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Miscanthus as energy crop: Environmental assessment of a miscanthus biomass production case study in France

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ABSTRACT

The cultivation of miscanthus (*Miscanthus* x *Giganteus*) as biomass for energy production has increased year by year due to its agronomical performances. In particular, in France, miscanthus is cultivated in the Bourgogne region and it is used as feedstock to produce pellet. In this paper, emergy assessment of different logistic (harvesting) strategies for miscanthus production in the Bourgogne region is presented. Emergy assessment is a particular methodology suited to quantify the resource use of a process and to estimate the percentage of renewability of products or services. The case study includes all phases to grow miscanthus, harvest the biomass as chips or short- or long-stranded bales and distribute it to a bioenergy plant. The aim of this study is to evaluate the sustainability performance of the whole process, from the field to the plant's gate. The emergy flow that represents the environmental cost of the whole process, the percentage of renewability (%R) and the Unit Emergy Values (UEV) that represent the resource use efficiency of the final products for each phase are calculated. Since miscanthus is reproduced by rhizomes, in addition to the system for growing and distributing miscanthus biomass, the system for producing miscanthus rhizomes is also analysed and a UEV for miscanthus rhizomes of 1.19E+05 seJ/J was obtained. Moreover, due the absence of other emergy assessments for miscanthus biomass for comparison, a sensitivity analysis has been made by considering different transport distances and different aboveground biomass yields. Comparing the harvesting methodologies, the bales made with short strands has the best performance. The aboveground biomass production was found to have an Energy Return On energy Investment (EROI), which is the double of that from an experimental miscanthus field in Italy. However, this implied a trade-off for the net energy production of about 50%.

1. Introduction

Environmental assessments of biomass used as feedstock for energy production are more and more requested for understanding the real asset of bioenergy systems. In the last decades, biomass has become one of the main feedstock for renewable energy production to be able to reach the target proposed by the EU commission concerning renewable energies. The importance of biomass is increasing year by year due the fact that it is a renewable feedstock, which is available in both rural and urban areas of all countries and it may be stored. Biomass energy supply chains were historically developed on available resources such as forest, agricultural and urban residues. Energy crops, i.e., plants that are cultivated for producing energy, allows a better management of quantity and quality of biomass. There is, however, a trade-off with respect to land use available for food and feed production. Miscanthus (*Miscanthus x Giganteus*) has been identified as one of the best energy crops because, compared with other energy crops, it has a high energy content and a low moisture content after harvest, which are important characteristics for maximizing the energy output (Kaltschmitt et al., 1997; Murphy et al., 2013). Moreover, it has high yield potential and can be grown extensively with low use of inputs. Its rapid growth and important plant cover limit the need for pesticides. In addition, miscanthus is very efficient at using nutrients because its rhizome system can recycle nutrients from soil and aboveground biomass for subsequent growing cycles (up to 20 years) and subsequent crops (Mann et al., 2013; Lewandowski et al., 2003).

Miscanthus has been imported in Europe in the 1960's from Asia as an ornamental plant and then, thanks to its good adaption to the different climatic conditions in Europe, several projects for growing

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miscanthus for energy purposes were carried out in Europe (Lewandowski et al., 2003). In the last decades, miscanthus has been introduced in France and its cultivation has increased year by year, especially in the Bourgogne Region (Eastern France), characterized by being a moist lowland, where miscanthus is highly yielding (Rizzo et al., 2014).

Different aspects of the miscanthus production have previously been studied focusing on, e.g., analysing the cultivation methods (Styles and Jones, 2007; Angelini et al., 2009), the economic and environmental performances of the production system (Smeets et al., 2009) and life cycle assessment of the hypothetical supply chain to produce energy from miscanthus biomass (Kaltschmitt et al., 1997; Murphy et al., 2013; Parajuli et al., 2015). There is a need for detailed environmental assessment based on a real case study, with its set of constrains and opportunities.

The aim of this work is to evaluate the environmental sustainability performance of miscanthus biomass supply chain in the Bourgogne Region. To accomplish this, the Emergy Assessment methodology is used. It is an important tool to estimate the environmental assessment of an agricultural system because it takes into account all the aspects of the system, both natural and human activities. It converts all inputs into the common unit of solar energy by means of Unit Emergy Values (UEV) that represents the resource use efficiency of the product under study. Moreover, one of its main characteristics is to provide an estimate of the percentage of renewability of the output by classifying the resources use of the process under study. In this work, the environmental cost, the resource use efficiency and the percentage of renewability of growing miscanthus, harvesting miscanthus as chips and bales of short or long strands and transporting the biomass to a plant facility are estimated. Moreover, the environmental performance and the resource use efficiency of producing miscanthus rhizomes is also provided with the aim of calculating UEV for both aboveground and underground biomasses. To verify the robustness of our results, a sensitivity analysis of two parameters of the miscanthus biomass production is carried out and the Energy Return On energy Investment (EROI) is compared to literature data.

2. Materials and methods

2.1. Case study description

The studied miscanthus biomass production system is based on actual practices regarding production, harvesting and transport of biomass representative for the Bourgogne Region. The total production of miscanthus biomass in this region is around 400 ha (1 ha = 10,000 m^2) and the fields are located on a radius averaging 70 km from a pellet facility. The analysis has been conducted on four phases: (1) the rhizome production phase of 6.3 years occurring in nursery fields, (2) the biomass growing phase with a whole crop cycle of 15.3 years, (3) the biomass harvesting phase and (4) the transport of biomass to the plant phase. Data has been collected based on trials and surveys between 2012 and 2015 within the LogistEC Project. Concerning nursery fields in the same region producing the rhizomes used to establish the crops, data are based on the management knowledge of local and international experts. All data on work by machinery and people are based on an estimate of the time taken for a specific machinery to do a specific process. The man-hours are set equal to these machine hours and converted to joules using that a person consumes in average 125 kcal/h. Further, the material input from each machinery is calculated from the proportion of the life span of the specific machinery used for the process. Calculating in this way, labour and machinery inputs are expected to be underestimated compared to the inputs in actual systems.

2.1.1. Nursery fields

The production of miscanthus rhizomes is taking place in dedicated fields, i.e. nursery fields, where rhizomes are harvested two times during a cycle covering a period of 6.3 years (Table 1). According to the practices representative for the Bourgogne Region, the crop establishment occurs in April by planting 19,000 rhizomes/ha whereas the rhizomes harvests occur in the same month after 3 and 6 years, respectively. Starting from the second year, the aboveground biomass is also yearly harvested with an average yield of 10.5 tdm/ha (where tdm is abbreviation of 'tons of dry matter'). The yield of rhizomes is 250,000 and 900,000 rhizomes/ha for the first and for the second harvest, respectively. After the last harvest, 4 months are dedicated to the destruction of the field (Table 1). For the energy content ('lower heating value' abbreviated LHV) of rhizomes, we use the energy content of roots and tubers, which is 5.5 GJ/tdm (Rosillo-Calle et al., 2015).

2.1.2. Miscanthus growing system

The crop cycle of miscanthus is assumed to last for 15.3 years considering current agricultural practices in the region (Table 2). Starting from the second year, the crop is annually harvested at the beginning of the spring (April) when the moisture content of the aboveground biomass is around 15%. We assume that on average for the 14 harvests, miscanthus aboveground biomass yields can potentially reach 16.3 tdm/ha/year (Dufossé et al., 2013). This means that the annual average yield, calculated as the potential yield multiplied by 14 harvests and divided by 15.3 years, is 15 tdm/ha/year. The first year of the cycle is dedicated to the crop establishment with soil preparation, rhizomes planting (19,000 rhizomes/ha) and chemical weeding. One additional chemical weeding is often applied the second year to ensure a good establishment of the crop, and then, no other treatments are applied until the crop destruction that takes places after the last harvest between June and August (Table 2). The chemical weeding refers to herbicide applications that take place three times: (1) during first year (two applications, i.e. S-metolachlore and dicamba with a rate of 1.9 and 0.3 kg of active substance/ha, respectively), (2) at the beginning of the second year (one application of dicamba, 0.3 kg/ha) and (3) in the last month of the field's destruction (one application of glyphosate, 2.1 kg/ha). The energy content (LHV) of the aboveground miscanthus biomass is 18 GJ/tdm (ECN, 2015).

2.1.3. Miscanthus harvesting system

The harvesting phase of miscanthus biomass refers to the 14 harvesting that take place during the crop cycle and it is represented by three different harvesting techniques (scenarios): chips (designated Chips), short stranded square bales (designated Bales S) and long stranded square bales (designated Bales L). For each harvest, we assume that 90% of the potential biomass, i.e. 14.67 tdm/ha/year, is harvested while the remaining 10% is left in the field as stubble residues. The difference between Bales S and Bales L is the length of the strands that constitute the bales. Bales S and Bales L are respectively characterized by 8–10 cm and 20–50 cm long strands. The three harvesting techniques differ with respect to machineries used in the harvesting operation (in parenthesis we refer to Table A1 in Supplementary material). In the fields where miscanthus is harvested as chips, the harvester (Silage harvester 480 hp) directly fills a trailer (Trailer 50 m^3) that will transport the biomass to the plant. In the fields where miscanthus is harvested as bales, several steps take place. At first, the harvester cuts the aboveground biomass either in short (Silage harvester 850 hp) or long (Silage harvester 480 hp) strands and then a tractor (Tractor 240 hp) with a baler (High density baler 70) allows the densification of biomass into bales. After bales are made in the field, they are collected in piles by using a telehandler (Telehandler 106