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# The influence of organic and inorganic fertiliser application rates on UK biomass crop sustainability

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ABSTRACT

Bioenergy and energy crops are an important part of the UK's renewable energy strategy to reach its greenhouse gas reduction target of 80% by 2050. Ensuring the sustainability of biomass feedstocks requires a greater understanding of all aspects of energy crop production, their ecological impacts and yields. This work compares the life-cycle environmental impact of natural gas and biomass from two energy crop systems grown under typical UK agronomic practice. As reported in previous studies the energy crops provide significant reductions in global warming potential (GWP) compared to natural gas. Compared to no fertiliser application, applying inorganic fertiliser increases the GWP by 2% and applying sewage sludge increases the GWP by a lesser extent. In terms of an equivalent GWP savings per unit area of land, the emissions associated with fertiliser production and application can be offset by a yield increase of <0.2 t/ha. However, very large increases in eutrophication and acidification levels are incurred compared to the natural gas reference case when applying either fertiliser. For sewage sludge the impact of varying the allocation factor between the function of wastewater treatment and that of crop growth is also illustrated.



## 1. Introduction

The depletion of fossil based fuels and the urgent need to reduce greenhouse gas (GHG) emissions to address the threat of climate change [1] have resulted in the UK government imposing legally-binding targets for carbon reductions [2]. One contribution to this will be increased use of renewable resources described in the UK government's renewable energy strategy [3], which sets challenging 2020 targets for renewable electricity (up to 30% from 5.5% in 2009); heat (up to 12% from negligible amounts in 2009) and transport energy (up to 10% from 2.6% in 2009). Substantial amounts of indigenous and imported biomass will be required to meet these targets, and the strategy envisages up to 2.2 Mha of energy crops by 2030 [4]. This is a 16,000% increase from the existing area of approximately 7500 ha of miscanthus and 6200 ha of SRC willow currently planted in the UK and is much higher than previous projections that 1 Mha could be used in the UK for non-food crops [5]. It is vital that this is achieved while protecting "our environment and natural heritage" and a commitment to better accounting for the sustainability of biomass and biofuels is seen as an essential part of this in the UK [3] and also in Europe, where 90% of respondents to a recent public consultation considered there was a need for a sustainability scheme for biomass for electricity and heating purposes [6].

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Of course the sustainability constraints on bioenergy development are much wider than just greenhouse gases [7] and any sustainability certification scheme must incorporate relevant and robust parameters and methodologies. Life-Cycle Assessments (LCA) have been regarded as one of the best methodologies in the literature to analyse the environmental impacts of biomass systems compared to fossil fuel or conventional alternatives [8].However, the large number of assumptions and parameters, such as soil carbon stocks and $N_2O$ emissions, make global warming savings through using bioenergy difficult to quantify [8]. Work carried out on behalf of the UK's regulatory body, the Environment Agency, noted that how the fuel is produced has a major impact on the greenhouse gas emissions, and recommended that minimum standards be set for biomass feedstocks for heat, transport fuel and power [9]; likewise Cherubini et al have also outlined key issues, ranges and recommendations for biofuel and bioenergy systems [8]. In addition to global warming potential, eutrophication and acidification potential often increase from the application of fertilisers during growth [10]. These are important parameters in energy crop growth and are often ignored.

This paper examines the LCA of current agronomic practice in the UK for Short Rotation Coppice (SRC) willow and miscanthus energy crop production and investigates how variations in fertiliser sources and application rates affect the resultant GHG emissions. In particular, it includes consideration of the application of sewage sludge to land, which has been ignored in most studies to date. The paper quantifies the full life-cycle GHG emissions for each option, and also looks at eutrophication and acidification impacts, evaluating their significance so that an informed decision can be made as to whether they should be included in any future certification regime. The paper also evaluates the rationale for any impact of different LCA allocation approaches on the final results for GHG emissions, and eutrophication and acidification potentials. This level of understanding is vital in developing methodological guidelines to accompany any new sustainability guidelines or certification systems.

## 2. Methodology

LCA is a methodology used to assess the environmental impact of a product or process from cradle-to-grave. The principles and framework of LCA are described in ISO 14040:2006 [11]. SimaPro 7.1, developed by Prě Consultants, was used to determine the environmental impacts of the different rates of fertiliser application and resultant emission allocations [12]. Ecoinvent [13] was used as a reference for the life-cycle inventory data and for the impact assessment methodology. The four sections of an LCA study are: goal and scope of definition, inventory analysis, impact assessment and interpretation. The goal states the reasoning for the study and what exactly will be assessed and the scope defines the boundaries of the study [14]. In the inventory analysis the production of biomass is described per functional unit. The impact assessment evaluates the prospective environmental impact of the material flows in the inventory according to set categories identified prior to the assessment. The impact categories assessed were: global warming potential (GWP) in kg $CO_2$ equivalent (eq); eutrophication potential (EP) in kg $PO_4$ eq; and acidification potential (AP) in kg $SO_2$ eq. When assessing GWP, EP and AP, the results for several impact assessment methods have been shown to be similar [15] and therefore the method choice is not a critical issue for this type of study. Consequently, the impact assessment used was the CML2 baseline 2000 method for mid-point assessment [16].

## 3. Goal and scope

The goal of this study was to determine the environmental impacts for large-scale biomass cultivation under UK conditions, using different fertiliser options for crop nutrition. Sewage sludge application was investigated and compared to the use of an inorganic fertiliser equivalent and an option for no fertiliser control. Direct emission allocation from sewage sludge was also investigated, as it can be argued that emissions should be attributed to either the wastewater treatment companies or the grower [17]. Sensitivity analysis also assessed the impact of $N_2O$ leaching on total GHG emissions and the influence of crop yield, which could be expected to fluctuate in response to N fertiliser, crop breeding and climate change.

The functional unit in this study was 1 MJ biomass, which has been delivered 90 km to the end-user (25 km maximum radius to end-user, with 50 km round-trip and 1.8 tortuosity factor), as this allowed for comparison between 1 MJ natural gas, delivered to the UK [18] (including infrastructure and construction life-cycle) and other bioenergy systems in the literature. The selected functional unit was appropriate for comparison of different fertiliser regimes and to place the focus on sustainability aspects of solid biofuels rather than the energy delivered. Consequently, these results do not represent the whole system and instead, just the fuel delivered to the end-user. In practice, the fuel would be utilised by the end-user, whereby conversion from natural gas would be more efficient, reducing the GWP benefits of biomass. However, in a previous study by Thornley et al. [19], the whole system was assessed and it was concluded that substantial savings could still be made.

### 3.1. Biomass feedstock

The UK has limited natural resources of biomass, ranking 19th out of the EU 27 for above ground biomass forest resources [20]. Limited quantities of agricultural waste are available, and there has been a substantial focus on the growth of energy crops in order to increase the indigenous supply level, as well as to promote associated socio-economic benefits [5]. SRC willow and miscanthus were selected as the biomass feedstocks for the study, as they are the main crops identified as having significant potential and the only dedicated biomass species grown on a commercial scale in the UK, other than forestry. Both SRC willow and miscanthus are perennial crops, with expected plantation lifetimes of around 20 years. Both species have low nutrient requirements and few pest or disease [21]. This gives the crops inherent low demands for soil cultivations, fertilisers or agrochemicals with consequent benefits for measures of sustainability. However, as research on the agronomy of the crops is still in its infancy, exact