



Research paper

Cultivating biomass locally or importing it? LCA of biomass provision scenarios for cleaner electricity production in a small tropical island

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ABSTRACT

Biomass is a promising renewable alternative to decarbonize and to secure energy production on small islands, as most insular power generation systems rely heavily on imported fossil fuels. Feedstock procurement is a key aspect of bioenergy chain sustainability, and local resources as well as imported biomass can be considered if the electricity generated presents environmental benefits. We used Life Cycle Assessment (LCA) to evaluate the environmental impacts of 1 kWh of electricity produced in Guadeloupe from the combustion of locally grown energy cane and imported wood pellets. The energy cane agricultural supply was simulated using a bio-economic model to elaborate and analyze five scenarios involving different biomass mixes and geographical areas of production. Our results show that electricity produced from energy cane reduced the impacts of ABIOTIC DEPLETION, ACIDIFICATION and PHOTOCHEMICAL OXIDATION by 29% compared with pellet-based electricity. The environmental impacts of the energy cane cultivation stage varied by a factor of 1.5–3.7 among regional areas of cultivation because of differences in yields, soil emissions and land conversion for energy crop farming. The substitution of 5% of fossil energy by biomass in the island electricity mix can reduce GLOBAL WARMING and ABIOTIC DEPLETION impact by 4.5%. However, this change requires 3.5 to 5.2 times higher LAND OCCUPATION per unit of energy produced. Given the limited land availability on small islands, this latter point confirms that the combination of locally grown energy crops with imported biomass will be a suitable strategy to develop sustainable bioenergy for small islands.

1. Introduction

Biomass is a promising renewable alternative to decarbonize and to secure energy production in small islands [1,2], as most insular power generation systems rely heavily on imported fossil fuels, which are costly and responsible for greenhouse gas (GHG) emissions [3,4]. The isolation from continental networks leads to the need for stable and autonomous energetic systems. Therefore, a higher level of biomass-based energy can enhance the reliability of the power production, as biomass provides continuous energy, whereas intermittent resources such as sun or wind depend on meteorological conditions [2]. Several other factors motivate the exploitation of biomass, such as job creation for resident workers and rural economic diversification [5], as food production is not always highly competitive in small island territories compared to imported foodstuffs.

In Guadeloupe, a small tropical archipelago in the Caribbean, biomass has to play a key role in reaching the ambitious objective of 50%

renewable energy in the final electric mix by 2020, as declared by regional energy policy [6]. As forest biomass is limited and located in the volcanic area, it is not easily exploitable. Therefore bioenergy feedstock is more likely to come from agricultural sources. Sugarcane (*Saccharum* sp.) is recognized as an excellent energy feedstock because of its high photosynthetic efficiency, its larger productivity than most other crops under tropical conditions and its high primary energy content per mass unit of cane [7–9]. In the sugar value chain, sugarcane provides a range of co-products such as bagasse and molasses that can be used as energy carriers and converted into biofuels, heat or electricity [8]. Bagasse, the fibrous residue after juice extraction, is used as a combustible in thermal plants and has generated 4% of the annual electricity production (1734 GWh) of Guadeloupe in 2014. As land availability is naturally limited on small tropical islands, the potential contribution of biomass to the electric mix can be further increased with “energy cane”, a dedicated crop grown from hybrid cultivars of sugarcane selected for high biomass production, high fiber content and low sucrose

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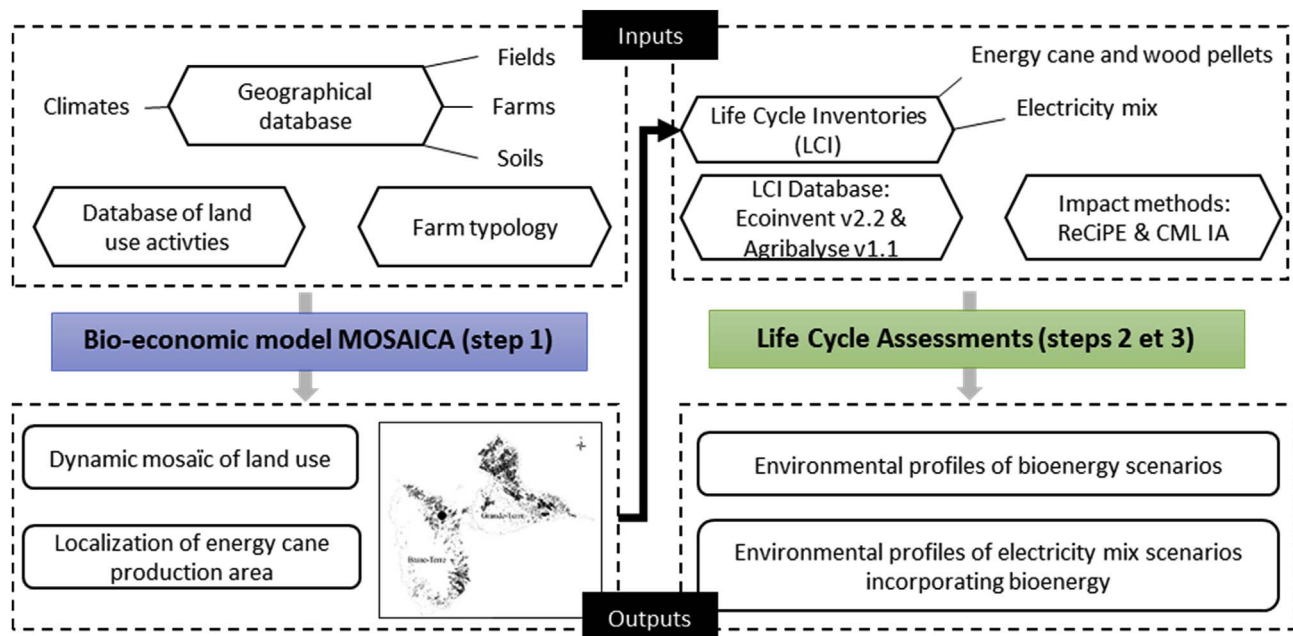


Fig. 1. Overview of the approach for ex ante assessment of biomass provision scenarios at the territory scale.

concentration [10,11]. Unlike conventional perennial sugarcane, these *Saccharum* cultivars can be used as a multipurpose energy crop (e.g. for the production of biofuels, electricity or gas) [8]. Among the fibrous plants, energy cane has one of the biggest potential for biomass production. Results from several breeding programs have indeed shown the high biomass potential of energy cane over other biomass crops like sorghum, elephant grass and eucalyptus [11–14].

Because feedstock provision is a key aspect of the viability and sustainability of bioenergy chains [15–17], three options are considered for electricity production in Guadeloupe with biomass power plant: 1) the local production of energy cane and 2) the import of wood pellets and 3) a mix of locally grown and imported biomass. A multibiomass supply chain has the advantage of ensuring a continuous feedstock supply, particularly as extreme climatic events might affect biomass growth and harvest. Therefore, multibiomass systems reduce economic risks for the industrial investors [18,19]. The import of wood pellets is becoming more common in bioenergy development, as this heating fuel shows interesting characteristics such as low humidity content, high density, practical handling and stable characteristics in long-term storage [20,21]. However, to be a sustainable energy option, energy cane and wood pellets should be less energy intensive and environmentally harmful than current energy sources [22]. Therefore, a comprehensive environmental assessment is crucial before investment decisions are made. For this purpose, Life Cycle Assessment (LCA) is an appropriate method.

LCA has been applied to the analysis of many bioenergy systems. Previous LCA analyses of sugarcane systems were oriented toward the use of sugar-coproducts for energy purposes in sugar industries [23–27] and, to a lesser extent, to dedicated sugarcane energy crops used for ethanol production from cane juice and electricity cogeneration from bagasse [28–30]. Only one environmental assessment of electricity generation from dedicated energy cane crop using LCA has been reported on La Reunion Island [31]. Many studies confirmed that bagasse electricity has produced reductions in GLOBAL WARMING and Non-renewable energy use when substituted for hard coal in boilers [24,25,27]. Great uncertainty has been observed in the results of LCA of valorization of sugarcane products, as in other bioenergy systems. The uncertainty is mainly due to 1) variability in cultivation stage due to regional conditions (soil, climate), agronomic parameters (yield, nitrogen fertilizer application) and emissions modeling (e.g., nitrogen (N)

emissions from soils and land use change) and 2) the choice of methodological approach for allocating impacts to the multiple outputs [15–17,32,33]. The environmental sustainability of wood pellets as a domestic or imported resource has also been questioned in number of LCA case studies [34–39]. These studies report that using wood pellets for energy has environmental benefits over fossil fuels even with long range transportation, as this latter causes modest GHG emissions compared to those of fossil fuel combustion. However, the environmental performance is expected to be lower than with locally produced biomass, and therefore a comparison with the environmental profile of local resources is necessary to find the best mix option of these two sources of biomass.

The goal of this paper was to assess through LCA the environmental impacts of electricity generation from the combustion of locally grown energy cane and imported wood pellets in a tropical island context (Guadeloupe). Five scenarios of biomass provision are compared to assess the environmental performances of electricity according to 1) the composition of the biomass mix and 2) the localization of biomass production areas. This latter is modeled using a regional bio-economic model that considers soil and farm diversity [40,41] and simulates the adoption of energy cane by farmers as a function of its profitability, farm constraints and policy context. In the LCA, a deeper focus on the impacts of the cultivation stage is then applied. Finally, we examined the environmental benefits and drawbacks of biomass electricity penetration within the energy mix and draw conclusions regarding the best options for developing sustainable biomass-based energy systems in the context of small tropical islands.

2. Methods

2.1. A generic approach to assess ex ante biomass benefit

We developed a simple and generic approach to assess the environmental benefit of developing energy cane based bioenergy in any territory. The approach, summarized in Fig. 1, is based on the coupling of two models and is structured as follow: (1) Investigate the potential geo-localization production of energy cane using the bio-economic model MOSAICA (described in 2.4.1) that simulates agricultural land use at the territory scale (Guadeloupe in our case); (2) Perform the LCA of biomass (energy cane and pellet in our case) and bioenergy

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