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Exploring strengths and weaknesses of bioethanol production from bio-waste in Greece using Fuzzy Cognitive Maps

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ABSTRACT

The production of renewable energy has become a priority in the European Union given the depletion of fossil fuels and the deterioration of the environment. Waste and specifically biowaste, the organic fraction of municipal solid waste, is considered as an ideal raw material for the production of bioethanol. However, bioethanol production from biowaste in large scale is a complex project that requires the participation and the engagement of different stakeholders that are involved in the different steps of the process from the collection of the waste to the production of the final product and the management of the residues. Fuzzy Cognitive Maps, a soft computing technique for analyzing complex decision-making problems, is applied to identify the critical factors that will affect the large-scale production of bioethanol from biowaste. Results indicate that the different groups of stakeholders have a different perception and identify different factors as the driving forces of the project. The effect of political, social and technoeconomic factors on the overall success of the project has been examined. Simulations have shown that the model developed is mainly sensitive to the political factors involved.

1. Introduction

Safe, secure, sustainable and affordable energy is a main prerequisite for social prosperity, industrial competitiveness and the overall functioning of society. Thus, the production of renewable energy has become a priority in the European Union given the depletion of fossil fuels and the deterioration of the environment. The strategy of the EU in the energy sector that has been adopted by the European Council, known as 20-20-20, has set the following goals: By 2020, at least 20% reduction in greenhouse gas emissions compared to 1990; saving of 20% of EU energy consumption compared to projections for 2020; 20% share of renewable energies in EU energy consumption, 10% share in transport (EC, 2010b). Additionally, provided the efforts are intensified, the European Commission believes that total independence from fossil fuels is feasible until 2050 (EC, 2012b).

On the other hand, the elimination and exploitation of waste is considered necessary for the environmental protection and the maintenance of the quality of life. According to the official statistics published by Eurostat, each year more than 240,000 t of waste is produced in the EU (Eurostat, 2017). Biowaste, the organic fraction of municipal solid waste, i.e. garden, kitchen and food waste, accounts for one third of the total waste and is considered as a valuable resource that could be utilized as raw material for the production of high value-added products including but not limited to fuels (EC, 2010a).

The potential of the sector of biorefineries is huge given the sustainability and the diversification of the raw material. The relatively high initial cost of the required investment is expected to be reduced due to technology-spillovers that will eventually be observed provided that research and innovation initiatives will be supported (Deswarte, 2017; Fava et al., 2015).

As far as fuel production from waste is concerned, there is extensive literature with regard to the technical aspects of the production of ethanol, methane, hydrogen and gas and it has been recently reviewed (Matsakas et al., 2017). Regarding bioethanol production, biowaste comprises an ideal raw material since it is rich in sugars, cellulose and starch that can be metabolized to ethanol by microorganisms after the necessary pretreatment (Thomsen et al., 2017). However, there is a long way for a process/product to go from the bench of the lab to the market.

Concerning bioethanol production in large scale, for the time being, the examples of successful plants that use biowaste as raw material in Europe are limited (Hirschnitz-Garbers and Gosens, 2015; PERSEOpresentation, 2009). Nevertheless, taking into account the EU goals regarding renewable energy and the proposal of the European Commission that the emissions for the production of biofuels and bioliquids from household waste and biomass fraction of industrial waste

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should be considered to be zero (EC, 2016), the sector is expected to boost in the coming years.

However, bioethanol production from biowaste in large scale is a complicated project that requires the participation and the engagement of the different stakeholders involved in the different steps of the process from the collection of the waste to the production of the final product, the management of the residues and the integration of the product in the existent fuel market.

The first step of the process is the collection and effective sorting of the waste. It is obvious that the success of the project relies on the willingness of the residents to participate and to sort their waste as well as on the adoption of best waste management practices from the part of the municipal authorities. Biowaste, because of its content, is sensitive to microbial degradation, so an important step of the process is the drying that has two consequent results: on the one hand it reduces the volume of the waste and on the other hand it eliminates the water content and it prevents the growth of microorganisms. Drying contributes significantly to the total cost of the process (Gwak et al., 2017) but is essential since the bioethanol yield depends on the content of the raw material in sugars, starch and cellulose, components that are consumed by microorganisms. Thus, the faster the waste is dried the better for the ethanol production.

The cost of the bioethanol production itself that can be divided to cost of the enzymes, cost of the plants required, cost for R & D actions etc. is another determinant factor for the viability of the project (Volynets et al., 2017). Last but not least, in terms of cost, it should be mentioned that bioethanol should be entered into an existent market, this of fuels. The integration of a new fuel requires changes in infrastructures, changes in networks, new investments whereas it may reduce temporarily the margin of profit for the industry.

Nevertheless, the factors that affect the future of the large-scale production of bioethanol from biowaste are not just economic. Producing biofuels from biowaste is a project totally integrated into the Bioeconomy Strategy of the EU (EC, 2012a). Policy mixture and legislation in national as well as international level cannot be neglected. All the stakeholders should comply with the legislation but can also influence policy makers in proportion to their power.

The aim of the present work is a) to identify the crucial factors that influence the production of bioethanol from biowaste and their interconnections via modeling the opinions of experts (academics, policymakers, market experts) and b) to explore the dynamics of the system. To the best of our knowledge, this paper comprises the first attempt to model this system and it will lead to the elucidation of the strengths and the weaknesses of the project as well as it will reveal the actions needed to be taken to support the development of the sector. Additionally, it is the first time that the approach of Fuzzy Cognitive Maps is utilized in the field of Bioeconomy.

2. Fuzzy Cognitive Maps approach

2.1. Introduction to Fuzzy Cognitive Maps

Political scientist Robert Axelrod introduced cognitive maps as a formal way of representing social scientific knowledge and modeling decision-making in social and political systems (Axelrod, 1976). In real life situations, hazy relations between concepts dominate. In order to include fuzziness, fuzzy logic was integrated into cognitive maps resulting to Fuzzy Cognitive Maps (FCMs) (Kosko, 1986).

FCMs are signed fuzzy digraphs which consist of nodes representing the concepts or factors used to describe the behavior of a system, while the connecting edges represent the causal relationships among concepts as weighted arcs, taking values in the interval $[-1, 1]$. More explicitly, FCMs consist of nodes, which represent concepts, C_i, $i = 1\ldots N$, where N is the total number of concepts. Each interconnection between two concepts C_i and C_j has a weight, a directed edge W_{ij}, which is similar to the strength of the causal links between C_i and C_j. W_{ij} from concept C_i to concept C_j measures how strong is the effect of C_i on C_j. The direction of causality indicates whether the concept C_i causes the concept C_j or vice versa. Weights, W_{ij}, can be < 0 indicating a negative effect of the one concept to the other, > 0 indicating a positive effect or $= 0$ indicating no causal relation between the concepts (Papageorgiou and Kontogianni, 2012). Spreadsheets or tables are used to map FCMs into comparison adjacency matrices [E] for further computation (Kosko, 1995).

The main advantages of FCMs that have led to their wide use are (van Vliet et al., 2010):

- easy to understand by stakeholders
- easy to instruct by interviewers
- easy to incorporate uncertainty
- high ability to demonstrate complexity
- not demanding in terms of funds and time

Due to the aforementioned characteristics, FCMs have gained considerable interest in a wide range of fields (Henly-Shepard et al., 2015; Misthos et al., 2017; Özesmi and Özesmi, 2003). More specifically, in the energy sector, FCMs have been applied to model: the energy service market (Basak et al., 2012), the factors determining the attractiveness of photovoltaic systems (Jetter and Schweinfort, 2011), the wind energy deployment (Amer et al., 2011) and the future of hydrogen-based transport (Kontogianni et al., 2013). This growing interest led to the need for making more reliable models that can better represent real situations and for developing analytical tools and indices to better interpret the models.

2.2. FCMs' structural analysis

The matrix representation of FCMs can provide information on the structural properties of FCMs on the basis of Graph Theory and Networks analysis. A range of routine metrics has been developed to uncover shared knowledge structure by measuring discrete dimensions of an individual's mental model structure, thereby permitting comparisons across individuals and groups (Gray et al., 2014). The most common indices used are: the number of concepts, the number of connections, the number of transmitter variables, the number of receiver variables, the number of ordinary variables, density, indegree, outdegree, C/N ratio, centrality, complexity, and hierarchy index.

The number of concepts refers to the number of variables included in the model; higher number of concepts indicates more components in the model (Özesmi and Özesmi, 2004). A higher number of connections indicates a higher degree of interaction between components in a model (Özesmi and Özesmi, 2004). Transmitter variables are the components which only have "forcing" functions; they affect other system components but are not affected by others (Eden et al., 1992). The components which have only receiving functions are known as receiver variables. They are affected by other system components but have no effect (Eden et al., 1992). Ordinary variables are those with both transmitting and receiving functions; they influence as well as they are influenced by other concepts (Eden et al., 1992). Centrality score of individual variables represents the degree of relative importance of a system component to system operation. Centrality is the most important measure for map complexity, arising as the summation of variable's indegree (i.e. the column sum of absolute values of a variable in the adjacency matrix E) and outdegree (i.e. the row sum of absolute values of a variable in the adjacency matrix E) (Kosko, 1986). The complexity index is the ratio of receiver to transmitter variables. It indicates the degree of resolution and is a measure of the degree to which outcomes of driving forces are considered. Higher complexity indicates more complex systems thinking (Eden et al., 1992; Özesmi and Özesmi, 2004). Hierarchy scores indicate the degree of 'democratic' thinking (MacDonald, 1983), and may indicate whether individuals view the structure of a system as top-down or whether influence is distributed evenly across the