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Biogas Production from Intercropping (Syn-Energy)

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The cultivation of two or more crops in association to each other is an ancient method of utilising agricultural area to get optimum crop productions. The increased cultivation of energy crops to fulfil energy requirements have led to the necessity of optimisation of bio productivity of the available land use, which should be carried out without compromising on the land quality and environmental conditions. Syn-Energy II is an Austrian national project, which focuses on the possibilities of synergetic expansion of agricultural biogas production. The field experiment results reveals that cultivation of intercrops for biogas production between the main crops enhances crop rotation yields, while it reduces erosion, greenhouse gas emissions and ground water pollution. Similarly synergetic calculations will be made for conservational soil cultivation and biological crop rotation systems. The project not only focuses on production of biogas for conventional use (heat and electricity production), but also biogas cleaning to natural gas quality (96 % methane content) which can be injected to the gas grid and its usage as an alternate fuel in the agricultural practice making a recycling loop (Niemetz and Kettl, 2012).

The ecological assessment is carried out utilising Life Cycle Assessment (LCA) based methodology known as Sustainable Process Index (SPI) (Krotscheck and Narodoslawsky, 1996). A web based tool SPIonWeb (http://spionweb.tugraz.at/en/welcome) is used to calculate ecological footprint and dynamic modelling for biogas production scenarios, based on comprehensive energy and material flows from a variety of intercrop-systems. The process evaluation provides reliable information to figure out ecological hotspots for process optimisation (Kettl and Narodoslawsky, 2013).

1. Introduction

There are different variables which drive renewable energy programmes, including climate change, insecure and uncertain supply and ever increasing prices of fossil oils. The European Union has set the aim of increasing renewable energy share up to 20 % of overall energy consumption in 2020. Within available renewable energies, biomass is one of the key elements for developing sustainable energy systems (Hermann, 2012). Biomass as an energy source is significantly contributing to renewable energy programmes as well as provides two advantages over other renewable energy sources: immediately removes CO_2 from the atmosphere and harvested crop is a storable energy sources (Shield, 2012).

A wide range of energy crops is available for biogas production. At present biogas is commonly produced from maize due to high production yields and highly innovative crop breeding activities. Ecological problems e.g. loss of biodiversity, nitrogen leaching, soil erosion and increased pesticide consumption in monoculture are observed due to this dominance. Another aspect is social acceptance of societies towards biogas production, due to growing concern about increased energy crop cultivation progressively competes with food production because of availability of limited arable area. In order to attain the amount of desired biomass for energy production without compromising on ecologic as well as social issues, double-cropping system or inter-cropping system have been suggested and intensively investigated over the last few years (Graßa et al. 2013).

Intercropping provides a possible smart solution for sustainable land use through its synergetic implementation of agricultural supply chain. It provides the opportunity of utilising the same area for bioenergy production between two main crops. It can play an important role in mitigating the problem of

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land use competition between energy, food and feed production. This practise stabilises or even increases humus content in the field and in turn reduces risk of soil erosion. N-fixation caused by leguminous intercrops decreases N-fertiliser input for the following main crop. It decreases the risk of N-leaching through no or demand-actuated supply of N-fertiliser (Niemetz and Ketll, 2012).

During the projects Syn-Energy I and II data from 4 crop trial places (Burgenland, Lower Austria, Upper Austria and Styria) about cultivation, consumption and environmental impacts of biogas production from intercrops has been collected. The acquired data includes yields of intercrops and main crops, export of N and C; measurements of soil balance and N-leaching. The inspected data is used for calibration of soil and water content, modulation of material transportation as well as overall evaluation of material and energy balances. Fertiliser input and machinery use is also included among other flows. So all in all the whole process chain, including precursors to cultivation (both main as well as intercrop) and biogas production has been taken into account. Figure 1 presents the mass, energy and natural resource flows in Syn-Energy II (Maier et al. 2014).

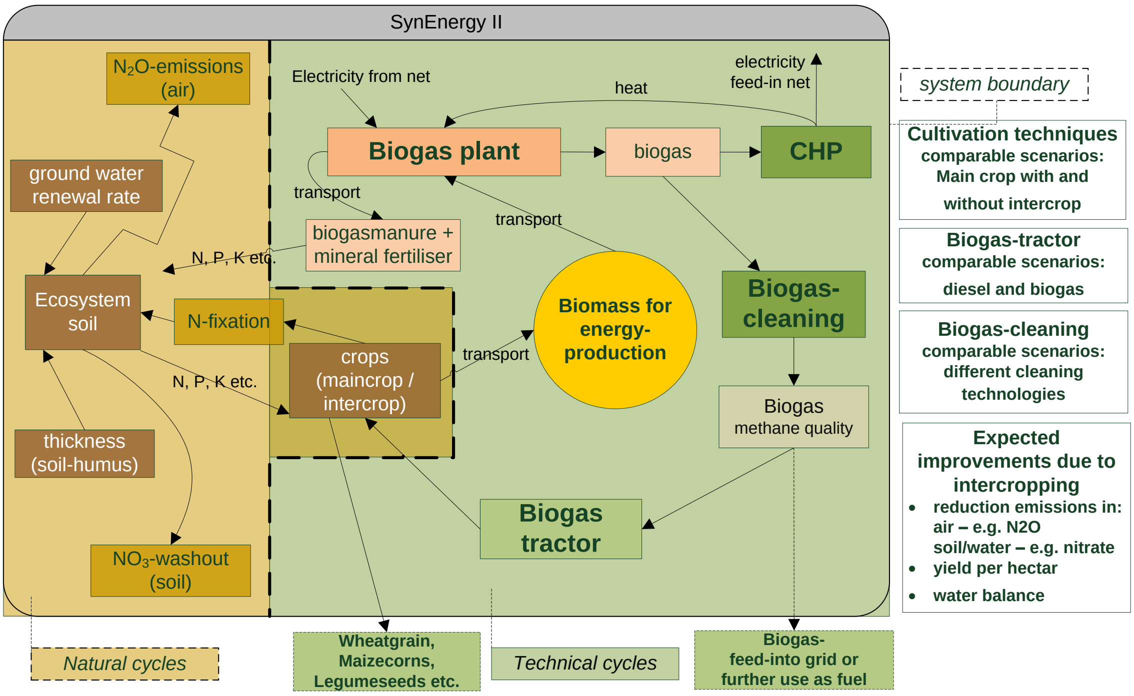

Figure 1: Graphic presentation of mass energy and natural flows in Syn-Energy II

These comprehensive material and energy balances provide the preliminary base for evaluating ecological impact of an agricultural practice in accordance to international standard for Life Cycle Assessment (LCA) (JRC Reference Report, 2012). However different methods can be used for quantification of ecological assessment with in LCA. In the current study a comprehensive ecological footprint method i.e. Sustainable Process Index (SPI) has been used. It provides an aggregate measure in the form of m^2 area, without losing information about different aspects of ecological impact (Narodoslawsky and Krotscheck, 1995).

1.1 Methodology

Material and energy flows resulting from crop cultivation, use of different arable farming approaches and biogas production systems within research test areas has been determined. Based on material and energy flows life cycle impact assessment has been carried out using Sustainable Process Index (SPI) methodology. SPI is a member of ecological footprint family. It evaluates the processes in accordance to the area required to embed them sustainably into the ecosphere (Krotscheck and Narodoslawsky, 1996). It evaluates the impacts ranging from resource use to emissions using only natural reference (Niederl and Narodoslawsky, 2005). It is a freely available web based software tool (available at: spionweb.tugraz.at) which can be accessed on any computing device (Linux, Mac, Windows, IOS etc.) irrespective of the operating system. Life cycle based evaluation of the products and services estimates their SPI footprint (m^2), life cycle CO_2 emissions and GWP (global warming potential).

This paper deals with effect of change of fertiliser type on ecological evaluation of two intercrop cultivation systems based on per ha (hectare) input and outputs:

System I: Wheat as main crop and summer intercrop for biogas production

System II: Maize as main crop and winter intercrop for biogas production

These systems are further divided into four different sub-systems which are:

S1. Intercropping system using diesel fuelled agricultural machinery input and use of mineral fertilisers

S2. Intercropping system using diesel fuelled agricultural machinery input and use of biogas manure as fertiliser

S3. Intercropping system using bio methane fuelled agricultural machinery and use of biogas manure as fertiliser

S4. Conventional Cultivation (Business as usual without intercropping system)

The biogas manure has been considered waste product from biogas production process. Being waste from another process it has zero footprint. The footprint caused by manure fertiliser is due to its transportation and application.

2. Results and discussion

The results discussed in this study are based on the data acquired during Syn-Energy II project. It is an Austrian national funded project which studies common biogas use (heat and electricity production) along with biogas cleaning and its use as a fuel. The effect of change of fertiliser type and fuel consumption per ton dry matter (DM) production is given in Table 1.

Table 1: SPI footprint m^2 / t DM (dry matter)

		S1		**S2**		**S3**		**S4**
System	Crops	Intercrop	Main crop	Intercrop	Main crop	Intercrop	Main crop	Main crop
I	Wheat	11,071	37,389	11,071	13,565	6,662	5,655	46,452
II	Maize	8,559	23,471	8,559	8,189	4,352	4,652	28,407

The footprint values vary depending on the inventory input values for energy, pesticides and fertilisers. Sub-system S4 has highest foot print m^2 / t DM for main crops both for maize as well as wheat. Sub-system S1 have overall 2nd highest footprint for main crop and highest among the intercropping systems. The lower footprint value than S4 is because of decreased fertiliser input due to N-fixation by legumes cultivation as an intercrop. The similar values for intercrop footprint values for S1 and S2 are due to similar inventory inputs i.e. no mineral fertiliser input, rather application of manure fertiliser in both cases. The reduction in footprint value for both main as well as intercrop in S3 is due to fuel exchange from diesel to bio methane in agricultural machinery.

Table 2: SPI footprint m^2 / ha DM (dry matter)

		S1		S2		S3		S4
System	Crops	Intercrop	Main crop	Intercrop	Main crop	Intercrop	Main crop	Main crop
I	Wheat	33,215	198,162	33,215	71,896	19,988	29969.39	246194
II	Maize	34,237	352,068	34,237	122,833	17,408	69778.38	426103

In accordance to the data obtained from the field studies average DM / ha biomass for main crop are 5.3 t for wheat and 15 t for maize. Similarly for intercrops average DM / ha, 3 t for winter intercrop and 4 t for summer intercrop has been reported. Calculated SPI footprint in m^2 / ha DM is shown in Table 2.

The comparison of footprint for sub-systems in system I, i.e. “wheat as main crop and summer intercrop (Sudan grass, sunflower, pea, clay etc.)” for biogas production is shown in Table 3.

According to our own calculations biomass of 1 t DM produces on average 300 m^3 biogas, showing a potential of 900 m^3 of biogas per ha summer intercrop. A unit SPI value of 20.08 m^2/ m^3 has been used to calculate SPI for biogas production from summer intercrops per ha cultivation area. Raw biogas is cleaned to enrich methane content from 60 % to 96 % utilising Austrian electricity mix. SPI for biogas cleaning is calculated using unit value of 100 m^2 per m^3 biogas. *Figure 2* shows the graphical comparison of SPI footprint for system I.

Table 3: System I: SPI wheat as main crop and summer intercrop for biogas production

	S1	S2	S3	S4
Biogas production (m³)	900	900	900	
Wheat per ha cultivation area	198,162	71,896	29,969	246,194
Summer intercrop per ha cultivation area	33,215	33,215	19,988	
Biogas production	18,073	18,073	18,073	
Natural Gas provision, replacement	-	-	-	486,360
Biogas cleaning (60 %->96 % CH4) AT	90,844	90,844	90,844	-
Total SPI [m²/ha] in AT	340,294	214,028	158,874	732,554

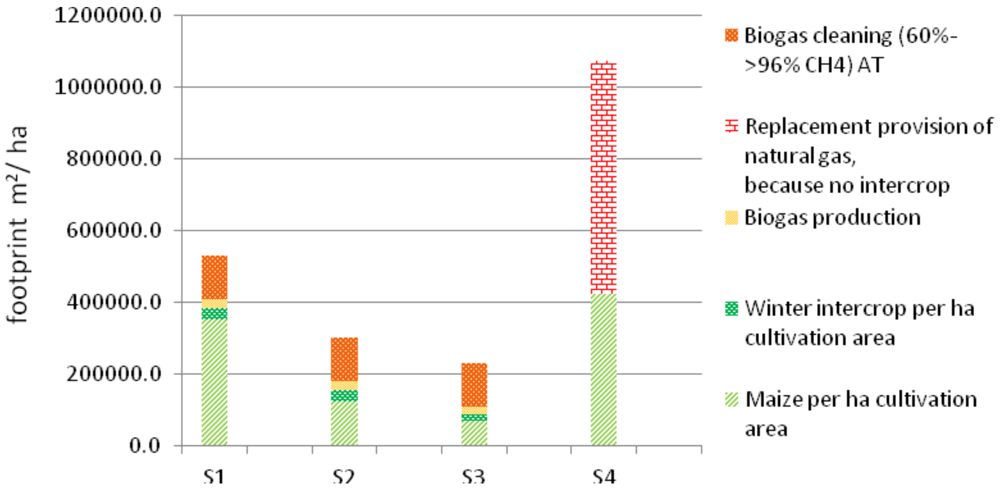

Figure 2: Comparison of SPI footprint / ha wheat and summer intercrop cultivation

The SPI foot print comparison for cultivation in accordance to system II is shown Table 4. As described earlier according to the data obtained from the field experiments winter intercrops average yields are 4 t DM biomass equivalents. It shows a potential of 1,200 m^3 biogas production potential per ha cultivation area.

Table 4: System II: SPI Maize as main crop and winter intercrop for biogas production

	S1	S2	S3	S4
Biogas production (m³)	1,200	1,200	1,200	
Maize per ha cultivation area	352,067	122,833	69,778	426,102
Winter intercrop per ha cultivation area	34,237	34,237	17,408	
Biogas production	24,097	24,097	24,097	
Natural Gas provision, replacement	-	-	-	648,480
Biogas cleaning (60 %->96 % CH4) AT	121,125	121,125	121,125	0
Total SPI [m²/ha] in AT	531,527	302293.2	232,409	1,074,582

In both systems I and II sub-system S4 represents cultivation according to business as usual and do not have the option of biogas production due to fallow. In order to make clear and rational analysis of footprint the equivalent amount of natural gas provision has been added to the sub-system S4 in both crop systems. *Figure 3* shows the SPI footprint comparison for system I.

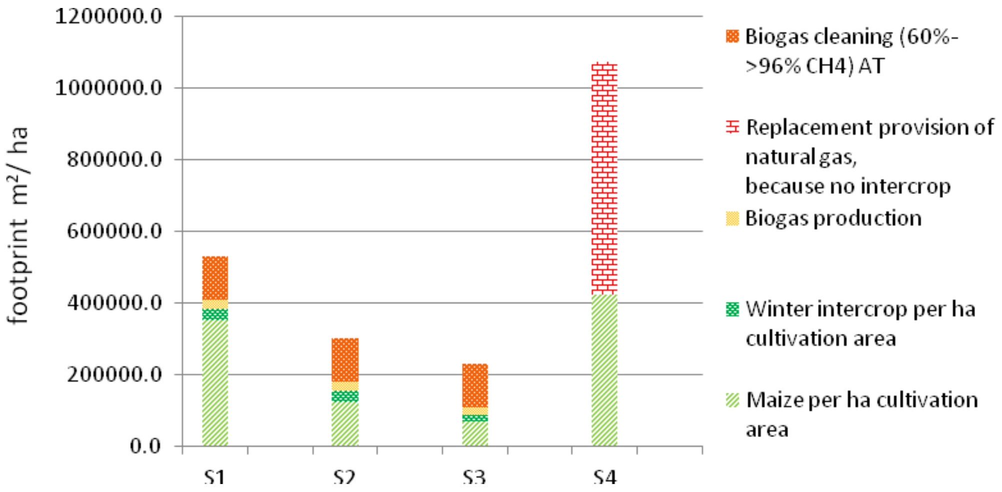

Figure 3: Comparison of SPI footprint / ha Maize and winter intercrop cultivation

System I and system II present SPI results for main crops and biogas production out of 1 ha utilising business as usual farming or agriculture, intercropping system, energy-production structure and integration of biogas manure with mineral fertilisers. The results show that sub-system S3 has the lowest footprint in both cropping systems. For system I, wheat and summer intercrop, S3 has 158,874 m^2 / ha, which is about 78 % less than the business as usual scenario subsystem S4. Similarly S3 has a 53 % and 71 % smaller footprint than sub-systems S1 and S2 respectively. Likewise for system II, maize and winter intercrop, cultivation shows an almost similar trend. For system II, S3 has 232,409 m^2/ha, which is about 78 % less than conventional business as usual practice S4. Also it has a 50 % and 72 % smaller footprint than S1 and S2. This cannot be called ecological assessment as the service unit is not the same for each system. These results are just an ordinary comparison of footprint built on input and output per ha DM and biogas production.

3. Conclusion

The results from the current study proves that the choice of agricultural practice have an effect on the whole cropping system which in turn have strong influence on environmental impacts of crop cultivation. The input reduction along with usage of renewable energy, within the agricultural phase increases the beneficial environmental effects on the crop cultivation. Intercropping have also shown positive environmental effects and more contribution to sustainable energy crop production through year-around soil cover and increased yield stability. This increased crop yield stability decreases competition for arable land between energy crops and food production.

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