Energy Policy 112 (2018) 334–348

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The networking dynamics of the Italian biofuel industry in time of crisis: Finding an effective instrument mix for fostering a sustainable energy transition

Pasquale Marcello Falcone[a], Antonio Lopolito[b,*], Edgardo Sica[c]

[a] Bioeconomy in Transition Research Group, IdEA, Unitelma Sapienza - University of Rome, Viale Regina Elena, 291, 00161, Roma, Italy
[b] Department of the Sciences of Agriculture, Food and Environment, University of Foggia, Via Napoli, 25, 71122 Foggia, Italy
[c] Department of Economics, University of Foggia, Largo Papa Giovanni Paolo II, 1, 71121 Foggia, Italy

ARTICLE INFO

Keywords:
Sustainable energy transition
Instrument mixes
Economic crisis
Fuzzy cognitive map
Biofuel

ABSTRACT

This paper aims to design the effective instrument mixes for fostering a sustainable energy transition in times of crises. We focus on a sufficiently developed green niche – namely the Italian biofuel sector – implementing a two-step investigation: 1) a social network analysis, to study the effects of the crisis on the basic niche development mechanisms, with the aim of eliciting its development needs; 2) a fuzzy inference simulation based on a causal-effect map drawn from experts' knowledge to identify the most effective instrument mix for the development of the niche studied. The major needs emerged in the case investigated are for an increase of actors' expectations towards the further development of the sector, and a need for a tailored networking activity, devoted to attracting specific knowledgeable actors. The results indicate that, among others, effective policy instruments are, in this case, the cooperation that has the best outcome in terms of networking, and the public procurement, which remarkably increases the level of expectation. The analysis presented constitutes a model to evaluate single policy drivers and their combinations to find adequate policy actions to promote the green energy transition in times of crisis.

1. Introduction

The dominant debate about the recent economic crisis has, so far, focused on issues such as stagnating growth, increasing unemployment, reducing consumption and investment, failing banks and nations, etc., almost completely overlooking the ecological and social issues. However, economic crises can affect the transition towards a decarbonized energy system by means of two opposing forces.

On the one hand, economic crises may consolidate the lock-in trajectories towards a fossil-based regime due to several aspects (van den Bergh, 2013). Firstly, the consumption of green goods and services may be significantly affected by the general decrease in aggregate demand during economic crises. Secondly, economic crises can constrain companies' green investments as a consequence of the associated financial crunch. Thirdly, austerity policies in response to economic crises may reduce public support of renewable energy, such as subsidies and feed-in tariffs. Finally, the possible reduction in fossil-fuel price during economic crises can bring lower biofuel prices due to their high degree of substitution, therefore hampering the profitability of investment in bio-refineries. For instance, the slump in renewable energy investments in the recent economic crisis has intensified, particularly at the beginning of 2009, with about a 40% drop in spending with respect to the end of 2008 (International Energy Agency, 2009).

On the other hand, economic crises can foster sustainable energy transitions by creating favorable conditions for greener production and consumption systems (Geels, 2013; Antal and Van Den Bergh, 2013). According to van der Ploeg and Withagen (2013), a combination of well-designed policy tools (e.g. tax relief, R&D subsidies, etc.) may drive growth from polluting to cleaner economic activities, making green growth a possible solution to escape the global economic crisis. Indeed, in times of economic crises, green industries can provide a relevant number of direct and indirect job opportunities, as occurred recently at the EU level where the number of jobs provided by green industries amounted to approximately 14.6 million in 2012 (EU Sustainlabour, 2013).

In this framework, the sociotechnical transition (STT) approach can provide a multidisciplinary framework that draws on different disciplines; this then offers an integrative system-wide view for investigating the relationship between some landscape shocks (e.g. economic crises, etc.) and new environmental challenges. Several studies

* Correspondence to: Department of Agricultural, Food and Environmental Sciences, University of Foggia, Via Napoli, 25, 71122 Foggia, Italy.
E-mail addresses: pm.falcone@bioeconomy-in-transition.eu (P.M. Falcone), antonio.lopolito@unifg.it (A. Lopolito), edgardo.sica@unifg.it (E. Sica).

http://dx.doi.org/10.1016/j.enpol.2017.10.036
Received 6 February 2017; Received in revised form 12 October 2017; Accepted 18 October 2017
0301-4215/

employ the Multi-Level Perspective (MLP) as a framework to analyse sustainable energy transition since it allows a focus on different dynamics occurring at various levels (Mattes et al., 2015; Falcone, 2014). In particular, it is possible to identify three linked levels, namely a macro-level (the landscape), a meso-level (the regime), and a micro-level (the innovation niches) (Rip and Kemp, 1998; Geels, 2002). The landscape level embodies exogenous determinants including material and social infrastructure, politics, natural setting, etc. The regime represents a stable set of institutional rules, technical knowledge, and social interaction patterns shaping the fundamental configuration of technologies. Finally, the innovation niche can be conceived as a protected space where promising technologies are developed and experimented.

It can be seen from this that sustainable energy transition results from the interaction of the MLP levels, namely when a sufficiently developed niche-innovation challenges the dominant regime which, in turn undergoes an adequate amount of pressure from the landscape (Hansen and Nygaard, 2014). However, governing the above co-evolutionary dynamics involves a number of challenges for policymakers who are called to identify the effective policy mix to foster the transition process (Hildingsson and Johansson, 2016). Such government challenges increase noticeably in time of crisis when decision makers face the problem of setting appropriate policy instruments to deal, simultaneously, with the economic downturn on the one hand and the decarbonization of the economy on the other (Solomon and Krishna, 2011). From this view, our knowledge about how to govern a sustainable energy transition in time of crisis still looks very limited (Costa-Campi et al., 2015).

For the purpose of our analysis, we posit the discussion concerning the economic crisis with reference to the Italian context. In particular, the country is among the major EU Member States with a relatively high consumption and production rate of biofuels (Assocostieri, 2015) as well as a frontrunner in the EU's bioeconomy context (Intesa San Paolo, 2015). However, the Italy's economy is still lagging behind its European peers (FocusEconomics, 2017). Specifically, while much of the world has recovered from the economic and financial crisis of 2008–09 (e.g. Asia, Latin America, USA), though with slower growth e.g. in the U.S., China and Western Europe, Italy's severe economic problems have lingered much longer. In this framework, Italy represents a highly relevant case for investigating which policy mix is most effective for a sustainable energy transition to occur in time of economic crisis. In other words, we seek the effective mix of instruments to give momentum to a sustainable energy niche to become a solid alternative to the dominant regime. In particular, our analysis is based on a two-step investigation addressed at a sufficiently developed green niche, namely the Italian biofuel sector. The first step is devoted to the analysis of the Italian biofuel niche, with the purpose of eliciting the development needs of the sector. More specifically, by means of the social network technique, we study the effect of the recent economic crisis on the fundamental niche development mechanisms. To this end, we initially carry out a stakeholder analysis aimed at identifying all the relevant actors for the Italian biofuel niche. Actors have then been surveyed to explore the networking evolution of the niche and to identify the effects brought by the economic crisis. The second step is addressed at the identification of the effective instrument mixes that can foster the niche development. Specifically, through a number of interviews with experts, we derive a causal-effect map of policy instruments by employing a fuzzy cognitive map method to understand effective instrument mixes that can contribute to drive the transition towards a decarbonized energy system in light of the recent economic crisis.

The rest of this work is organized in the following way: Section 2 depicts the state-of-the-art; Section 3 reports the case-study and methodology; Section 4 deals with the results achieved; Section 5 contains some discussion of results; finally, some concluding remarks are provided in Section 6.

2. Literature review

2.1. Sustainability transitions and policy mixes

When an innovation is specifically developed to address environmental problems, a ‘double externality problem’ arises, with this type of innovation combining both private and social benefits (Hemmelskamp, 1997). Adding these two externalities justifies, therefore, the need for policy combinations to drive companies' innovative effort (Ziegler and Rennings, 2004). As a matter of fact, the importance of policy mixes for driving the decarbonization of the energy system has been increasingly acknowledged in the sustainability transition literature (Markard et al., 2012). In this context, the debate to what extend policy mixes can foster the transition towards a more sustainable system has recently gathered growing interest among policymakers and academics concerned with the emerging topic of socio-technical transition theory. Several contributions relies upon the notion of ‘policy mix’ proposed by Borrás and Edquist (2013, p. 1514) who refer to *“a set of different and complementary policy instruments to address the problems identified”* in a national or regional innovation system. However, wider interpretations have been provided recently. Essentially, policy mixes are “complex arrangements of multiple goals and means which, in many cases, have developed incrementally over many years” (Kern and Howlett, 2009, p. 395). These include the integrate consideration of traditional technology push and demand pull instruments as well as the systemic concerns relevant for the transition towards sustainability (Rogge and Reichardt, 2016).

Originally, much attention was placed upon the mere interaction of diverse policy instruments for an effective outcome (Gunningham and Grabosky, 1998; Gunningham and Sinclair, 1999; del Río González, 2007), and on the process of policy shaping and design of such instruments to develop a prescriptive framework for policymakers (Howlett and Rayner, 2007).

Lately, a broader conceptualization of the policy mix notion appeared so as to propose a more comprehensive background for examining the cause-effect relations between policies and technological innovation. The rationale of referring upon a broader policy mix conceptualization is justified by the presence of multiple traits looking beyond a mere policy instrument in combinations, in terms of long-time policy aims, and the other policy mix properties such as consistency, comprehensiveness, credibility and stability (Costantini et al., 2017; Uyarra et al., 2016; Reichardt and Rogge, 2016; Sovacool, 2009). In this vein, Reichardt and Rogge (2016) have contributed to the debate on policy mixes for sustainable transitions by providing: (i) an extended interpretation of the policy mix in order to better capture the intricacy and dynamics of real world, going beyond the mere combination of instruments and strategies for long lasting aims; (ii) a comprehensive analytical framework able to facilitate empirical study focusing also on neglected aspects, in order to allow a more accurate policy proposal. Likewise, Quitzow (2015) suggests an integrating framework for comparative policy evaluation, concentrating on some explicit challenges concerning the spread of sustainable innovations. To this end, the author further develops the conceptualization of the “policy strategy” also including the normative dimension of policy making (e.g. value judgements, political opportunities and societal pressures) as well as the objectives, measures, and processes at the basis of a specific mix of policy. Finally, Kivimaa and Kern (2016) emphasizes that ‘ideally’ policy mixes for sustainable transitions embrace elements of ‘creative destruction’, concerning both policies aimed at the ‘creation’ of new and for ‘destabilising’ the old. Essentially, they propose a new analytical framework by expanding the notion of ‘motors of innovation’ to ‘motors of creative destruction’ that consider both policy mix dimensions (‘creation’ and ‘destruction’). Therefore, transitions involve not only the creation or diffusion of innovative and environmentally friendly technologies, but also a broader shifting of the current unsustainable system.

In this paper, far from dismissing the relevance of policy mixes for sustainability transitions through 'creative destruction', we enrich the recent empirical contributions on the topic (see Kivimaa and Kern, 2016; Quitzow, 2015) by identifying the effective mix of policy instruments able to support a sustainable energy transition in times of crises, through a policy fuzzy inference simulation. For the purpose of our empirical investigation, although we see merit in the wider conceptualization of the policy mix, we focus on what Borrás and Edquist (2013) would describe as instrument mixes.

2.2. Economic crisis and innovation policy

From the innovation system perspective, the rationale for a combination of different policy instruments to drive sustainable energy transitions is founded on the necessity for addressing transition, lock-in and institutional failures (Smith, 2000; Grubb and Ulph, 2002). In other words, policies can contribute to sustainability transitions by providing public support in these areas (Weber and Rohracher, 2012).

Today, however, policy instruments aimed at driving sustainable energy transitions must deal with the consequences of the recent economic crisis that has affected most economies at the worldwide level. For this reason, the relationship between policy instruments, transitions towards decarbonized systems, and economic crises looks complex and manifold, and the way a combination of policy instruments can foster a sustainable energy transition in time of crisis still remains an unclear outcome. Indeed, while some scholars seem to share a positive view about the possibility of policy instruments re-orienting crises towards a new sustainable energy regime, others exhibit a more pessimistic opinion, by recognizing a number of obstacles that can be overcome with difficulty (van den Bergh, 2013).

Perez (2013), for instance, suggests that the current era can offer the chance of entering a "green golden age", by exploiting the potential of innovation that can be triggered by means of an opportune mix of proactive public policies. In particular, the author emphasizes the need for a deep institutional change for a sustainable energy transition to happen, comparable to Bretton Woods and the New Deal, in order to open the way to green innovations and investments.

O'Riordan (2013) investigates the interaction between international, national and local levels of governance, suggesting that only well-functioning policy institutions may contribute to transitions towards a decarbonized system. In particular, a mix of local-level initiatives and related experiments in those localities mostly affected by economic crises are believed to foster both environmental sustainability and green jobs, by boosting a process of reform in governance at higher levels.

Geels (2013) explores the extent to which economic crises affect transitions towards sustainability by following four different perspectives which acknowledge the relevant role played by policy instruments to accelerate the transition. The first considers economic crises and environmental problems as arising from modern capitalism. According to this view, crises can produce a positive effect on sustainability transitions insofar as public policies are able to recognise and re-orient the structural root of the crisis. The second considers the economic crisis linked to a potential sixth green Kondratieff wave. Following this perspective, a combination of measures is needed to enable the dissemination of the novelties at their full potential. The third is founded on the concept of 'green growth', which allows the achievement of a win-win solution where both environmental and economic problems are solved. According to the author, green growth should be supported by a combination of policies, including green taxes, public spending on green investments, investments in new technologies, human capital, infrastructures, etc. Finally, the fourth distinguishes economic crises and environmental issues based on different time-spans, sources, and recovery strategies. Consequently, the policies should be addressed at the struggle against the delay in bio-based transitions caused by economic crises.

Loorbach and Lijnis Huffenreuter (2013) believe that economic crises are a symptom of a more fundamental unsustainability, which suggests the existence of persistent problems that can be regarded as systemic lock-in. Although such lock-in can be reinforced by network externalities, economies of scope, and complementarities that exist within a given institutional framework, they can also lead to a general change on multiple levels and scales, thus favoring a shift towards a new sustainable energy regime. In other words, crises can disrupt existing institutions, therefore providing chances for a significant departure from the lock-in paths.

Antal and Van Den Bergh (2013) propose a variety of micro- and macro-level policies that can contribute to exploiting economic crises as an opportunity for undertaking the direction towards a new sustainable regime. Starting from the idea that the financial system is the main driver of the economic crisis, the authors provide alternative proposals for financial instruments to enable sustainable energy transitions, such as creative project funding schemes, interest free rates, local currencies, and ethical banking.

Finally, Falcone and Sica (2015) study the consequences of the recent economic crisis on sustainable energy transitions by investigating the biofuel industry in Italy. In particular, the authors assess the biofuel niche readiness according to three interlinked key mechanisms, i.e. learning, expectations, and networking. Their findings provide evidence that the ongoing economic crisis has severely affected the socio-technical transition towards a new sustainable energy system, and that a mix of tax relief and subsidies can foster investments, job opportunities, favoring energy transition.

3. Case study and methodology

3.1. The Italian biofuel niche

EU energy policy is increasingly pursuing the goal of a green and competitive energy supply (Dassisti and Carnimeo, 2013). In particular, in the context of growing demand for a new sustainable energy system, the EU Commission has recognised bio-based industries as being of great socio-economic importance and pointed at biofuels as a key sector for the accomplishment of the 2020 EU sustainability targets. Consequently, policymakers are called to identify the most powerful policy instruments that can drive the development of the biofuel sector (Pries et al., 2016). Moreover, the EU Commission has recently issued a policy agenda oriented towards the period 2020–2030 (COM (2014) 15 final) which integrates the existing 2020 policy objectives for climate and energy. The new agenda raises a large-scale EU approach whose aim is founded on a cutback of 40% in overall greenhouse gas emissions in 2030 compared to those in 1990.

Two tailored policies have boosted the development of biofuels in the EU:

- The "*Fuel Quality Directive*" – FQD (**2009/30/EC**) that fixed sustainability criteria for biofuels. Specifically, it was intended to reduce the lifecycle greenhouse gas emissions per unit of energy by 6% by 2020, compared with the 2010 level.
- The "*Renewables directive*" – RES (**2009/28/EC**) aimed to increase the average level of energy derived from renewable resources for public transport by 2020. In particular, each Member State must ensure that at least 10% of their transport fuels come from renewable sources.

Following the EU Commission's proposals, Italy is actively involved in the development of a more competitive biofuel sector, triggering investments, aimed at creating job opportunities and, thus, local economic growth. In order to encourage advancements in the biofuel sector, the Italian legislative framework has gone through a systemic process of change over the last decade. In particular, the measures adopted were aimed at giving effect to the impulses resulting from the

EU framework on the one hand, and at establishing appropriate forms of incentives to encourage the production of biofuels on the other. With regard to the first point, currently, the main legislative act in place is D.lgs 28/2011 (so called *Decreto Rinnovabili*), which implements Directive 2009/28/EC laying down the mandatory quota of biofuels blended with petrol and diesel at 4% for 2012 and 5% for 2014 in order to reach the 10% target by 2020. Moreover, with regard to the incentive mechanisms for the production of biofuels, since 1998 Italy has promoted the possibility of obtaining a form of tax exemption, in whole or in part, from the excise duties normally applied to all petroleum products. It is worth noting that, since 2011, any excise exemption in the Italian biofuel market has been completely removed.

Despite having adopted policies in support of renewable energies sector a few years ago, Italy shows a gradually increasing energy dependence trend. The high share of imported energy, accounting for 97.1% of total inland consumption, leads to a high energy dependence rate. This rate is significantly higher than the EU average, generating a strong sensitivity to the dynamics of political and economic development of the main supply markets.

Italy is among the most relevant biofuel producers and consumers in the EU. However, the structural and productive framework of the domestic sector is difficult to read due to the heterogeneity and divergence of the available data provided by industry associations and national bodies. Against this background, and looking at the most recent data (2015) collected from the Italian biofuel sector association (*Assocostieri*) as well as from informal and anecdotal observations, the number of active producers (primary transformation) amounts to 21, 1 of which is a second-generation biofuel company (world-first commercial-scale cellulosic ethanol plant) (see Fig. 1).

The Italian biofuel industry is slowly developing in order to meet the EU's mandatory 10% biofuel use in transportation fuels. The graph below (Fig. 2) shows the main indicators (i.e. production capacity, actual production, domestic consumption and imports) related to the industry in the period 2008–2014.

The available data (Assocostieri, 2015) related to the 2008–2014 period allow us to delineate a more complete picture of the sector. A stagnation of production capacity can be seen immediately, which emphasizes the difficulties of the sector during the last five years of economic crisis. Moreover, in the same period, the domestic production of biofuels records significant changes, showing an average volume of 760,000 t between 2008 and 2010. From 2011 to 2012, we can observe a sudden collapse (about 70%) of the total production caused by the complete removal of tax incentives. As a consequence, an increase in biofuel imports was necessary to offset the lower domestic production in order to comply with the EU directive. However, in 2013 and 2014 the domestic production of biofuels increases; however, domestic consumption slightly decreases by entailing a reduction of the import

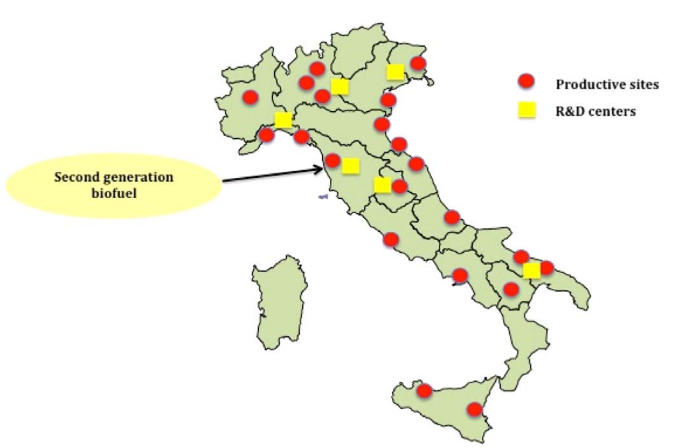


Fig. 1. Maps of the Italian biofuel plants.
Source: Own elaboration.

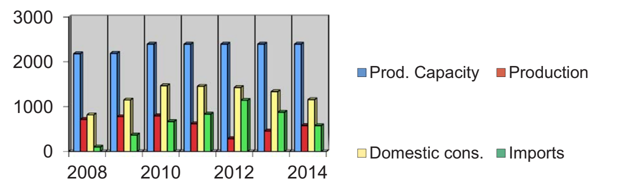


Fig. 2. Main indicators of the Italian biofuel sector (thousand tonnes).
Source: Assocostieri (2015).

volume. Finally, the average rate of utilization of the production capacity decreases considerably as a consequence of the removal of the tax relief (2012) and, although it records a marginal increase in subsequent years, a high degree of under-utilization of plants is noticed when compared with other EU members. This can arise from the calculation method used by the legislator to allocate quotas for subsidized biodiesel that, being based on the installed capacity, has led operators to oversize Italian plants.

3.2. Methodology and data

In order to investigate the policies that, dealing with the consequences of the recent economic crisis, can contribute to drive a transition towards a sustainable energy system in Italy, we have implemented a two-step analysis. The first step was aimed at drawing a picture of the Italian biofuel niche by investigating its evolution during the recent economic crisis; this was carried out, first, by means of a stakeholder investigation, followed by a social network analysis (SNA). In contrast, the second step of our investigation has employed a fuzzy cognitive map (FCM) with the aim of identifying the effective instrument mixes that can foster the transition towards a new sustainable energy regime.

3.2.1. The first step: the analysis of the niche

The stakeholder analysis was aimed at drawing the set of potential subjects acting in the Italian biofuel sector. To this end, we contacted the Italian biofuel association (*Assocostieri*) that provided us with a relevant list of biofuel actors. This list was then integrated by adding further actors that were identified by means of web-sites, reports, and documents concerning the biofuel niche in Italy.

By means of a specifically designed questionnaire, biofuel producers were asked on the relations they have each other and with the stakeholders identified in order to derive the niche network structure.

The questionnaire was administrated by means of the CAWI (Computer-Assisted Web Interview) technique: initially, actors were informed telephonically about the purpose of the study, and, when accepted to be surveyed, they received a web-link to the questionnaire via their inbox. This allowed them to complete the questionnaire online. Such questionnaire was articulated in two sections.

The first section aimed at collecting details on the biofuels market in Italy, and related actors' expectations on the potential niche growth in terms of total replacement of the current fossil based sociotechnical regime. Moreover, respondents were asked about their opinion on the effect of the recent economic crisis on the sector under investigation. We employed respondents' opinions in the second step of our investigation to define the potential policy instruments to adopt.

The second part was conceived with the aim of implementing an SNA, by gathering information on actors' interaction. In particular, we considered a link between two actors when they communicate and exchange information about biofuel. The SNA methodology allows a straightforward appraisal of several architectural features of a given set of actors' relationships (Wasserman and Faust, 1994). Briefly, such method allows the modelling of the relationships among a group of actors to depict the frame of the investigated environment. Therefore, it is a useful instrument for scrutinizing and learning the manifold nature of network relationships regarding heterogeneous actors forming the biofuel industry investigated in this paper (i.e. producers, suppliers, institutions, etc.).

As already emphasized, an economic crisis can affect the transition towards a decarbonized energy system. With the aim of isolating the effect of the recent economic crisis on the biofuel sector in Italy, we explicitly asked the respondents to indicate in which way the network has settled from 2007 to 2014, due to the recent economic crisis. In this way, we could gather two different networks' pictures, i.e. before and during the crisis. Results achieved were analysed according to the strategic niche management frame, by focusing on the evolution of the structural features of the relationships and looking at basic niche formation processes: 1) convergence of expectations, 2) learning mechanism, and 3) networking (Lopolito et al., 2011; Kemp et al., 1998).

First, articulating *expectations* is necessary to build consensus and gather an adequate amount of means, especially when the technological niche is in an initial phase of implementation, when both its effectiveness and social acceptance are uncertain. Then, the *learning process* is commonly considered as central for a sustainability transition to occur (Kemp et al., 1998). Such mechanism can take place both at the individual level (e.g. biofuels producers will expand their knowledge merely "by doing"), and at the collective level (e.g. biofuels producers and other stakeholder will also increase their knowledge by sharing their own expertise and experiences). Finally, networking is very relevant for a technological niche to succeed. In particular, as the niche is usually characterized by a small set of dedicated actors, the architecture of the social relationships could turn out to be crucial in facilitating necessary interactions for the niche development and breakthrough.

Bearing this in mind, SNA enables us to recognise the most relevant actors involved in the Italian biofuel niche, and to assess the evolution of their relationships due to the recent economic crisis, highlighting some weaknesses and strengths regarding the future development of the investigated niche. In order to grasp a general frame of cause-effect relationships to understand the effective instrument mixes required to address a sustainable energy transition, we employ a fuzzy cognitive map (FCM) method.

3.2.2. The second step: the identification of the effective instrument mixes

In order for policy modelling to be achieved, we looked for an approach capable of disentangling the manifold nature of the investigated phenomenon and its multifaceted effects in a data poor situation. Our strategy was to define a knowledge base drawn from the experts' experience. To this end, the use of Fuzzy Cognitive Maps (FCMs) has proven particularly suitable, as it is not based on empirical data but allows the modelling of a system starting from the perception of stakeholders or experts (Kosko, 1986). Its principal output is a social cognitive map obtained from the tacit knowledge of the people involved, which is then used as a computational model capable of summarizing the main causal relations among the system variables (Ozesmi and Ozesmi, 2004). Thus, a cognitive map is formed of two elements, 1) a set of variables, and 2) their causal relations (Fig. 3).

Using fuzzy inference based on neural networks calculation, FCMs enable the analysis of how a non-linear system works (Çoban and Seçme, 2005). While the model based on FCMs does not allow for statistic inference, this approach has a two-fold property. Given a fixed relations' pattern, it can be used to trace the system dynamics 1) without and 2) with external interference, which means the potential of describing the endogenous evolution of the system and its reaction to exogenous (policy) action. Being grounded on social perceptions, this kind of analysis is particularly relevant to simulate the policy effect where a multitude of actors are involved (Ozesmi and Ozesmi, 2004). FCMs also guarantee flexibility in depicting systems, since the number of variables, relations and feedback among them, as well as the sources of knowledge used (e.g. different kinds of experts and stakeholders), is subjected to any limitation.

The breakdown of the FCM operation adopted in this work identifies three fundamental steps, that are 1) the identification of the system variables, 2) the identification of the causal relations among the variables social cognitive map, and 3) the analysis of the system. This latter step is in turn split into two sub-steps 3a) the static analysis and 3b) the dynamic analysis.

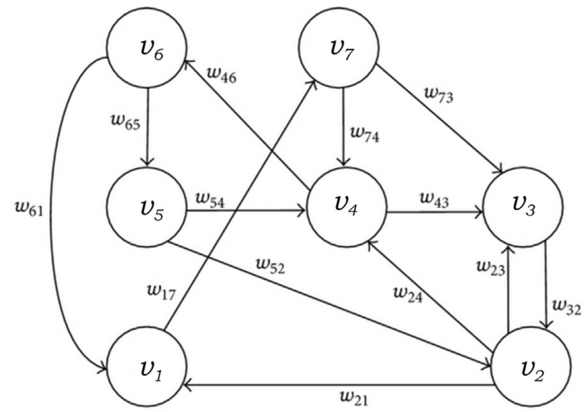


Fig. 3. A simple FCM.
Source: Adapted from Peng et al. (2015).

1) ***The identification of the system variables***. The identification of the system variables (v_i). of the Italian biofuel sector was performed looking at the literature review and at the hints arising from SNA investigation (Sections 2 and 4); these are reported in Table 1.
In addition to an "id" and the name of the variable (columns 1 and 2), the third column associates each variable to a univocal label as used in the remainder of the paper. The table contains also a brief description (fourth column) of each variable as communicated to the respondents. Since the objective of this phase is to draw a social map of the system capable of grasping and integrating the tacit knowledge of the experts on a rational base, the description of the variables is intentionally simple and vague in order to allow the emergence of the perception of the respondents, avoiding any influence or external bias. As reported in the last column, according to the theoretical background the variables are distinguished in three categories, according to their role within the system: 1) policy instruments, this category includes all those variables susceptible of being used as policy drivers, 2) negative effects, including the variables that represent crisis' negative impacts on the functioning of the sector, and 3) positive effects, that instead contains the variables that can positively affect the operation of the sector, or that can be conceived as positive outputs of the sector. In addition, the starred variables directly relate to the three fundamental niche mechanisms, respectively networking, learning and convergence of expectations.
2) ***The identification of the causal relations.*** In order to identify the cause-effect relations connecting the system variables ($v_i \rightarrow v_j$), a pool of experts was individually interviewed. The six experts engaged for this task were those belonging the STAR*AgroEnergy research group, an Italian excellence research task on agroenergy with wide and recognised expertise in renewable energy.[1] Each respondent was asked to draw its own individual cognitive map, identifying the principal causal relations between the 19 variables defined in Table 1, their sign (positive/negative), and their intensity according to a three-degree verbal scale (strong, medium, weak). This was not a simple task, proven that it means to recognise ($19 \times 18 = 342$ elements). To facilitate the respondent work, each of them

[1] This group was formed within the Star*Agroenergy 7th FP project (Coordination and Support Action) aimed at "Unlocking and developing the Research Potential of research entities established in the EU's Convergence Regions and Outmost Regions" (visit http://www.star-agroenergy.eu).

Table 1
Biofuel sector variables.
Source: Own elaboration.

Id	Variable	Abbreviation	Description	Category
1	Taxes on traditional fuels	TAX	Green taxes (also called "environmental taxes" or "pollution taxes") are excise taxes on environmental pollutants, or on goods whose use produces such pollutants (i.e. tradable permit, carbon tax). *Stage of application*: already implemented at national level.	Policy Instrument
2	Investments and infrastructural subsidies	INV	It includes donor funds aimed at the installation of new environmentally friendly plants (i.e. biofuel plant, R & D centre), infrastructural subsidies (e.g. storage platforms biomass serving biofuel producers) and subsides for pilot plants. *Stage of application*: designed, it will be implemented at regional level.	Policy Instrument
3	Tax relief and production incentives	INC	Any programme or incentive that reduces the amount of tax owed by an individual or business entity. Examples of tax relief could be an exemption on excise duties for the biofuels sector. *Stage of application*: proposed instrument.	Policy Instrument
4	Cooperation	COO	Incentives for the realization of public and private consortia. *Stage of application*: designed, it will be implemented at regional level.	Policy Instrument
5	Public procurement	PRO	Public administration commits to purchase a part of biofuel production *Stage of application*: proposed instrument.	Policy Instrument
6	Credit crunch	CRED.CRUNCH	Reduced availability of financial resources due to a bank based system	Negative Effect
7	Reduced private investment	REDUCED INVEST	Reduced purchase of a capital asset that is expected to produce income.	Negative Effect
8	Reduced private R & D	RED.PRIV R & D	Reduced investments in private R & D activities, namely, the sum of R & D expenditures of firms and non-profit private institutions.	Negative Effect
9	Reduced public R & D	RED.PUB R & D	Reduced public R & D are considered within three categories: (i) reduced R & D tax credits and direct subsidies, (ii) less support for the university research system and the formation of high-skilled human capital, and (iii) no support of formal R & D cooperation across a variety of institutions.	Negative Effect
10	Reduced competitiveness of biofuels' price	RED.PRICE	Breaking down of the competitiveness of biofuels' price owing to the removal of the excise duty exception in Italy (2011)	Negative Effect
11	Reduced raw materials (biomass) price	RAW.MAT.RED.PRICE	Reduced prices of the principal biodiesel feedstocks (e.g. rapeseed, soybean, and palm oils)	Negative Effect
12	Networking	NETWORK*	Level of relationship established among different actors operating in the biofuel network	Positive Effect
13	Knowledge level in biofuel sector	KNOWL.*	Degree of knowledge about biofuels criticalities among different actors operating in the biofuel network	Positive Effect
14	Biofuel sector profitability	PROFIT	The efficiency of the biofuels sector at generating earnings. Is generally expressed in terms of several indicators, namely, value added, returns on assets, and so on.	Positive Effect
15	Employment in the biofuel sector	JOB	Employment rate of green jobs in the biofuel sector.	Positive Effect
16	EU biofuel targets	EU.TARGET	The Renewable Energy Directive in 2008 required Members States to meet 10% of transport energy from renewable sources by 2020.	Positive Effect
17	Increased green awareness	GREENAWAR.	Consumer awareness concerning green products and processes	Positive Effect
18	Increased social acceptance of the plant	SOCIAL.ACCEPT.	A social reaction to something that is proposed externally. In particular a new plant	Positive Effect
19	Expected fuel replacement	FOS.FUEL.REPLAC.*	Possibility of replacement of traditional fuels	Positive Effect

The starred variables directly relate to the three fundamental niche mechanisms, respectively networking, learning and convergence of expectations.

was endowed with a *table allowing qualitative paired comparisons* among the variables. Moreover, the quadrants of the table were colored with different grey scale according to the three different variables categories (policy instruments, negative effects and positive effects) to facilitate the visual identification of similar elements and speed up the process (see Fig. 4). Once obtained the individual cognitive map, we transformed the expert verbal judgment on relation intensity in numerical data mathematically tractable, applying a simple scoring method that assigns values along a six-degree scale (Table 2).
The scoring method allowed to obtain an *adjacency matrix* per each respondent. The typical element of the matrix $a_{i,j}$ represents the value of the relation among the variables *i* and *j*. Once obtained the experts adjacency matrices, these can be combined to obtain the *social adjacency matrix*. This combination was achieved by additively superimposing the individual *k* matrices (Kosko, 1992) as follows:

$$\bar{a}_{i,j} = \sum_{k=1}^{N} a_{i,j} \tag{1}$$

where is the element of the social adjacency matrix, *N* is the number of respondents. This operation allows a comprehensive representation of the system. Indeed, the advantage of summing the matrixes in this way is that agreement on causality reinforces the connections among the variables forming a shared vision, while conflicting relations with opposite signs decrease the cause-effect relation (Ozesmi and Ozesmi, 2004). In order to ease the fuzzy inference explained in the next step, the social adjacency matrix is normalised in turn in the range − 1, 1 as follow:

$$w_{i,j} = \frac{\bar{a}_{i,j}}{max|\bar{a}_{i,j}|} \tag{2}$$

The element of the *normalised social adjacency matrix* represents the weight of the relation from variable *j* to variable *i* used for the fuzzy inference calculation (see Eq. (6)). Thus, the normalised social adjacency matrix is a way to represent in a mathematical form the social cognitive map based on the perception of the experts. The process that leads from the questionnaires to the final map is laid out in the Fig. 5.

3) ***The analysis of the system***. Basically, the analysis of the system is performed both at a static and at a dynamic level. In order to analyse the fix structure of the relations, basic network indicators are used. The dynamics of the system are analysed using auto-associative neural networks (Reimann, 1998); this allows the investigation of where the system will go following the baseline dynamic and the variation with external shocks, as policy actions.

			POLICY INSTRUMENTS					NEGATIVE EFFECTS						POSITIVE EFFECTS							
			TAXES	INVESTMENTS	INCENTIVES	COOP	PROCURM	CREDIT	REDUCED INVEST	PRIV R&D	PUB R&D	PRICE	RAW MATERIALS	NETWORK	KNOW	PROFIT	JOB	EU	AWARE	ACCEPTANCE	REPLACE
	id	VARIABLES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
POLICY INSTRUMENTS	1	Taxes on traditional fuels																			
	2	Investments infrastructural Subsidies																			
	3	Tax relief and production incentives																			
	4	Cooperation																			
	5	Public procurement																			
NEGATIVE EFFECTS	6	Credit crunch																			
	7	Reduced private investment																			
	8	Reduced Private R&D																			
	9	Reduced Public R&D																			
	10	Reduced competitiveness of biofuels' price																			
	11	Reduced raw materials (biomass) price																			
POSITIVE EFFECTS	12	Networking																			
	13	Knowledge level in biofuel sector																			
	14	Biofuel sector profitability																			
	15	Employment in the biofuel sector																			
	16	EU biofuel targets																			
	17	Increased Green awareness																			
	18	Increased Social acceptance of the plant																			
	19	Expected fuel replacement																			

Fig. 4. The table for paired comparisons.
Source: Own elaboration.

Table 2
Scoring method applied to expert responses.
Source: own elaboration.

Sign of the relation	Verbal value	Numerical value
positive	strong	3
positive	medium	2
positive	weak	1
negative	weak	− 1
negative	medium	− 2
negative	strong	− 3

3a) The static analysis. This analysis relates both to the social cognitive map as a whole and to its single components. To analyse the entire map, we used some basic network indexes as 1) the number of variables, which gives an idea of the total size of the map; 2) the number of connections, 3) the density, which measures the total interaction of the variables and their level of cohesion; and 4) the degree of complexity, which is the ratio between the number of variables receiving and transmitting stimuli, and the number of variables that send these stimuli to the rest of the system.

The latter point opens the issue of the role of the variables. According to their position and kind of connections, they can be conceived as, a) senders, i.e., those variables that send stimuli to others but do not receive any; b) transmitters, i.e., variables that gather stimuli from senders and transmit theme to other variables; c) receivers, i.e., that only receive inputs from other variables but does not send theme in turn (Çoban and Seçme, 2005). The punctual indexes used to classify the variables according to these roles are the in- and out-degree and centrality degree. These three network measures of a variable (v_i) are calculated as follows:

$$out_{degree}(v_i) = \sum_{j=1}^{n} w_{i,j} \quad (3)$$

$$in_{degree}(v_i) = \sum_{j=1}^{n} w_{j,i} \quad (4)$$

$$Centrality_{degree}(v_i) = od(v_i) + id(v_i) \quad (5)$$

where n is the number of variables. In other words the in-degree of the variable (v_i). On the other hand, the out-degree accounts for the number of connections exiting the variable.

In other words, the out-degree is the row sum of absolute values of a variable in the normalised social adjacency matrix, and it measures the whole strengths of relation ($w_{i,j}$) exiting the node; while the in-degree is the column sum of absolute values in the matrix, and accounts for the number and magnitude of the connection entering the variable. By summing in- and out-degree, we obtain the centrality of a variable, which measures the whole relational activity of a variable.

Of course, the senders have 0 in-degree and positive out-degree, while receivers have vice versa. The transmitters have both positive in- and out-degree. We expect that this variable feature also reflects their conceptual categorization. In other words, those variables conceived as

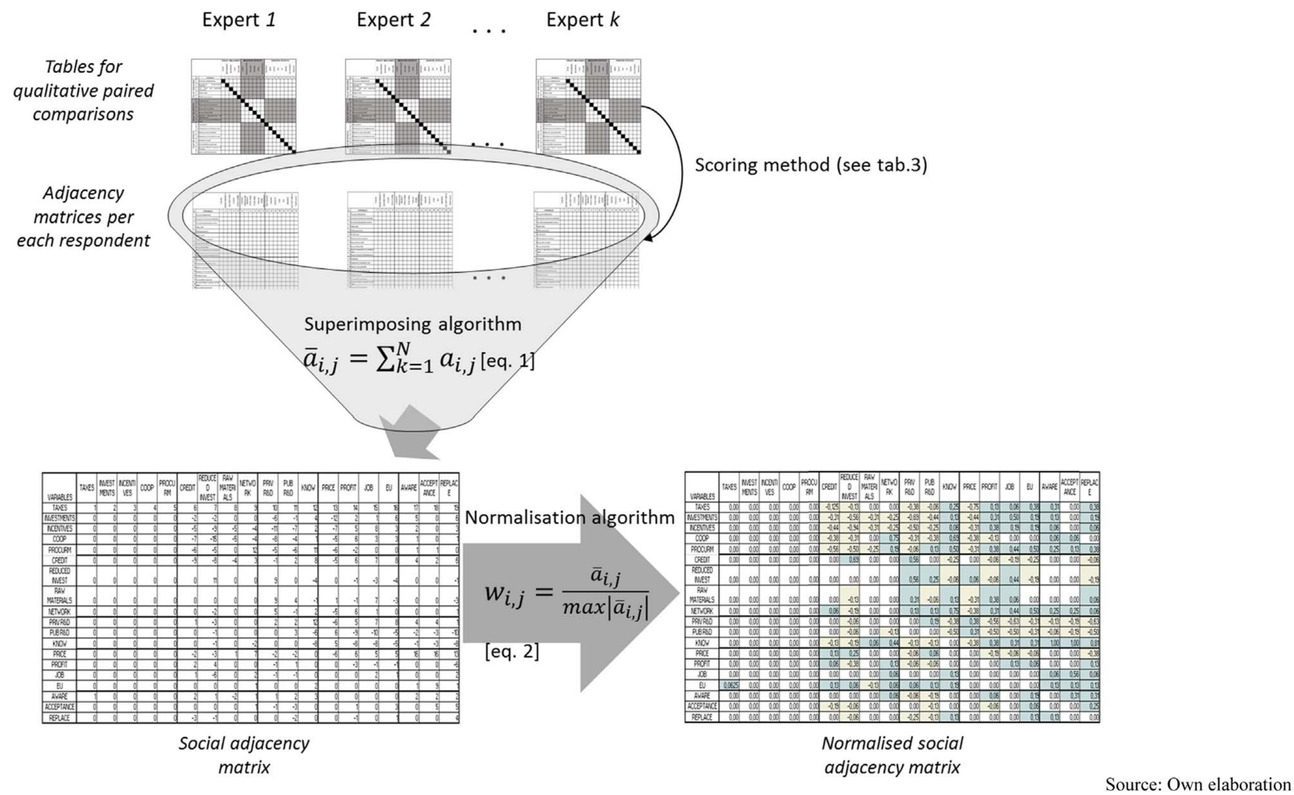


Fig. 5. The fuzzy cognitive mapping process in a nutshell.
Source: Own elaboration.

policy instruments (see Table 1) are expected to exhibit sender type characteristics, while the crisis' effects (positive and negative) are supposed to be transmitters of receivers at least.

3b) The dynamic analysis. The dynamic analysis rests on the so-called fuzzy inference, consisting of the use of a specific back-forward artificial neural network (ANN) (Reimann, 1998). The ANN is built on the social cognitive map obtained in its matrix form, and its elements are (Kok, 2009): a) the system *variables* (v_i); b) the variables *relations* ($v_i \rightarrow v_j$); c) the *variables state*, defined by the state vector $C = (c_1, c_2, \ldots, c_n)$, that assumes values in the range [0, 1]; d) the *normalised social adjacency matrix* ($W = (w_{i,j})$), defined above.

The fuzzy inference is performed by means of a simulation process that has two phases (see Fig. 6), the i) initialisation one, where model input are set, and in particular the variables state vector is fixed at 1 for all the variables; and ii) the iteration phase, where the output of the model is calculated. In particular, the principal output of the fuzzy inference is represented by the dynamics of the state vector. In each iteration, the state vector is multiplied with the adjacency matrix. The new state of the variable v_i at the iteration t is calculated as:

$$v_{i,t} = f\left(v_{i,t-1} + \sum_{j=1}^{n-1} v_{j,t-1} w_{i,j}\right) \tag{6}$$

where $v_{i,t-1}$ and $v_{j,t-1}$ are, respectively, the values assumed by variables i and j at the reiteration t-1, $w_{j,i}$ has the same meaning above, and the

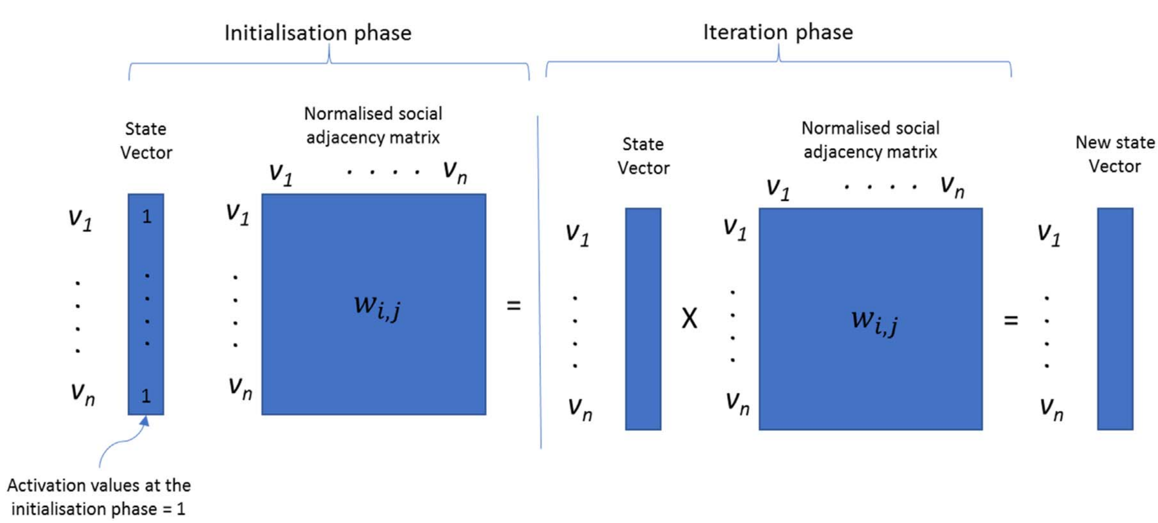


Fig. 6. The fuzzy inference.
Source: Adapted from ⟨http://www.fcmappers.net⟩.

function *f* is a monotonic increasing transformation. As in Ozesmi and Ozesmi (2004), we used the simple the logistic function $1/1 + e_{i,t}^{-V}$.

During the model calculation, four kinds of possible equilibrium can be reached (Kok, 2009): (1) the values collapse, that is all theme converge to zero; (2) the values explode, that is all variables continuously increase; (3) values flows towards a limit cycle, assuming periodically the same value; (4) values rest at a constant value, that is the final state of the variables. This final state is called *steady state* that is the value at which the variable is at its equilibrium and cannot change more).[2] The structure of the equation used here allows for the search of variables steady state that is the main ANN output. The steady state of a variable can be interpreted as the importance of that variable within the system as perceived by the respondents. Thus, the comparison of the steady states allows obtaining an idea of the internal evolution path of the system, that is, where the system will go without external intervention. The policy analysis can be then performed maintaining at their maximum the value of certain variables (those representing policy instruments) during the simulations. Then, the difference between the new variables state with their steady state can be interpreted as the effect of the policy intervention.

4. Results

4.1. The analysis of the niche

By implementing a stakeholder analysis, we were able to identify 21 biofuel producers (18 biodiesel producers and 3 bioethanol producers), 1 of which is a second-generation biofuel producer (world-first commercial-scale cellulosic ethanol plant). Table 3 below shows the full list of biofuel producers.

Table 3
Italian biofuel producers.
Source: Own elaboration on Assocostieri (2015).

Producers	Type of biofuel	Location
ALCHEMIA ITALIA SRL	Biodiesel	Rovigo (RO)
BIO.VE.OIL OLIMPO SRL	Biodiesel	Corato (BAT)
CAFFARO BIOFUEL SRL	Biodiesel	Udine (UD)
CAVIRO DISTILLERIE SRL	Bioethanol	Faenza (RA)
CEREAL DOCKS SRL	Biodiesel	Camisano Vicentino (VI)
COMLUBE SRL	Biodiesel	Castenedolo (BS)
DP LUBRIFICANTI SRL	Biodiesel	Aprilia (LT)
ECOIL SRL	Biodiesel	Augusta (SR)
FOX PETROLI	Biodiesel	Pesaro (PU)
FOREDBIO SPA	Biodiesel	Nola (NA)
ECO FOX SRL	Biodiesel	Vasto (CH)
I.M.A. SRL	Bioethanol	Partinico (PA)
ITAL BI OIL SRL	Biodiesel	Monopoli (BA)
ITAL GREEN OIL	Biodiesel	San Pietro di Morubio (VR)
GDR BIOCARBURANTI	Biodiesel	Cernusco sul Naviglio (MI
MYTHEN SPA	Biodiesel	Ferrandina (MT)
NOVAOL SRL	Biodiesel	Porto Corsini (RA)
OIL.B SRL	Biodiesel	Solbiate Alona (VA)
MASOL CONTINENTAL BIOFUEL SRL	Biodiesel	Livorno
MOSSI AND GHISOLFI	Bioethanol 2nd gener.	Crescentino (VC)
IM BIOFUEL ITALY Srl	Biodiesel	Milano

Moreover, by means of web-sites, reports, and documents concerning the biofuel niche in Italy, we have identified a further 30 actors that allowed us to better represent the Italian biofuel industry. Therefore, the final list of actors includes 51 actors, 21 of which are biofuel producers, 6 biofuel suppliers, 7 biofuel distributors, and 17 biofuel-related organisations (e.g. national authorities, universities, NGOs, etc.).

Biofuel producers were then surveyed online from February to May 2015 with the aim of collecting information about their networking activity as well as their opinion about the changes occurred to the sector from 2007 to 2014 because of the economic crisis. We received back 11 complete questionnaires for a response rate of 52.3% The specific questionnaire design and the use of the SNA research method allowed partially overcoming the problem of missing answers. For instance, if actor A declared to have a 'communication' relationship with actor B, this implies that actor B also has the same kind of relationship with actor A (bidirectionality). In this way, it was possible to draw the general picture of the niche architecture in terms of relations among actors, despite some of them refused to be surveyed or returned an incomplete or invalid questionnaire.

The results achieved from the questionnaire were analysed by means of the UCINET 6 software package and used to carry out a twofold analysis. Firstly, we considered the biofuel network of communication disregarding attributes and examining the structural differences when moving from 2007 to 2014 (i.e. before and during the economic crisis). Secondly, we also focused on the actor's typicality, which is characterized by single or multiple attributes.

A visual inspection of the communication network reported in Fig. 7 allows us to notice that the actual density of connections reduces slightly when passing from the 2007 to the 2014 network. Overall, three actors stay out of the network, with the inclusiveness index (see Table 4) decreasing from 96% to 94%. This early finding would suggest that, despite the recent economic crisis, the Italian biofuel network appears to be well connected, with more than 90% of all potential connections among actors actually used in order to communicate and share information concerning the biofuel niche.

Moreover, looking at the architectural structure of the niche, a moderate change occurs when moving from 2007 to 2014. In particular, focusing on the latter network, the general framework turns out to be more linked (the number of ties increases from 219 to 288) and clustered (the clustering coefficient increases about 4%), with a number of actors (mainly biofuel producers) directly connected with the central clique. Finally, looking at the core of the communication network, some organisations (two in 2007 and one in 2014) reach a crucial position in the network, revealing that, jointly with a restricted number of producers, further actors (mainly organisations) gain a central role in communicating within the Italian biofuel niche.

Looking at the above key indicators for the Italian biofuel networks of communication, we can observe a quite similar trend for the considered indicators. Overall, inclusiveness, density and average degree indexes seem to confirm an improvement of the networks' cohesion. In particular, if we compare the values of the average degree index with regard to the communication networks before and during the crisis, namely 4.6 (2007) and 5.6 (2014), we can notice an increase in the average power of communication among actors. Briefly, the communication network becomes more and more clustered since, on average, every actor communicates with one more actor. This brings actors to muster around their trade association (*Assocostieri*) whose function in channeling the exchange of knowledge among actors turns out to be more and more relevant for the potential development of the biofuel niche.

Looking at actors' typicality, networks can display different relationship types among nodes that are characterized by single or multiple *attributes.* Analysis of the attribute enriches our understanding of the Italian biofuel social networks and enables us to further explore some actors' attitudes and typicality. In order to better depict the collaborative networks existing among different actors, we have decided to look at the effects of two network attributes, namely, *knowledge* and *expectations.* For the appraisal of these attributes, we took into account

[2] In other words, the steady state value for the variable v_i is the same at *t1* and *t2* (i.e. two subsequent steps in the model reiteration).

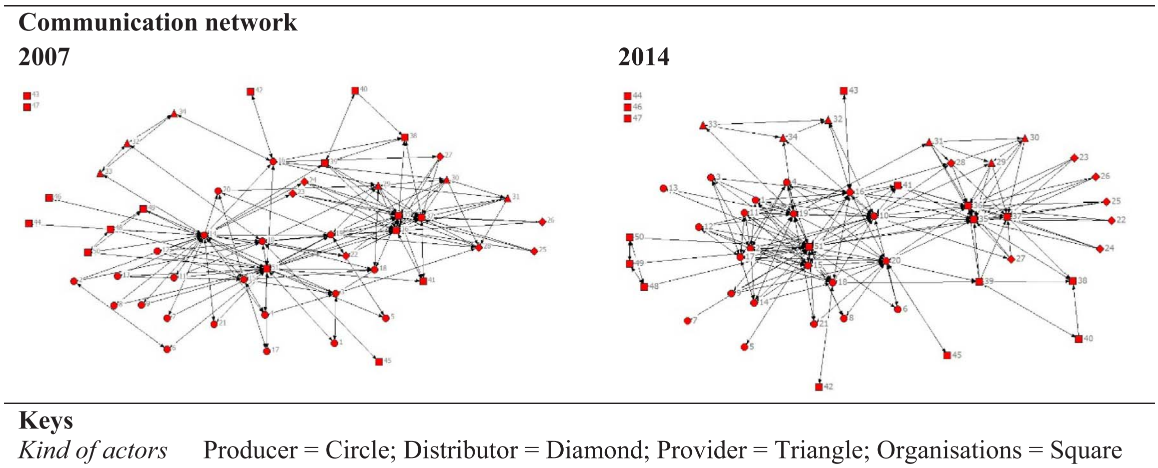


Fig. 7. General architectural features of the Italian biofuel network (2007 versus 2014).
Source: Own elaboration.

Table 4
The Italian biofuel networks – *key indicators.*
Source: own elaboration.

	Communication network	
Years	**2007**	**2014**
Number of ties	219	288
Density	0.094	0.113
Inclusiveness (%)	96.07	94.01
Average degree	4.686	5.647
Clustering coefficient (overall graph)	0.566	0.592

the first section of the questionnaire related to the general information about the respondents.

Table 5 provides an overview of the attribute distribution concerning respondent actors.

At first sight, we observe that the knowledge attribute is, overall, greater than the expectations attribute.

In Fig. 8 we report the *communication* network, considering both *knowledge* and *expectations* attributes.

Looking at the communication network in 2014, and focusing on the *expectation* and *knowledge* attributes, we notice a group of central actors (both producers and organisations) showing a low degree of expectations about the future replacement of the current fossil based socio-technical regime in comparison with 2007. Such a finding is a critical issue of the network structure with reference to the upward convergence of expectations essential for an innovation niche to break through. Moreover, since these key actors also exhibit a high degree of knowledge, the concern appears to be even more serious. Indeed, the presence of a group of well-informed and connected actors is completely offset by the low degree of expectations about the future development of the biofuel niche given the negative impact of the recent economic crisis on their business activity. This represents a significant weakness of the investigated niche that could effectively hamper the on-going process of energy transition in Italy.

A further result arising from the graphic analysis is related to a certain misallocation of resource within the system. In fact, a non-negligible group of very knowledgeable subjects is peripheral or completely detached from the central component of the network, therefore causing them to be unable to give their contribution to the niche development. Again, these “misplaced” resources might, hypothetically, support the niche development but, for some reason, are inhibited in their action by the architectural features of the studied network.

Table 5
Attribute distributions.
Source: own elaboration.

		Knowledge about the niche	Expectations about the niche
Producers	Very low	0	9
	Low	0	0
	Medium	0	9
	High	21	3
Distributors	Very low	0	0
	Low	1	4
	Medium	6	3
	High	0	0
Providers	Very low	0	0
	Low	0	3
	Medium	0	3
	High	6	0
Institutions	Very low	3	0
	Low	2	0
	Medium	1	13
	High	11	4

4.2. *The identification of the effective instrument mixes*

4.2.1. *Static analysis*

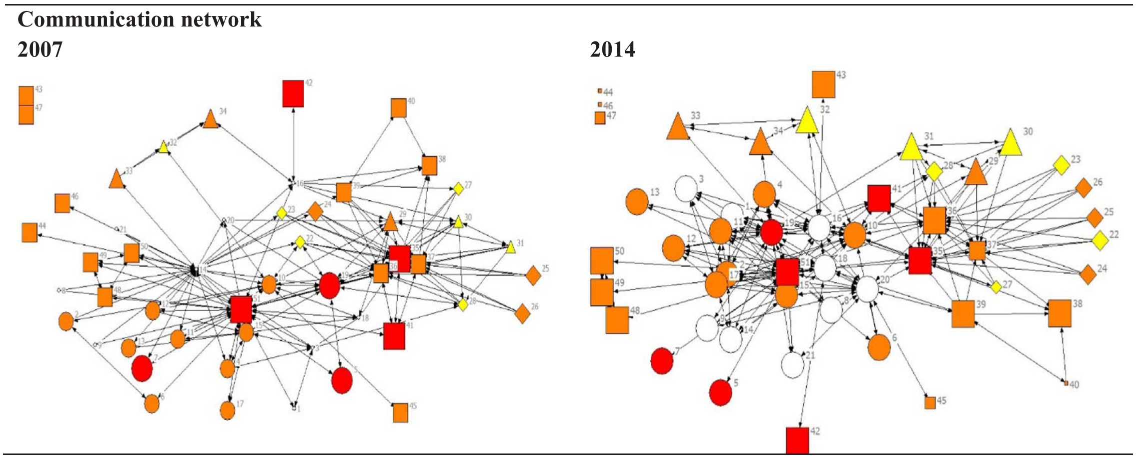
This step revealed some key features of the social cognitive map. The structural issues are summarized in Table 6. The variables of the system are seen to be very connected, with 180 cause-effect relationships. The index of complexity was calculated as the ratio between the transmitters and the senders. It is rather high, and indicates that relatively few forcing functions control many variables.

How representative is this framework? To determine if the embedded knowledge of this system has been sufficiently sampled in choosing the respondents, we examined the number of connections recognised by each respondent (Table 7). We then derived the accumulation curve of the number of new connections added to the social map versus the number of interviews (Fig. 9).

The figure shows that as the number of experts increases the number of new relationships connecting the variables decreases. This is due to an accumulation mechanism of the embedded knowledge of the experts that stratifies progressively as the number of interviews augments. As shown, the last interview does not add up to the social map in terms of new connections. This indicates that the system is depicted at a sufficient level of accuracy, generated a comprehensive framework that cannot be captured by any individual participant.

Table 8 contains the network information related to the single component of the map.

These data empirically confirm the rationality of the theoretical



Keys	
Kind of actors	Producer = Circle; Distributor = Diamond; Provider = Triangle; Organisation = Square
Knowledge	High = Big Size; Medium = Medium size; Low = Small Size; Very Low = Very Small Size
Expectations	High = Red; = Medium = Orange; Low = Yellow; Very low = White

Fig. 8. Communications network with attributes (Actors-Expectations-Knowledge – 2007 and 2014).
Source: Own elaboration.

Table 6
Map indexes.
Source: Own elaboration.

Network index	Value
1 – Number of variables	19
2 – Number of Connections	180
3 – Density	0.50
4 – Index of Complexity	3.75

Table 7
Number of connections per interviews.
Source: Own elaboration.

Interviews	Number of connection recognised	Number of new connections
Expert 1	104	104
Expert 2	101	44
Expert 3	71	21
Expert 4	61	10
Expert 5	57	4
Expert 6	57	0

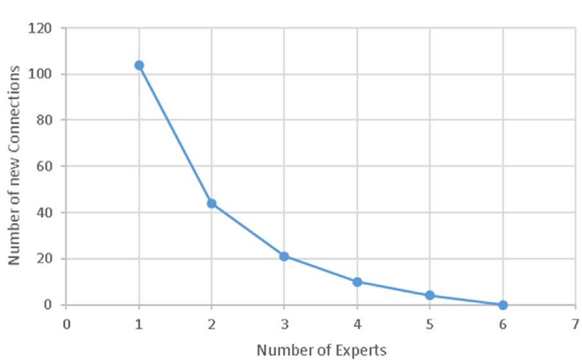


Fig. 9. Number of new connections – accumulation curve.
Source: Own elaboration.

Table 8
Variables network indexes.
Source: Own elaboration.

id	Variable	Out-degree	In-degree	Centrality	Kind
1	TAX	2,94	0,06	3,00	Transmitter
2	INV	4,44	0,00	4,44	Sender
3	INC	3,94	0,00	3,94	Sender
4	COO	3,44	0,00	3,44	Sender
5	PRO	4,56	0,00	4,56	Sender
6	CRED.CRUNCH	2,06	2,50	4,56	Transmitter
7	REDUCED INVEST	1,81	4,56	6,38	Transmitter
11	RED.PRIV R & D	1,44	1,06	2,50	Transmitter
12	RED.PUB R & D	3,44	2,31	5,75	Transmitter
8	RED.PRICE	3,44	4,13	7,56	Transmitter
9	RAW.MAT.RED.PRICE	3,06	2,69	5,75	Transmitter
13	NETWORK	5,25	4,13	9,38	Transmitter
10	KNOWL.	1,19	4,00	5,19	Transmitter
14	PROFIT	1,00	3,88	4,88	Transmitter
15	JOB	0,88	3,94	4,81	Transmitter
16	EU.TARGET	1,19	3,63	4,81	Transmitter
17	GREENAWAR.	1,19	2,56	3,75	Transmitter
18	SOCIAL.ACCEPT.	0,75	2,81	3,56	Transmitter
19	FOS.FUEL.REPLAC.	0,81	4,56	5,38	Transmitter

framework presented in Table 1 concerning the identification of the variables of the biofuel sector and their nature. Indeed, by comparing Tables 8 and 1 it emerges that those variables classified as senders in Table 8, were correctly identified as "policy instruments" in Table 1 (excepting for TAXES that, although is a transmitter, has a very low in-degree (0,06)). This means that, as expected, the respondents implicitly considered these variables as controlling forces that can be properly intended as policy drivers. This analysis validates the social map drawn as a robust computational model for policy simulations, providing the rational basis for single driver policies and instrument mixes simulation as reported below.

4.2.2. Dynamic analysis

The dynamic analysis gives information both on the importance of the variables of the system themselves and on the potentiality of policy intervention. Table 9 tidies up the crisis effects according to the value of their steady state It emerges that among the negative impacts, the major threats for the experts are the reduction of public and private R & D and the credit crunch. At the same time, among the variables representing positive impacts, the most important are the social acceptance of new plants, the green awareness and the positive expectation toward the fossil fuel replacement. Other potential favorable effects are the increase of the technical knowledge in the sector, the achieving of the EU targets and green job opportunities. The variables exhibiting the

Table 9
The steady state of the variables representing the crisis effects.
Source: Own elaboration.

Negative impacts	Steady state	Positive impacts	Steady state
RED.PUB R & D	0,322769053	SOCIAL.ACCEPT.	0,845784692
RED.PRIV R & D	0,292538619	GREENAWAR.	0,826784976
CRED.CRUNCH	0,276717453	FOS.FUEL.REPLAC.	0,811386552
RED.PRICE	0,174334587	KNOWL.	0,795860885
REDUCED INVEST	0,159368502	EU.TARGET	0,780557129
		JOB	0,713795081
		PROFIT	0,689933383
		NETWORK	0,680898877
		RAW.MAT.RED.PRICE	0,380994708

greatest room for improvement (i.e., they have a relatively low steady state) are the sector profits, networking and the reduced price of raw materials.

How can this intricate bulk of effects be managed in a desirable way? The policy analysis based on the fuzzy inference above described helps to find viable paths.[3] The simulated effects of the activation of the i) single policy instruments and of ii) their combination in instrument mixes are summarized in Figs. 10 and 11 respectively.[4] In the panels, there is a bar per each variable measuring the difference between its new state and its steady state, and represents the effect of policy. In interpreting these measures, it should bear in mind that the policy instruments analysed, at the present, are at various stages of application (see details on *Stage of application* in Table 1).

Fig. 10 shows the effects of the single policy instruments on the negative (panel A) and positive (panel B) variables of the system.

In general, the policy instruments appear to be able to mitigate the negative effects and favor the positive ones with some interesting exceptions. Panel A concentrates on the negative variables. As shown, all the measures exhibit a certain degree of effectiveness against the major crisis threats (Panel A). The complexity of the operation is well represented by the use of public procurement (PRO) that has conflicting outcomes. While it is seen as the most effective measure in mitigating the credit crunch, it is also perceived as a factor that can worsen the reduction of the public R & D. At the same time, this last issue can be looked at favorably when employing investments and infrastructural subsidies (INV) and Cooperation (COO) that foster interaction among enterprise and public research institutes. Finally, the reduction of private R & D is mitigated by tax relief and production incentives (INC) and investments and infrastructural subsidies (INV).

Panel B reports the effects of policy instruments on those variables identified as positive effects, and highlights some contrasting results. First, it results that the best profit enablers are represented by the policy instruments of tax relief and production incentives (INC), investments and infrastructural subsidies (INV), and public procurement (PRO), but all these measures have negative side effects on the potential for networking and the price of raw materials. The investments and infrastructural subsidies (INV) are also assumed to foster the creation of green job opportunities. The principal driver for knowledge increase is the cooperation (COO) that also has a positive effect on the networking activities. The measure that is better able to activate the social part of the system (green awareness, social acceptance, and expectation on the

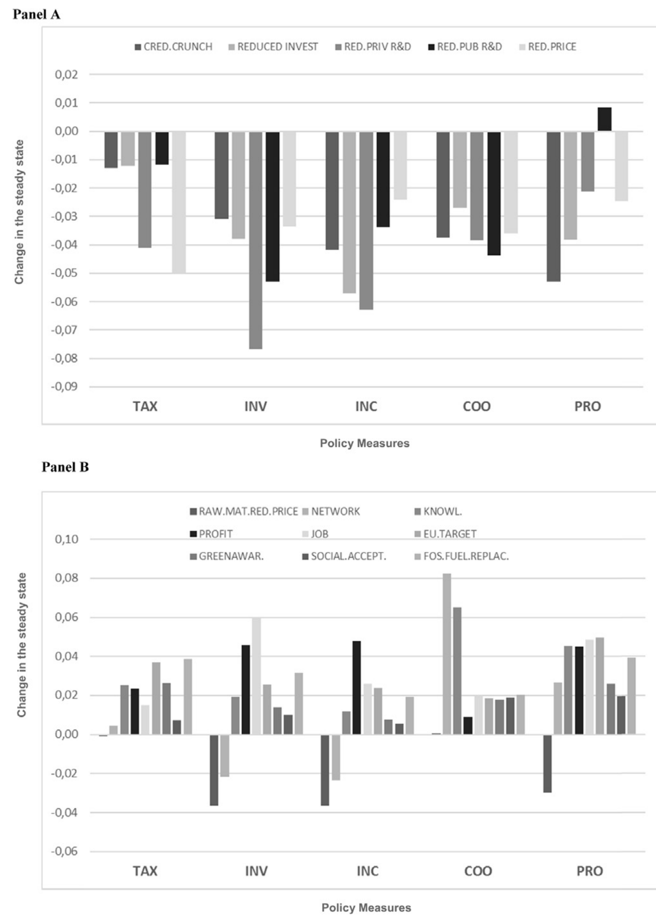


Fig. 10. The effects of policy instruments.
Source: Own elaboration; for abbreviations meaning see Table 2.

replacement) is the public procurement (PRO), which is conceived as a source for income diversification and integration.

The analysis of the potentiality of these policy instruments is completed with the simulation of instrument mixes, which are the combinations of the different instruments in mixes of two, three, four, and five. These are shown in Fig. 11. It reports all the mixes of policy instruments taken two at time, and the most important mixes (those with higher impact) formed of three and four measures.

The top side of the picture (panels A and B) reports the mitigating effects of the mixes (reduction of negative variables), while the bottom side (panels C and D) focuses on the reinforcement of the positive variables. The left side of the picture (panels A and C) contains ten mixes (drivers taken two by two), the right side (panels B and D) reports the mixes formed of three, four and five drivers. The picture shows that the mixes have self-reinforcing effects. Indeed, the contemporary use of several driving forces enlarges the positive actions of the policy but can also accentuates possible side effects. Of course, the most important action is exerted when all the drivers are used together. This mix can reach the largest reduction for the variable reduced private R & D, and the higher values for profit and job. The comparison of the instrument mixes offers a useful information basis to find the best-tailored policy strategy with respect to multiple objectives.

5. Discussion

As argued in Section 3, the occurrence of the three niche basic processes (i.e. convergence of expectations, learning, and networking) is strictly required for a niche to develop. According to Caniels and Romijn (2008), such mechanisms strictly interact with each other, as

[3] Thus, the measures here presented are based on specific calculation procedure and are not the direct results of expert opinion. The expert opinions were used only in the early stage of the analysis to define cause-effect relations between variables, with the end of drawing a social cognitive map of the system. The effects of the single policy instruments and their mixes have been simulated by means of a fuzzy inference procedure (see note 3). Thus, it can be said that results reflect expert perception of the system. Limitation of this procedure is briefly discussed in the conclusions.

[4] As explained in Section 3, we performed the policy simulation by maintaining at their maximum (that is 1) the values of those variables representing policy instruments during all the steps of model runs. Then, the difference between the new variables state with their steady state can be interpreted as the effect of the policy intervention.

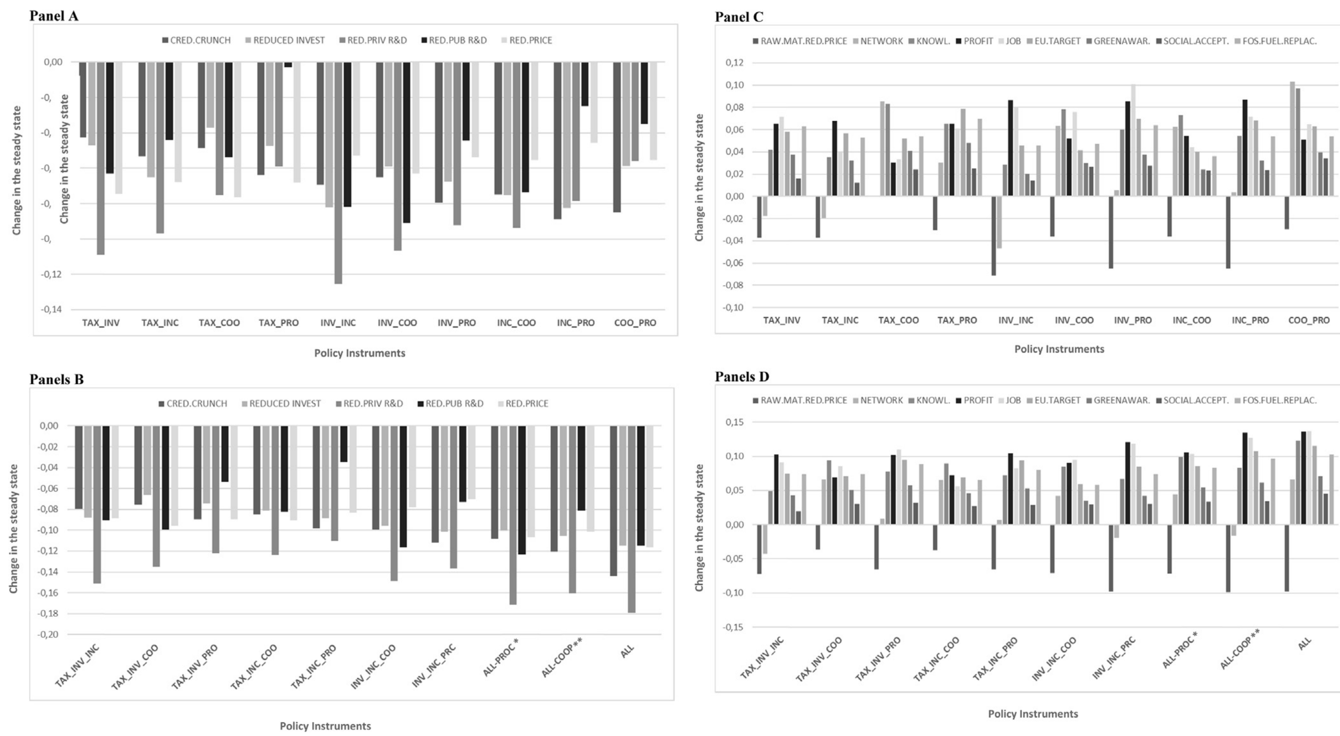


Fig. 11. The effects of instrument mixes.
Source: Own elaboration; * all instruments excepted public procurement; ** all instruments excepted cooperation; for abbreviation meaning see Table 2.

learning and convergence of expectations can succeed whether or not a high degree of networking among actors occurs, and the existence of an adequately relational structure might play a key role for a successful learning mechanism and an increasing convergence of actors' expectations.

In such context, the SNA carried out highlights two major shortcomings in the niche development process:

1. The level of expectations, particularly for those actors located at the core of the network, has significantly decreased;
2. The level of knowledge is augmented, but several well-informed actors rest in a very peripheral position, providing only a limited contribution to the learning process;

Therefore, a clear need for an increase in expectation toward the further development of the sector emerges, as well as a need for a tailored networking, devoted at attracting specific knowledgeable actors.

From this perspective, results achieved from the FCM show that policy instruments can dissimilarly affect the different elements characterizing the Italian biofuel industry. This requires to be very carefully in designing instrument mixes especially from a strategic niche management viewpoint, since, as the results show, some policy instruments can have contradictory effects on the niche development. More specifically, fiscal-oriented measures, which are particularly useful in the short-run, can result scarcely effective in supporting the biofuel niche development in the medium-long term. This is the case of investments and incentives measures that instead of fostering the development of the niche, negatively affect the networking activity within the sector, and at the same time are quite inefficient in stimulating the learning mechanism. In other words, although drivers can be used in the short run to revive the biofuel actors' profits abated by the recent economic crisis, they can produce distortive effects on the biofuel sector development in the medium and long run, by eroding crucial niche mechanisms (i.e. networking) or making them stagnant (i.e. learning). Consequently, instrument mixes designed to foster the immediate recovery of biofuel companies should be well-balanced by including those policy instruments capable to trigger niche mechanisms for not preventing the full sector development in the medium-long run. To this end, policy intervention should focus on those drivers that positively impact the network and the expectation variables, namely "NETWORK" and "FOS.FUEL.REPLAC" more than others. Looking at Fig. 10 (panel B), these drivers are the cooperation (COO) that, as expected, has the best outcome in terms of networking, and the public procurement (PRO) that remarkably increases the level of expectation. As shown in Fig. 11 (panel C), their combination (COO_PRO) can exert synergistic effects on the niche mechanisms of networking and convergence of expectations. The matching of the two steps of the analysis allows hence the identification of the appropriate mix of instruments in the specific situation analysed.

6. Conclusions

Governing transitions towards a new sustainable energy regime involves a number of challenges for policymakers who are called to identify the effective instrument mixes to foster the transition process. Such government challenges are particularly complex during economic crises when policymakers also face the problem of dealing with the economic downturn. From this viewpoint, the present paper has investigated which instrument mixes are effective for a sustainable energy transition to occur in times of economic crisis.

To this end, we have explored the case of the Italian biofuel niche, implementing a two-step investigation. In the first step, we have analysed the development needs of the Italian biofuel sector by running a SNA aimed at studying the impact of the recent economic crisis on niche development mechanisms. In the second step, we have identified the potential policy instruments to foster the niche development, by employing a FCM method to understand the effective mix of instruments that can contribute to drive the transition towards a decarbonized energy.

Our results provide evidence that:

1. The recent economic crisis has negatively affected the Italian biofuel

sector, by reducing both expectations and knowledge of involved actors, jeopardising thus the transition process to a sustainable energy regime.
2. Policy instruments can differentially impact the sector under investigation. Fiscal policies are slightly effective particularly in fostering the biofuel niche development in the medium-long term, while they are particularly useful in the short-run.
3. Instrument mixes should be well-balanced by looking at those policy instruments that support the niche-development mechanisms so as not to preclude the biofuel energy transition in the medium-long run.
4. Cooperation activity among firms, public organisations, and research institutions, along with public procurement are particularly effective in supplementing fiscal policies by exerting synergistic effects on the niche mechanisms of networking and convergence of expectations.

Overall, our investigation suggests that any policy intervention should exclude, or at least carefully use, policy instruments that can further reduce the networking process. Reasonably, the effective instrument mixes to drive the transition towards a new sustainable energy system should be addressed towards those drivers that positively impact the network and the expectation variables, namely cooperation and public procurement. Such results support the need for a policies combination to overcome the limitations of one-fits-all approaches. In this vein, this study enables the identification of the most tailored mixes to deploy the synergistic effect of the policy instruments' interaction. From this perspective, the FCM represents a flexible tool for designing instrument mixes in contexts with asymmetric information and unpredictability (e.g. how the economic crisis will evolve in the next years), but also in the case of policy and sustainability contentions (e.g. the biofuel sector development) (Falcone et al., 2017).

One issue concerning this methodology is represented by the validation of the model obtained from experts' opinions. Validation refers to establish how representative of the system realism the map is. Proven its qualitative nature, statistical validation cannot be applied. The method adopted in this work refers to the accumulation curve of the number of new connections added to the social map versus the number of interviews. Moreover, following Ozesmi and Ozesmi (2004), validation can be performed by empirical comparison with real phenomenon (i.e. reality check). Finally, it should bear in mind the qualitative nature of the model implies that policy instruments' impacts can be only compared, and not measured in terms of targets reached. This directly reflects on the usability of the model that, within a typical policy process framework, primarily relates to the phase of policy formulation rather than the phase of policy budgeting. In other words, the model can help in recognizing the best policy combinations but cannot be used in calculating the funding of each policy instrument. Nonetheless, this approach is fundamental to give clear direction to the policy making process.

Future empirical studies could apply our two steps methodology to other sectors that are relevant for sustainability transitions (e.g. bioplastic, waste) in order to define a comprehensive set of policy instruments that can positively foster a full sustainable energy transition.

References

Antal, M., Van Den Bergh, J.C.J.M., 2013. Macroeconomics, financial crisis and the environment: strategies for a sustainability transition. Environ. Innov. Soc. Transit. 6, 47–66.

Assocostieri, 2015. Biodeisel producers. 〈http://www.assocostieribiodiesel.com/bio/statistiche/〉, (Accessed 16 September 2005).

Borrás, S., Edquist, C., 2013. The choice of innovation policy instruments. Technol. Forecast. Soc. Change 80, 1513–1522.

Caniels, M.C.J., Romijn, H.A., 2008. Actor networks in strategic niche management: insights from social network theory. Futures 40, 613–629.

Çoban, O., Seçme, G., 2005. Prediction of socio-economical consequences of privatization at the firm level with fuzzy cognitive mapping. Inf. Sci. 169, 131–154.

Costantini, V., Crespi, F., Palma, A., 2017. Characterizing the policy mix and its impact on eco-innovation: a patent analysis of energy-efficient technologies. Res. Policy 46, 799–819.

Costa-Campi, M.T., Garcia-Quevedo, J., Trujillo-Baute, E., 2015. Challenges for R & D and innovation in energy policy. Energy Policy 83, 193–196.

Dassisti, M., Carnimeo, L., 2013. A small-world methodology of analysis of interchange energy-networks: the European behaviour in the economical crisis. Energy Policy 63, 887–899.

del Río González, P., 2007. The interaction between emissions trading and renewable electricity support schemes: an overview of the literature. Mitig. Adapt. Strateg. Glob. Change 12 (8), 1363–1390.

EU Sustainlabour, 2013. Green Jobs and Related Policy Frameworks: An Overview of the European Union. (Accessed 16 September 2005). 〈http://www.sustainlabour.org/〉.

Falcone, P.M., 2014. Sustainability transitions: a survey of an emerging field of research. Environ. Manag. Sustain. Dev. 3 (2), 61–83.

Falcone, P.M., Lopolito, A., Sica, E., 2017. Policy mixes towards sustainability transition in the Italian biofuel sector: dealing with alternative crisis scenarios. Energy Res. Soc. Sci. http://dx.doi.org/10.1016/j.erss.2017.09.007.

Falcone, P.M., Sica, E., 2015. How much does economic crisis affect sustainability transitions? A social network analysis of the Italian biofuel sector. Econ. Reg. 1, 264–270.

FocusEconomics, 2017. Italy economic outlook. 〈http://www.focus-economics.com/countries/italy〉, (Accessed 20 June 2017).

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274.

Geels, F.W., 2013. The impact of the financial-economic crisis on sustainability transitions: financial investment, governance and public discourse. Environ. Innov. Soc. Transit. 6, 67–95.

Grubb, M., Ulph, D., 2002. Energy, the environment, and innovation. Oxf. Rev. Econ. Policy 18, 92–106.

Gunningham, N., Grabosky, P., 1998. Smart Regulation Designing Environmental Policy. Oxford University Press, New York.

Gunningham, N., Sinclair, D., 1999. Integrative regulation: a principle-based approach to environmental policy. Law Soc. Inq. 24 (4), 853–896.

Hansen, U.E., Nygaard, I., 2014. Sustainable energy transitions in emerging economies: the formation of a palm oil biomass waste-to-energy niche in Malaysia 1990–2011. Energy Policy 66, 666–676.

Hemmelskamp, J., 1997. Environmental policy instruments and their effects on innovation. Eur. Plan. Stud. 52, 177–193.

Hildingsson, R., Johansson, B., 2016. Governing low-carbon energy transitions in sustainable ways: potential synergies and conflicts between climate and environmental policy objectives. Energy Policy 88, 245–252.

Howlett, M., Rayner, J., 2007. Design principles for policy mixes: cohesion and coherence in 'new governance arrangements', Policy Soc. 26 (4), 1–18.

International Energy Agency, 2009. The Impact of the Financial and Economic Crisis on Global Energy Investment. (Accessed 16 September 2015). 〈https://www.iea.org/publications/freepublications/publication/the-impact-of-the-financial-and-economic-crisis-on-global-energy-investment.html〉.

Intesa San Paolo, 2015. Report on the Bioeconomy in Europe. (Retrieved at: 〈http://www.group.intesasanpaolo.com/scriptIsir0/si09/sostenibilita/ita_studi_ambiente.jsp#/sostenibilita/ita_studi_ambiente.jsp〉, Accessed 20 June 2017).

Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technol. Anal. Strateg. Manag. 10, 175–195.

Kern, F., Howlett, M., 2009. Implementing transition management as policy reforms: a case study of the Dutch energy sector. Policy Sci. 424, 391–408.

Kivimaa, P., Kern, F., 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Res. Policy 451, 205–217.

Kok, K., 2009. The potential of fuzzy cognitive maps for semi-quantitative scenario development, with an example from Brazil. Glob. Environ. Change 19 (1), 122–133.

Kosko, B., 1986. Fuzzy cognitive maps. Int. J. Man-Mach. Stud. 24, 65–75.

Kosko, B., 1992. Fuzzy associative memory systems. In: Kandel, A. (Ed.), Fuzzy Expert Systems. CRC Press, Boca Raton, pp. 135–162.

Loorbach, D.A., Lijnis Huffenreuter, R., 2013. Exploring the economic crisis from a transition management perspective. Environ. Innov. Soc. Transit. 6, 35–46.

Lopolito, A., Morone, P., Sisto, R., 2011. Innovation niches and socio-technical transition: a case study of bio-refinery production. Futures 43, 27–38.

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 416, 955–967.

Mattes, J., Huber, A., Koehrsen, J., 2015. Energy transitions in small-scale regions – what we can learn from a regional innovation systems perspective. Energy Policy 78, 255–264.

O'Riordan, T., 2013. Sustainability for wellbeing. Environ. Innov. Soc. Transit. 6, 24–34.

Ozesmi, U., Ozesmi, S.L., 2004. Ecological models based on people's knowledge: a multistep fuzzy cognitive mapping approach. Ecol. Model. 176, 43–64.

Peng, Z., Peng, J., Zhao, W., Chen, Z., 2015. Research on FCM and NHL based high order mining driven by big data. Math. Probl. Eng.

Perez, C., 2013. Unleashing a golden age after the financial collapse: drawing lessons from history. Environ. Innov. Soc. Transit. 6, 9–23.

Pries, F., Talebi, A., Schillo, R.S., Lemay, M.A., 2016. Risks affecting the biofuels industry: a US and Canadian company perspective. Energy Policy 97, 93–101.

Reichardt, K., Rogge, K., 2016. How the policy mix impacts innovation: findings from company case studies on offshore wind in Germany. Environ. Innov. Soc. Transit. 18, 62–81.

Reimann, S., 1998. On the design of artificial auto-associative neural networks. Neural Netw. 11, 611–621.

Quitzow, R., 2015. Assessing policy strategies for the promotion of environmental

technologies: a review of India's National Solar Mission. Res. Policy 44 (1), 233–243.
Rip, A., Kemp, R., 1998. Technological change. In: Rayner, S., Malone, L. (Eds.), Human Choice and Climate Change. Batelle Press, Washington D.C, pp. 327–399.
Rogge, K.S., Reichardt, K., 2016. Policy mixes for sustainability transitions: an extended concept and framework for analysis. Res. Policy 45, 1620–1635.
Smith, K., 2000. Innovation as a systemic phenomenon: rethinking the role of policy. Enterp. Innov. Manag. Stud. 11, 73–102.
Solomon, B.D., Krishna, K., 2011. The coming sustainable energy transition: history, strategies, and outlook. Energy Policy 39, 7422–7431.
Sovacool, B.K., 2009. The importance of comprehensiveness in renewable electricity and energy-efficiency policy. Energy Policy 37, 1–1529.
Uyarra, E., Shapira, P., Harding, A., 2016. Low carbon innovation and enterprise growth in the UK: challenges of a place-blind policy mix. Technol. Forecast. Soc. Change 103, 264–272.
van den Bergh, J.C.J.M., 2013. Economic-financial crisis and sustainability transition: introduction to the special issue. Environ. Innov. Soc. Transit. 6, 1–8.
van der Ploeg, F., Withagen, C., 2013. Green growth, green paradox and the global economic crisis. Environ. Innov. Soc. Transit. 6, 116–119.
Wasserman, S., Faust, K., 1994. Social Network Analysis: Methods and Applications. Cambridge University Press, Cambridge, ENG and New York.
Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change: combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. Res. Policy 41, 1037–1047.
Ziegler, A., Rennings K., 2004. Determinants of environmental innovations in Germany: do organizational measures matter? A discrete choice analysis at the firm level. ZEW Discussion Paper No. 04-30. Centre for European Economic Research, Mannheim.