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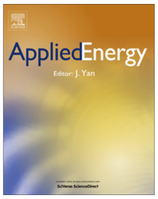

Energy and climate benefits of bioelectricity from low-input short rotation woody crops on agricultural land over a two-year rotation ☆

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HIGHLIGHTS

- A full energy and GHG balance of bioelectricity from SRWC was performed.
- Bioelectricity was efficient; it reduced GHG by 52–54% relative to the EU non-renewable grid mix.
- Bioelectricity required 1.1 m^2 of land kWh^{-1}; land conversion released 2.8 ± 0.2 t CO_{2e} ha^{-1}.
- SRWC reduced GHG emission when producing electricity during the 1st rotation period.

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ABSTRACT

Short-rotation woody crops (SRWCs) are a promising means to enhance the EU renewable energy sources while mitigating greenhouse gas (GHG) emissions. However, there are concerns that the GHG mitigation potential of bioelectricity may be nullified due to GHG emissions from direct land use changes (dLUCs). In order to evaluate quantitatively the GHG mitigation potential of bioelectricity from SRWC we managed an operational SRWC plantation (18.4 ha) for bioelectricity production on a former agricultural land without supplemental irrigation or fertilization. We traced back to the primary energy level all farm labor, materials, and fossil fuel inputs to the bioelectricity production. We also sampled soil carbon and monitored fluxes of GHGs between the SRWC plantation and the atmosphere. We found that bioelectricity from SRWCs was energy efficient and yielded 200–227% more energy than required to produce it over a two-year rotation. The associated land requirement was 0.9 m^2 kWh_e^{-1} for the gasification and 1.1 m^2 kWh_e^{-1} for the combustion technology. Converting agricultural land into the SRWC plantation released 2.8 ± 0.2 t CO_{2e} ha^{-1}, which represented ∼89% of the total GHG emissions (256–272 g CO_{2e} kWh_e^{-1}) of bioelectricity production. Despite its high share of the total GHG emissions, dLUC did not negate the GHG benefits of bioelectricity. Indeed, the GHG savings of bioelectricity relative to the EU non-renewable grid mix power ranged between 52% and 54%. SRWC on agricultural lands with low soil organic carbon stocks are encouraging prospects for sustainable production of renewable energy with significant climate benefits.

1. Introduction

Renewable electricity represented 19.6% of the European Union (EU) grid mix power generation in 2009 [1]. Limited in natural resources, the EU imports large quantities of non-renewable fuels for its electricity production. Shifting electricity production away from non-renewable fuels towards renewable energy sources could increase the diversity of the generation mix, reduce the import bills, and help to mitigate climate change [2,3].

Biomass has the potential to provide non-intermittent renewable base-load electricity and thus could contribute to meeting the EU's renewable energy targets in 2020 [4–6]. Within the biomass portfolio, short-rotation woody crops (SRWCs) with e.g. poplar (*Populus*) or willow (*Salix*) are candidates for large-scale application [7,8]. Compared to food crops SRWCs require low agrichemical inputs and less fertile land. Wood chips from SRWC can be burned, gasified, or co-fired with coal to produce electricity. In

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addition to the non-renewable electricity offsets, SRWC may also store carbon in agricultural soils [9,10], thus helping to reach the EU climate and renewable energy policy targets, whilst maintaining a reliable electricity system.

The greenhouse gas (GHG) performance of bioelectricity from SRWCs can also be affected by carbon stock changes due to land conversion from the previous land use. Converting agricultural lands to SRWC plantations may lead to losses of soil organic carbon (SOC) within the first two years following soil disturbance, although these changes are seldom statistically significant due to the high background variability in soil carbon stocks [10–12]. Such losses of carbon due to land use changes can compromise or even cancel the GHG saving benefits of bioenergy [13,14]. Also, biogenic methane (CH_4) and nitrous oxide (N_2O) emitted during crop production may outweigh the GHG benefits of SRWC-based bioelectricity [15]. Thus, an analysis of bioenergy impacts should consider its full life-cycle costs and benefits before policies aiming at large scale commercialization are adopted and implemented.

Much of the existing science on the energy and GHG performance of bioenergy has focused on liquid biofuels [16,17] with fewer studies investigating the energy and GHG balances of bioelectricity from SRWC [18–22]. The majority of these studies in turn have concentrated on CO_2 emissions from fossil fuel combustion during management activities rather than biogenic GHG emissions from land use change. Direct land use change (dLUC) emissions have been particularly neglected [23], even though the initial loss in soil organic carbon (SOC) as well as emissions of CH_4 and N_2O from agricultural soils may be substantial [24]. Moreover, the accounting of farm labor inputs, and land requirement are missing in earlier studies. Furthermore, the lack of reliable measurements of GHG fluxes (CO_2, CH_4, and N_2O) during the SRWC production increases the degree of uncertainty of previous estimates.

Here we report and document quantitative data on the land requirement, energy yield and GHG offsets of bioelectricity production from SRWCs on former agricultural land. In order to obtain quantitative data on the land requirement, energy yield, and GHG offsets of bioelectricity from SRWC, we managed an industrial-sized SRWC plantation for bioelectricity production without supplemental irrigation or fertilization for two years. We included all energy and GHG emissions incurred during the production and conversion of biomass from SRWCs to bioelectricity.

2. Materials and methods

2.1. Site location, soil carbon, and plant material

An operational SRWC plantation was installed in Lochristi, Belgium (51°06′N, 3°51′E, 6.25 m asl). The long-term mean annual temperature was 9.5 °C and the average rainfall was 726 mm a^{-1} [25]. The soil texture in the top 30 cm was 86.8% sand, 11.4% clay, and 1.8% silt with a mean pH of 5.51 (Table S1). The region of the site is considered to be a sandy region with a poor drainage [26]. Historically, the site was cleared of the original forest in the early 20th century and has since been under agricultural land use, regularly plowed and fertilized at 200 kg N ha^{-1} for production of cereals (wheat and maize) and tuberous (potatoes) crops. Prior to deep plowing, we carried out detailed soil survey in March 2010 by analyzing soil samples taken at 110 locations, uniformly distributed over the agricultural land. Soils were sampled to a depth of 15 cm using core sampling. The conversion of the agricultural land

Table 1

General inventory data for the production of short rotation woody crops. The columns from left to right denote the field activities, the implement used, tractor used, the operating rate, total fuel consumption, the area covered, and the material inputs.

Activities	Implement used		Tractor used			Operating rate (h ha^{-1})	Total fuel consumption (l)	Total lubricant consumption (l)	Coverage (%)	Input rates (unit ha^{-1})
	Type	Weight (kg)	Type	Weight (kg)	Power (kW)					
Chemical treatment	HBS	800	Fendt V 415	7000	119	0.43	42	0.3	32	3.5 l
Deep plowing	PF	820	Fendt V820	9000	157	0.95	105	2.1	32	–
Plowing	CP	820	Fendt V820	9000	157	0.93	285	5.0	100	–
Flattening	R	716	Fendt V415	7000	119	0.72	242	4.4	100	–
Planting	LP	600	Massey F6480	5000	97	3.44	302	5.2	78	8000 cuttings
Application of PPEH	HBS	800	Fendt V415	7000	119	0.21	54	0.9	78	0.3 l AZ500
Application of PEH	CBS	200	Iseki TU 165	400	12	2.52	32	0.1	33	1 l Tomahawk
Application of PEH	CBS	200	Iseki TU 165	400	12	2.52	32	0.1	38	1 l Matrigon
Application of PEH	HBS	800	Fendt V415	7000	119	0.36	45	0.8	78	2.5 l Aramo
Mechanical weeding	ST	500	Fendt V712	5000	97	2.76	120	1.7	78	–
Mechanical weeding	GS	–	GS. FS 400	8	1.9	17.36	28	–	62	–
Mechanical weeding	GM	–	GM Rapid euro	237	14.6	6.11	45	–	62	–
Mechanical weeding	HDM	–	HDM	78	3.2	1.24	28	–	62	–
Manual weeding	–	–	–	–	–	–	–	–	78	49.1 h
Harvesting	E-harvester	7000	JD 6920T	14 000	110	1.66	710	1.0	78	–

The data were collected on-site. HBS, hardy bomb sprayer; HDM, heavy duty machine; GM, grass mulcher; CBS, custum build sprayer; LP, leek planter; R, roller; PF, plow 4 furrow; GS, grass strimmer; E-harvester, energy harvester; CP, chilser plow; ST, steketee; JD, John Deere; PPEH, pre-emergent herbice; PEH, post emergent herbicide. Deep plowing, plowing and flattening have been grouped into land preparation.