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Exploring strengths and weaknesses of bioethanol production from biowaste 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 components in a more democratic nature. When *h* is equal to 1 then the map is fully hierarchical and when *h* is equal to 0, the system is fully democratic. The density refers to the number of connections compared to number of all possible connections. The higher the density, the more potential management polices exist (Hage and Harary, 1983; Özesmi and Özesmi, 2004). The ratio number of connections (C) to the number of variables (N) is a measure of the connectedness of the system. The lower the C/N score, the higher the degree of connectedness in a system (Özesmi and Özesmi, 2004).

2.3. Constructing FCMs: from the individual to the collective FCMs

On the basis of the aforementioned indices, FCMs can be analyzed and characterized in terms of their structure. However, the process of constructing FCMs primarily relies on human knowledge and experience (Özesmi and Özesmi, 2004). The first step of the process of constructing an individual FCM is to ask an expert on a given domain to identify the concepts that influence the system. Afterwards, the interconnections between the concepts are described and weights (W_{ij}) are attributed to them either with an if-then rule that infers a fuzzy linguistic variable from a determined set or with a direct fuzzy linguistic weight, which associates the relationship between the two concepts and determines the grade of causality between the two concepts (Axelrod, 1976; Papageorgiou and Kontogianni, 2012).

However, an individual FCM is usually not sufficient to give a complete, accurate and reliable picture of the system modeled. The participation of more experts is required. There is no predetermined number of experts that need to participate in a survey aiming at constructing a collective FCM of a system. FCMs are created with different people until the population to be represented has been sampled sufficiently. To determine this, accumulation curves of the total number of variables versus the number of interviews as well as the number of new variables added per interview are examined (Özesmi and Özesmi, 2004).

The construction of collective cognitive maps can be done by combining the individual maps. This can be accomplished by different aggregation techniques (Gray et al., 2014): a) by average individual FCMs together; assessing the expertise and weighting individual FCMs may be required for small sample sizes (Cannon-Bowers and Salas, 2001) and b) researcher subjectively condenses/clusters individuals mental model concepts in more generic (because most of them present the same meaning with a different word) (Özesmi and Özesmi, 2004) and then average individual mental models together to produce a group model (Papageorgiou and Kontogianni, 2012). In the second case, several subgraphs are substituted with a single unit by making use of the most central variables with their weighted connections (Papageorgiou and Kontogianni, 2012; Papageorgiou et al., 2017).

2.4. Using FCMs to explore the dynamics of a system

After the cognitive maps are drawn and the adjacency matrix coded, the system's steady state can be predicted. The mathematical representation of FCMs provides a snapshot of how the variables and linkages of the system given the current system's configuration would resolve themselves in the absence of change or intervention, with all feedback loops played out:

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j \neq i \\ j=1}}^{N} A_j^{(k)} * W_{ji}\right) \tag{1}$$

where $A_i^{(k+1)}$ is the value of concept C_i at simulation step k + 1, $A_i^{(k)}$ is the value of concept C_j at step k, W_{ji} is the weight of the interconnection between concept C_j and concept C_i and f is an activation threshold function (e.g. logistic or sigmoidal function) which gives values of concepts in the range [0,1] (Gray et al., 2015; Kontogianni et al., 2013; Özesmi and Özesmi, 2004).

It is also possible to ask "what–if" questions and determine what state the system would go to under different conditions or if different policy options were implemented (Özesmi and Özesmi, 2004). In order to investigate such scenarios, different input vectors are used as initial stimuli. In any case, the activation level takes values in the interval [0,1]. For n number of concepts, the input vector is 1 by n, the FCM adjacency matrix is n × n, and the output is 1 by n (Papageorgiou and Kontogianni, 2012).

In addition to understanding the structure and function of a system, the modeling process itself, i.e., developing an FCM with stakeholders, has also helped policymakers frame regulations in a manner responsive to the needs and terms of stakeholders (Gray et al., 2015; Özesmi and Özesmi, 2004). Moreover, defining a desired or undesired state for a component can reveal the shift of the state of the system versus the steady state.

3. Exploring the bioethanol production and use from biowaste via the FCM approach

3.1. Survey design

Nine experts on the production and use of bioethanol from biowaste were recruited for the construction of the FCMs. The interviews with the experts took place in Athens during May and June 2017. Because of the complexity of the project and the many aspects it has, an effort to include the opinions of all the stakeholders and, thus, to create a more complete and reliable model, was made. As a result, the experts interviewed are of different origins: academics/researchers in the field of bioethanol production or waste treatment, policy makers, local government officials, executives of the fuel industry. More explicitly, the expert panel involved three academics/researchers in the field of bioethanol production, three executives of the fuel industry and three central and local policymakers.

After the individual maps were drawn, we proceeded to construct the collective FCM following 5 steps: Identification of factors describing the problem, clustering individual factors into groups, identification of causal relations and their strengths, estimation of causal link strength in collective FCM, collective FCM presentation and simulation (Kontogianni et al., 2013).

A computer-based FCM tool called Mental Modeler, freely available at http://www.mentalmodeler.org/ was used to create the FCMs. This approach "*facilitates the exploration of the dynamics and learning features of mental model representations by collecting and standardizing individual and collective community knowledge using simple modeling tasks in a real-time and participatory modeling environment*" (Gray et al., 2015).

3.2. Steady state analysis of the individual and collective FCMs

Table 1 presents the full list of concepts as stated by the experts during the interviews for the construction of their individual FCMs. In total, the experts have identified 65 concepts influencing the production and use of bioethanol from biowaste, though some of them are practically the same concepts with different linguistic identification. The concepts mentioned cover a wide range of issues from legal and political to technical and economic. It should be mentioned that some issues such as legislation are dominant for most of the experts but some others depend on the area of interest/expertise of each expert. For example, experts coming from the local government sector consider as crucial the factors influencing the waste management system (legislation, organization, control) omitting or neglecting the technical aspects of the bioethanol production process. On the other hand, experts from fuel companies give more weight to the potential consequences of using bioethanol as fuel: new networks and investments needed, consequences to the marginal profit of the companies etc.

The indices characterizing the individual FCMs according to the

Table 1
Full list of concepts as stated by the experts for the construction of the individual FCMs.

Components	Variables
C1	Bioethanol production and use
C2	Political willingness of local government
C3	Initiatives from municipalities-Political willingness
C4	Political willingness of central government (elimination of corruption phenomena)
C5	Political willingness
C6	Stringency of political leaders- No tolerance to conciliation
C7	Legislation for waste management (e.g. waste disposal)
C8	Legislation for biofuels
C9	Compliance with legislation
C10	Financial incentives
C11	Incentives for the private sector (e.g. tax reduction)
C12	Incentives/Return/Connection to the local market
C13	Economic incentives "pay as you throw"/reduce of cost
C14	Incentives
C15	Economic incentives/Subsidy
C16	Counterincentives for the trade of fossil fuels
C17	Development strategy/Investment priority
C18	Investment (units, delivery network, management etc.)
C19	Infrastructures for mixing/delivery/storage
C20	Infrastructures
C21	Infrastructures/network creation
C22	Refineries' technology
C23	Engine technology
C24	Production technology
C25	Technical background
C26	Production cost
C27	Process cost
C28	Economic crisis (increased cost)
C29	Waste sorting on the spot (from the citizens)
C30	waste sorting on the spot (from the municipalities)
C31	Organization of waste management system
C32	Control of waste management
C33	Faster and more substantial control of waste management-Cooperation of public and private sector
C34	Ability of local government
C35	Energy consumption for drying
C36	Drying in house
C37	Policy of municipalities for decentralized drying
C38	Central drying
C39	Social acceptance
C40	Citizens' acceptance
C41	Biofuels' acceptance
C42	Final product acceptance
C43	Citizens' participation
C44	Attitude/acceptance of media/entrepreneurs/social media
C45	Problems from the use of bioethanol in fuels/Wastewater management
C46	Problems of final product stability
C47	Problems of mixing
C48	Fuel prices
C49	Bioethanol price
C50	Bioethanol price paid by refineries
C51	Reduction of marginal profit for fuel companies
C52	Acceptance from refineries/fuel companies
C53	Waste availability
C54	Waste stability, availability, quality, quantity
C55	Quality of raw material
C56	Waste collection frequency
C57	Time between source and treatment
C58	Potential use of residues
C59	Residues' management
C60	Removal of legislative restrictions for the disposal of residues
C61	Citizens' sensibilization
C62	Change of attitude- Education
C63	Communication/Education/Change of attitude
C64	Change of attitude in waste management/collection
C65	Alternative ways of biomass use

graph theory are given in Table 2. The number of components mentioned by the experts varies from 6 to 16 with an average of 9.9. Respectively, the average number of connections was 18.6, ranging from 8 to 33. Maps had an average density, which is a measure of how connected or sparse a map is, of 0.21. The average number of transmitter variables, i.e. variables that only have "forcing" functions, was found equal to 3.7 (ranging between 0 and 6) whereas the average number of ordinary (bidirectional) variables was 5.2 (from 1 to 10) and the number of receiver variables was 1. Moreover, the ratio between connections per variable, which is an indicator of the density between the described variables and the casual relations, was 1.78 (from 1.14 up to 3). Furthermore, the average hierarchy index was calculated at 0.135 (between 0.05 and 0.3). As mentioned, the closer to zero the hierarchy index of an FCM, the more democratic the FCM is, i.e. the influence is distributed evenly across the components in a more democratic way.

In order to construct the collective FCM of the group of experts, some concepts (either identical ones expressed in other words or similar ones) were condensed. This approach results in less complex maps that can be used as the basis to run different scenarios and to analyze the possible outcomes of shifts in some components of the system. Fig. 1 presents the collective FCM of the group of experts. Table 3 summarizes the concepts used for the creation of the map. For example, the clustered component "Incentives" used in the collective FCM includes the components "Financial incentives", "Incentives for the private sector (e.g. tax reduction)", "Incentives/Return/Connection to the local market", "Economic incentives "pay as you throw"/reduce of cost", "Incentives", "Economic incentives/Subsidy" and "Counterincentives for the trade of fossil fuels" that have been used for the creation of the individual FCMs of the experts. It should be mentioned, here, that condensation is a semi-subjective procedure, which is not well documented or standardized so far and needs further development (Wildenberg et al., 2014). The total number of components of the collective FCM is 28. It is noteworthy that a collective FCM is not the average of the individual FCMs but a new representation of the system with different characteristics. According to Table 4, the collective FCM has 108 total connections resulting in 3.9 connections per component. The density is equal to 0.143 whereas the connections per component are 3.857. The biggest differentiation of the collective map compared to the individual maps regards the hierarchy index. The hierarchy index of the collective map is 0.002. It can be concluded, thus, that the more perceptions an FCM includes the more democratic it is meaning that the system's steady state is more resistant to the shifts of individual factors.

The most central variable of the collective FCM is -as expected- the "production and use of bioethanol from waste" with a centrality of 4.53. The most central concepts affecting the production and use of bioethanol with the corresponding indegree, outdegree and centrality are presented in Table 5. These concepts belong to three distinct groups: political factors, social factors and technoeconomic factors. "Legislation", "social acceptance/participation", "political willingness of the central government", "acceptance from refineries/fuel companies" and "incentives" are the most influencing factors of the process.

3.3. Dynamic analysis of the collective FCM

A number of simulations were conducted aiming at exploring the dynamic interactions between the concepts included in the collective map. The dynamic analysis can either focus on the equilibrium end states or the transient behavior during the iteration steps (Gray et al., 2015). Via a process known as "clamping" (Kosko, 1986), key variables are increased or decreased continually, and the values of the final vector of the clamped procedure are compared to the steady state vector (Vasslides and Jensen, 2016). The absolute values of the final vector of the clamped procedure are of minor importance. However, the relative changes observed compared to the initial steady state indicate trends that can serve as guidance for decision-makers, and for a better appraisal of the system dynamics. Following the procedure described above (in the section "Fuzzy Cognitive Maps approach"), the adjacency matrix of the collective FCM was multiplied by an initial steady state vector (a value of 1 for each element of the vector) to generate the steady state. Then, simulations were performed using the FCM Tool, a

Table 2
Graph theory indices for the individual FCMs.

Expert	Total components	Total connections	Density	Connections per component	Number of driver components	Number of receiver components	Number of ordinary components	Complexity score	Hierarchy index
No1	9	20	0.278	2.222	1	1	7	1	0.295
No2	16	32	0.133	2.000	5	1	10	0.2	0.047
No3	13	25	0.160	1.923	6	1	6	0.167	0.076
No4	12	22	0.167	1.833	5	1	6	0.2	0.120
No5	11	33	0.300	3.000	0	1	10	Infinity	0.251
No6	7	8	0.190	1.143	4	1	2	0.25	0.070
No7	8	10	0.179	1.250	4	1	3	0.25	0.089
No8	6	8	0.267	1.333	4	1	1	0.25	0.153
No9	7	9	0.214	1.286	4	1	2	0.25	0.116
Average	**9.889**	**18.556**	**0.210**	**1.777**	**3.667**	**1**	**5.222**	**0.321**	**0.135**

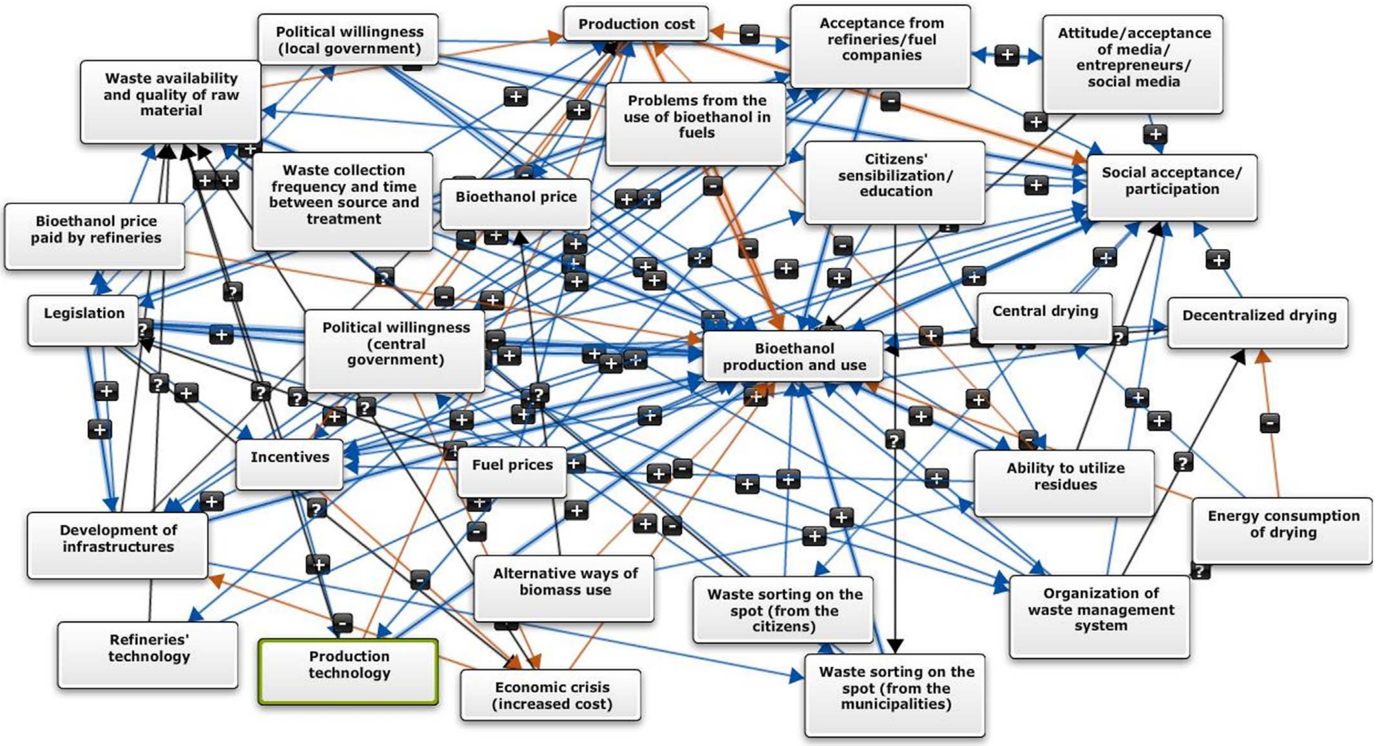

Fig. 1. Collective FCM.

software that works in Matlab environment (http://www.cs.ucy.ac.cy/fcmdss/index.php?option=comcontent&view=article&id=61&Itemid=68). In all simulations, the initial values used for the concepts under investigation were sequentially set to values ranging from 0 to 1, representing all possible situations, i.e. from "non-existence" to the highest possible level. Concepts mentioned by the experts were grouped into three categories: political factors, social factors and technoeconomic factors. The simulation process took place for each grouped concept separately as well as for the combination of the three groups.

In the absence of relevant studies that would define the current state of the factors involved (political, social, technoeconomic) the steady state of the system (generated as described above) has been considered as the base case scenario. In comparison to this base case scenario, we have carried out simulations for a worst case scenario at which the initial value of all the factors examined (political, social and technoeconomic) is set to 0.1 and a best case scenario at which the initial value of all the factors examined is set to 1. Fig. 2 presents the corresponding results. In the worst case scenario, a decrease of 20% is observed in the "production and use of bioethanol from waste" compared to the initial steady state. Furthermore, the "waste availability and the quality of the raw material" is influenced negatively (−5% compared to the steady state). On the other hand, in the best case scenario, a slight increase (of 2%) is expected in the "production and use of bioethanol" as well as the "waste availability and the quality of the raw material".

A sensitivity analysis, i.e. a study of how uncertainty in the output of a model can be attributed to different sources of uncertainty in the model input, has shown that the model is more sensitive to changes in political factors. More explicitly, "political willingness of the central government", "political willingness of the local government", "legislation" and "ability to use residues" are the concepts of the FCM grouped as political factors. Fig. 3 summarizes the findings of the simulations. When the initial values of these variables are set to 0.1, the "acceptance of refineries/fuel companies" drops by 7% whereas the "bioethanol production and use" and the "waste management system organization" drops by 6%. Moreover, there is a decline in the "incentives" and the "development of infrastructures" and a rise of the "production cost" of 5% compared to the steady state. On the contrary, if the political factors take the optimal value (1), the "organization of the waste management system" and the "acceptance from refineries/fuel companies" is improved by 3% compared to the initial steady state.

Table 3
Clustered variables used for the creation of the collective FCM.

Components	Variables
C1	Bioethanol production and use
C2	Political willingness of local government
C3	Political willingness
C4	Legislation
C5	Incentives
C6	Development of infrastructures
C7	Refineries' technology
C8	Production technology
C9	Production cost
C10	Economic crisis (increased cost)
C11	Waste sorting on the spot (from the citizens)
C12	Waste sorting on the spot (from the municipalities)
C13	Organization of waste management system
C14	Energy consumption for drying
C15	Decentralized drying
C16	Central drying
C17	Social acceptance/participation
C18	Attitude/acceptance of media/entrepreneurs/social media
C19	Problems from the use of bioethanol in fuels
C20	Fuel prices
C21	Bioethanol price
C22	Bioethanol price paid by refineries
C23	Reduction of marginal profit for fuel companies
C24	Waste availability and quality of raw material
C25	Waste collection frequency and time between source and treatment
C26	Ability to utilize residues
C27	Citizens' sensibilization/education
C28	Alternative ways of biomass use

As far as social factors are concerned, namely "social acceptance/participation", "attitude/acceptance of media/entrepreneurs/social media" and "citizens' sensibilization/education", less variables are influenced and in lesser extent. The variable "waste sorting on the spot (from the citizens)" is mostly affected by the changes in the above-mentioned factors. A deviation ranging from −3.5% to +1% compared to the initial steady state is observed when the initial stimuli take values from 0.1 to 1 (Fig. 4).

Finally, concerning the technoeconomic factors influencing the system ("incentives", "production technology", "fuel prices", "bioethanol price", "development of infrastructures", "production cost", "waste management system organization", "acceptance from refineries/fuel companies"), they seem to affect mostly the "bioethanol production and use", the "refineries' technology" and the "social acceptance/participation". The deviations range from −4.0% to 0.9%, from −3.1% to 1.2% and from −3.0% to 1.2%, respectively dependent on the values of the initial stimuli (Fig. 5).

4. Conclusions and policy implications

Large-scale biofuels production from biowaste is an ambitious target for the EU since it can contribute, on the one hand, to the better organization of the waste management system and the elimination of waste and, on the other, to meeting the targets concerning the production of renewable energy. Bioethanol production from biowaste is a multifactorial system and the success of the project requires the cooperation of different stakeholders, from policymakers and fuel industry executives to researchers and citizens. This paper presents, to the best of our knowledge, the first attempt to model the bioethanol production from biowaste system applying the FCMs approach and thus to identify its determinant factors and the way they interact.

Table 5
The most central concepts in the collective FCM.

Concepts	Outdegree	Indegree	Centrality
Bioethanol production and use	0.00	4.53	4.53
Legislation	1.41	0.33	1.74
Social acceptance/participation	0.56	0.82	1.38
Political willingness (central government)	1.13	0.11	1.24
Acceptance from refineries/fuel companies	0.73	0.44	1.18
Incentives	0.57	0.41	0.98
Production cost	0.36	0.58	0.93
Development of infrastructures	0.38	0.54	0.92
Political willingness (local government)	0.74	0.09	0.83
Waste availability and quality of raw material	0.34	0.42	0.77
Ability to utilize residues	0.41	0.22	0.63
Organization of waste management system	0.23	0.27	0.50

More specifically, the analysis revealed that concepts such as "Legislation", "social acceptance/participation", "political willingness of the central government", "acceptance from refineries/fuel companies" and "incentives" are the most influencing factors of the process. Furthermore, based on the results of the simulations concerning changes in different political, social and technoeconomic factors that influence the system, it is concluded that political factors have the largest impact. Apart from the direct impact on the production and use of bioethanol from biowaste, political factors have also an indirect impact via the influence they have on technoeconomic and social factors. The cost of the processes, as well as the cost for the development of new infrastructures, might be high, mostly for the fact that the industry dealing with such issues is still underdeveloped and therefore dominated by high costs. Such costs can be significantly reduced by intensifying research & development. The low or no cost of starting material along with the environmental benefits coming from the concomitant biowaste disposal would offset the high capital costs for initiating biorefineries (Fava et al., 2015). Besides, the experience from the electricity production sector (from renewable sources) has shown that changes in the policy mixture can lead to endogenous technological change that is reflected in the reduction of the cost (Wiebe and Lutz, 2016). Thus, a policy mixture that would support the biorefineries' sector would have an analogous impact on the cost reduction of bioprocesses and consequently would lead to the development of the sector. Furthermore, political factors affect social factors, as well. Appropriately designed policies aiming at promoting educational actions and sensibilization initiatives can change the attitude of citizens (Henly-Shepard et al., 2015) and enhance their participation in the project, resulting in better quality of the raw material and better yield in ethanol. To sum up, political willingness (at central as well as at local level) and more effective legislation are the key driving forces that will determine if the EU will meet its targets concerning waste management and biofuels production.

There are, however, some shortcomings to this study, which should

Table 4
Graph theory indices for the collective FCM.

Total components	Total connections	Density	Connections per component	Number of driver components	Number of receiver components	Number of ordinary components	Complexity score	Hierarchy index
28	108	0.143	3.857	5	1	22	0.200	0.002

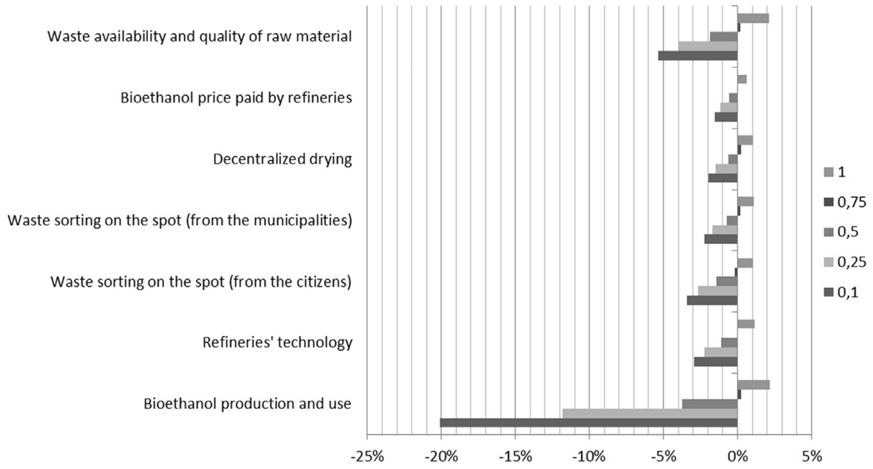

Fig. 2. The combined effect of political, social and technoeconomic shifts on the other concepts of the collective FCM.

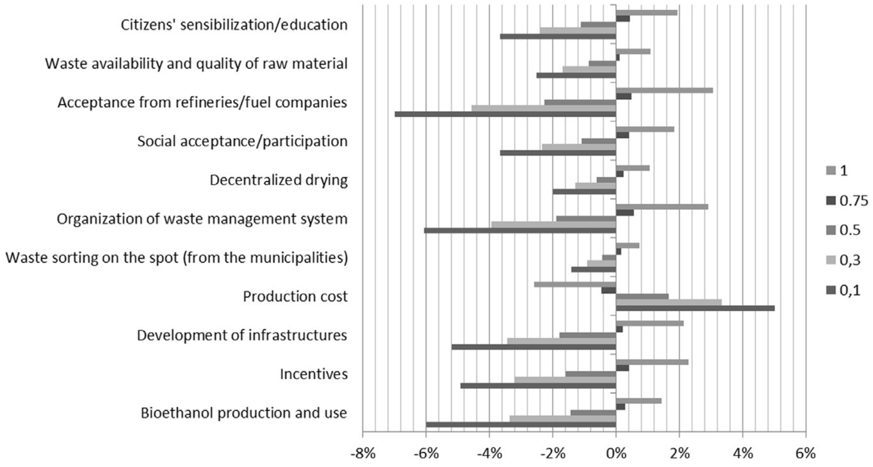

Fig. 3. The effect of political shifts on the other concepts of the collective FCM.

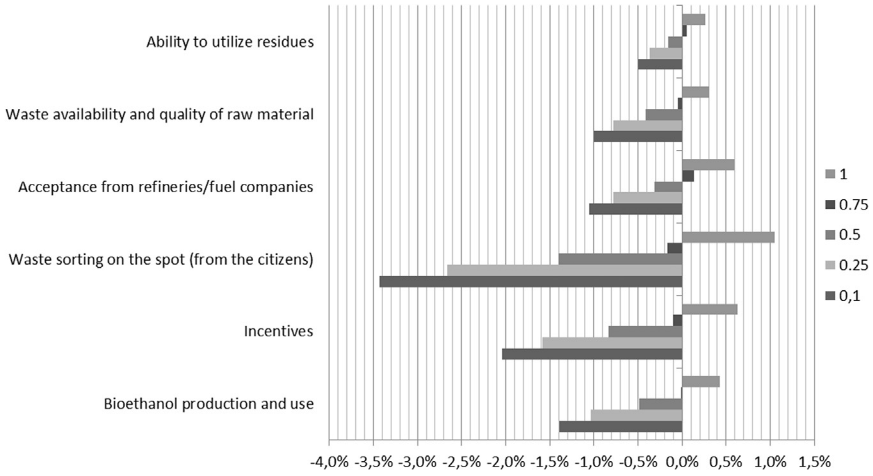

Fig. 4. The effect of social shifts on the other concepts of the collective FCM.

be taken into account. First, the representation of the system and its dynamic behavior correspond to Greece's local conditions. Second, the number of experts deployed and charged with the task of developing the FCMs may be considered a limiting factor given the complexity of the system. Towards improving the conceptual model describing the bioethanol production system more reliable and representative maps need to be constructed. Thus, much work remains to be done to gain a better understanding of the problem and, thereby, design more effective and efficient policies. For instance, an extensive pan European survey could be conducted by recruiting experts with different disciplinary backgrounds from different Member States. Further, it would be also of great interest to engage local communities in the project by eliciting the view of lay people, as a means to amend burdens relating to social factors. Despite these limitations, this research identifies the crucial factors of the project and the ways they interact in the current situation as well as in possible scenarios at which selected factors have been shifted. Thus, it offers insights that may prove useful, as a first step, to policymakers, program planners, and those interested in developing bioethanol production from waste.

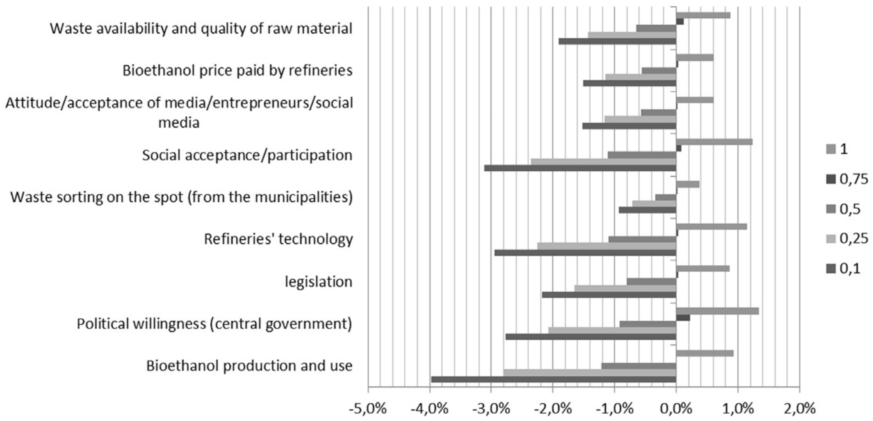

Fig. 5. The effect of technoeconomic shifts on the other concepts of the collective FCM.

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