ENVIRONMENTAL ASSESSMENT OF AN AGRO-BIOGAS CHAIN IN THE APULIA REGION (ITALY)

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ABSTRACT: In the last few years, agro-biogas has received great attention, since allowing for replacing natural gas, it thus represents a tool to reduce greenhouse gas (GHG) emissions and other environmental impacts.

The aim of this study was to identify, quantify and environmentally weigh the main inventory flows so as to find out the impact indicators best representing the agro-biogas local chain. The analysis was conducted in accordance with the ISO 14040 and 14044 (2006). All data was loaded into SimaPro 7.3.3 accessing the Ecoinvent v.2.2 database and then processed using the Impact 2002+ calculation method for carrying out the Life Cycle Impact Assessment (LCIA) phase. The research was developed in collaboration with a farm, located in the province of Foggia (Apulia region in Southern Italy) involved in the agro-biogas system. The study highlighted that the most impacting phase is durum wheat cultivation for production of fine bran in the amount needed for producing 1 kWh of electricity from 0.548 m^3 of biogas. This was because of land occupation, ammonium production and all the transport involved. Environmental impact reduction could be obtained through transport system optimisation and fertilisation management oriented to promoting the use of organic fertiliser, such as digestate solid fraction.

Keywords: animal residues, energy crops, biogas, electricity, life cycle assessment (LCA), sustainability

1 INTRODUCTION

In the last two decades, renewable energy has been receiving a great deal of attention, since allowing for replacing fossil fuels, it thereby represents a tool to reduce greenhouse gas (GHG) emissions. In particular agro-biogas, if sustainably managed, could provide a significant contribution to these environmental and economic aspects because it can be used instead of natural gas.

Biogas may derive from the methanization natural process of organic waste present in landfills or from anaerobic digestion of sludge, energy crops, agro-industrial by-products and animal effluents (sewage and manure). Once produced, biogas is mainly used to produce both electricity and heat through cogeneration and, also, through a purification process, bio-methane to be injected into the natural gas network [1].

According to the 13th annual overview barometer, primary energy production in the EU - 27 settled in 2012 at about 12 Mtoe growing by 15.7% compared to 2011, while gross electricity production improved from 37.86 TWh (2011) to 46.25 TWh (2012). In this context, Italy played a significant role recording an increase of almost more than 7% in biogas primary production and of about 36% in terms of gross electricity [2].

This is stressed by the number of Italian agro-biogas plants that rose significantly passing from 499 in 2011 to 1179 in June 2013, mostly localised in Northern and Central Italy [3; 4]. This positive trend is mainly due to the governmental incentives to produce electricity from renewable energy established by Legislative Decree nr. 387 of 2003 [5] and Ministry Decree of 6 July 2012. The latest, that came into force on 01 January 2013, introduced specifically new different financial supports depending on the use of products, by-products or waste to feed the biogas plant. Furthermore, it rewards high-efficiency cogeneration plants and agro-biogas chains with low nitrogen emissions. In other words, this rule promotes small plants (less than 300 kW) and encourages, in terms of financial incentives, the use of residual biomass rather than energy crops and so, in general, agro-biogas sustainable production and final use [6].

This paper aims to evaluate, using Life Cycle Assessment (LCA) methodology, the environmental sustainability of an agro-biogas chain as produced by a plant located in the province of Foggia in Apulia. This is a region of Southern Italy with a relevant agricultural and agro-industrial vocation, which leads, in turn, to a high potential for energy production from vegetable and animal biomass residues. Nevertheless, such a potentiality is not completely exploited as confirmed by the low number (7) of operating plants deployed in regional territory. The present study progresses from a previous one dealing only with the analysis of the inventory flows related to the same biogas plant [7].

LCA methodology is based on the definition provided by the International Standards ISO 14040-44:2006 and allows indeed for the compilation and evaluation of the inputs, outputs and of the potential environmental impacts due to a product system throughout its life cycle. At the international level, in reality, several studies have dealt with environmental assessment of agro-biogas chains, using almost exclusively an LCA approach. Among these studies, the most relevant ones were mentioned and briefly discussed by Tricase et al. (2012), bringing out similarities and differences in terms of scope, application field and impact assessment results [8].

As highlighted by Tricase et al. (2014), in Italy a very few number of researchers carried out studies on the sustainability of agro-biogas chain from anaerobic digestion plant and none of these were done in Southern regions [7]. Furthermore, in agreement with Dressler (2012) and Cherubini (2010), it should be observed that biogas environmental impacts vary according to regional farming procedures and, therefore, to climate conditions, crop yield, soil management and cultivation technique [9; 10].

The present research paper is believed to be significant because it studies an agro-biogas chain, which uses resources and crop cultivation practice (no tillage), typical of the territory in which the plant is located. As a matter of fact, biogas is produced from a substrate mixture of sewage, manure, silages of both maize and triticale, and milling waste (fine bran). They are all produced by local agro-zootechnical farms. For all these considerations, it seems to be very fitting and useful to examine an agro-biogas plant located in a Southern Italian region making the present paper original.

2 DESCRIPTION OF THE AGRO-BIOGAS CHAIN UNDER STUDY

The analysed plant is handled by a local farm, which is locally acknowledged to be the most important and representative of the Apulia region agro-zoo-technical realities. For some years, the farm has shown its interest in renewable energy sources. Recently it has indeed equipped itself with both wind-power and photovoltaic systems and with two anaerobic digestion plants as well. Their function is to produce biogas from a substrate mixture generally made of zoo-technical effluents, energy-crops, both food-industry and agricultural residues. After production, biogas is purified and then sent to a cogeneration section for producing electricity and heat. The plant has a 1 MW_e nominal power and was started-up in February 2013: the design operational time is 8000-9000 hours per year.

Daily-input amount of substrate is equal to 120 t and is made of: sewage 45%, manure 20%, silages (maize and triticale) 20% and finally milling durum wheat waste (fine bran) 15%.

Regarding crop (maize, triticale and durum wheat) cultivation, it should be noticed that the farm has adopted for about twenty years a conservation agriculture (CA) system based on No Tillage (NT), with the aim of preserving soil quality and productivity. Indeed, when roll chopping is performed, about 10% of the plant stem is left above ground allowing for Soil Organic Carbon (SOC) to be accumulated. The farm integrates mineral (50%) with organic (50%) fertilisation using the digestate solid and liquid fractions recovered from the biogas plant so as to increase soil organic matter content. In this way, the farm also contributes to reduction of organic matter losses and environmental impacts coming from chemical fertiliser production. Furthermore, no other tillage is operated, thus avoiding SOC oxidation and also contributing to its accumulation. According to the standard practice, seeds are placed into otherwise untilled soil through opening a sufficiently wide and deep furrow in order to properly place and cover seeds. Generally, as required by no tillage, the farm applies an adequate weed control using herbicides, such as glyphosate.

Digestate is extracted every day in the amount of 110 m^3 from the digestion chamber, representing 90% of the input substrate. After this procedure, digestate is addressed to a centrifugation treatment so as to be separated in two fractions, solid (30%) and liquid (70%). The former is used to fertilise fields located nearby the plant, including those for cultivating the crops used for biogas production. On the contrary, the latter is sent to an underground storage tank (80%) and used for fertigation (20%).

The biogas is released from the digestion plant with a 460 m^3/h flow-rate and is composed generally in % vol. of: oxygen (O_2) 0-1%; hydrogen <1%; carbon dioxide (CO_2) 15-40%; methane (CH_4) 55-80%; ammonia (NH_3) <100ppm; and hydrogen sulphide (H_2S) $\leq$2000 ppm.

The latter component must be removed to avoid the damaging of the cogeneration engine. For this reason, it undergoes a biological desulphurization treatment so as to bring its content to lower concentration. In this phase, biogas passes through a plate column in which it is subjected to a water shower and at the same time to an air - flow. Furthermore, injection of two different types of bacteria is performed into the column for transforming hydrogen sulphide into sulphuric acid, which, thanks to its water-solubility, is removed by the water used. For this purpose, the bacteria are fed with a nutrient solution, mainly rich in nitrogen, phosphate, potassium, calcium and manganese.

At the end of this treatment, the biogas temperature is 40°C and hydrogen sulphide is removed by 97%. Moreover, as already clarified by Tricase et al. (2014), input and output biogas composition and flow-rate comparison highlighted that: 1) CO_2 concentration is reduced by about 2% because used by bacteria; 2) output biogas is enriched with oxygen and nitrogen respectively representing 1.1% and 7.3% of its composition; 3) biogas output flow-rate is increased by almost more than 8% compared to the input value [7].

After purification, biogas is directed to cooling with the aim of lowering its temperature to values between 6 and 7°C; this phase is needed for allowing for its input into the cogeneration engine. On average, 24 000 kWh of electricity is produced every day: 10% is consumed by the farm, while the remaining 90% is entered into the national grid. Per each kWh_e thus produced, 0.987 kWh of heat are obtained: 48% is used for warming both the substrate within the digestion chamber and the water, used for purification treatment. The remaining 52% is not used and so emitted in air as waste.

3 MATERIALS AND METHODS

For the study development, Life Cycle Assessment was used because it allows for highlighting and assessing both critical points and margins for improvement in products' life cycle [11]. The analysis was carried out according to the ISO standards 14040:2006 [12] and 14044:2006 [13], and, therefore, divided into the phases reported in the following framework (Fig. 1).

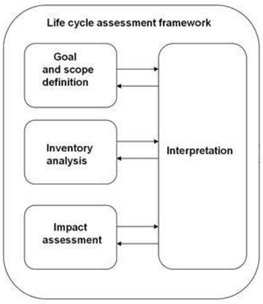

Figure 1: LCA framework

According to the ISO standard 14040:2006, the inventory analysis phase involves data collection, classification and interpretation. All the collected data were processed using SimaPro in its latest version (7.3.3) [14], accessing the Ecoinvent v.2.2 [15] database and choosing Impact 2002+ [16] calculation method for carrying out the impact assessment phase. On the basis of what is reported within the ILCD handbook entitled "Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment (LCA)" [17], this method allows for a feasible implementation of a combined midpoint/endpoint approach, linking LCI results via midpoint categories to endpoint categories. In this regard, Impact 2002+ provides the distinction between impact and damage categories as shown in Table I. Furthermore, this method calculates the non-renewable energy consumption and recognises carbon dioxide as the emitted substance which most affects the greenhouse effect and, in turn, climate change. Finally, the method is set-up so as to be more comprehensible for insiders and also more accessible if compared to other methods (such as EcoIndicator 99; EPS 2000; CML 2000 and EDIP 2003).

Table I: Damage and impact categories in Impact 2002+

Damage Category	Impact Category
Human Health	Carcinogens Non-carcinogens Respiratory inorganics Respiratory organics Ionizing radiations Ozone layer depletion
Ecosystem Quality	Aquatic eco-toxicity Terrestrial eco-toxicity Terrestrial acidification/nitrification Aquatic acidiphication Aquatic eutrophication Land occupation
Climate Change	Global warming
Resources	Non-renewable energy Mineral extraction

Regarding the LCIA, this phase was conducted using both a mid-point and an end-point approach, thereby including in the assessment also the optional elements, namely Normalisation and Weighing.

3.1 Goal and scope definition

The main goal of this research is to assess and improve, from an environmental perspective, the chain of an agro-biogas produced by a farm located in the province of Foggia (Italy). For this purpose, LCA was used because, according to the definition provided by the ISO 14040:2006, it allows for the compilation and evaluation of the inputs, outputs and the potential environmental impact of a product system throughout its life cycle.

The study is addressed to LCA practitioners as well as to all the researchers and stakeholders involved in the agro-energy sector so as to inform them about the main material and energy flows, as well as the highest environmental impact related to the agro-biogas chain in question. From this point of view, the present paper will allow for useful comparisons with the aim of highlighting all differences existing among different types of biogas production and use chains.

In accordance with the International Standards, in this phase of the study, a functional unit was chosen and the system boundaries were defined together with the goal and scope of the study. The main functional unit is 1 electrical kWh produced from biogas in a cogeneration plant corresponding to 0.987 kWh of heat. The system boundaries include all the main phases characterizing the agro-biogas chain and in particular the:

- energy-crops cultivation and ensilage;
- durum wheat cultivation and milling;
- biogas production from substrate anaerobic digestion;
- biogas desulphurisation for purification;
- electricity and heat production from biogas purified in the cogeneration section.

As already reported by Tricase et al. (2014), the use of digestate component fractions after separation, including all the involved transports and processes, were considered attributable to the anaerobic digestion phase and so included within the system boundaries [7]. For this reason, digestate was not considered as a co-product, but as a process-waste to be treated for avoiding using resources, materials and processes. Doing so, it was possible to avoid damage *allocation* and to maximize the system environmental yield thanks to digestate valorisation. The system boundaries were shown in the flow chart reported in Fig. 2, which was extrapolated from Tricase et al. (2014). It can be observed that all the activities and materials believed most contributing to damage were indicated [7].

3.2 Input data inventory analysis

The LCI analysis quantifies the use of resources and energy and the environmental releases associated with the system to be evaluated [19]. According to Tricase et al. (2014), this phase is needed for correctly developing the study, so as to create a model as close as possible to reality. For this reason, data collection can be considered the core of LCA because, if not properly done, it may affect the quality and reliability of the final results [7].

Details on the inventory phase development and results can be found in the already mentioned paper.

4 RESULTS AND DISCUSSION

4.1 Life Cycle Impact Assessment

This phase allowed to highlight that total damage is equal to 0.000163 pt and is mainly attributable to the biogas purification process due, in turn, to the anaerobic digestion inclusive of crop cultivation. Figure n. 3 shows the different contributions of the damage categories.

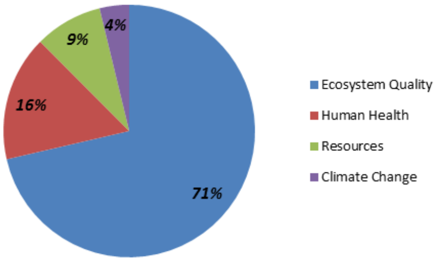

Figure 3: Damage distribution per damage categories

In Table II, a detail of damage categories was reported illustrating, for each of them, weighing point and damages assessment value. It should be observed that Ecosystem Quality is the most impacted damage category due to the processes involved in cultivation of the crops used for biogas production.

Table II: Weighing points and damages assessment values per damage categories

Damage category	Weighing (pt)	Damages assessment	Units
Ecosystem Quality	0.000117	1.6	PDF*m^2*y
Human Health	2.62E-5	1.86E-7	DALY
Resources	1.43E-5	2.17	MJ Primary
Climate Change	6.22E-6	0.0610	kg$_{eq}$CO$_2$

DALY (Disability-Adjusted Life Year): a measure of the overall severity of a disease, expressed as the number of years lost due to illness, disability or premature death.
PDF (Potential Damage Fraction): the fraction of species that have a high probability of not surviving in the affected area due to unfavourable living conditions.

Per each damage category, the most impacting substances emitted and resources used were extrapolated from the output flow inventory and listed in Table III with indication of the related amounts.

Table III: Most significant output inventory-flows

Substance/ resource	Emission compartment	Amount	Unit
ECOSYSTEM QUALITY			
Occupation, permanent crop, intensive	---	1.27	m^2*y
HUMAN HEALTH			
Nitrogen oxides	air	872	mg
Particulates, <2.5 µm	air	90.5	mg
RESOURCES			
Coal, hard, unspecified, in ground	---	16.2	g
Gas, natural, 35 MJ per m^3, in ground	---	0.01003	m^3
Oil, crude in ground	---	30	g
Uranium, in ground	---	624	µg
CLIMATE CHANGE			
Carbon dioxide, fossil	air	97.2	g
Carbon dioxide avoided due to SOC accumulation in the soil	air	-130	g
Dinitrogen monoxide	air	486	mg

Regarding Table III, it should be observed that, in terms of substances emitted in the air:

- nitrogen oxides emission affects human health (41.7%) and it is due to ammonium nitrate production (32%), seeding (13%) and EURO 3 transport (lorry 3.5-7.5 t) (11.4%);
- particulates (grain size <2.5 micron) are emitted in the air in the amount of 90.5 mg and affect human health (34%). Their emission is due to ammonium nitrate production (29.1%), to slurry tanker production (19.5%) and to seeding (9.61%);
- carbon dioxide (fossil) impact on climate change is equal to 9.81E-6 pt and it is due to ammonium nitrate production (51.7%), to slurry tanker production (28.2%), to EURO 3 transport (lorry 3.5-7.5 t) (15%) and to the heat produced by the cogeneration plant and partially used for warming the digestion chamber (-53.7% - avoided damage);
- the damage coming from dinitrogen monoxide emission is equal to 7.65E-6 and is due to ammonium nitrate production (74.2%), to durum wheat cultivation (27.2%) and to the production of fertiliser N (-13.3% - avoided damage);
- NT with cover crops allows for soil to behave as a carbon sink, thus accumulating SOC accumulation in the soil. For this reason, CO$_2$-emission from soil was avoided contributing to avoid an equivalent damage of -1.32E-5 pt.

In terms of resources consumption, it is underlined that:

- the impact on ecosystem quality is originated by “occupation, permanent crop, intensive” by 91.4%. This is due, in turn, to durum wheat cultivation (87.6%) and to triticale and maize (8.87% and 3.58% respectively);
- crude oil (in ground) affects resources (63.3%) because of ammonium nitrate production (25%), of diesel (at regional storage) production (20.2%) and of EURO 3 transport (lorry 3.5-7.5 t) (15%);
- natural gas (35 MJ/m^3, in ground) impacts resources by 16.2% entirely due to its production for electricity and heat production;
- uranium (in ground) consumption, damaging resources by 16.1%, is attributed to slurry tanker production (38.9%), to irrigating operations (15.5%) and to ammonium nitrate production (13.7%);
- 13.3% of the damage occurred to resources is due to hard coal (in ground). This is because of slurry tanker production (62.4%) and of ammonium nitrate production (11.2%).

The impact categories have been listed in Table IV, indicating, for each of them, the corresponding characterisation value and the weighing point.

Table IV: Most significant impact categories

Impact category	Weighting (pt)	Characteri-sation	Unit of measurement
Land Occupation	0.00011	1.39	m^{2}org.arable
Respiratory Inorganics	2.33E-5	0.000236	kg$_{eq}$PM$_{2.5}$
Non - renewable energy	1.42E-5	2.16	MJ primary
Global warming	6.22E-6	0.0616	kg$_{eq}$CO$_2$

4.2 Life Cycle Impact Interpretation

Based on the Life Cycle Impact Assessment results it was possible to observe that the most impacting processes are ammonium nitrate production; slurry tanker production; and, all the EURO 3 transport (lorry 3.5-7.5 t) involved in the analysed system (see Figure 4).

The highest contribution to total damage is given by “occupation, permanent, crop, intensive” which was considered for cultivation of the three crops, but which results higher in durum wheat cultivation because of a much reduced production yield compared to the other crops. As already brought out in the impact assessment section, NT cultivation operation allows for the accumulation of SOC in the average amount of 280 kg/ha*y, thus resulting in avoiding the annual emission of about 1 t of CO_2 per ha. Digestate solid fraction reuse for land fertilisation allows avoiding fertiliser N production and environmental impact. Furthermore, benefits, in terms of avoided CO_2-emission, are related to the use of 48% of the heat produced by biogas cogeneration for warming the digestion chamber.

4.3 Life Cycle Impact Improvement

This is the phase of LCA in which improvement solutions are identified and assessed from an environmental point of view so as to allow for total damage reduction and, so, for the increase of the sustainability level of the analysed product under examination. On the basis of the LCIA results, some damage reduction when replacing ammonium nitrate with urea was verified. This was done considering that, in urea, N content is equal to 46%, thereby resulting in an input flow of urea of about 230 kg per ha of cultivated field. It must be remember that N content in ammonium nitrate is 35% and therefore the administrated amount settles at 300 kg. This substitution allowed for a damage reduction equal to 18%, thus justifying the use of this alternative fertiliser. The comparative analysis was done considering that urea and ammonium nitrate are supplied by the same producer.

Another improvement solution could result from replacing 100% of ammonium nitrate with the digestate solid fraction produced in the biogas plant belonging to the farm. This solution was applied and resulted to be effective since it allows for a 15% damage reduction. The latter was resulted to be less effective than replacing urea because, in this case, the amount used is double and consequently the transportation and spreading operations redouble. Nevertheless, since the farm produces digestate from biogas, it could be economically convenient to utilise this organic fertiliser. This aspect should be assessed by performing an appropriate economic evaluation tool. Furthermore, a EURO 5 transport could be used in substitution of the one currently used (EURO 3, lorry 3.5-7.5 t), decreasing by an additional 15% the damage. A general improvement could result from using more energy efficient agricultural machinery, reducing GHG emissions and fossil fuel consumption.

No improvement solutions were considered for mitigating the impact due to cropland occupation because it is necessary to have land to cultivate.

This study could be used as a starting point to carry out a sensitivity analysis in order to verify any change in biogas environmental sustainability and electricity production yield with different substrate matrices.

Finally, the remaining 52% of the heat produced could be used in a number of applications, such as agricultural food product drying and/or remote heating. This would result in further environmental benefits in terms of avoiding fossil fuel use and combustion.

5 CONCLUSION

The study attained the proposed objective, thereby developing a detailed LCA for highlighting environmental hotspots and improvement potentials related to an agro-biogas chain in Southern Italy. The analysis showed that the most impacting phase is durum wheat cultivation for production of fine bran in the amount needed for producing 1 kWh of electricity from 0.548 m^3 of biogas. This was because of land occupation, ammonium production and all the transport involved.

Generally speaking, the investigated farm could used the results of this analysis for different purposes: the elaborated inventory flows to realize a quality management system, according to ISO 9001:2008; the whole LCA to apply a procedure for ISO 14001:2004 certification of the biogas plant or/and EMAS regulation.

Finally, it should be observed that this study is believed applicable to other agro-biogas plants with similar characteristics, and so useable as a starting point for defining a standard procedure. Furthermore, it could contribute to drawing the guidelines for the implementation of an agro-biogas LCA.

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8 LOGO SPACE

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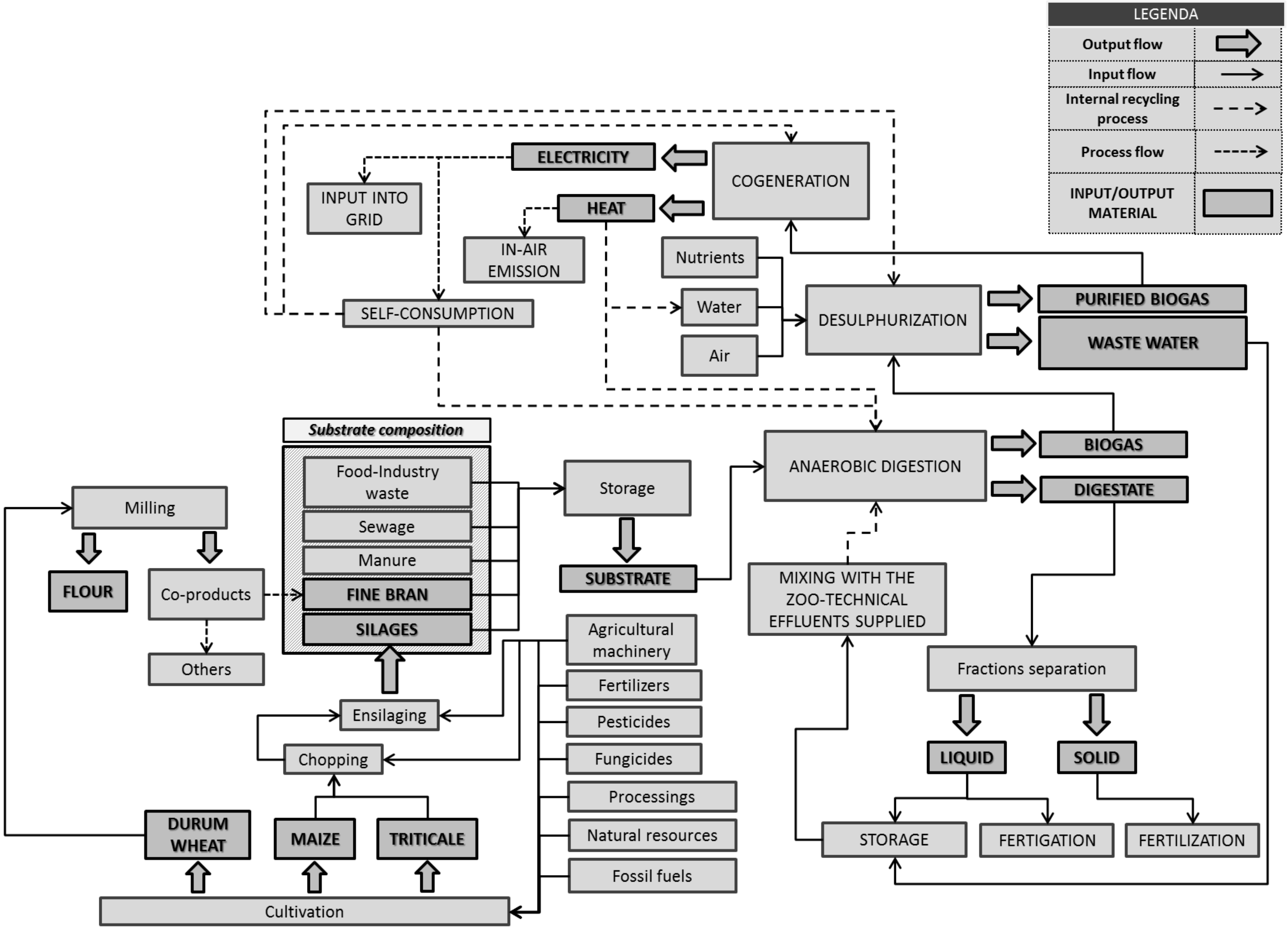

Figure 2: System boundaries

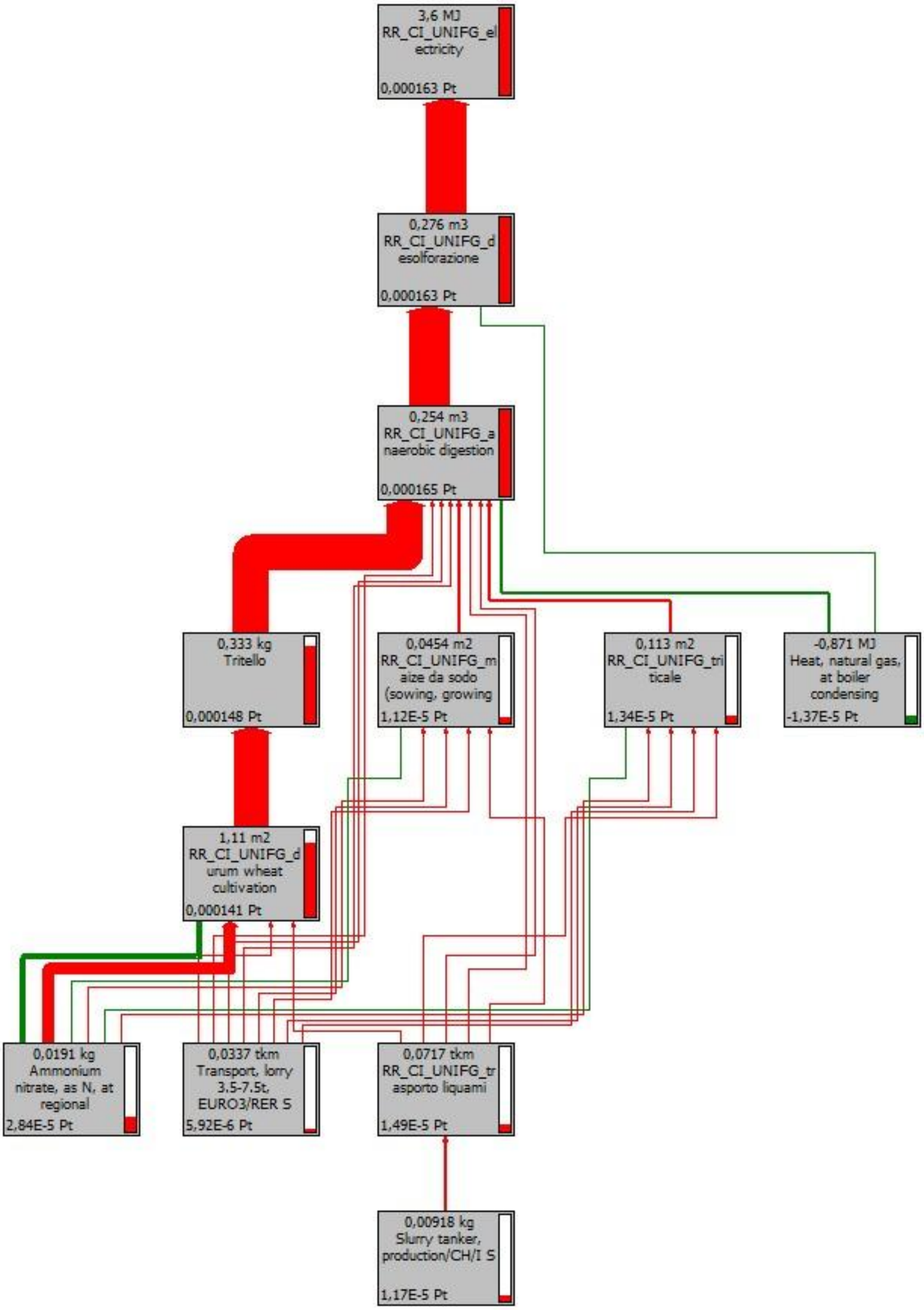

Figure 4: Damage flows