Case study European Sugar: important insights for environmental footprinting

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ABSTRACT

With regard to PEF development, this study provides an insider view on processes that contribute relevantly to the results, on the significant environmental impacts of beet sugar production in the EU & the method best suited for allocating specific impacts to the products of sugar beet processing. Data were collected from 11 sugar companies covering 18 countries (years 2008-2012). Depending on the year, the data covered 89-96% of the total harvested area in Europe and approximately 90% of EU beet sugar production. A hotspot analysis was run over 15 environmental impact categories and the respective single score using 4 different LCIA methodologies (ILCD, ReCiPe, Eco-scarcity and Impact 2002+). Furthermore, a sensitivity analysis on the 11 by-products comparing 7 allocation approaches was performed. The functional unit was one ton of white beet sugar of average quality. Agricultural production of sugar beet relevantly contributed to most environmental impacts on midpoint and single score. Quality requirements were derived for all the inputs and field emission calculations. The single score methods showed significantly different results regarding the relevance of different impact categories. Only seven of the 12 impact categories turned out to be significant for production of one ton of EU beet sugar. Depending on the allocation methodology, the share of environmental impacts distributed to beet sugar ranged from 91% (allocation by sucrose content) to 29% (mass allocation). The net environmental impact distributed to the white sugar when using substitution was close to zero or even negative depending on the substitutes. The EU sugar association (CEFS) will use the conclusions of the study to develop a Product Category Rule for EU beet sugar.

Keywords: data quality requirements, relevant impact categories, allocation, LCA of European sugar

1. Introduction

Sustainability issues and environmental management have gained strongly increasing attention in corporate strategy development in the last decade. Life cycle assessment (LCA) is thereby one of the central tools in supporting strategy building to foster corporate environmental sustainability. Due to its integrative character, assessing impacts on the environment over the entire life cycle and integrating a vast spectrum of different impact types, LCA is the established tool for status quo analyses, environmental hotspot identification and the development of selective measures for environmental impact reduction.

However although standardized in a set of international guidelines (ISO) and diverse handbooks, the different applications of the LCA methodology for identical products often lead to considerably different results. A major reason is that most of these guidelines are on a too generic level and therefore fail to grasp essential, specific properties of individual product categories.

This highlights the need to establish scientifically reliable, practical and harmonized codes of practice and methodological guidelines to conduct LCA for specific product categories. Data quality requirements, handling of data gaps, allocation of co-products, impact categories considered in different life cycle impact assessment methods are prominent issues to be tackled in order to increase quality and usefulness of LCA results.

With its participation in testing the Envifood Protocol of the EU Sustainable Consumption and Production Roundtable initiated by the European Commission, CEFS exactly addresses this gap and aims at developing scientifically reliable methodological foundations for fair and robust environmental reporting in the EU beet sugar sector. As a starting point for this endeavor, the initial part of the project at hand consists in conducting an attributional LCA.

2. Methods

Goal and Scope

With regard to PEF development, the project at hand pursues the overarching goal of conducting a scientifically reliable, attributional LCA of the "average" European beet sugar, by

- Developing a sector average (i.e. representative) EU beet cultivation scenario and factory setup to be modelled and assessed.

- Identifying the relevant environmental impact categories for the life cycle based assessment of environmental impacts of EU beet sugar.
- Analyzing sensitivities of LCA results to different methods for co-product allocation (i.e. system expansion by substitution, physical and economic allocation).
- Determining quality requirements for the input data used to model the three foreground processes (i.e. inventory recommendations).

Functional unit

The production of 1 ton of white, granulated beet sugar was chosen as functional unit.

System boundary

The investigated product system comprises all processes from resource extraction to produced white, granulated beet sugar in factories (see figure 1). According to a classical cradle-to-gate analysis this involves the following foreground processes:

- Agricultural cultivation of sugar beets
- Transport of sugar beets from farms to factories
- Processing beets to sugar in the sugar factories

The geographical boundary for the foreground processes refers to the EU and includes all countries that cultivate beets and/or produce sugar. The temporal system boundary of the study corresponds to an up-to-date average of the years 2008-2012. In case of significant changes in cultivating countries or factory setups (e.g. switching factory fuels from coal to natural gas) deviating time periods were chosen for the sake of representativeness. The perennial perspective is crucial due to considerable variations between years being related to changing climate and weather conditions impacting yield and sugar content of sugar beets.

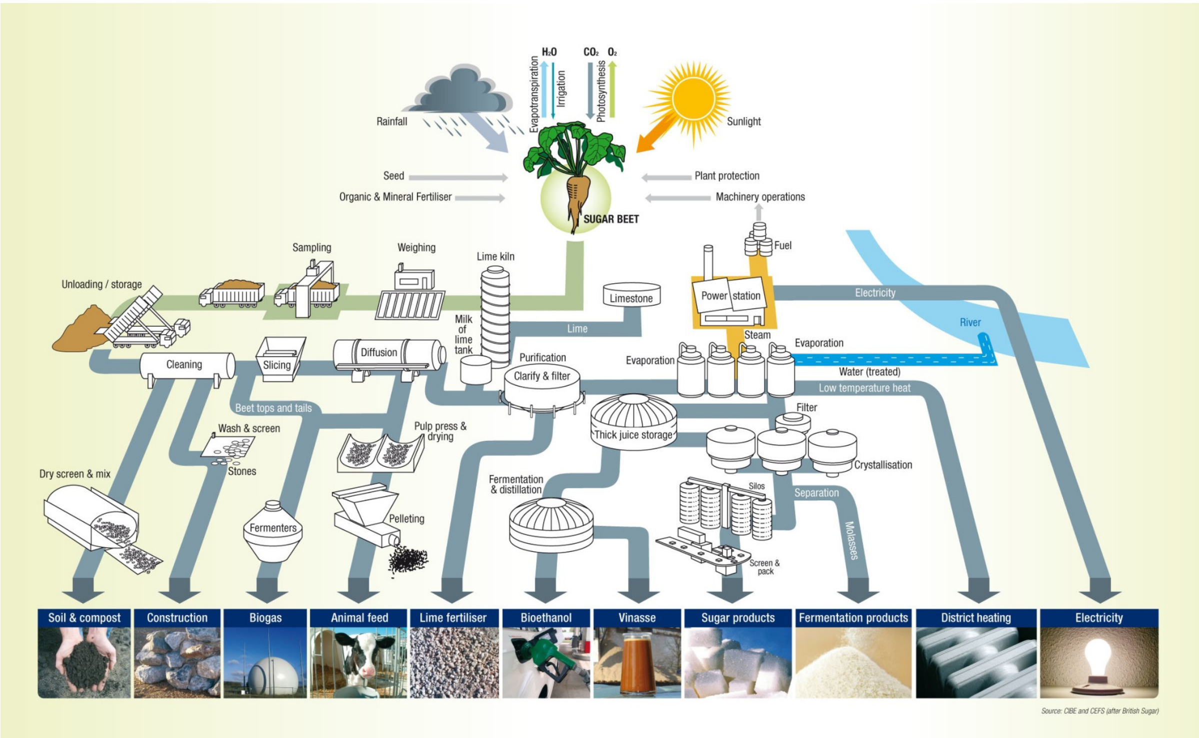

Figure 1: Investigated product system for the LCA on EU beet sugar (Source: CIBE and CEFS according to British Sugar).

Data inventory

Data for the three foreground processes (i.e. input data, information on coproduct characteristics) were collected from 11 sugar companies covering 18 countries (years 2008-2012). Depending on the year, the data covered 89-96% of the total harvested area in Europe and approximately 90% of EU beet sugar production. The direct field emissions were calculated based on well-established models, e.g. Nemecek and Kaegi (2007) for the calculation of ammonia emissions related the fertilizer application.

Impact assessment methods

In the course of the study at hand, the LCIA relied on four commonly applied, up-to-date LCIA methods: ILCD (European Commission, 2011); ReCiPe 2008 (Goedkoop et al., 2009), Ecological scarcity 2013 (Frischknecht and Büsser Knöpfel, 2013) and Impact 2002+ (Jolliet et al., 2003). The ILCD handbook does not provide normalization and weighting factors for the aggregation of environmental impacts of single midpoints to an aggregated total impact (endpoint). In the study at hand, the aggregation was performed based on the normalization factors specified by the European Commission (2012) and with reference on the weighting factors published by Huppes and van Oers (2011). In order to determine which of the impact categories most significantly contribute to the total environmental impacts of EU beet sugar, we analyzed the relative contribution of the different midpoints to the aggregated total impacts for each of the four LCIA methods. The determination of the relevant impact categories for the EU beet sugar was basically performed by considering the average contributions of all four LCIA methods.

Allocation methods

In line with the study's context the study considers seven different allocation methods of the ISO hierarchy: Avoidance by substitution, physical (mass, dry mass content, digestible energy, net calorific value), and economic.

3. Results

Environmental impact contribution

Figure 2 displays the relative contributions of the three supply chain stages (i.e. beet cultivation, beet transports, sugar factory) to the midpoint categories and endpoints) of the ILCD method (for the results of the other impact assessment methods please see Spoerri & Kägi 2015 a, b).

Regarding the endpoints (aggregated TOTAL) and all midpoint categories, agricultural beet cultivation and processing beets to sugar clearly dominate the environmental impacts of the EU beet sugar. On the endpoint level, the contribution of these two life cycle phases ranges between round 97% (ReCipe, Impact 2002+) and round 98% (ILCD, Eco-scarcity). For the different midpoints, the contribution of these two phases range between 87% (POP into water in Eco-Scarcity) to 100% (e.g. water resource depletion or land use). Farm-to-factory transports of the harvested sugar beets are of minor to negligible relevance, accounting for short 2% (Eco-scarcity and ILCD) to round 3% (Impact 2002+) of the total environmental impacts.

Comparing the relative contributions of agricultural beet production and the sugar factory to the endpoints reveals considerable differences between the four LCIA methods. Whereas Eco-scarcity and ILCD put more emphasis on impacts from agricultural production (around two-third of total impacts for beet cultivation versus a short third for the sugar factory), ReCiPe and Impact 2002+ weight the impacts from these two phases almost equally (50% and 47% in ReCiPe, 45% and 52% in Impact 2002+, which is the only LCIA method putting more emphasis on the sugar factory).

On the midpoint level, the differences between the impact shares of these two phases are much more significant. With a share of more than 95%, the upper bound of agricultural dominance relates to the following midpoints: depletion of water resources (ILCD, Ecological Scarcity), terrestrial and freshwater ecotoxicity (ReCiPe, Eco-scarcity), and land use (ILCD, ReCiPe, Eco-Scarcity, Impact 2002+). The lower bound on the other hand e.g. refers to impacts on fossil depletion (17%, ReCiPe), climate change (28%, ILCD), non-renewable energy (Impact 2002+, 18%) or carcinogenic substances into air (Eco-scarcity, 8%). These impact categories are dominated by the sugar factory and basically relate to impacts resulting from harmful emissions in the atmosphere (greenhouse gas emissions, i.e. climate change (68% - 74%), emissions of ozone-depleting substances (49% – 62%), particulate matter (63%, ILCD) or fossil depletion (62% – 79%). This is majorly related to the use and combustion of fossil fuels with relatively large shares of emission-intensive energy carriers such as coal for the production of process heat. The beet transports only exhibit a noteworthy share to those impact categories that predominantly capture air-related traffic emissions, e.g. stratospheric ozone depletion (6% in ILCD, Eco-scarcity, and Impact 2002+), photochemical formation of ozone (8% in ILCD and ReCiPe), respiratory effects (7% in Impact 2002+) or POP emissions ending up in water bodies (13% in Eco-scarcity).

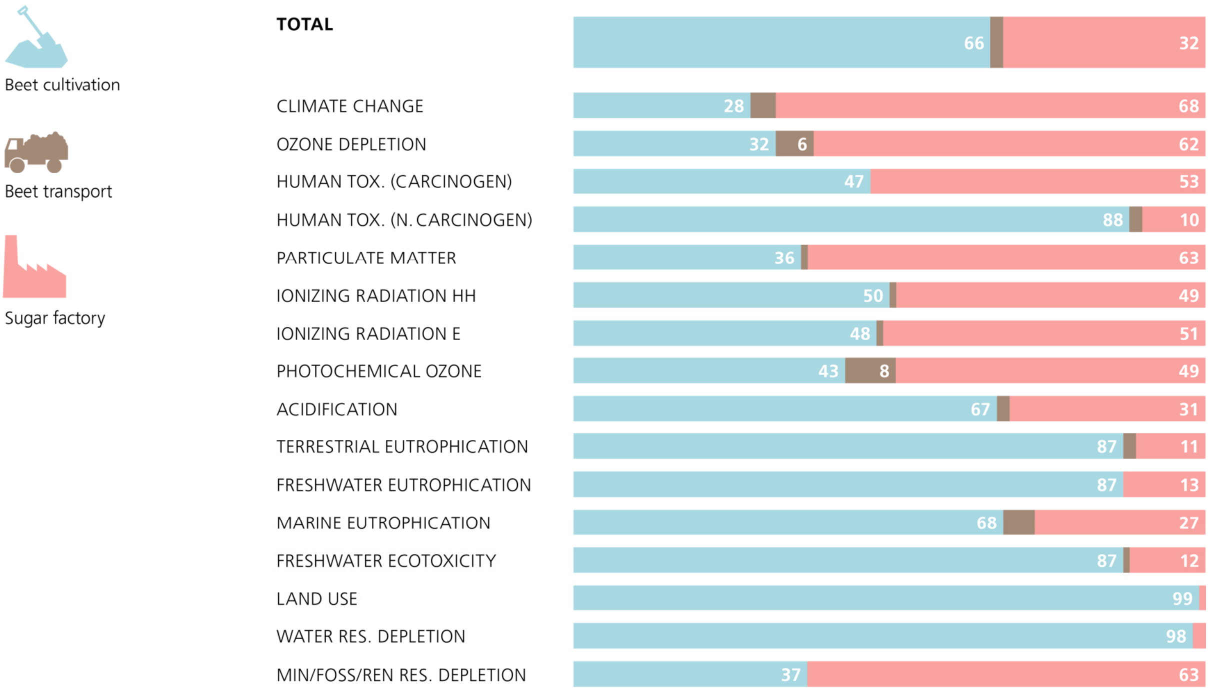

Figure 2: Environmental impact contribution of beet cultivation, beet transport and sugar production using the ILCD method.

Relevant impact categories

To assess the relevance of the midpoint categories, their relative contributions to the total aggregated impacts were determined. This was done by using the four endpoint methodologies ILCD, ReCiPe, Eco-scarcity and Impact 2002+ and subsequent average building. The respective results are summarized in Figure 3.

The midpoint contributions to the aggregated total impact reveal an ambiguous picture. Whereas the contribution of certain midpoint categories are more or less of similar magnitude across all four LCIA methods (i.e. climate change, ozone depletion, ionizing radiation, photochemical ozone, water resource depletion), other midpoints exhibit largely different contributions to the aggregated total impact (i.e. human toxicity, particulate matter, acidification, eutrophication, ectoxicity, land use, mineral/fossil/renewable resource depletion).

Regarding the average across the four LCIA methods, almost two third of the aggregated total impact are attributed to the four midpoint categories “climate change “ (27%), “depletion of mineral/fossil/renewable resources” (13%), “land use” (13%), and “particulate matter” (12%). Another fifth is added by the midpoints “ecotoxicity” (8%), “human toxicity” (6%), and “eutrophication” (6%). These seven midpoints altogether grasp the major share of the aggregated total impact of almost 85%.

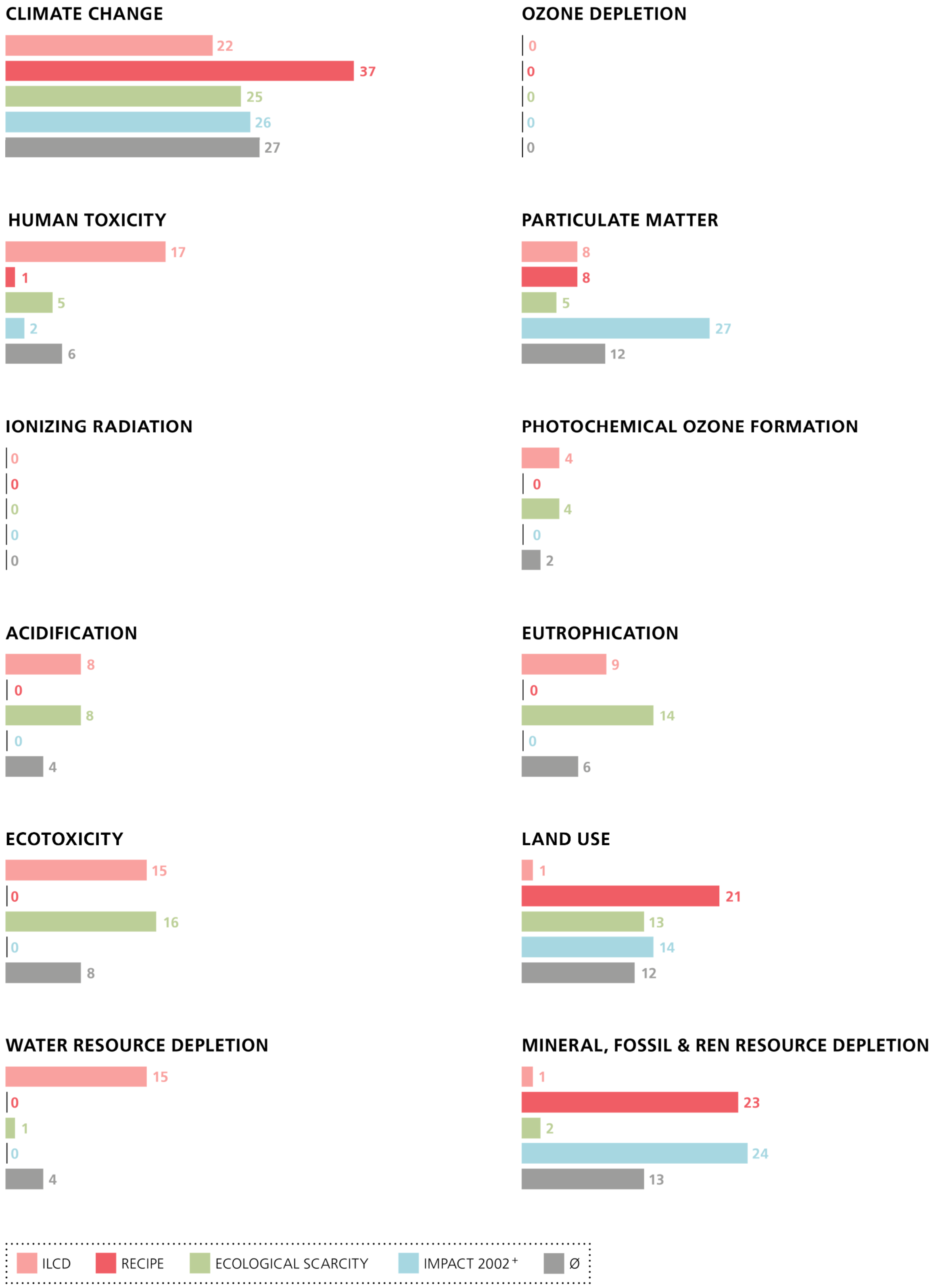

Figure 3: Relevance of impact categories (the bars indicate the relative contribution of the respective midpoint categories to the aggregated total impact).

Having a closer look at the respective midpoint contributions for specific LCIA methods highlights significant differences among the method-specific shares of the different midpoints. Whereas the contribution of certain midpoint categories are more or less of similar magnitude across all four LCIA methods (i.e. ozone depletion, ionizing radiation, photochemical ozone), the other midpoints exhibit largely different contributions to the aggregated total. The most considerable differences refer to the midpoints “mineral/fossil/renewable resource depletion”, “particulate matter”, “ecotoxicity”, and “water resource depletion”. The ILCD method, for instance, is the only method putting relatively strong emphasis on water use and effects on human toxicity, whereas land use or the depletion of resources is weighted comparatively low. Results from the ReCiPe method are to a very large degree sensitive to emissions of greenhouse gases (i.e. climate change), resource depletion and land use. On the other hand, the LCIA methods “Ecoscarcity”, “Impact 2002+” and “ILCD” lead to a more balanced (i.e. homogenous) distribution of the impact shares across the different midpoints. The analysis provides clear evidence that LCA results, at least on the level of the specific environmental impact categories, strongly depend on the chosen method underlying impact assessment based on the same inventory data.

Allocation

Figure 4 provides an overview of the sensitivities of LCIA results to the choice of allocation methods. For each allocation method it shows how the unallocated environmental impacts are partitioned between the main product “white sugar” and the co-products.

First of all it becomes obvious that the net environmental impact attributed to white sugar is largely sensitive to the selected allocation method. The results are displayed for the aggregated total impact (endpoint). The allocation effects on midpoint categories are for all methods – with the exception of the two substitution variants – the same as on the endpoint level, i.e. same partitioning of impacts to sugar and co-products, since all impacts are simply multiplied with the allocation factor and therefore reduced to equal extents.

Despite the allocation by substitution which can lead to negative values, mass allocation results in the lowest impact for beet sugar followed by dry mass allocation. Major reason is the comparatively large share allocated to mass-intense co-products such as beet soil, sand/stones as well carbonation lime, whereas energy co-products (heat, electricity) are neglected.

The maximal environmental impact load for the white sugar results from the application of the sucrose content, attributing most of the impacts to the white sugar and to a minor extent to the different pulp types and the molasses. Effects of the other three methods (i.e. lower heating value, net energy digestible and economic) lay somewhere in between and are of similar size (64%, 73%, 70%).

The two calculated variants for the substitution of functionally equivalent primary products lead to completely different results. In substitution variant 1, depicted in the credits related to substituted petrol (bioethanol), maize silage (wet and pressed pulp), dried lucerne (dried pulp mixed with molasses, dried pulp mixed with vinasse/raffinate) and maize starch (molasses), the impact allocated to coproducts amount to 70% (ReCiPe) until 82% (IMPACT 2002+) of the unallocated impact. In contrast, credits in variant 2, depicted in the credits related to substituted corn-based bioethanol (bioethanol) and fodder barley (all pulp types and molasses) range between 157% (Impact 2002+) to 245% (Eco-scarcity), resulting in a negative environmental impact load for sugar (minus 57% and minus 145%).

Figure 4: Sensitivity of LCIA endpoint results to allocation methods by showing the partitioning of unallocated environmental impacts on “white sugar” and the coproducts.

4. Discussion

Inventory recommendations

The more sensitive foreground data are, the more accurate they need to be for a robust and sound impact assessment. For that purpose, the input data for the three foreground processes were categorized applying a three-level sensitivity scale, ranging from high over medium to low sensitivity. The higher the sensitivity the higher the data quality requirements are. With the exception of beet transports and beet seed production, all upstream processes are highly sensitive for at least one of the considered impact categories. Regarding the processing of sugar beets to sugar in the factories, only the energy consumption in the sugar factory is of high sensitivity, i.e. significant relative contribution to the aggregated total impact

Relevance of impact categories

In order to determine the relevance of the different impact categories (i.e. midpoints), their relative contribution to the aggregated environmental impacts (i.e. single score) was determined. The results from the application of all four considered LCIA methods were taken into account. Based on the described procedure, the resulting recommendations on environmental impact categories that need to be taken into account in the development of the PCR and EPD on EU beet sugar are listed below. The basic idea is to grasp the major share of environmental impacts of EU beet sugar production in a smallest possible set of midpoint categories.

Seven of totally twelve environmental impact categories are judged with high relevance in terms of their contribution to the respective aggregated total impact (endpoint). Independent of the chosen LCIA method the consideration of these seven impact categories would assure that the major share of the aggregated total impact (around 85%) are captured and represented. The other five impact categories (three of medium and two of low relevance) play an insignificant to negligible role for the development of environmental product declarations:

- The seven midpoint categories “Climate change”, “Land use”, “Human toxicity”, “Resource depletion”, “Particulate matter”, “Ecotoxicity”, and “Eutrophication” need to be considered and incorporated in the PCR development and EPD.
- Depending on the aspired coverage of the aggregated total impact, all or selected impact categories with medium relevance could be added to the selection (e.g. acidification).
- Due to their negligible relevance, the impact categories “Ionizing radiation” and “Ozone depletion” do not require to be considered in PCR development and EPD on EU beet sugar.

Allocation of co-products

The results and respective conclusions are strongly affected by the chosen method for the allocation of the co-products from the sugar factory.

To judge the suitability (or adequacy) of the different options for co-product allocation in the case of EU beet sugar, the authors specifically developed a new approach in the course of the project at hand. In doing so, four criteria (robustness, coverage, representativeness, data availability) were elaborated and defined that allow a multi-criteria based assessment of the suitability of the different allocation methods applied in the LCA study. Each of the criteria is judged on a four-level ordinal scale ranging from highly suitable (i.e. 3) to completely unsuitable (i.e. 0). Based on criteria-specific weighting the single judgments are aggregated to an overall judgment, based on which the selection of the most suitable allocation methods is derived. The criteria definition, the judgment of the criteria for all allocation methods as well as the weighting factors are developed and determined by the authors of the study and do not represent any additional expert perspective or evidence from LCA literature. The authors tried to show how the problem of choosing a suitable allocation method could be solved. For a solid and more robust evaluation, a broader stakeholder panel needs to be involved.

The physical allocation based on lower heating value (LHV) and sucrose content of the co-products seems to be most suitable for LCA application on EU beet sugar production. The other physical allocation options based on mass and dry mass, respectively, have the strong disadvantage of not representing the environmental relevance “quality” of the co-products. Substitution can be considered unsuitable for application in attributional LCA (upon which EPD or PEF are developed), but best fitting for consequential LCA (cf. Hitchhikers Guide to LCA). Therefore system expansion may not be the appropriate way for a product declaration, especially as it can also lead to negative net environmental impacts for the main product “beet sugar”.

However, if the scope of the study would be extended to other food products, economic allocation may be the only feasible and suitable allocation method.

5. Conclusions

Data availability with regard to both primary data (e.g. company data) and available independent databases (e.g. Ecoinvent) affects final results in terms of accuracy. This is a sign that data quality requirements and handling of data gaps are prominent issues to be tackled at EU level in order to increase the quality, reliability and flexibility of LCA results to suit different production processes. Despite being standardized in a set of international guidelines such as the ISO14040 and the ILCD handbook, the study showed that different LCA methodologies when applied to the same product and using the same dataset often lead to considerably different results in terms of determining the significant impact categories for beet sugar production. Finally, allocation of environmental impacts to the different products from beet sugar production is highly sensitive to the allocation method. Further harmonization is needed in choosing one fitting allocation method. The EU sugar association will use the conclusions of the study, especially those on the allocation methodology to develop a Product Category Rule for EU beet sugar. This sectorial guideline will be used in the testing of the European Commission's Product Environmental Footprint methodology in alignment with the PCRs of other primary food processing industries.

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