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The ecological impact of the sugar sector- Aspects of the change of a key industrial sector in Europe

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Abstract

The paper will explore the ecological impact of sugar industry, using the Sustainable Process Index (SPI). This evaluation reveals weak points in the conventional sugar process, especially in the energy provision. Modification of the process utilising by-products and farm residues can considerably lower the environmental impact of the sugar sector. This is also interesting from the point of view that sugar may be seen as an important starting point for the production of ethanol, a prime contender for clean fuel.

Keywords

ecological process evaluation, sustainable process index, sugar production

1. Introduction

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.

From the point of view of process optimisation it is necessary to evaluate the impact on the environment posed by the different steps in the process and then compare these impacts. This comparison can then be used to pinpoint the most problematic aspects of the process. Concentrating the efforts on these process steps will improve the ecological performance of the process in general.
One major problem arising in ecological evaluation of technical processes is the fact that these processes interact in diverse ways with the environment. The emission of CO_2 will adversely effect global climate whereas the emission of sulphur oxides may have impacts on forests and the emission of heavy metals will be dangerous for soils. It is in the nature of technical optimisation that one effect on the environment will usually replaced by another. Meaningful evaluation therefore must on the one hand make the impacts of different process steps comparable. It must however also allow comparing different types of impact in order to avoid driving out devil with Beelzebub. Technical optimisation therefore is dependent on highly aggregated and reliable evaluation methods.

2. The Sustainable Process Index (SPI)

The paper uses the Sustainable Process Index [1,2,3] as ecological evaluation method.
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 SUSTAIN [4].
The sustainable process index SPI is a member of the ecological footprint family and is compatible to the modus operandi described in the ISO 1400x standard. It aggregates different ecological pressures to one number. This number represents the area necessary to embed a process (or a whole life cycle) sustainably 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 that engineers 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 gases 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.

2.1. Calculation of the SPI

The SPI calculates 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 AR stands for the area necessary to produce raw materials, AE represents the area requirement to provide process energy, AI takes into account the area attached to physical installations, Ast is the area required for staff and AP denotes the area to accommodate products and by-products in the ecosphere.
As the area Atot corresponds to real technical processes, e.g. sugar plant of 100 000 t production capacity per year, a_{tot} is the area for a single unit of product or a single unit of service, like 1 kg sugar. Supposing that the technical process provides n_s units per year, 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.

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

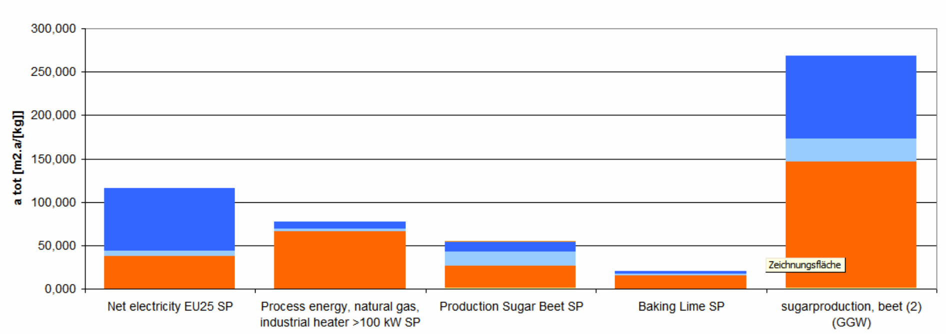
More details about the calculation of the SPI and the sub areas can be found in the works of Niederl [5] and Sandholzer [6]. The SPI can be calculated using free software available on the internet [7].

3. The case of the sugar industry

Figure 1 shows the specific area for 1 kg of sugar following a conventional sugar process [8]. In this figure, the block on the right side represents the whole environmental pressure of the production. It is the sum of the pressures of energy provision, the production of lime and the agricultural production of sugar beet. In all these steps, the lower part of the column represents the pressure caused by fossil raw materials (including the green house effect), the next part represents emissions to air and the top part emissions to water.
As can be seen from this figure, the dominant contribution comes from electricity production (calculated with the energy mix for the EU 25, including a high nuclear energy contribution), followed by process heat. The agricultural

production comes in third, followed by the environmental pressure caused by lime baking. The total environmental pressure of 1 kg of sugar is considerable, comparable to the production of 0,5 kg of fossil fuel, despite its origin from renewable resources.

Fig. 1: Ecological footprint of conventional sugar production



From this figure it becomes clear that the first priority must be laid on changing the energy system for the sugar production. In general there are two approaches to this problem: reducing the energy consumption and changing the system of energy provision to more sustainable patterns.

Sugar plants are, as a result of intense competition, already relatively energy efficient. The necessary considerable reduction of environmental pressure can therefore not be achieved by conventional efficiency increasing measures. Reducing the energy demand drastically can thus only be achieved by dramatic changes in the technology of sugar production, e.g. by introducing membrane processes and chromatographic separation steps as a replacement for conventional thermal processes like concentrating the sugar solutions via evaporation. Although such technological changes are certainly possible (and currently a source of debate within the industry), they are still some time away from practical implementation. This means, that a change in the provision system for process energy might be the best available alternative to date.

The sugar extraction of sugar actually utilizes only about 16-20 % of the mass of the raw material sugar beet. A sizable part of the beet (25-30%) is structural material that eventually ends up in the pressed chips. On top of that, sugar beet is not the only product from cultivation: there is always a considerable mass of leafs also produced alongside beets. This means that there is ample biomass available to supply the energy for processing sugar beets.

Sugar beet chips as well as leafs may be used in various forms to produce energy. Chips may be burned (after being dried) or may be fed to a biogas unit. Leafs are very suitable for biogas production, either directly or in the form of silage.

As an example of the possible impact of a change in the production system we will investigate the application of a biogas unit within the sugar factory. There are two possible ways to feed a biogas unit: utilize the sugar beet chips which are a direct by-product in the process or utilize chips plus leafs. In the first case the chips might be utilized in wet state, reducing the need to condition them via drying either for sale as fodder or for utilization in a burner. This in itself reduces the energy demand considerably. In the latter case one has to evaluate the impact of additional transport of leafs to the biogas unit.
A first analysis shows that by utilizing chips the electricity demand of the sugar process may be covered to 114 %. The heat demand however would only be covered by 34 %, leaving a gap that only can be closed by utilizing (environmentally problematic) fossil fuels.
In the latter case of utilizing leafs alongside chips, the heat demand of the sugar process (provided as heat from a combined heat and power installation working with biogas as fuel) can be covered by 118 %. This however leads to a surplus electricity provision of up to 6 times the demand of the sugar process. This excess electricity may readily be sold as “green electricity” at a premium price.
Figure 2 shows the environmental evaluations of the case when sugar beet chips as well as leafs from sugar beets are utilized to provide energy for the sugar process.

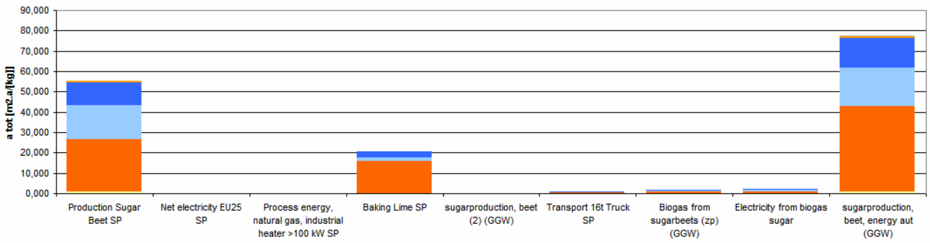


Fig. 2: Footprint of renewable energy provision case for sugar industry

It can be seen from this figure, that the change towards a system providing energy from the by-products of sugar beet production and the sugar mill itself will dramatically lower the ecological impact of the sugar industry by a factor of three. In the new situation, when the sector provides its own energy, the agricultural production (the bar on the left side) dominates the footprint. This calls for actions in the agricultural sector, especially lowering the use of fossil fuels as well as re-thinking the fertilization strategy.
It must be said that in the case of utilizing beet chips as well as leafs, the sugar sector is providing green electricity for society. In the calculation of fig. 2 there is no bonus for this excess provision included. From the point of energy efficiency, this setting is very attractive as it utilizes heat at the site of the

combined heat and power generation. Electricity is then provided at a very high rate of utilization for the raw material.

4. Conclusions

The paper reveals huge potentials for more sustainable production of sugar just by utilizing by products of the process of sugar production and sugar beet cultivation. This is just the starting point for more in-depth analysis, including the ecological evaluation of different technologies to produce sugar (as a guideline to future development of the sector) as well as the evaluation of more complex value chains based on sugar and its by products, including the production of ethanol, biopolymers and the utilization of leafs in green biorefineries. In general, the sugar sector can act as an important hub for the transformation of bio-raw materials in a sustainable way.

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