Life Cycle Assessment of roadside grass verges in Flanders

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1 Overview

It is estimated that Flanders generates approximately 50,000 tonnes (in dry matter) of roadside grass clippings per year. Leaving it untreated would ensue in high greenhouse (GHG) emissions (~39,200 kg CO_2-equivalents) and therefore, the verge decree of 1984 (Bermbesluit 27/06/84) stipulates that roadside grass be composted as a minimum requirement.

While composting of roadside grass offers benefits in terms of biomass stabilization and carbon sequestration, recovery of biogas through anaerobic digestion (AD) is acknowledged as a cost-effective mitigation technology for GHG. Furthermore, there are questions regarding the sustainability of using energy crops in the AD sector, and grass could be a potential substitute, given its similar biogas potential.

The goal of this study, in the framework of Grassification, is to assess the environmental consequences of co-digestion of roadside grass with pig manure.

1.1 LCA approach

A life cycle assessment (LCA) has been considered to evaluate the environmental footprint of the value chain. LCA is a structured, comprehensive, and internationally standardized method that quantifies all relevant emissions and resources consumed and their related environmental impacts associated with any goods or products.

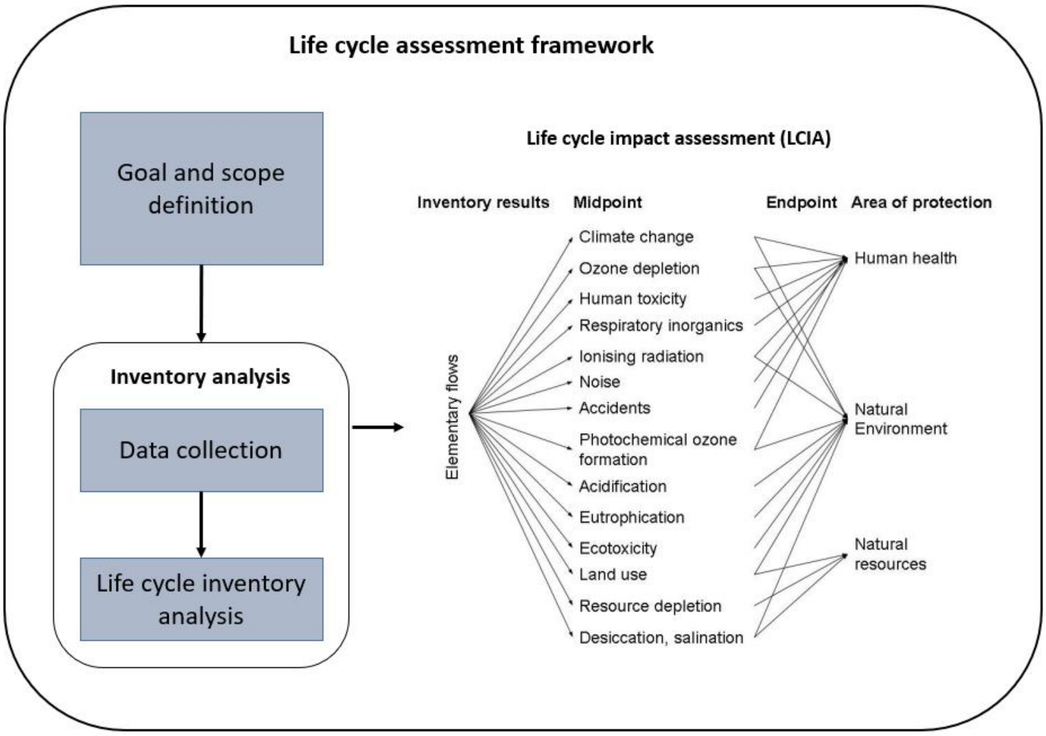

Figure 1. *Phases of an LCA (Adapted from ISO 14040)*

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The Life cycle impact assessment (LCIA) stage interprets the inventory of a value chain by translating its emissions into environmental impact scores. This is done using characterization factors that indicate the environmental impact per functional unit. The characterization factors can be derived either through midpoint or endpoint indicators (Figure 1), and their selection depends on the goal and scope of the study.

There are two modeling approaches to an LCA: attributional (aLCA) and consequential (cLCA). The selection of these approaches depends on the goal of the study as well as the data availability. An aLCA, also referred to as “accounting”, “book-keeping”, “retrospective”, or “descriptive” depicts the environmental impacts of a product over its life cycle, which includes the upstream flows along the supply chain and the downstream flows following the product’s use and end-of-life value chain. A cLCA however, attempts to estimate how flows to and from the environment will change as a result of different potential decisions (Figure 2).

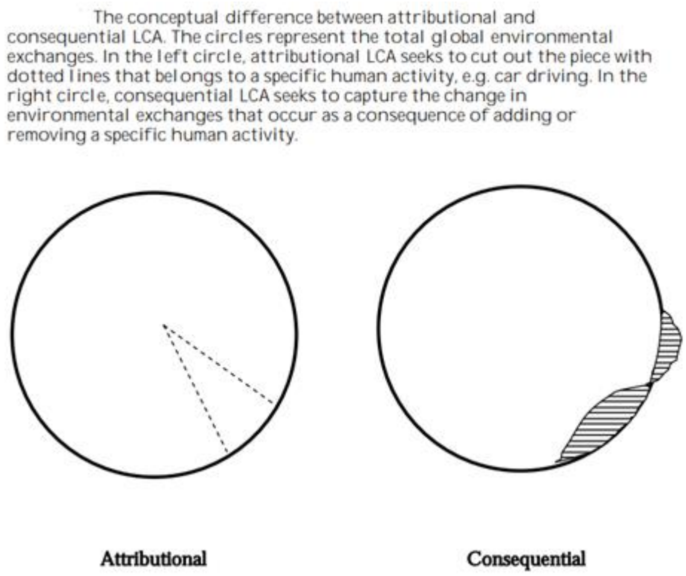

Figure 2. *Conceptual difference between aLCA and cLCA (Ekvall et al., 2016)*

The salient features of aLCA versus cLCAs are highlighted in Table 1.

Table 1. *Salient features of aLCA and cLCA*

	aLCA	cLCA
Goal & Scope	Descriptive	Measures consequences of changes
System Boundary	A complete global system of activities	Considers only affected parts, or in other words, marginal activities/ suppliers
Constraints	Ignored	Identified/ captured
Co-production	Allocation	System expansion
Market effects	Ignored	Captured
Data	Average	Marginal

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1.2 System boundaries for LCA

The system boundaries follow a 'cradle-to-farm gate'[1] pathway and we use a consequential approach for the LCA. The functional unit of the system is **1 tonne of mowed grass** and 2 scenarios, baseline, and project, are relevant (Figure 3).

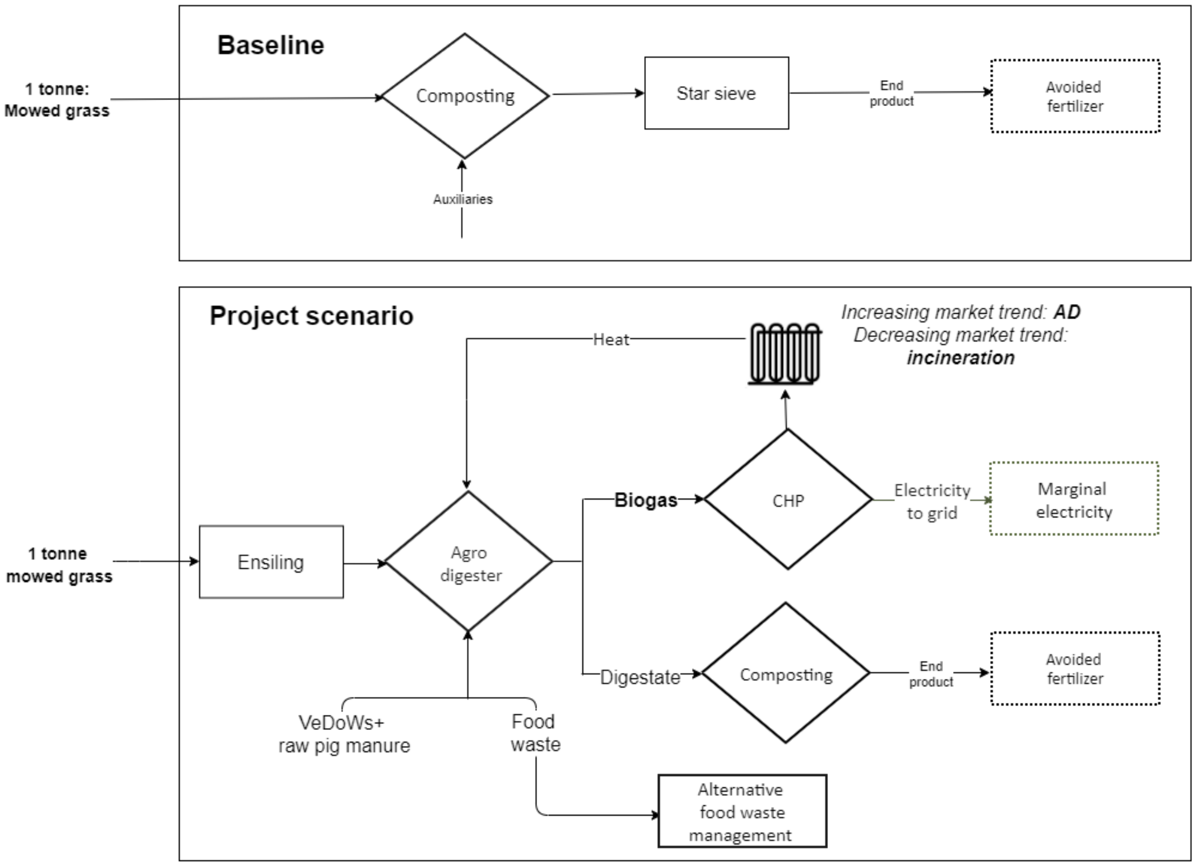

Figure 3. *System boundaries for LCA. Dotted lines indicate avoided processes*

As per legislation (Flemish verge decree-1984), roadside grass must be composted, and hence, windrow composting is the baseline. This is compared versus the project scenario, where the grass is ensiled and co-digested along with the VeDoWs solid fraction and raw pig slurry. These fractions come burden-free into the system.

Typically, mono-digestion of N-rich feedstock such as manure is not recommended due to problems such as NH_3 inhibition and chances of foaming in the digester. To counteract these problems, a common practice is to include a C-rich co-feedstock to balance the C/N ratio, and here roadside grass is considered.

Valorising roadside grass in the digester would mean the feedstock that was originally used would have to find an alternative management pathway. Based on market statistics, roadside grass would ideally substitute food waste/ biowaste since the latter dominates the Flemish market share for AD substrates

[1] System boundary ends at the farm gate, i.e. impacts with regard to field application of compost is not included

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(manure (27.10%), biowaste[2] (62.30%), and energy crop (10.60%)). Thus the effects of alternate food waste management are captured in the consequential model (Figure 3 and 4).

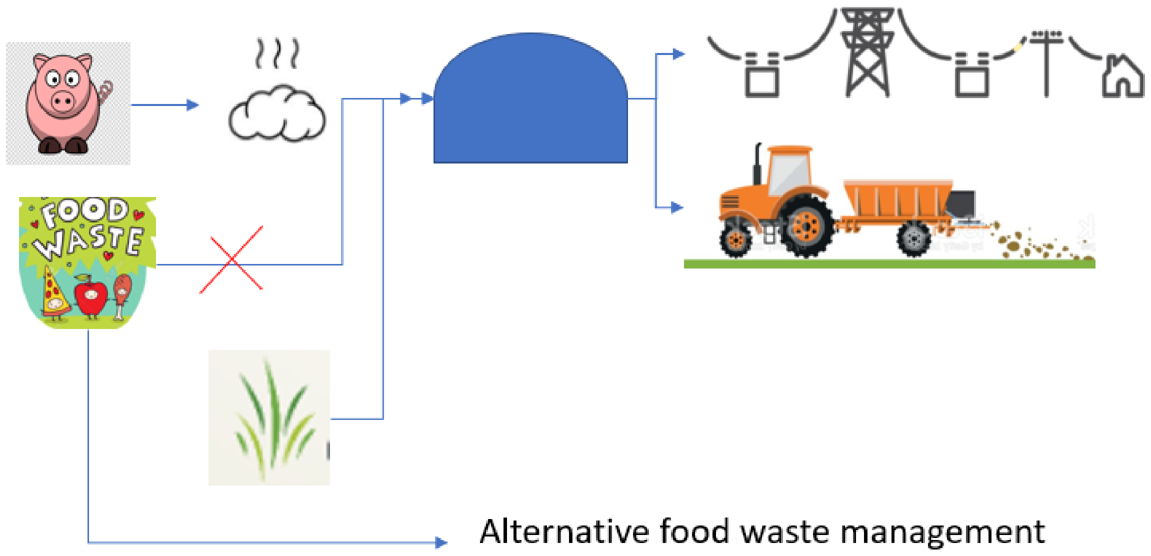

Figure 4. *An alternative pathway for food/ biowaste management as a consequence of manure and grass co-digestion*

According to (Braekevelt, 2017), valorisation (anaerobic digestion) precedes removal/ destruction (incineration/ landfilling) in the order of preference for food waste management (Figure 5). This results in two possibilities - AD of food waste or incineration.

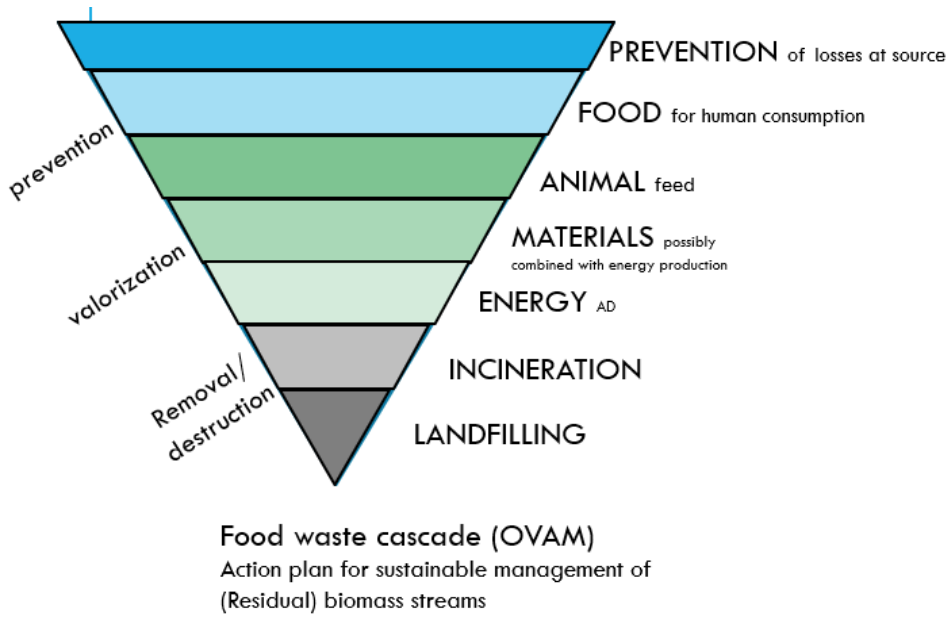

Figure 5. *Food waste cascade in Flanders ((Braekevelt, 2017))*

[2] Biowaste mostly includes food waste from industry, food retail etc

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Whether this food waste is subject to AD or incineration depends on the current AD market. According to (Weidema, 2003) (Figure 6), when a market shows an increasing or stable trend, then the marginal supplier is the most competitive technology (AD), whereas if there is a negative trend, then the least competitive technology is considered to be the marginal supplier[3].

We used the data provided by (Tessens, 2021) and ran a Mann-Kendall test to ascertain whether or not there is a statistically significant trend (increasing or decreasing) in the time series data for organic and biological waste processing.

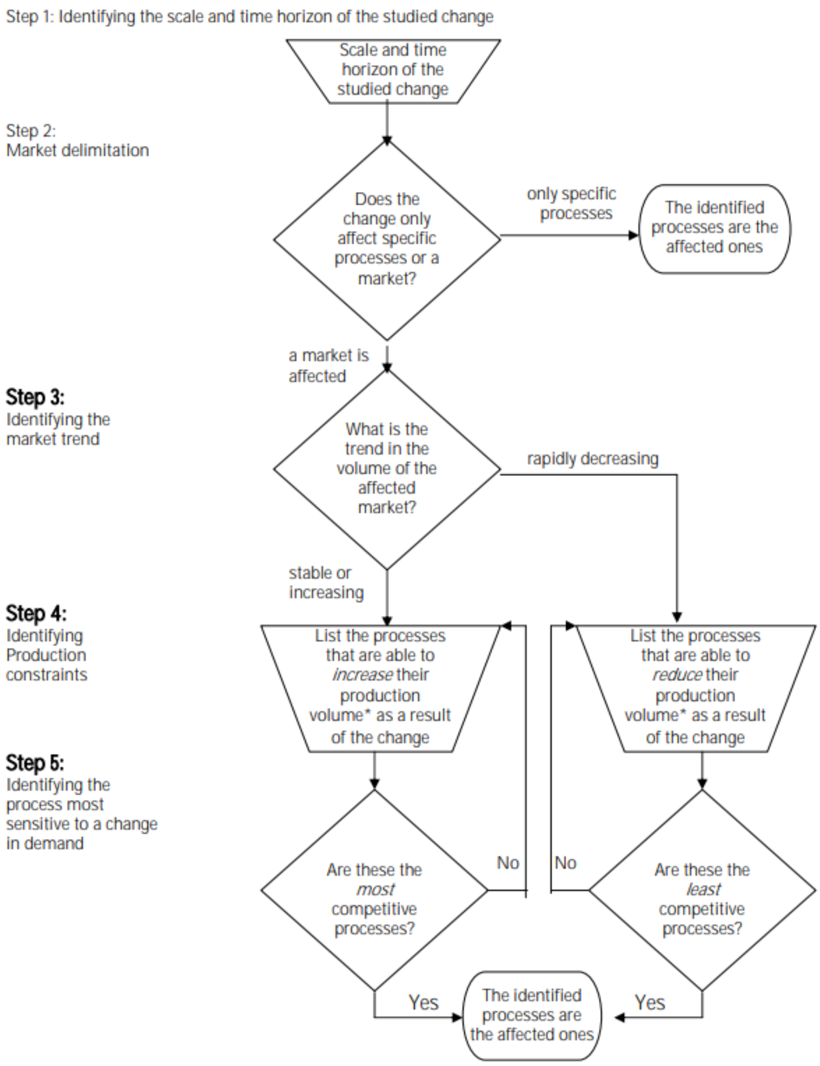

Figure 6. *Decision tree to identify the marginal process for consequential LCAs (Weidema, 2003)*

[3] A supplier/producer that will change production capacity in response to a change in demand for a product (increase or decrease) (Weidema, cLCA blog).

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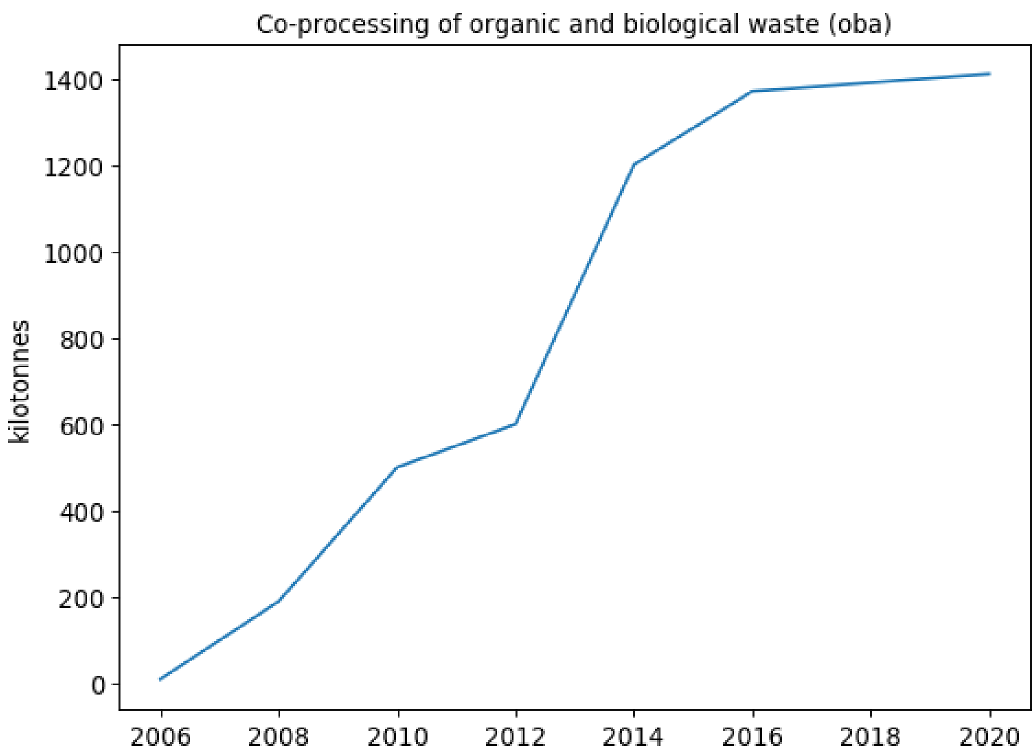
1.3 Life Cycle Inventory

The life cycle inventory (LCI) (mass and energy flows, auxiliaries) for the baseline scenario is obtained from (VLACO, 2014) and (Velghe, 2014) whereas for the co-digestion scenario, we use primary data from Inagro (for agro-digestion) and (VLACO, 2014) for composting of digestate. The complete LCI is available on Github (on request).

2 Results and Conclusion

2.1 Market trend

Figure 7 shows the time series of organic and biological waste processing in Flanders. A Mann-Kendall trend test on the time-series showed an increasing trend (Figure 21). Therefore the alternate technology for food waste/ biowaste treatment is anaerobic digestion, which implies that digesters in the area can cater to this marginal supply.



Trend	*h*[4]	*p-value*	*z value*	*Tau*	*s*[5]	*Var_s*	*Slope*	*Intercept*
Increasing	True	0.0008	3.34	1	28	65.33	213.75	151.875

Figure 7. *Time series of 'oba' waste management in Flanders and results from the Mann-Kendall test*

[4] h is True if there is a trend

[5] Mann-Kendal's score

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2.2 Overall results and contribution analysis

The overall results for climate change (kg CO_2), freshwater and terrestrial acidification (mol H+ -eq), human health (comparative toxicity unit for humans-CTUh) and land use (points) are presented for the baseline and project scearios (Figures 8 and 9). Despite the market trend (increasing) pointing towards AD of the marginal biowaste (Project_AD), we included incineration (Project_Inc) to understand the impacts if the market for biowaste showed a decreasing trend.

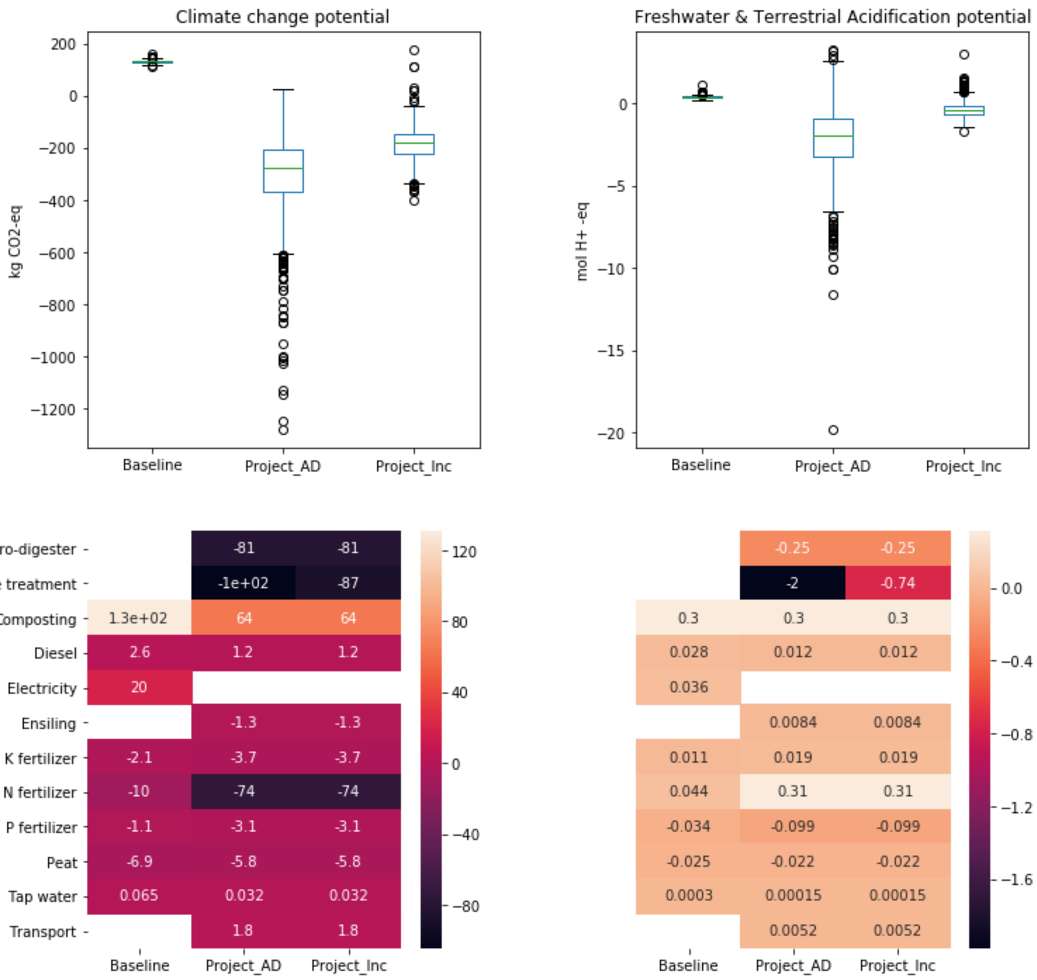

Figure 8. *Climate change and ecosystem quality (freshwater and terrestrial acidification) impacts. Box plots represent overall impacts after 1000 Monte Carlo runs and heatmap represents individual contributions*

Climate change potential

For climate change, the project scenarios (-277 kg CO_2-eq for Project_AD and -180 kg CO2-eq for Project_Inc) were better off relative to the baseline scenario (131 kg CO_2-eq). This can mainly be attributed to the benefits of producing heat and power in the agro-digesters (-81 kg CO_2-eq). Also, the benefits due to avoided NPK fertilizer (-80.8 kg CO2-eq) in the project scenarios are due to the higher nutrient content supplemented by manure in the 'composted' digestate. In the composting scenario, however, the nutrient content in the end-product is low since grass is just co-composted with other C-rich biomass (structure material). In addition to this, the emissions during composting (130 kg CO2-eq)

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and the use of auxiliaries (22.6 kg CO_2-eq) contribute to higher impacts in the baseline scenario. For alternate biowaste treatment, it can be seen that AD is a better option (-104 kg CO2) when compared to incineration (-87 kg CO_2 eq).

Freshwater and terrestrial acidification potential

Acidification is mainly caused by airborne NH_3, NO_2, and SO_X emissions and impacts ecosystem quality. The characterization factor for freshwater and terrestrial acidification (FTA) is expressed in Mole H+-equivalents (moles of charge per unit of mass emitted). The overall FTA impacts follow a similar pattern to climate change potential (0.35 moles H+ for baseline; -1.95 and -0.43 moles H+ for project_AD and project_inc). From the contribution analysis, it can be seen that the agro-digestion step and biowaste treatment contribute to net benefits for FTA in the project scenario. For biowaste treatment, although both AD and incineration offer net benefits (-2 and -0.74 moles H+), the latter has relatively higher impacts due to upstream contributions from the Polish electricity market.

Human health, carcinogenic effects

The human health (HH) characterization factors were developed by the USEtox model and is caused by metal emissions to air, water and soil.

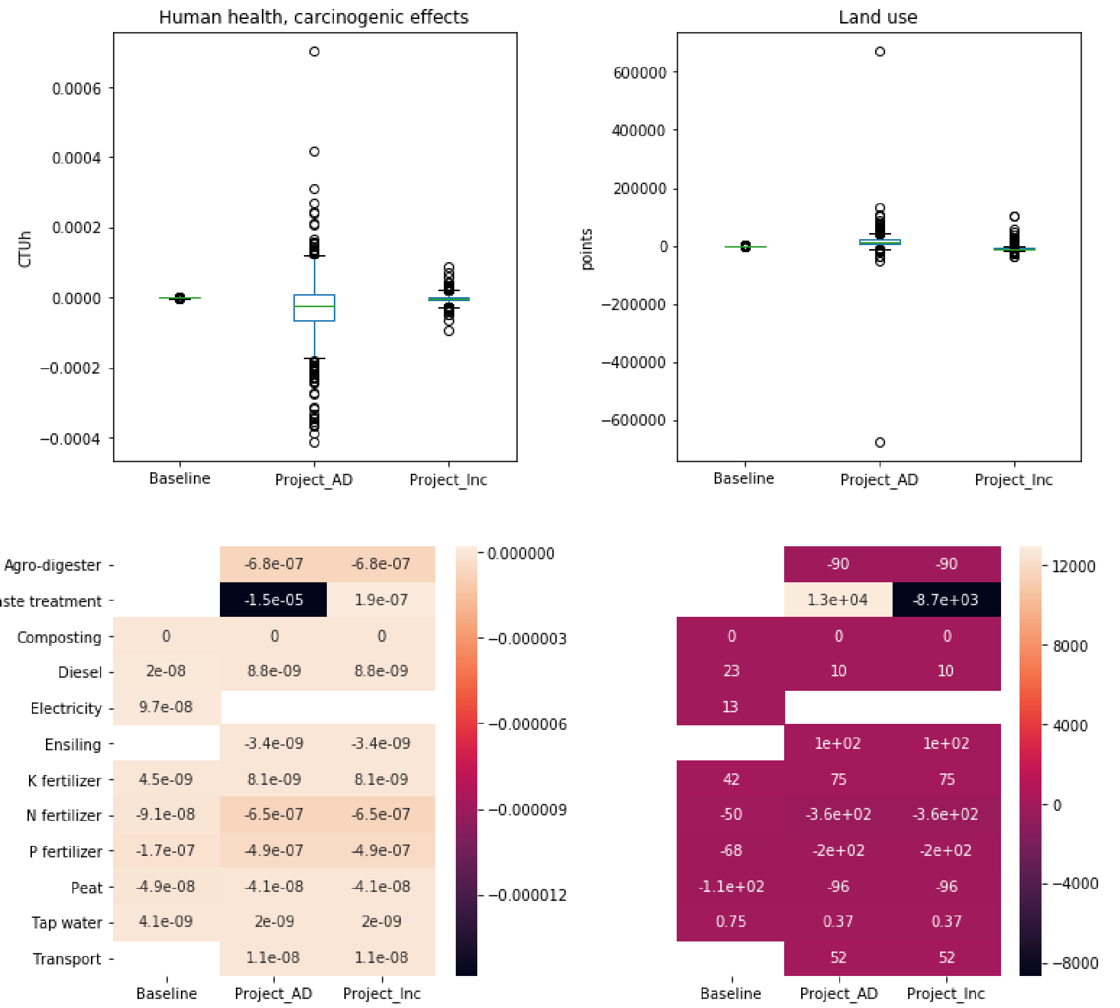

Figure 9. *Human health and land use impacts. Box plots represent overall impacts after 1000 Monte Carlo runs and heatmap represents individual contributions*

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From Figure 9, it can be seen that the median HH values for the project scenarios (-2.437195e-05 for Proj_AD and -3.011033e-06 for Proj_Inc) are relatively better when compared to the baseline (-3.395137e-07). The benefits from reduced HH impact in the Project_AD scenario are from biowaste treatment (-1.5e-05), whereas in the Project_Inc scenario, the HH impacts from the incineration of biowaste contribute to a burden (1.9e-07).

Land use

The characterization factors for land use (LU) is based on the LANCA LCIA model (Bos, Horn, Beck, Lindner, & Fischer, 2016), which provides 5 indicators for assessing impacts due to the use of soil, namely-erosion resistance, mechanical filtration, physico-chemical filtration, groundwater regeneration, and biotic production. The single score index (in points) is calculated by aggregating these indicators.

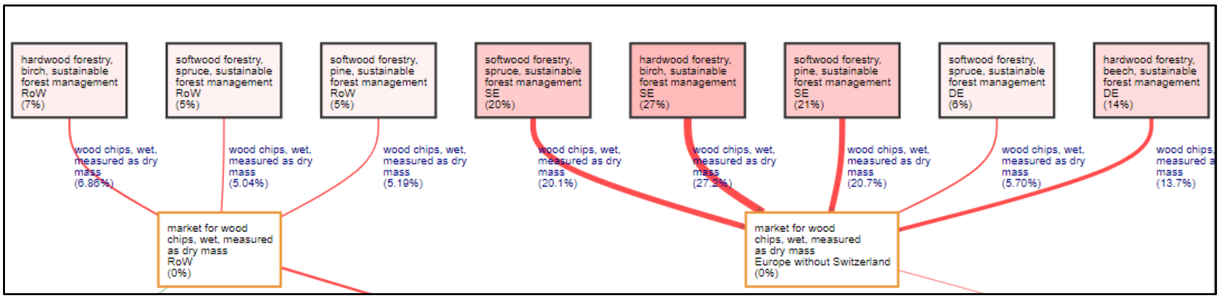

Figure 10. *Upstream impacts from "market for wood-consequential"*

The LU impacts show contrasting results compared to other impact categories. Here, the baseline (198 points) performs better relative to the project scenarios (33,137 points for Proj_AD and 8381.25 points for Proj_Inc). From the contribution analysis, it can be seen that biowaste treatment through AD causes high LU impacts. Further analysis upstream revealed that these impacts are caused by the heat requirement during AD of biowaste. As a consequence, an increase in heat demand creates a marginal increase in demand for wood, thereby affecting the "market for wood" process. The individual impact contributions for the "market for wood" process are listed in Figure 10.

2.3 Conclusion

From the LCA, it appears that co-digestion of grass with manure leads to increased environmental benefits for all impact categories except land use. To mitigate land use impacts, the stakeholders and AD plant operators could focus on improved heat recuperation during AD of biowaste.

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