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Integrating stakeholder preferences into assessment of scenarios for electricity production from locally produced biomass on a small island

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ABSTRACT

Biomass is a potential source of renewable energy that can be produced in agricultural fields. However, its introduction at regional scale should not only provide energy, but also economic, social and environmental benefits. In order to study the potential benefit of introducing energy cane cropping systems for electricity production, we developed 62 scenarios for energy cane-based biomass power plants, for which impacts were modeled with a regional bioeconomic model. Impacts were calculated and aggregated with weights on 14 issues obtained from 51 stakeholders using an analytic hierarchy process. Regression models were applied to explain the determinant of sustainability. The results showed that stakeholder preferences for local development priorities fell into four different types, while the impacts of the scenarios also differed greatly according to their attributes. The main issues appeared to be "Disruption of existing agricultural sectors", "Potential loss of biodiversity" and "Change in farmers' revenue". The factor "Output of power plant" was positively correlated with the level of contribution to local development and to "Quantity of bagasse" and "Sustainable management of energy cane". Developing energy cane biomass appears therefore to be potentially beneficial for local development, with options favoring power plants relying on different forms of biomass produced in the vicinity and managed in a sustainable way. The novel approach devised here helped to address the complex multi-dimensional development issues regarding production of biomass and to provide satisfactory compromise solutions for different stakeholders. It can also provide guidance on exploration of options to obtain the most sustainable scenario.

1. Introduction

Biomass represented 10–15% of the energy consumed worldwide in 2009 and it remains the major source of renewable energy in the EU-28, accounting for more than 62% of all renewable energies [1]. It is a source of energy that is generally available locally and there are none of the problems with stocking found with some renewable energies [2], such as wind and solar energy that are naturally fluctuating [3,4]. On small tropical islands around the world, biomass is a great source of energy that is very often underexploited [5–8]. Renewable energy sources, particularly biomass, have the potential to undercut the cost of current modes of electricity generation on small islands [9,10]. Biomass cultivation provides different types of services, such as production of electricity for the population [11,12] and reduced erosion [13] or loss of soil organic matter with fast-growing species harvested at an appropriate removal rate [14,15]. However, production of this energy should be achieved in a sustainable way by maximizing the provision of beneficial services while reducing potential disservices such as pollution of rivers and soils with intensive cropping systems or replacement of cropping system contributing to food security [16]. Production of renewable energy in the form of biomass potentially competes for other sources of ecosystem services provided to the human population and should thus be studied in terms of its economic, social and environmental impacts before being implemented in small regions [17].

Multi-criteria analysis is required to assess the multiple consequences of implementing renewable energy industries in small

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regions [18–20]. Different scenarios for the development of the sector are possible, depending on several factors, including: spatial suitability (e.g., dispersion of biomass production locations) [21], agronomy (crop management and rotations), morphology (e.g., type of soil or size of plots) [22], logistics (e.g., centralized or decentralized collection) [23,24], operating considerations (e.g., on-site or fixed-location processing, size of power plant) [25], and economics (e.g., price for biomass paid to farmers) [26,27]. While many scenarios can be developed by combining different options for scenario parameters, it can be difficult to assess whether scenarios are satisfactory for local policy-makers considering the magnitude of change in economic, social and environmental outcomes [28]. Multi-criteria assessment and aggregation can be useful in this regard by providing some indication of the contribution of scenarios to local development. The approach helps to compare the different values of scenarios and to identify a few variables that allow policy makers to determine whether a scenario is of interest [29–31]. While published research on such aggregation can be broadly found for different agricultural systems at plot or farm level [32,33], it is very scarce at the regional level. In the few available studies, Liu and Zhang [34] aggregated scores of sustainability at the level of Chinese regions, while König et al. [35] aggregated sustainability score in different case studies.

In parallel, multi-criteria assessment of scenarios should account for the diversity of local policymakers' views and beliefs on sustainable development [36,37], in order to identify the conditions in which implementation of biomass production would best contribute to sustainable development of a region. Integrating the beliefs and views of stakeholders into decision-making tools can ease the decision-making process by identifying characteristics in the scenarios that best fit the expectations of different groups of stakeholders. In the same manner, identifying the sources of sustainability can help guide the search for new options that best fit the views of stakeholders.

In this study, we sought to devise an approach for integrated assessment of the impacts of several scenarios for development of biomass-based power plants and the different dimensions of local development and the views of stakeholders. We also examined the origins of differences in impacts and outcomes. We applied this assessment method to the case of implementation of a biomass-based power plant for electricity production on the French island of Guadeloupe.

2. Material & methods

2.1. Study context

In Guadeloupe, a 1600 km^2 archipelago located in the Caribbean, the total power distribution is currently 493.1 MW, of which nearly 90% derives from fossil fuels and only 10% is renewable (mainly geothermal, wind, and solar energy) [38]. The regional council has set the goal of increasing the proportion of renewable energy to 50% by 2020 and to 75% by 2030 [39]. To meet this goal, the local authorities propose growing energy cane locally for electricity production, thus reducing the proportion of fossil fuels in the energy mix (Conseil Régional de la Guadeloupe, 2010).

2.2. The integrated assessment method

Our integrated assessment method comprises three steps: i) Scenario definition, which helps produce different types of location scenarios that are assessed with regional indicators to create a sustainability tree; ii) scenario sustainability assessment, which is aimed at identifying the best options according to stakeholder preferences; and iii) identification of scenario sustainability determinants by means of regression (see Fig. 1).

2.2.1. Scenario and sustainability definition

2.2.1.1. Scenario definition. A set of 62 scenarios of electricity production from energy cane biomass were defined jointly with stakeholders from the project, by mixing different types of characteristics (Table 1).

The options used to define scenarios were: i) minimum size of fields in which to grow energy cane, ii) provision of an agri-environmental subsidy per hectare, iii) output of the power plant, which determines the quantity of energy cane required, iv) proportion of energy cane in the mix, v) power plant location, vi) zone of production of biomass, vii) energy cane management system and viii) potential substituted crop (Table 1). All these characteristics have several potential values that determine the quantity of biomass produced and the location of the fields in which the biomass is grown. Others sources of biomass considered were imported wood pellets produced from sustainably managed forest outside Guadeloupe and bagasse, which is a residue from the production of sugar from sugarcane. Energy cane can be produced under two different crop management systems, “as sugarcane”, which requires application of around 800 kg NPK 19-9-28 fertilizer and two doses of herbicides per hectare and year, or as “sustainable”, where chemical fertilization is combined with compost application of 9.5 t ha^{-1} yr^{-1} for the six years of the cane plantation's life and replacement of herbicides with mechanical weeding. The power plant can be located in one of three different cities (Lamentin, Capesterre-Belle-Eau, and Port-Louis), which changes the transport distance from the area of production to the area of biomass processing and the price of transport. The price to pay to obtain the required quantity of biomass is the value of biomass production (here calculated with the MOSAICA model) associated with the constraint of the quantity of biomass that can be produced.

The consequences of the 62 different scenarios were modeled with the MOSAICA bioeconomic model, which simulates farmers' decision-making process in terms of crops allocated to plots spatially located in a region. This generic bioeconomic model uses data on cropping systems, fields, and farms to produce a cropping mosaic that represents the location of biomass production areas in the region (see Fig. 1). The model is further described in Chopin et al. [40].

2.2.1.2. Sustainability definition. In the present study, we incorporated broad-based stakeholder preferences into the assessment in order to facilitate public-private collaboration in a locally supported biomass production project that is endorsed by the local authorities. The sustainability problem investigated was “contribution to sustainable development of the region” for the different scenarios. The problem was divided into the three pillars of sustainability, namely economic, social and environmental. For each pillar, we selected a set of issues to which the different locations of biomass and power plant characteristics must respond. These issues were discussed with stakeholders in order to obtain a shared vision of the sustainability problem based on a pre-existing list of issues [41]. Then, based on a first internet-based survey, the list of issues was modified by each stakeholder by adding or deleting local issues. The questionnaire used was very simple and only presented all the sustainability issues and associated indicators. The first question is “Do you consider the list to be complete (yes/no)?” and “If no, what issue would you add?”. The list of indicators was then presented for each sustainability issue and stakeholders were asked to either suggest new indicators or modify the existing ones. Once the list of issues and indicators had been established, indicators are calculated for each scenario to determine their response of scenario to regional issues. The indicators were calculated for each cropping