Natural Resources, 2015, 6, 230-236
Published Online April 2015 in SciRes. http://www.scirp.org/journal/nr
http://dx.doi.org/10.4236/nr.2015.64021

Multi-Criteria Assessment of Biofuel Production in Small Islands

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Received 14 February 2015; accepted 3 April 2015; published 7 April 2015

Abstract

This paper discusses various policy alternatives for the implementation of a biofuel crop on an island scale. It adopts an integrated approach by carrying out Multi-Criteria Assessment, as well as using a Geographical Information System. The assessment is based on an interdisciplinary research project carried out by the University of La Laguna to evaluate the agricultural and chemical feasibility, and the socio-economic implications of the cultivation of Jatropha as a source of biofuel on one of the Canary Islands, Fuerteventura. A number of alternatives were analysed for growing Jatropha, and the results suggest that the best alternative involves using Typic Torrifluents soil and irrigation with reclaimed Recycled Urban Wastewater at 75% evapotranspiration cover.

Keywords

Jatropha Crop, Biofuels, Multi-Criteria Assessment, Arid Soils

1. Introduction

This article aims to assess the potential implementation of biofuel crop cultivation on an island scale to contribute to the sustainable development of Fuerteventura in the Canary Islands, Spain. It explores both the positive and negative economical and environmental consequences of introducing this crop and the effects it might have on transport sector fuel to aid regional and local authorities in reaching 2020 EC targets.

At the end of the 1990s and at the beginning of the 21st century, there was a clear commitment in the Canary Islands to Renewable Energies (RE), particularly to wind power energy. However, a lack of government licenses for new projects and a change in legislation (Royal Decree 413/2014, 6 June) have led to stagnation or even a setback in the commitment to these forms of energy. To mention one example, on the island of Fuerteventura,

How to cite this paper: Legna-de la Nuez, D., Corral-Quintana, S. and de Lara, D.R.-M. (2015) Multi-Criteria Assessment of Biofuel Production in Small Islands. *Natural Resources*, **6**, 230-236. http://dx.doi.org/10.4236/nr.2015.64021

there have been no new RE installations since 1998, and wind power production has remained still at 11,385 MW [1] since then.

However, it is important to note that fuel used in the land transport sector represents a third of the total direct energy consumption in the Canary Islands [2]. Additionally, this consumption has special relevance given the requirement imposed by the European Directive regarding the use of energy from renewable sources [3] in reference to the 2020 objective in its article 16: "[...] *a mandatory* 10% *minimum target to be achieved by all Member States for the share of biofuels in transport petrol and diesel consumption by* 2020". This is mainly due to the fact that the transport sector is responsible for 21% of Greenhouse Gas Emissions (GGE), according to the European Commission's biofuels strategy [4].

Specifically, Spain's Royal Decree 459/2011 established objectives of 6.1%, 6.5% and 7.0% for biofuels for 2011, 2012 and 2013, respectively. However, it will be extremely difficult for Spain to achieve the 20% target by 2020 imposed by the European Directive given that the current percentage of biofuel use is only 5%, unless actions and studies like the one presented here on the feasibility and implantation of biofuels are encouraged.

The decisions that must be taken to implement biofuels in a territory can be complex owing to the multiple dimensions involved. Initially, there are the purely technical problems, such as agricultural and chemical ones. Secondly, there are economic and environmental obstacles to be overcome, and finally a clear institutional and public support is needed. In the specific case of the island of Fuerteventura, there are entangling factors such as water and energy consumption constrains, which could end up limiting the sustainability of such a project. This complexity requires an integrated approach that also considers social, ethical and other aspects that are difficult to quantify, and thus leading to a relatively high degree of uncertainty. Funtowicz and Ravetz have studied in depth this type of uncertainty since the beginnings of the 1990s. Above all, they focus on political and environmental decisions, defining the concept of Post-Normal Science [5] to refer to a research method appropriate for cases in which traditional (normal) methodology cannot cover all the dimensions that need to be assessed. This is the reason why this study has also resorted to the use of Post-Normal Science.

One of the most prominent features of policy processes is their social nature. Policy issues cannot be analysed in isolation from the social context in which they occur [6]. These are bound by different perceptions, perspectives, opinions, knowledge, and interests. As Lindblom [7] argues, "*there is a deep and persistent unwillingness in Western culture to acknowledge the difficulties arising from the world's complexity and human's modest cognitive abilities... and unless political action is adjusted to take into account the fact that complex problems cannot be understood fully, policy-making will fare much worse than it needs to*".

Integrated assessment, used in this study, is a process of holistic analysis and assessment in which knowledge about ecosystems, people and public policies are linked with the aim of developing the tools and information necessary to make decisions [8].

2. Case Study

Spain is one of the most energy dependent countries in Europe (approximately 80%, compared with a European average of 55%) according to Spain's current Renewable Energy Plan [9]. In the case of the Canary Islands, their geographical location and insular fragmentation results in absolute energy dependence on oil derivatives [3]. However, the islands' relief, volcanic origins, favourable climate and position with respect to the main ocean currents give them numerous opportunities to take advantage of renewable energies: sun, wind, geothermal, tidal, water hydrolysis, etc. [10]-[13].

In this study, the island of Fuerteventura has been chosen to assess possible biofuel crop cultivation. Its initial selection was due to the availability of large areas of abandoned farmland, desertification process and semi aridity [14]-[16] on the island. The abandonment of farmland has been caused by a change in the economic model of the island towards the service and construction sector associated with tourism [17]. Currently, estimate for the area of abandoned farmland is over 95% [16]. This together with climatic conditions of strong winds has led to 41.9% of island's surface area being at a high or very high risk of suffering from wind erosion [16].

Given these conditions, the Jatropha plant (*Jatropha curcas* L.) has been chosen due to its adaptability to these arid conditions and its effectiveness at recovering abandoned or marginal areas [18]-[21]. Also the fact that it is not used for human consumption avoids generating competition in the food sector, with the resulting increase in prices, as in the case of first generation biofuel crops, such as soya or maize [22]-[27]. Additionally, Jatropha's effects on the environment are limited [27]-[29], it does not affect biodiversity as in the case of palm oil production, which requires extensive forest clearing [30].

As mentioned Jatropha adapts well to arid conditions, and on Fuerteventura, water is almost entirely from non-conventional sources like desalination plants or water treatment plants, which in turn require a significant amount of energy [31]. These non-conventional sources have been used in the pilot project to grow Jatropha (*Jatropha curcas* L.) on Fuerteventura [32].

The initial pilot project was structured in three successive phases: an initial phase of crop growth, experimenting with two varieties of seeds and several combinations of irrigation techniques and soil qualities. Second and third phases were carried out after harvesting to assess the quality of the oil and biofuel, respectively, obtained from Jatropha seeds.

In order to tackle the feasibility of the different alternatives of biofuel production, an integrated approach was proposed. It was aimed at assessing the technical, economical and environmental feasibility of the various alternatives of crop and biofuel production and at defining the potential surface area that might be used to grow Jatropha on an island scale. Insights from the methodology applied as well as the most relevant findings of its application are dealt with in the following sections.

3. Integrated Assessment of the Feasibility of Biofuel Production from Jatropha

In recent years, several authors have written about the complexity of environmental assessment processes [5] [33] [34], specifically about the complexity related to natural resource planning [35]-[46]; and the importance of the involvement of stakeholders [38] [40]-[42] [45] [47]-[50]. Funtowicz and Ravetz [5] proposed using Post-Normal Science to ensure the quality of these assessment processes, which requires involving citizens, namely the "extended peer community". The integrated assessment approach applied here consists of the combination of social techniques with multi-criteria ones to improve the quality and understanding of the results. It follows previous research of De Marchi *et al*. [51], Corral Quintana [52] [53], Munda [33] and Paneque *et al*. [54]. Specifically, it integrates participatory techniques; multi-criteria assessment methods and finally the assessment results are represented using a geographical information system in order to extrapolate the pilot results to an insular scale. The information obtained from the different social techniques and the criteria applied to the alternatives are incorporated into a multi-criteria model. Second, the multi-criteria analysis allows different alternatives to be explored as a function of the chosen criteria. The result of this examination will determine a ranking of alternatives to be investigated by the analyst, concentrating on the positive and negative aspects of each one. This outcome that includes an analysis of the social context—in which public policies are developed—promotes a better understanding of the social and economical interrelations in which decisions are taken.

As mentioned, this research project consisted of three phases; an initial phase of crop growth, and second and third phases related to the production of oil and biofuels, respectively. Each of these phases were assessed independently to provide the best compromise solution among environmental, technical and economic aspects in the definition of policy actions with regard to an effective implementation of Jatropha as a source of biodiesel on Fuerteventura.

These three complementary assessments were driven by different objectives. In the first case, the assessment pursued highlighting how crop production alternatives performed according to environmental and economical criteria. The second phase evaluation had two objectives, from a technical perspective, it aimed to optimise the oil extraction process from the seeds of the experimental crop. Secondly, it aimed to find the best compromise between economic and environmental parameters. Finally, the third phase assessment addressed the performance of biodiesel production from the oil extracted from the seeds, though, at the same time, still considering the best compromise between environment and economics.

During the pilot project, a set of alternatives for the experimental crop of Jatropha were proposed based on several agricultural parameters that would influence crop production: seed origin (Cape Verde or Brasil), soil type (Typic Torrifluents or Typic Haplocambids), type of drip irrigation (subsurface or surface), percentage of evapotranspiration cover (100% or 75%) and non-conventional water resources used (Reclaimed Urban Wastewater (RUW) or Desalinated Brackish Water (DBW)). The combination of these parameters resulted in a total of 32 combinations that were considered as the assessment alternatives[1].

[1]The alternatives hereby discussed are based on the results obtained over three years of cultivation of Jatropha on an experimental farm in Pozo Negro, Fuerteventura. The farm had two fields, each of 1200 m^2, devoted to this project with two different soil types: Typic Torrifluents (TT) and Typic Haplocambids (TH), according to the USDA soil classification (Soil Survey Staff: Keys to soil taxonomy, 2010, cited by Dorta *et al*. [32]). In each of the two selected fields, six experimental plots separated by 2 m aisles (10 m^2 in size with 10 plants in each one) were created in a random block design with three replicates for each treatment.

With the aim of defining assessment criteria, a series of guided interviews were held with the most relevant stakeholders connected with water and agricultural management, energy production and distribution on Fuerteventura, as well as experts in the field of biofuel production. After this consultation process and a prior data gathering process, a shortlist was prepared, classifying the resulting criteria according to three dimensions: economic, technical and environmental criteria for each assessment phase. Thus, in phase I, the alternatives' assessment was carried out based on a set of economic and environmental criteria, such as, sapling purchase cost, initial investment, water cost, direct labor cost, indirect labor cost, fertilizer cost, energy cost, seed production, water consumption and energy consumption. In phase II, in addition to the economic and environmental ones used in phase I, a series of oil quality criteria were also used in the evaluation: oil viscosity, oil density, oil acidity, oil production, global oil efficiency, oil efficiency, percentage of white seed. Finally in phase III, these alternatives were then assessed using the following technical criteria: biodiesel production, biodiesel density, biodiesel acidity, biodiesel cinematic viscosity, biodiesel fames and percentage of biodiesel obtained from oil used during chemical reaction; percentage of biodiesel obtained from white seed and percentage of biodiesel obtained from seed[2].

Based on the alternatives and the criteria three impact matrices—one for each biofuel production phase- were built, using the knowledge provided by both the reviewed scientific literature and the experts' opinions. The horizontal axis of the impact matrix represents the 32 alternatives, while on the vertical axis the evaluation criteria are presented. Meanwhile, each cell reflects how the alternative is influenced qualitatively by the selected criterion.

Once the impact matrix was built; through the implementation of NAIADE [55] [56] a ranking of alternatives is achieved. Initially, the alternatives that represented the best compromise between economics and environment were those that use TH soil with seeds from Brazil, watered with RWW using surface drip irrigation covering 100% or 75% ETP (there were no differences in the sum of criteria for either of these alternatives).

Regarding Phase II, the resulting assessment indicates the differences between the alternatives was quite different from the one obtained for Phase I. In fact, the alternative corresponding to TH soil irrigated in the subsurface with RWW and ETP percentage cover of 75%, it highlight over the rest.

In phase III, the alternatives were assessed in order to find out those reaching the best biofuel performance. In fact, 12 of the initial 32 alternatives were rejected since they did not cope with the minimum standards to be considered biofuels based on the chemical analysis of the following criteria: total biodiesel production, percentage of biodiesel per gram of white seed, percentage of biodiesel per gram of oil, density, viscosity, FAMES content, and acidity index.

The remaining alternatives were subjected to a new analysis involving 3 new criteria, which evaluated more precisely the quality of biodiesel obtained: oxidation stability, iodine index and number of peroxides.

Once again, the results showed that TH soil, Brazilian seeds and using RWW for surface irrigation and covering 100% of ETP was the most appropriate solution to the compromise between environment and economics according to the criteria considered and data available. Differences among other alternatives were slight; for example, it would be practically the same if irrigation were subsurface instead of surface and 75% ETP cover or the seeds originated from Cape Verde.

In summary, it could be observed that in all three phases, the best alternatives were those that use RWW with the second determining parameter being soil type as those plants grown in TH soil are highest in ranking. The other parameters considered do not appear to be so relevant in selecting alternatives in any of the phases: seed origin (Brazil or Cape Verde), irrigation system (surface or subsurface), or ETP cover (75% or 100%)

4. Conclusions

This integrated study has assessed the feasibility of growing Jatropha in Fuerteventura. It has integrated various aspects: 1) First, the study has considered Jatropha production from an overall perspective, covering the three phases of production (cultivation, oil and biodiesel); 2) Second, not only technical information but also information from interviews with a range of experts has been included, which has provided important data and considerations for this study; 3) Third, this participative process has been integrated with the technical data in each of the phases, as well as economic and environmental data, and carrying out an assessment using MCA; 4) Finally,

[2]These criteria were established to determine the quality of the Oil and Biodiesel by a research team of the Dept. of Chemical Engineering of the University of La Laguna.

the resulting information has not just been considered from an experimental perspective, but an assessment has also been made on an island scale.

The results from the Multi-Criteria Assessment of the alternatives and defined criteria show that the optimum solution is cultivation in TH soil with seeds from Brazil and using RWW to provide surface irrigation covering 100% of ETP. When ETP cover is only 75%, there is hardly any difference except that this might result in a slight economic saving in the final product without significantly affecting production.

This study has shown that MCA is a useful tool in the decision-making process, since it is able to identify the most feasible alternatives, based on data from an experimental crop currently being grown. Once these data have been obtained, they must be extrapolated and validated with the population, therefore, a more participative study would be required that would involve a range of actors in the decision-making. This approach would follow recent works from Corral Quintana [6], De Marchi [51] and Paneque [54] among others and focus on the relevance of extended participatory assessments [57]-[59].

Finally, Jatropha's extensive system of roots would have an additional positive effect on stabilizing the soil and could contribute to preventing erosion [14] [15] [32].

Acknowledgements

This study has been funded by DISA company within the framework of the Project "*Viabilidad de la producción de Jatrofa con recursos hídricos no convencionales. Evaluación de la calidad del aceite y análisis socioeconómico*" (Feasability of Jatropha Production with non-conventional water resources. Assessment of oil and socio-economic analysis) between 2010-2014. Thanks must also be given for the invaluable collaboration of the research teams from the Departments of Edaphology and Chemical Engineering of the University of La Laguna.

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