Applied Energy 156 (2015) 449–464

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Simulation of environmental impact scores within the life cycle of mixed wood chips from alternative short rotation coppice systems in Flanders (Belgium)

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HIGHLIGHTS

- Life Cycle Assessment was used to compare Short Rotation Coppice (SRC) alternatives.
- SRC based on mixed species showed the best yields and environmental performances.
- SRC based on poplar clones suggested greater opportunities for carbon sequestration.
- Decrease in climate change and land use impacts compensated other negative effects.
- Uncertainty and Monte Carlo analyses allowed determining critical parameters.

ARTICLE INFO

Article history:
Received 24 March 2015
Received in revised form 8 June 2015
Accepted 10 July 2015

Keywords:
Carbon accounting
Environmental impact
Life Cycle Assessment (LCA)
Poplar
Short Rotation Coppice (SRC)
Willow

ABSTRACT

The expansion of Short Rotation Coppice (SRC) practices is mainly driven by the viability of SRC wood as an alternative to other renewable and non-renewable fuels in energy production, but also to the capacity of increasing biodiversity and the supply of ecosystem services locally. To delve into these environmental synergies and possible trade-offs, the Life Cycle Assessment method was applied to seven SRC experimental sites recently implemented in Flanders (Belgium). These have differing land use objectives and, thus, present different species proportions and plantation density. For instance, most sites are either planted with willow and poplar clones, or with a mix of the two with local tree species in order to activate temporary unused industrial lands or enhance the local ecosystem functionality. A regular 3 to 7-year rotation was simulated up to year 2033 using CO2FIX given that trees were yet to be harvested at the time of the assessment. Yields were first estimated over time: SRC systems composed by mixed species presented the highest productivity and also the best environmental performance profiles. Overall, the highest environmental impacts were due to consumption of diesel during the cyclic harvests, but also to fertilization activities. Uncertainty distribution ranges were determined for the most critical parameters and a Monte Carlo analysis was performed to obtain average impact scores with variability ranges. While replacing hardwood with wood from SRC chips was not found to be advantageous because of e.g. larger metal, fossil and ozone depletion potentials, benefits were observed for land use reduction and climate change mitigation. Due to frequent rotations, the beneficial trends for the latter seem sufficient to compensate the negative effects of the other impacts on human health and ecosystems quality.

1. Introduction

The cultivation of Short Rotation Coppice (SRC) is a well-established planting technique of semi-natural trees harvested to produce ‘fast’ wood material for renewable energy production purposes or for utilization in the biochemical industry [1–3]. The underlying goal of any SRC plantation is to promote sustainable development, improving environmental efficiency and developing economically-feasible supply-chains of energy production [4–6]. According to the principle “plant once and harvest several times”, SRC enables the production of timber over a typical

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http://dx.doi.org/10.1016/j.apenergy.2015.07.032
0306-2619/

period of 20–25 years from species that operate with rotations of 2–10 years, such as poplar, willow, acacia or eucalyptus. Some of the main benefits that have been highlighted for SRC are the reduced workload and predictable paybacks on income [7,8].

Exploitation of wood from SRC plantations has been increasingly recognized, being a viable energy source alternative to fossil fuels [9–11]. This is particularly true in the European Union (EU) and North America, where the climatic conditions appear to be most favourable to maintain existing [12] or establish new plantations of SRC species, such as those typically based on poplar and/or willow clones [13–15]. For the latter, clones can be grown for specific SRC purposes and then imported and planted at their final destination areas [12,15]. Moreover, it has been observed that the inclusion of native species in SRC plantations can increase the biodiversity and the supply of ecosystem services at regional scale [16–18], allowing an effective phytoremediation of metal-contaminated areas [19–23]. Hence, solutions exist to provide synergic ecological benefits to the main energy-oriented goal of the SRC. However, examples of best available practices with mixed SRC plantations including native species are still scarce in the literature.

In order to meet the 2020 climate change mitigation targets fixed by the EU [24], many European governments are subsidizing farmers to implement integrated SRC systems. This is the case in Sweden, France, Germany or the UK, all of which have a long history of SRC-related initiatives [9,25–32]. In recent years Belgium has also moved towards the implementation of an intensive SRC activity, and has recently disseminated numerous findings describing the performance of SRC growth systems, as well as their potential for bioenergy production [33–36].[1]

Besides the proven environmental benefits of using renewable fuel sources (e.g. wood chips) from SRC as compared to conventional fossil fuel sources [10], researchers and policy-makers still debate on the absolute advantages underpinning the SRC-based wood compared to other wood-related sources, such as conventional forest wood or energy crops [4,37–40]. In fact, the frequent harvesting operations and the use of fertilizers may constitute important sources of environmental burdens that can negatively re-balance the benefits obtained from SRC in terms of resource and ecosystem service supply efficiency. A vast literature in the field of environmental sustainability evaluation demonstrates the importance of analyzing the embodied energy and carbon budgets throughout all the phases of the biomass feedstock production system [9,41] and energy production from SRC wood (e.g., [13,42–45]). In fact, these results are often compared with the performance of energy biomass production from conventional forestry or agriculture [46,47]. In most of these studies, the Life Cycle Assessment – LCA [48,49] method has been applied, as it allows revealing the hidden and cumulative impacts of the wood production from the holistic perspective of the complete supply-chain. Moreover, LCA has been particularly suitable when the goal was to expand the environmental impact analysis to other relevant ecological burdens, such as resource depletion, acidification, eutrophication, ozone depletion, ecotoxicity, land use, etc. (e.g., [50–54]).

This paper aims to report the LCA results of a series of seven experimental SRC pilots in Flanders (Belgium). This analysis is part of an on-going project aiming at activating new biomass streams and supporting the development of technological solutions and regional strategies for improved sustainable biomass utilization [55]. The objective of this LCA study was, therefore, to compare the environmental performance of each of the seven SRC plantations, which are composed by varying mixes of willow/poplar clones and native tree species. This perspective allows to support and complement, with quantitative findings, the outputs from other impact analyses performed by project partners (e.g. feasibility evaluations, economic assessments, etc.; [55]). The SRC activities, all initiated in 2012, were promoted to add an additional value to the existing land use concepts, such as biodiversity enhancement or the activation of unused industrial land), through the implementation of a long-term management strategy over a 21-year period [56]. Although the present analysis was not specifically addressed to evaluate the impacts of the subsequent wood utilization steps, these were estimated for simulation purposes using existing life cycle technology data (see Section 2.4). Moreover, yield data for the first rotation were not disclosed due to the fact that trees were yet to be harvested when this assessment was conducted. Hence, the case studies presented were partially based on an extensive review of the existing literature on SRC to collect appropriate yield data.

As a consequence, the present paper represents rather a predictive analysis of environmental performance associated with possible SRC plantations in specific locations in Belgium. To contribute to further development in this field, the life cycle inventory (LCI, i.e. collection of process input and output data) of the individual sites was improved with information retrieved from simulating the carbon dynamics over the 21 years using specific carbon accounting modelling techniques, as effectively demonstrated by other studies in the field of SRC-LCA [57–59]. To this end, comparing the complete rotation system of seven plots with different mixes of species and soil conditions allows estimating the effects of clones' variability over a relatively large lifespan (21 years).

2. Methodology

2.1. Scope (system function)

Table 1 illustrates the main characteristics of each of the seven experimental sites compared in the study, including number and species of the cultivated trees. The plantations were all established in 2012, and the first harvest was foreseen for winter 2015.

The first general function assumed for the SRC system was to produce virgin wood chips. Therefore, the LCA model had the general goal of evaluating the environmental burdens related to 'wood chips production from SRC'. However, this wood biomass will be ideally valorized in supply-chains of energy production, and chips potentially burned to generate electricity and/or heat, and/or converted to synthetic gas. This second type of function was also assumed as an additional scenario (see below).

2.2. Functional units

The system function in LCA is evaluated by means of the functional unit (FU), which is the quantification of a common reference product flow in the life cycle model to which any other input and output process flow can be referred to (ISO, 2006). In the existing LCA literature, a typical FU adopted for SRC is the average hectare of plantation [54,60]. In this study, a similar rationale was considered, but a more complete comparison of environmental efficiency across the SRC systems was possible by using the average loose volume (comparison of 1 m^3) of wood chips, which thus represents the previously described 'first type' of function.

Furthermore, comparisons among four alternative uses of wood chips from SRC vs. wood chips from conventional forestry systems were performed to assess the 'second-type' of SRC function. In these cases, the FU varied depending on the analyzed technologies (i.e. transport of one passenger by car, with FU = 100 person km; electricity at 1400 kW_{th} co-generation plant, with FU = 1 kW h;

[1] An extensive set of reports and data on SRC in Belgium can be found in the deliverables folder of the POFULL project: http://uahost.uantwerpen.be/popfull/index.php?page=project&lang=en.