of databases is available free of charge from the world wide web [7] further information can also be found at that web site or at Sandholzer [6]

2 Case studies

The concept of the SPI has been applied successfully to a number of engineering problems, were it was necessary to decide between different variants and options [8]. The two following applications of the SPI methodology are the European sugar industry and small-scale bioethanol plants.

2.1 Sugar industry

International pressure is currently forcing the EU to change its policy in the sugar sector considerably. This is a situation to rethink the general ecological situation of this sector, both as a support for political bargaining and technological development.

Sugar from beet is currently a major agricultural product and drives a divers and considerable industrial sector in Europe. Sugar itself is the base for many industrial products, ranging from the food sector to the pharmaceutical sector to energy provision and biotechnology. The ecological impact of its provision therefore influences the sustainability of many industrial sectors.

The ecological analysis must be seen as complementary to economical scenarios. Long term sustainability can only be achieved if a sector develops in a direction that generates high value while inflicting only small environmental impacts. Thus in the situation of an inevitable change in the structure of a certain sector like in the case of the sugar industry in Europe, environmental considerations will help to shape strategic decisions.

One problem all beet sugar factories face is their dependency on external energy sources, in comparison cane sugar factories are able to supply their energy needs by burning the left over cane fibres in the boilers. As energy costs are in large parts responsible for the operating costs, this makes it much harder for European beet sugar suppliers to compete with their competitors' that produce largely cane sugar.

A possible answer to this problem may be to produce biogas from the extracted beet chips and a part or all of the leftover leaves from the beet harvest. This biogas would then be used in a combined heat and power plant to fulfil the energy needs of the sugar factory. Calculations show that by using only the beet chips it would be possible to supply 35% of the process heat and 110 % of the electricity needed by a state of the art sugar factory, by using part of the leaves it would be possible to produce all the heat and surplus electricity could be sold. The ecological pressure of these options is computed using the program SPIonExcel:

Table 1: Ecological pressure a_{tot} for the production of 1 kg white sugar.

	m^2 a unit^{-1}
combined heat and power; natural gas	$a_{tot} = 140$
combined heat and power, biogas	$a_{tot} = 110$

The main factor influencing the ecological pressure of the biogas option is the mean transportation range for the leaves. For above calculations a mean transport range of 50 km by 16 t truck was assumed, corresponding to a beet growing area of about 7500 km².

2.2 Biofuels

The trend towards biofuels as environmentally compatible alternatives is stipulated by the EU Biofuels Directive, and increases the importance of bioethanol. The SPI calculated with the program SPIonExcel was used to compare the ecological pressures of different conventional and biofuls. Figure 2 shows the area a_{tot} that is necessary to produce 1 kWh of energy

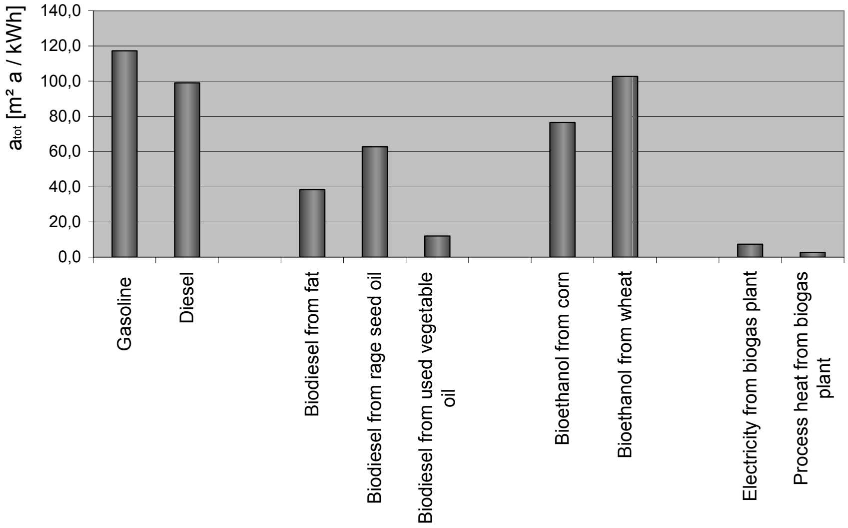

Figure 2: Ecological pressure a_{tot} of different energy sources.

The ecological impact of most biofuels shown in Figure 2 is very low because they are produced out of waste material like fat or in the case of the biogas option shown above from communal waste. The main part of the ecological pressure is allocated to the main product, e.g. fried chicken in the case of used vegetable oil. The bioethanol options are high in comparison to the other examples as in this case corn and wheat are grown for this purpose. If biogas from draff or straw from the cereals is used for supplying the energy to the biogas plants, the area a_{tot} of bioethanol will be significantly reduced.

3 Conclusions

With the SPI concept, process engineers have a versatile tool for quick and reliable environmental assessment of processes. On the one hand this is due to the possibility of using easy accessible engineering data in the valuation process. On the other hand the SPI can be used to pinpoint ecological bottlenecks of technologies and therefore may be used for technological optimisation in process industry and related technological fields already at an early stage of development.

It can be shown that the production of biogas out of extracted beet chips and leaves from the sugar beets can be an ecological and economical sensible option. The ecological bottleneck in this case is the transportation range of the beet leaves. Further research will be done to study other options, like production of biogas from the beet leaves in smaller plants along the main beet growing areas and using it for the operation of the trucks delivering the sugar beets to the factory.

The ecological pressure of bioethanol from cereals is large in comparison to other biofuels if for the operation of the plant fossil energy sources are used. An ecological sensible solution would be to use biogas from draff or straw from the cereals for supplying the energy of the plant. Due to the size of the plants this may only be possible in small-scale bioethanol plants. These questions are currently examined as part of an Austrian research program.

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