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Electricity Generation from Anaerobic Digestion in Italy: Environmental Consequences Related to the Changing of Economic Subsidies

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In recent years, the increasing market trend of Renewable Energy Sources (RES) in the European Union has been connected with the public subsidies guaranteed to encourage their production. In Italy, the northern regions have played a leading role and contributed deeply to increase the share of RES in the national energy mix. An increase in the number of Anaerobic Digestion (AD) plants fed with agricultural feedstock has been detected, reaching 1800 units in only 20 years. AD is considered as one of the most promising technologies for RES production, especially when wastes are used as feed. In fact, the use of wastes brings to increase the added value and reduces the economic and environmental costs related to the waste treatment as well as the energy purchase. Despite these advantages, the economic subsidy framework has encouraged entrepreneurs to increase the productivity of plants by using dedicated crops as feed, of which maize silage is the most widely used. Since the economic subsidy for bioenergy production has already been reduced, it can be expected its end in the future, thus potentially making the feeding of plants with dedicated crops uneconomic. In particular, subsidies could be essential to guarantee revenues and to cover the feeding supply costs.
This study aims to evaluate the consequences of the potential deletion of the subsidy framework for AD production plants. Consequential life cycle assessment (cLCA) method was implemented in order to evaluate the environmental effects related to: (i) the substitution of dedicated crops in the feeding mix with pig and cow slurry; (ii) the end of plants fed with dedicated crops and the substitution of the related renewable energy production with non-renewable energy in the national energy mix.
Results highlighted that the substitution of cereal silages with an additional share of animal slurry entails an environmental improvement respect to the BASELINE scenario. Considering the displacement of land use towards the cultivation of cereals for feeding, the contraction of import contributes to an improvement of environmental impacts. The higher nitrogen efficiency of the digestate could also reduce the volume of supplemental fertilisers for crops cultivation. Moreover, slurry storage at farm in traditional open tanks causes an increase in Greenhouse Gas Emissions (GHG) due to emissions to the atmosphere. The achieved results support the decision of policy makers to drive the future towards a more sustainable energetic production.

1. Introduction

Over the last years, thanks to the provision of public subsidies, the production of electricity from renewable sources has grown strongly throughout Europe (Hernández-Figueroa et al., 2014). All Member States provide subsides for renewable energy production, among which for biogas from Anaerobic Digestion (AD). In 2016, Germany, the world's largest producer of electricity from AD (29.4 TWh), had about 4.2 TW of installed electricity capacity (Bacenetti et al., 2016). Italy is the third largest world producer of electricity from AD, however, the trend of growth has slowed down due to the revision of the subsidy framework.
Nevertheless, this exponential growth contrasts with some problems, first of which the land exploitation to produce dedicated crops. About 50-55% of European biomass production used for anaerobic digestion (AD) plants derives from dedicated energy crops (cereals silages above all), by withdrawing fodder from the

livestock sector (Meyer et al., 2017). In 2012, in Germany, 2.5 million hectares of energy crops were cultivated, especially dedicated to maize cultivation. This crop is the most used matrix (about 90%) in agricultural AD plants (Negri et al., 2016), due to its high yields.

The Italian subsidy framework was modified recently to encourage the use of by-products and to improve plants' efficiency, which has involved also the improvement of the environmental performance of the supply chain. Therefore, an objective assessment of the criteria to be used in decision making is needed to define a future subsidy framework able to consider the environmental impacts.

The aim of this study is to assess the environmental consequences of the current subsidy deletion, which would make the use of cereal silages economically disadvantageous. The assessment of future scenarios was carried out using the Consequential Life Cycle Assessment (cLCA) method (Ekvall and Weidema, 2004), introducing as a shock to the current framework the removal of subsidies for electricity produced by dedicated crops. According to Ekvall and Andrae (2006), cLCA aims to estimate the effects that a change in the technology used within the life cycle, defined marginal technology, can cause in terms of physical flows and environmental impacts. These changes are the consequence of the demand variation in the markets and are caused by the substitution of marginal with new technology (Rehl et al., 2012). This is the main difference with attributional LCA (Falcone et al., 2017), which, instead, considers average technologies (Marvuglia et al., 2013). In more details, the consequential life cycle model does not represent the real (or expected) production chain but a hypothetical future scenario that derives from market dynamics potentially influenced by different internal and external factors including, for example, political interactions and changes in consumer behaviour (Sandén and Karlström, 2007). A key element of cLCA modelling is the identification of marginal technology, i.e. affected by the new technologies. A simplified approach or general or partial equilibrium modelling could be used to assess market consequences and to estimate the changes in the supply and demand of other goods and services caused by direct and indirect shocks (Igos et al., 2015). To the best of the authors' knowledge this work is the first one that tries to address environmental issues related to the change of the subsidies framework for producing biogas in Italy.

2. Methodological implementation to the case study

In the present study, the change of subsidy framework for Anaerobic Digestion (AD) production was analysed to identify its influence on the renewable energy market. Additionally, also the effects that such change could cause in terms of national energy mix modification, slurry management and organic and chemical fertilisation contribution were studied. In the report by the Italian Energy Services Operator (GSE) on renewable energy trend to 2020 (GSE, 2016), it was hypothesised that the removal of subsidies for bioenergy production will cause the end of plants that are based on purchased matrixes; this is because costs will exceed revenues. Starting from this point and considering that AD is one of the main methods to produce bioenergy, the following scenarios were modeled (Figure 1):

- BASELINE: represents the marginal technology in which about 1800 AD plants fed with agricultural feedstock generate 8.2 TWh of electricity per year (GSE, 2015);
- FS1: represents a new hypothetical scenario in which the end of subsides causes the substitution of silages and other dedicated matrixes with an additional quantity of animal slurry in the digester. The silage volume is replaced by cow and pig slurry with a replacement ratio of 1:1. The change of the digester feeding mix leads to a reduction of about 65% of electricity production, counterbalanced by an increase in the share of non-renewable energy in the national electricity mix.
- FS2: represents a new hypothetical scenario in which the end of subsides causes the end of AD plants and involves the substitution of the share of renewable energies with additional fossil energy in the national energy mix.

Table 1 shows the composition of feeding mix in BASELINE and FS1 scenarios as well as the generated energy flow as function of the matrix used.

Table 1 - Mass flows and generated energy flows for different matrixes considered in BASELINE and FS1 scenarios.

Matrix	Mass Flow		Generated Energy Flow	
	BASELINE	FS1	BASELINE	FS1
Maize silage	30 %	0 %	62 %	0 %
Other silage	10 %	0 %	16 %	0 %
Pig slurry	25 %	46 %	3 %	20 %
Cow slurry	25 %	46 %	8 %	47 %
Other matrix	10 %	9 %	12 %	33 %

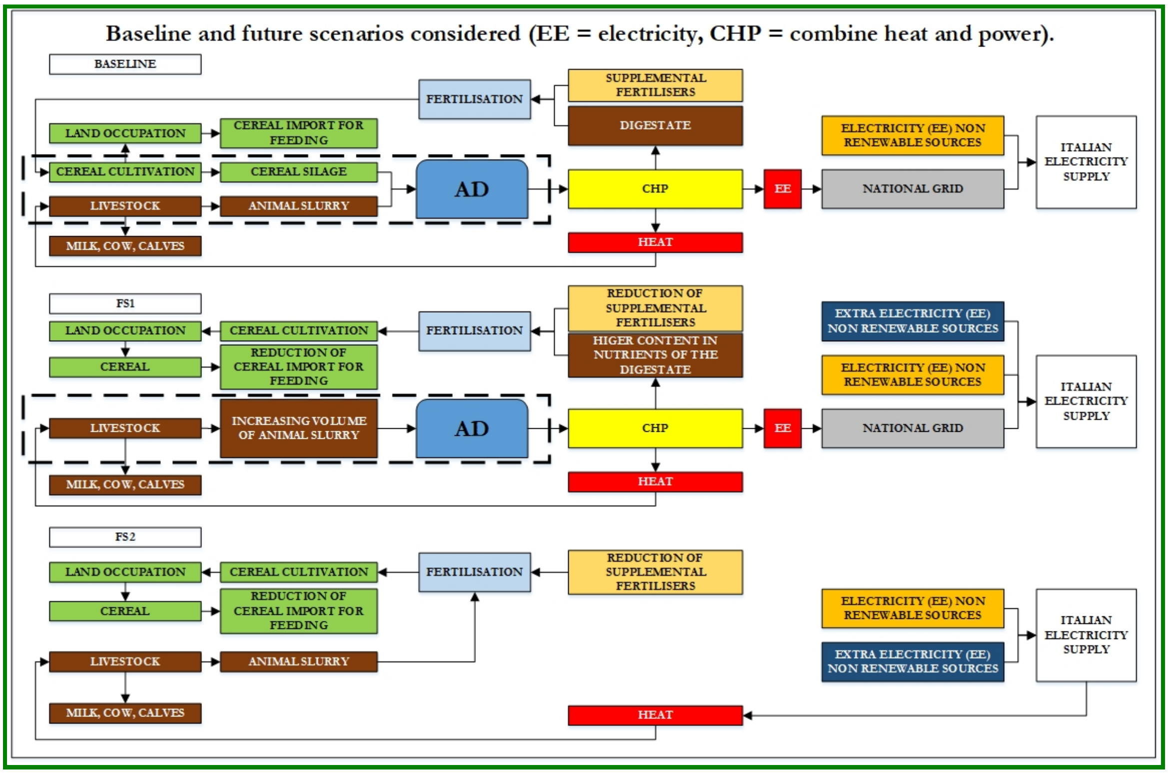

Figure 1: System boundary flow chart

To model the scenarios the following criteria were considered:

1) Anaerobic digestion of animal slurry allows:

- eliminating their storage, traditionally carried out in open tanks, and consequently avoiding emissions of methane, ammonia and nitrous oxide that are released during fermentation. In environmental terms, this brings to a benefit on all the environmental impact categories linked to these pollutants emissions;
- increasing the ratio N-NH_3-N in the digestate and, consequently, its Mineral Fertiliser Equivalent (MFE). Anaerobic digestion allows the substitution of a larger share of mineral N-fertilisers with digestate in respect to the use of animal slurry "as it is", due to the higher concentration of NH_3-N in digestate. Table 2 shows the characterisation of the two types of slurry considered (i.e. pig and cow) that, once digested in the AD plant, increase the MFE share to 65% and 75%, respectively.

2) For all scenarios, the heat cogenerated by Combined Heat and Power (CHP) units is used only to satisfy the internal heating requirements of the plant (i.e. digesters' temperature regulation) while the surplus is dissipated.

3) In the two hypothetical scenarios, the lack of electricity from AD plants is replaced with electricity from non-renewable sources, according to the current national electricity mix, considering as lost the share from AD.

4) In FS1 scenario, slurries used to replace silage's share were transported over a longer distance than at present, because slurry must be delivered from several farms to meet the plant capacity: this involves increasing distances. In more details, an average distance of 5 km was considered. The higher use of slurries for AD implies, according to the abovementioned point 1), the replacement of an additional share of mineral nitrogen fertilisers and, consequently, an environmental benefit.

5) In FS2 scenario, the entire renewable electricity production must be replaced by non-renewable energy and the benefits of AD production from slurry are completely lost. This is contrariwise to FS1 scenario, where the increased use of slurry has a twofold environmental benefit (emissions avoided by traditional storage and higher share of mineral nitrogen fertiliser).

Table 2 - Average characterisation of wastewater

Matrix	Total solids	N-Total	N-NH_4	MFE	N-available
	%	kg/t	kg/t	%	kg/t
Pig slurry	3.00 %	2.50	1.83	60 %	1.50
Cow slurry	9.50 %	3.75	1.48	50 %	1.88

Table 3 - Summary of the hypothesised consequences (compared to BASELINE scenario) of the modification of subsidy framework.

Scenarios	Decrease in EE from AD	Benefits from the absence of traditional storage	Benefits for substitution of mineral fertilisers	Transport distance of slurry
FS1	-65 %	Increased	Increased	Increased
FS2	-100%	Nullified	Nullified	Nullified

The selected functional unit was 1 kWh of electricity supplied to the national electric grid. The characterisation factors reported by the ILCD method were used. The following twelve impact potentials were evaluated according to the selected method: climate change (CC), ozone depletion (OD), human toxicity, non-cancer effects (HTnoc); human toxicity, cancer effects (HTc); particulate matter (PM), photochemical ozone formation (POF), acidification (TA), terrestrial eutrophication (TE), freshwater eutrophication (FE), marine eutrophication (ME), freshwater ecotoxicity (FEx) and mineral, fossil and renewable resource depletion (MFRD).
Land Use Change (LUC) modelling was performed through a "backwards looking" approach, a simplified modelling system by Schmidt (2008) that assesses the historical trend of cereal silages area and focuses on "statu quo ante" of the building of AD plants. The trend analysis from 1961 to 2013 (FAOSTAT, 2018a and 2018b) showed that the use of cereal silage for AD did not cause relevant LUC thanks to the intensification of productions.

3. Results and discussion

Figure 2 shows the relative comparison of the three scenarios for the studied 12 environmental impact categories. For each indicator analysed, the scenario with the worst performance (i.e. with the highest environmental load) is put equal to 100 %, while the others are proportionally scaled. The FS2 scenario has the highest environmental impact on 10 of the 12 categories, except for "human toxicity, non-cancer effects" and "marine eutrophication", where the BASELINE scenario, which represents the marginal technology in the current AD chain, has loads 25 % and 50 % higher, respectively. This is due to the cultivation of silage matrices and to their fertilisation. Even if FS2 scenario obtained the worst results for "acidification", "terrestrial eutrophication" and "freshwater ecotoxicity" categories, the impacts of BASELINE scenario are similar.
Contrariwise, the BASELINE scenario is more efficient in the categories "climate change", "ozone depletion", "human toxicity, carcinogenic effects" and "freshwater eutrophication", due to the increased use of non-renewable energy in FS1 and FS2 scenarios. For all other impact categories, FS1 scenario achieves a significant improvement in environmental performance compared to both BASELINE and FS2 (NO AD) scenarios, thanks to the replacement of silage by cattle and pig slurry in the AD process.

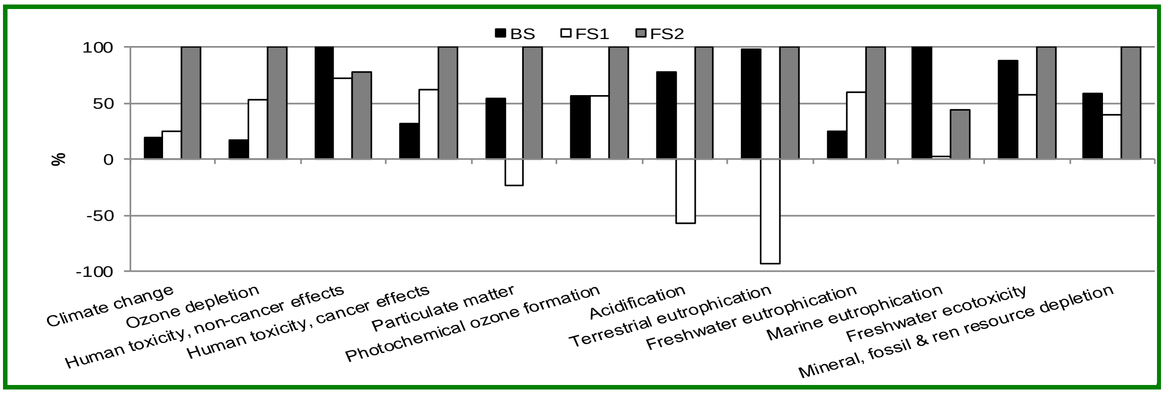

Figure 2 – Comparison between scenarios

Figure 3 shows the input and output contribution that characterises the two alternative scenarios in terms of environmental impact. Negative values are a benefit to the environment, while values greater than zero describe a negative effect on the environment. For FS1 scenario, it can be noted that, for all environmental impacts assessed, there are benefits linked to the replacement of nitrogen fertilisers and/or to the replacement of the traditional slurry storage in open tanks. Thanks to this mitigation effect, the benefits for the categories of “particulate matter”, “acidification” and “terrestrial eutrophication” are higher than the impacts, which motivates why the value shown in Figure 2 is below zero. The impact of slurry transport is limited, except for the categories “human toxicity, non-cancer effects” and “mineral, fossil and renewable resources depletion”. Instead, in FS2 scenario the positive effects of slurry use for AD are lost. Since there is no environmental benefit in FS2, all values are greater than zero. For both scenarios, the replacement of electricity produced from AD by energy from non-renewable sources is the main cause of the negative effects on the environment.

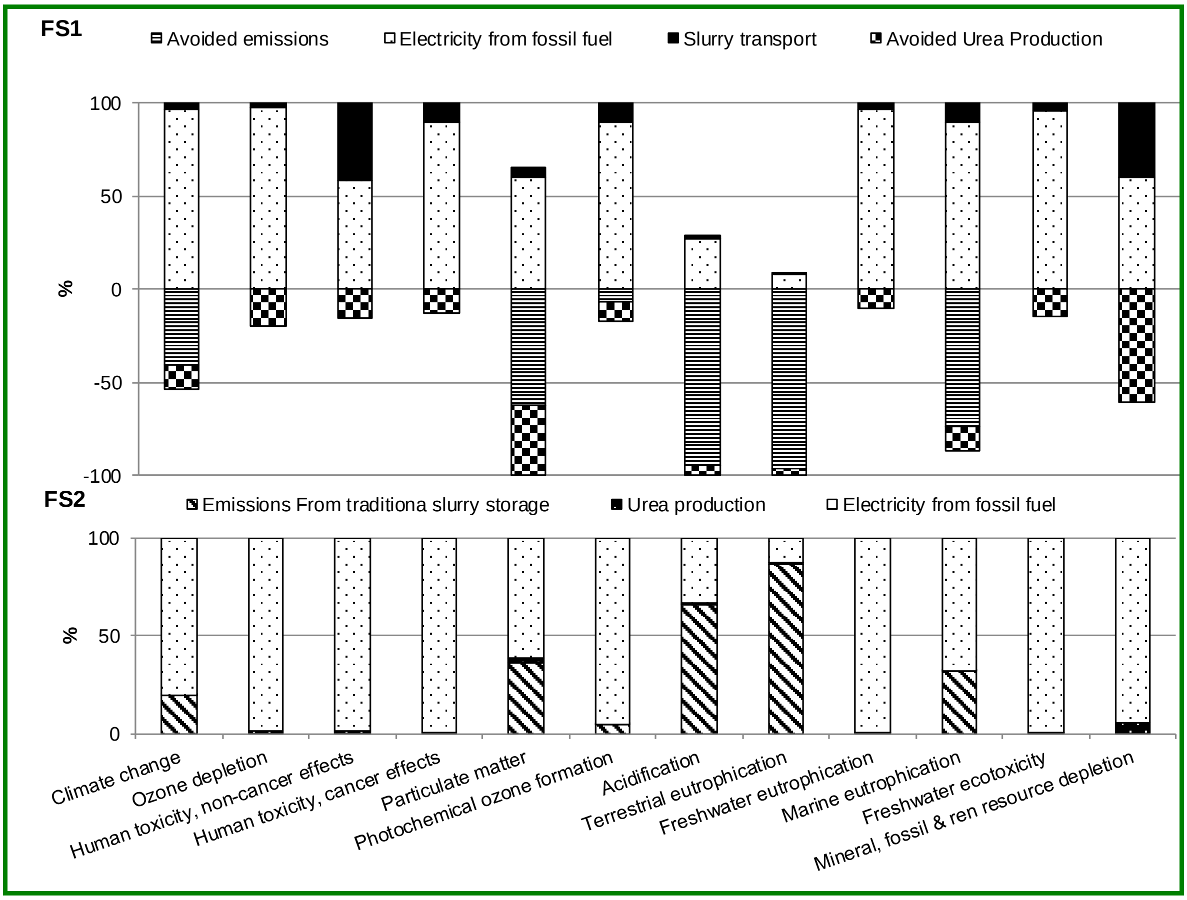

Figure 3 - Impact contribution in the two hypothetical scenarios.

4. Conclusions

In Italy, AD from agricultural products and by-products has been strongly encouraged by the payment of substantial public subsidies. This initiative was aimed to achieve the ambitious European Union objectives to increase the share of electricity produced from renewable sources. However, while the subsidy effect resulted positive for renewable energy production, it is also necessary to analyse its effects in terms of reduction of the environmental impact, not only considering greenhouse gas emissions. Besides this, a new subsidy framework should be design to promote the development of a sustainable energy supply chain based on a comprehensive set of environmental indicators.

The results of this study show that the subsidy framework adopted until the end of 2012, which considered the size of the plant (electric power < 1 MW electricity) as unique constraint obtaining the higher feed-in-tariff, was consistent with the objective of reducing emissions of climate-changing gases. However, the renewable electricity produced hides a dark side, being more sustainable in terms of climate change but more impacting in terms of “Human Toxicity, non-cancer effects”, “Marine eutrophication”, “Acidification”, “Terrestrial eutrophication” and “Freshwater ecotoxicity” categories, compared to the alternative solutions.

The new subsidy framework introduced a modularity of subsides as function of the share of by-products used, and is moving in the right direction also from an environmental point of view. The results of this study and the methodology applied can be a valuable support for public decision makers in the development of renewable energy policies.

References

Bacenetti J., Sala C., Fusi A., Fiala M., 2016, Agricultural anaerobic digestion plants: What LCA studies pointed out and what can be done to make them more environmentally sustainable? Applied Energy, 179, 669-686. doi:10.1016/j.apenergy.2016.07.029.

Ekvall T., Andrae A., 2006, Attributional and consequential environmental assessment of the shift to lead-free solders, International Journal of Life Cycle Assessment, 11(5), 344–53.

Ekvall T., Weidema B., 2004. System boundaries and input data in consequential life cycle inventory analysis, International Journal of Life Cycle Assessment, 9, 161-171.

Falcone G., De Luca A.I., Stillitano T., Iofrida N., Strano A., Piscopo A., Branca M.L., Gulisano G., 2017, Shelf life extension to reduce food losses: The case of Mozzarella Cheese. Chemical Engineering Transactions, 57, 1849-1854. DOI: 10.3303/CET1757309.

FAOSTAT, 2018a, Crop Production <www.fao.org/faostat/en/#data/QC> accessed 12.03.2018.

FAOSTAT, 2018b, Crops and livestock products trade <www.fao.org/faostat/en/#data/TP> accessed 12.03.2018.

GSE - Gestore dei Servizi Energetici, 2015, Rapporto statistico sulle energie da fonti rinnovabili in Italia, <www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/Rapporto%20statistico%20GSE%20%202015.pdf> accessed 12.03.2018.

GSE - Gestore dei Servizi Energetici, 2016, Energie rinnovabili al 2020 - Scenari tendenziali, <www.gse.it/documenti_site/Documenti%20GSE/Studi%20e%20scenari/Energie%20rinnovabili_scenari%20al%202020.pdf> accessed 12.03.2018.

Hernández-Figueroa M.A., Martinez-Patiño J., Ireta-Moreno F., Lozano-García J.M., 2014, Electrical parameters of the electric power production using biogas, Chemical Engineering Transactions, 39, 343-348. DOI: 10.3303/CET1439058

Igos E., Rugani B., Rege S., Benetto E., Drouet L., Zachary D.Z., 2015, Combination of equilibrium models and hybrid life cycle-input–output analysis to predict the environmental impacts of energy policy scenarios, Applied Energy, 145, 234-245

Marvuglia A., Benetto E., Rege S., Jury C., 2013, Modelling approaches for consequential life-cycle assessment (C-LCA) of bioenergy: Critical review and proposed framework for biogas production, Renewable and Sustainable Energy Reviews, 25, 768-781. doi: 10.1016/j.rser.2013.04.031.

Meyer A. K. P., Ehimen E. A., Holm-Nielsen J. B., 2017, Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production. Biomass and Bioenergy.

Negri M., Bacenetti J., Fiala M., Bocchi S., 2016, Evaluation of anaerobic degradation, biogas and digestate production of cereal silages using nylon-bags, Bioresource Technology, 209, 40-49. doi: 10.1016/j.biortech.2016.02.101.

Rehl T., Lansche J., Müller J., 2012, Life cycle assessment of energy generation from biogas - Attributional vs.consequential approach, Renewable and Sustainable Energy Reviews, 16, 3766-3775. doi:10.1016/j.rser.2012.02.072

Sandén B.A., Karlström M., 2007, Positive and negative feedback in consequential life-cycle assessment, Journal of Cleaner Production, 15, 1469-1481. doi.org/10.1016/j.jclepro.2006.03.005

Schmidt J., 2008, System delimitation in agricultural consequential LCA-outline of methodology and illustrative case study of wheat in Denmark, International Journal of Life Cycle Assessment, 13(4), 350-64.