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SPIonWEB – Ecological process evaluation with the Sustainable Process Index (SPI)

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Abstract

Chemical engineers however need quick and reliable cradle-to-grave evaluations, conforming to the ISO norm 14040, already at the design stage in order to assess the ecological performance of their design compared to design alternatives as well as to identify ecological hot spots in order to decrease the ecological impact of the process in question.

The Sustainable Process Index methodology has been particularly developed for this purpose and has been widely applied to the measurement of the ecological performance in production systems. Ecological performance is expressed in aggregate form as Ecological Footprint per service unit, thus allowing the engineer to take decisions. De-aggregation into different environmental pressure categories that this methodology allows as well helps the engineer to understand, what causes the engineer to pinpoint the process steps that are critical to the overall performance of the ecological pressure in a certain process step. For the modelling of these problems the software tool SPIonExcel has been in use in the last decade.

SPIonWeb is a web browser based software tool substituting SPIonExcel, which allows to model industrial processes on a thoroughly revised data base and a still more encompassing methodological base. Basic processes like electricity, transport, base chemical production chains are provided in a life cycle based database. Dynamic modelling allows creating process loops which allows simulating changes in the final product ecological performance if sub-process modification are assumed. Besides the Ecological Footprint (calculated with the SPI method) the program also features process visualization, detailed material balance for inputs and emissions, CO_2 and GWP life cycle emissions.

The paper provides examples of ecological process evaluation for different chemical engineering applications, in particular processes providing energy from different renewable sources and bio-chemical processes, e-g. bio-plastic production. Analysing these thoroughly different process chains will be used to highlight the information that can be gleaned from ecological process evaluation during chemical engineering design.

Keywords: Ecological Footprint, Ecological Performance, Sustainable Process Index on Web, Dynamic Lifecycle Impact Assessment

1. Introduction

A wide variety of assessments methods are available, depending on the goal and context of the studies (Mayer, 2008). The ultimate need to measure the pressure exerted by humanity on the environment required an appropriate set of indicators. Similarly increased awareness about environmental issues, life cycle impact assessment has become an important issue for access to consumer as well as international market. As a result processes that provide products or service has to be ecologically optimized (Sandholzer and Narodoslawsky, 2007). Life cycle assessment (LCA) is an important assessment method which helps to successful execution of product or process development under environmental sustainability framework. It is an assessment technique which measures environmental performance of a process, product or service unit along its life cycle (Khan et al., 2004), including resources extraction until waste handeling (Harst and Potting 2013). In the recent times footprint indicators have become important tools for researchers, consultants and policy makers, in order to assess different aspects of sustainability (Fang et al. 2014). The SPI is a member of the ecological footprint family and is compatible with the procedure of the life cycle analyses described in the EN ISO 14,000. It provides the opportunity to describe the relevant ecological pressures of a process including process chain and product usage and disposal.

Methodology

Sustainable Process Index (SPI)

The Sustainable Process Index (SPI) is a tool for the evaluation of environmental impacts of processes. It was developed by Krotscheck and Narodoslawsky based on the assumption that a sustainable economy builds only on solar radiation as natural income (Krotscheck and Narodoslawsky, 1995). The Sustainable Process Index is calculated by using material and energy flows of a product or service extracted from and dissipated to the ecosphere and compares them to natural flows. The sum of total area A_{tot} i.e. ecological footprint of a process or service, required for sustainable embedding of it into the ecosphere is calculated as:

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

According to equation 1, A_{tot} is the sum of partial areas. A_R, is area required for raw material production. A_E, Area required to provide process energy (heat and electricity). A_I, area required for infrastructure facility or Installations. A_S, area required for staff support and A_P is the area required for sustainable disposal of wastes and emissions to the ecosphere (Gwehenberger and Narodoslawsky, 2007). For technological optimization calculation of impact per unit product, good or service is of importance. It is known as the overall footprint of the product a_{tot} and calculated as:

$$\mathrm{a_{tot}} \left(\frac{\mathrm{m}^2}{\mathrm{unit}}\right) = \mathrm{A_{tot}}/\mathrm{NP} \qquad (2)$$

NP represents the number of products or services provided by the process under observation for a reference period, which is 1 year in general, practice. This per service unit area itself is a relative sustainability measure. To make it more prominent it is further divide by available area per inhabitant (a_{in}) in the region which is relevant to the process. It is theoretical mean area (per capita) available per inhabitant for goods and energy supply to each person.

$$\mathrm{SPI} = \frac{\mathrm{a_{tot}}}{\mathrm{a_{in}}}\ \mathrm{cap/unit} \qquad (3)$$

SPIonWeb is built on basic SPI methodology following sustainability principles. The only difference between SPIonExcel and SPIonWeb methodology is calculation of dissipation emission areas. The dissipation areas for emissions into different compartments were used to sum up in SPIonExcel, while SPIonWeb uses eq. 4 to define the dissipation area for emission flow. The largest area among these partial dissipation areas is identified as key emission area and it is assumed that if area is provided for the key area, loading of impacts in all other replenished compartments will take place safely below natural concentrations.

$$a_p = \max(a_{ew}, a_{es}, a_{ea}) \qquad [m^2] \qquad (4)$$

SPIonWeb is an online web based free software tool, which can be used on any computing device (computer, smartphone or tablet), equipped with a browser regardless of operating system (windows, Linux, Mac, IOS etc.). It helps the user to assess life cycle of a product or service and estimates its SPI footprint, life cycle CO_2 emissions and GWP (global warming potential). It provides the opportunity of making quick scenarios for comparison and evaluation of recycled material (making loops). It's more user friendly and addresses to students, engineers and experts in LCA modelling.

This paper deals with ecological evaluation of PHA production from animal slaughtering waste utilizing SpionWeb. A basic scenario (PHA_EU27) was executed producing PHA utilising conventional energy resource (electricity EU27 mix and natural gas for process energy). In the next scenario (PHA_biogas_conventional), energy (electricity and process energy) is provided by burning conventional biomethane (produced from 50 % mixture of conventional corn and manure) in the combined heat and power (CHP) unit. In the final scenario (PHA_biogas loop) biomethane produced from biomass (50 % mixture of biological corn silage and manure) cultivated using purified biogas as fuel in the agricultural machinery (Kettl and Narodoslawsky, 2013).

Biopolymer Polyhydroxyalkanoate (PHA)

The results discussed in this study are based on the data acquired during ANIMPOL project, it studies production of biopolymers "polyhydroxyalkonates (PHA)", utilising slaughtering waste as starting material. The overall process consists of following sub-process: hydrolysis, rendering, biodiesel production and fermentation process. The process inventory data for 1 Ton (t) PHA production, obtained from different project partners is shown in Table 1 (Shahzad et al., 2013).

Table 1: Inventory inputs for PHA_EU27_natural gas process

Input	Unit	Inventory
Ammonium Hydroxide	t	0.0770
Glycerol production	t	0.2370
Inorganic Chemicals	t	0.0060
Iron Sulfate	t	0.0001
Net electricity EU-27, medium voltage	MWh	0.3214
Phosphoric acid (H3PO4)	t	0.0524
Process energy, natural gas, industrial heater > 100 kW	MWh	0.2921
Sodium Chloride	t	0.0002
Sodium Sulfate	t	0.0192
Waste water treatment, average	m^3	8.1178
Biodiesel_EU27	t	1.8588
Nitrogen from hydrolysis_EU27	t	0.0043
Process water (Europe) m3	m^3	8.1178

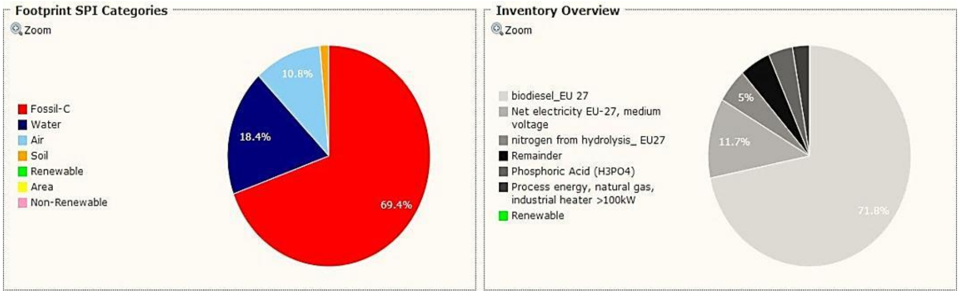

Figure 1: Screen snapshot of graphical inventory overview of PHA_EU27_natural gas process

The electricity consumption (Net electricity EU27, medium voltage) includes stirring, transfer of media and downstream processing. The process energy (process energy, natural gas, industrial heater > 100 Kw) consumption constitutes sterilisation of the media and maintenance of media temperature at 37 ˚C (Shahzad et al., 2013).
Figure 1 is a snapshot of automatically generated graph, which shows the distribution of foot print in SPI categories and share of different inventory Inputs.

The SPIonWeb also automatically generates process hotspots to figure out optimisation potentials as shown in Figure 2. In the current study, optimisation potential are in electricity consumption, biodiesel production, process heat consumption and PHA production (fermentation process). Biodiesel production has shown the highest potential, due to highly energy intensive production from tallow and maximum consumption as a raw material in the fermentation process.

In the light of hotspot results it is decided to evaluate the whole process using renewable energy resources. In PHA_biogas_conventional scenario, energy system is replaced with electricity and heat produced from conventional biogas using combined heat and power (CHP) unit. In PHA_biogas loop scenario, energy provision in the PHA production process is replaced with energy obtained from biogas produced using mixture of 50 % biological corn silage and manure. In this case biomass is produced using biogas fuelled machinery in agricultural practice (for ploughing, harvesting and transportation), creating a loop of biogas and purified biogas used in the machinery (Kettl and Narodoslawsky, 2013).

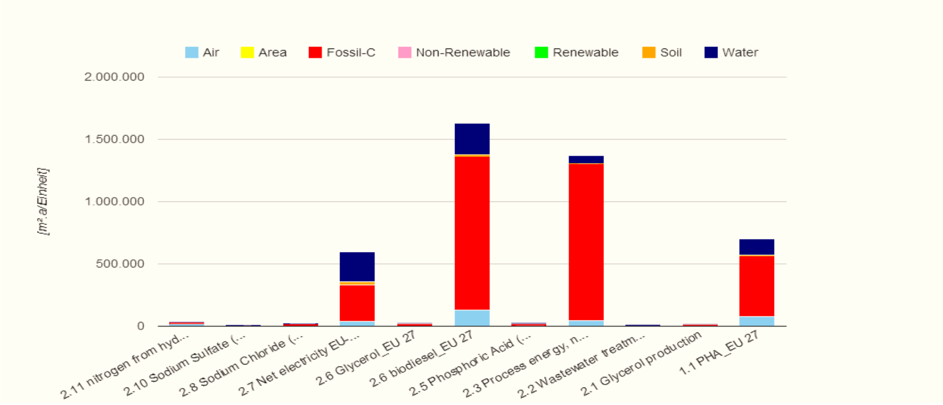

Figure 2: Screen shot of SPI hot spot graph for PHA_EU27_natural gas

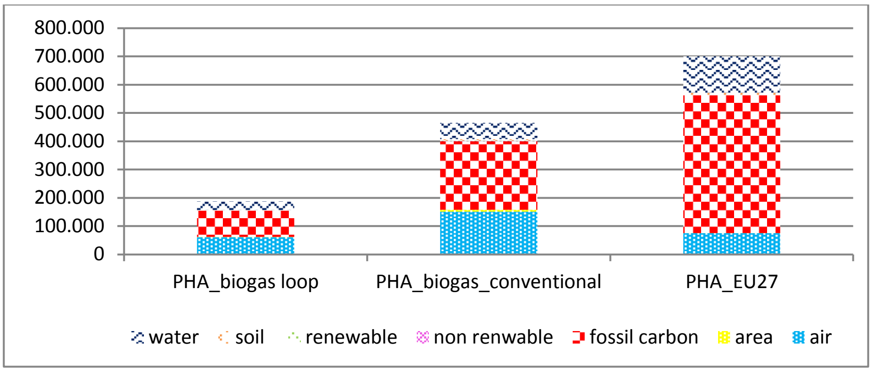

Figure 3: Comparison of overall SPI footprint in different scenarios

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Figure 3 represents the comparison of SPI footprints for 1 (t) of PHA production in different scenarios based on ANIMPOL process. SPIonWeb also calculates SPI footprint, CO2 life cycle emissions out of fossil carbon category, as well as global warming potential (GWP) as shown in Table 2. PHA_biogas_conventional scenario has 33 % lower ecological pressure than PHA_EU27 (normal industrial practice) production scenario, while PHA_biogas loop scenario has 73 % reduction in ecological pressure. Similarly life cycle CO2 emissions comparison show a maximum reduction of 81 % for PHA_biogas loop scenario and 50 % reduction for PHA_biogas_conventional scenario. The GWP results show similar trend for PHA_EU27 and PHA_biogas loop scenarios while PHA_biogas_conventional have highest GWP. The higher GWP values are related to NOX (nitrogen oxides) emissions in the agricultral practises. The highest GWP value for PHA_biogas_conventional is due to the usage of diesel fuel in the agricultural machinery input and application of synthetic fertilizers and pesticides in conventional agriculture.

Table 2: Comparison of footprint, CO_2 emissions and GWP in PHA production processes

Comparison of footprint, CO_2 emissions and GWP			
	Footprint (m^2)	CO_2 emissions (kg)	GWP (kg CO_2 e.)
PHA_EU27	697,769	3,556	63,323
PHA_biogas_conventional	462,269	1,766	101,373
PHA_biogas_biogas loop	184,207	671	61,856

2. Conclusions

SPI provides the opportunity to include ecological assessment in technology selection as well as planning of regional development. It can be computed utilising basic input-output flow (mass and energy balances, prices for installations and raw material) data. It computes clear, understandable and meaningful results which allow comparative analysis of alternative technologies in the process industry and regional optimization. Similarly it is very useful tool for process design, development and optimisation, using early stage ecological assessment for decision making.

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