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Method Article

A Combined method to model policy interventions for local communities based on people knowledge



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A B S T R A C T

Policy interventions to promote innovative industries in peripheral regions are often hampered by lack of information on the functioning of the local socio-economic systems, due to their complexity. This might result in mismatches between policy objectives and the actual needs and capability of local communities. To overcome this drawback, it is crucial to obtain appropriate knowledge on the local system, which nevertheless is typically embedded in local actors' minds in uncoded and tacit form. Fuzzy Cognitive Maps (FCMs) have been employed to decode this kind of knowledge in a reproducible manner. However, some problems remain as to how to integrate the necessary vagueness of local actors' heuristic with experts' knowledge into a rational framework.

The following methodology customization is proposed:

- Combine the FCMs with the Discourse Analysis to obtain relevant narratives (i.e. concepts, visions, insights, etc.) needed to define system boundaries and variables.
- Employ individual interviews – rather than a participatory approach – to define the causal relations among system variables.
- Integrate tacit and uncoded knowledge embedded in local actors within experts' scientific knowledge.

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Method details

The FCMs approach [8, 14] is a technique which allows: (i) gathering information on variables and interactions forming a complex system; (ii) representing the system as a computational model; (iii) analyzing future evolution of the system by means of fuzzy inference. This approach has been applied to a variety of problems such as climate change, drought forecast, landscape change, sustainable transition, rural development planning – to cite only some recent works see: [2, 4, 5, 10–13]. The principal output of the FCM is a map representing the causal relations among the system components as perceived by the actors forming the system itself. The underlying idea of this method is that the knowledge relevant to the structure and functioning of a social complex system is embedded into the minds of its members. This knowledge is framed into three main elements forming the FCMs: (1) a set of concepts or variables forming the system under investigation; (2) a set of causal relationships among these variables; and (3) a set of fuzzy weights, measuring the intensity of these causal relationships. Applying Fuzzy inference, the cognitive map is in turn used to simulate possible scenarios under two different conditions (i.e. without external interference, with external intervention).

In what follows, we present a customization of the protocol presented in Ozesmi and Ozesmi [14] to build and analyze an FCM. The proposed protocol is articulated in three phases:

1. Identification of system boundaries and variables;
2. Identification of causal relations among variables;
3. Fuzzy inference.

Each phase, in turn, is articulated in several steps, which will be discussed in the following subsections.

Phase 1 - Identification of system boundaries and variables

The identification of the system boundaries and relevant variables (x_i) is done by employing the Discourse Analysis technique. This technique allows to frame narratives in a certain context, taking into consideration ideas, opinions and facts through which “actors try to convince others of their positions, suggest certain practices, and criticize alternatives” ([7]: 71). Following Rosenbloom et al. [16], the authors propose the following three interrelated traits for the selection and inclusion of documents in the study and for an accurate understanding of relevant visions surrounding the investigated topic (i.e. narratives): first, the text should have a clear reference to the phenomenon under investigation; subsequently, the manuscript should include a well-defined idea or value judgement with regard to the area of investigation; finally, there should be an adequate narratives’ extension to enable qualitative analysis .

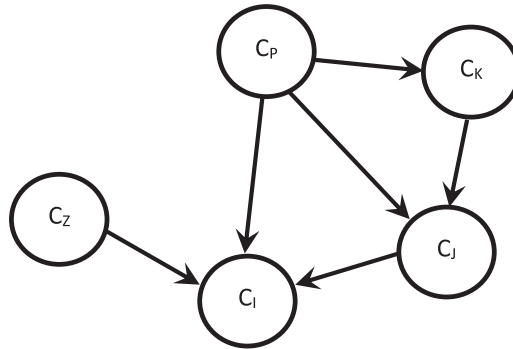


Fig. 1. System variables relationships

Selected articles are then qualitatively examined through the QDA Miner 5.0 software package [15] in order to identify and code relevant text segments that, in turn, would lead to the characterisation of related narratives [5]. System variables are obtained by carefully examining the semantic perspective in which the narratives are used, in each scrutinized article [1].

As this phase aims at identifying system variables able to grasp and integrate in the next phase (i.e. fuzzy mapping) the tacit knowledge pertaining to the experts, the description of variables is purposely simple and vague so as to enable the emergence of respondents' opinions, avoiding any influence or external bias [6]. Identified variables are divided into three main groups (Figure 1), according to their role played within the system: (i) senders (e.g. c_p , c_z), whose role is to send stimuli to the rest of the system; (ii) transmitters (e.g. c_k , c_j), who can both send and receive inputs being the connecting fabric of the system [9]; and (iii) receivers (e.g. c_i), who only receive inputs from other variables but not send them [3].

Therefore, a cognitive map is characterized by two main components: (1) a bundle of system variables, and (2) their cause-effect relationships – to be discussed in the next subsection.

Phase 2 - Identification of causal relations among variables

To complete the representation of the system structure, after the identification of its variables it is necessary to trace the cause-effect relationships among them. Usually, this is done by using a participatory approach that implies the organisation of interaction events among people, such as focus groups and workshops. Although this approach is useful to analyze group dynamics, it is expensive in terms of both time and money. In what follows an alternative method, relying on individual interview, is proposed as a viable way to get the same information. In this approach, interviews are directed to a set of actors composing the system under investigation. This phase requires the following steps:

1. Respondents recruitment;
2. Respondents interviews;
3. Numerical codification of verbal responses;
4. Aggregation of the individual cognitive maps into a social map;
5. Normalization of the social map.

1. Respondents recruitment - This operation is done based on the recognition of the various categories of stakeholders according to Fig. 2. All the relevant stakeholders belonging to these categories are identified and recruited, via email to be sent from the research institution in charge of the research. Personal contacts and relationship established in conferences are also used.

2. Respondents interviews - Each respondent is asked to recognize the cause-effect relationships among the system variables identified in phase 1. This task requires that, per each ordinated couple of variables (x_i , x_j) in the system, the respondent ascertains whether a cause-effect relation (v_{ij}) exists, that is, according to its knowledge, whether x_i affects the state of x_j , and whether this effect is positive

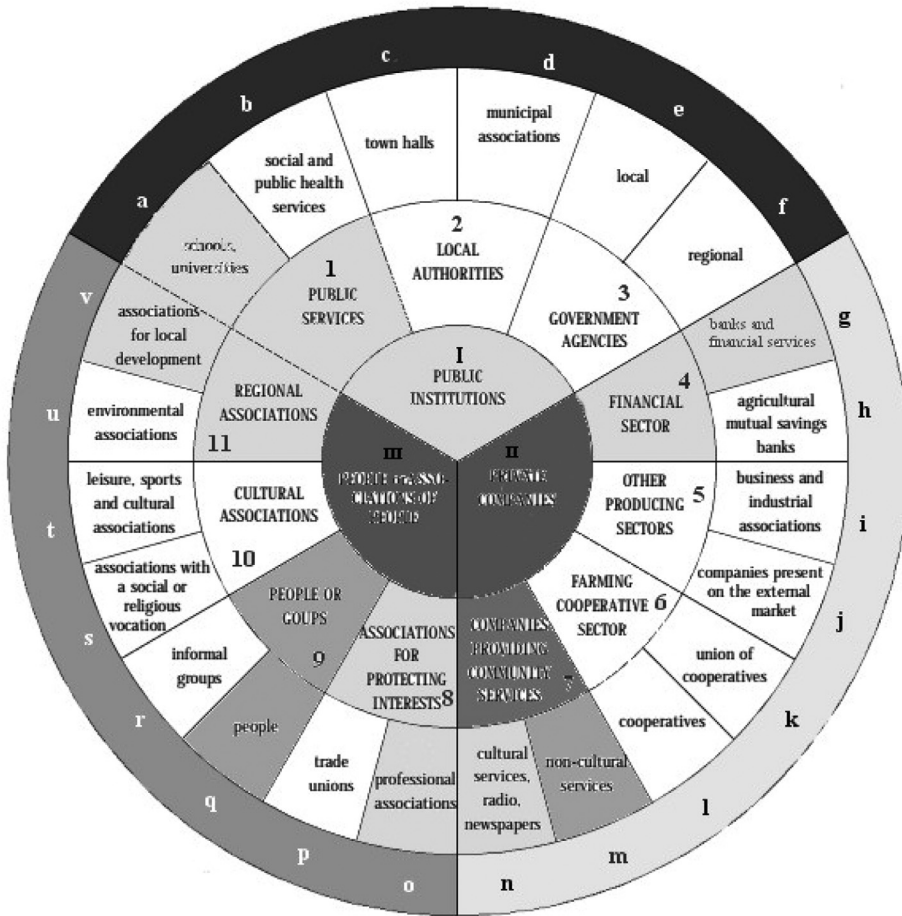


Fig. 2. The categories of stakeholders
Source: Source: Leader European Observatory, 1997

(negative), that is if x_j status augments (diminishes) the operation of x_i . The respondent identifies also the force of the relationship in a verbal form, quantifying it according to three qualitative judgment levels - i.e. strong, medium and weak. Operatively, this enquiry can be carried out by means of a square table of paired comparisons (Fig. 3) reporting on rows and columns the n system variables.

Setting, for instance, $n=30$, a thirty-variables table would contain $(30 \times 29=)$ 870 relationships, which would represent a heavy workload for any respondent. To lighten this potential exhausting task (which might lead to loss of concentration and rationality), variables can be visually grouped in different categories (see section 1.1) by means of coloured cards (Fig. 4), each group forming a sort of meso-variable. This allows respondents to exclude the existence of relations among variables based on their nature or logical functioning - e.g. system drivers are typically not influenceable by other variables, that is they do not receive any causal relation - reducing *a priori* the number of couples to investigate.

3. *Numerical codification of verbal responses* - To make the gathered data tractable within a computational process, the individual verbal evaluation of the causative relations $v_{i,j}$ made by the respondent is transformed into numerical form recurring to a simple onto function g , which associates

| | Variable 1 | Variable 2 | Variable 3 | Variable 4 | Variable 5 | Variable 6 | . | . | . | Variable n |
|------------|------------|------------|------------|------------|------------|------------|---|---|---|------------|
| Variable 1 | | | | | | | | | | |
| Variable 2 | | | | | | | | | | |
| Variable 3 | | | | | | | | | | |
| Variable 4 | | | | | | | | | | |
| Variable 5 | | | | | | | | | | |
| Variable 6 | | | | | | | | | | |
| . | | | | | | | | | | |
| . | | | | | | | | | | |
| . | | | | | | | | | | |
| Variable n | | | | | | | | | | |

Fig. 3. The comparison table.

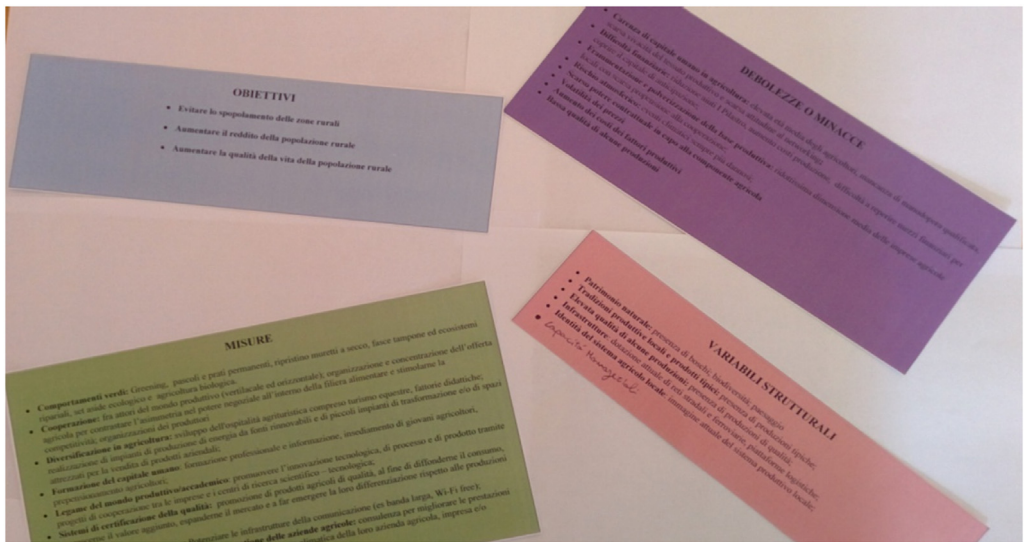


Fig. 4. Variables-categories cards

to each verbal evaluation $r \in L$, with $L = \{weak, medium, strong\}$, a numerical index $k \in K$, with $K = \{1, 2, 3\}$, as specified in Fig. 5.

Then, the index $(R_l)_{l \in K}$ associated to each relation v_{ij} is multiplied by the sign of the relation declared by the respondent, to derive the individual weight $iw_{i,j}$ of $v_{i,j}$ as specified in [1]:

$$iw_{i,j} = \begin{cases} (R_l)_{l \in K} & \text{if positive} \\ (R_l)_{l \in K}(-1) & \text{if negative} \end{cases} \tag{1}$$

This operation allows transforming the comparison table of each respondent into a numerical matrix containing individual weights associated to each causal relation among variables. This represents the basis from which a social map can be obtained.

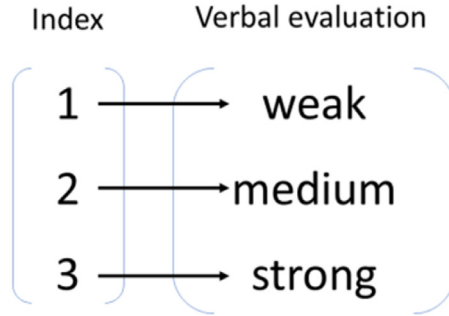


Fig. 5. Indexing function

4. *Aggregation of the individual cognitive maps into a social map* – The social map is a combination of individual weight matrixes. This operation is directed at obtaining a single weight per each relation representing a summary of the single M ($=$ number of respondents) evaluations. It is denoted as $w_{i,j}$ and calculated as:

$$w_{i,j} = \sum_{m=1}^M iw_{i,j} \tag{2}$$

This procedure aims at providing a reliable depiction of the complex system under scrutiny, considering that the summation of individual weights amplifies the power of the relations on which respondents share a similar vision, while it weakens relations with different signs – reproducing a conflicting vision [14].

5. *Normalization of the social map* – Values obtained with step 4 can vary significantly, presenting calculation and comparison problems. In order to avoid these issues, a normalization step is added. This is done by dividing each $w_{i,j}$ by the absolute value reached to obtain a normalized weight $\hat{w}_{i,j}$:

$$\hat{w}_{i,j} = \frac{w_{i,j}}{\max|w_{i,j}|} \tag{3}$$

The purpose of this normalization is to narrow the relations weight in the range $[-1, 1]$ making the calculations easily tractable. Indeed, $\hat{w}_{i,j}$ is the element of the connection matrix W of the system variables which represents, in turn, a numerical depiction of the social cognitive map and, at the same time, the basis of the fuzzy inference.

Phase 3 - Fuzzy inference

This final phase of the proposed methodology is carried out by using the artificial neural network approach. The neural network used is a back-forward type, which has proven particularly suitable to analyse the dynamic of complex systems, due to its capacity to represent the typical causative loops and feedbacks interconnecting the variables of an FCM by means of its back-forward logic.

Phases 1 and 2 provide the fundamental elements to perform the neural network calculations, that are: (i) the variables forming the system; and (ii) the set of cause-effect relationship connecting them. These data are operationalised respectively by means of a state vector $S=(a_1, \dots, a_i, \dots, a_n)$ containing the activation values of the variables a_i (with $a_1= \dots a_i \dots =a_n=1$), and the connection matrix $W=(w_{i,j})$. To simulate the dynamic of the system, S and W are multiplied and transformed (see subsection below) at the activation time-step t_0 to calculate the new state vector $S_{new}=(s_1, \dots, s_i, \dots, s_n)$. In the subsequent model time-steps t , S_{new} is reiteratively calculated by multiplying S_{new} at t_{-1} by W .

This calculation is repeated through the running period $T=(t_1, \dots, t_n)$ needed to reach the system steady state, represented by the final state vector S_s (i.e. the vector of variable values which do not vary anymore, that is the state value is the same at t_{n-1} and at t_n).

Two specific steps can be identified to model policy interventions, (1) the natural dynamic simulation; and (2) the policy intervention simulation.

(1) *The natural dynamic simulation* – With this step the researcher uses the model to predict the way the system will evolve, according to peoples' knowledge, without external influence. To calculate the single variable value s_i at time t , the algorithm used is:

$$s_{i,t} = f\left(s_{i,t-1} + \sum_{j=1}^{n-1} s_{j,t-1} w_{i,j}\right) \quad (4)$$

where f is the logistic function in the form:

$$\frac{1}{1 + e^{-x}} \quad (5)$$

This transformation allows to maintain the variables values in the interval $[0, 1]$. It provides non- negative values that are easy to compare and allows to reach a steady state equilibrium. The steady state value assumed by the variable x_i under the natural simulation scenario ($s_{j,tn}^n$) reflects its importance within the system according to peoples' knowledge and provides an idea of the evolution of the system in an autarchic context.

(2) *The policy intervention simulation* – This simulation is performed to answer the question “how would the system evolve, if subject to external interventions?”. To this purpose, the first thing is to select those variables that are likely to be used as policy drivers (these drivers are identified from among senders or transmitters). The simulation is performed by applying the same procedure described above with the only difference that, at each time-step t , variables representing the policy drivers are clamped at their maximum value (normally set equal to 1). The effect of the policy measure analyzed can be evaluated by calculating the difference of the steady-state of variables representing the policy objectives (e.g. some of the receivers or system ends), with and without the policy intervention. This is done by applying the followings:

$$p_{i,j} = s_{j,tn}^n - s_{j,tn}^p \quad (6)$$

Where $p_{i,j}$ is the effect of policy intervention i on the objective represented by the variable j , and $s_{j,tn}^n$ has the same meaning above, and $s_{j,tn}^p$ represents the steady state of variable j in the policy simulation scenario.

Method validation

In this section, we present an exemplificative application of phase 3 of the method explained above. Data are drawn from a case study, using an online available resource targeted at performing FCMs simulation, that is an excel macro implementing the procedure described in paragraphs 1.2 and 1.3 and the calculation algorithm presented in eq. [4] (FCMapper, see next section). The variables and the connection matrix used are a subset of data concerning a study on rural development interventions. Tables 1 and 2 report, respectively, the list of variables used and the connection matrix.

The connection matrix is copied and pasted into the matrix sheet of the FCMapper tool (available at <http://www.fcmmappers.net/joomla/> under open license) to run the model. The GUI interface of the FCMapper excel tool is reported in Fig. 6. The check matrix button performs a check of the general characteristics of the matrix and applies to the value entered eq. [3] to normalise values in the range $[-1,1]$. Then, the connection matrix appears as in Fig. 7.

The FCM_Scenarios sheet shown in Fig. 8 is used to run the simulations. Cells B6:B23 represent the activation vector S and the “calculation selected scenario” button performs the scenario corresponding to the one reported in cell B3. Scene 1 runs the natural dynamic simulation (step 1, phase 3) and applies eq. [4] to the data. Cells E6:E23 contain the $s_{j,tn}^n$ values that are the steady states of the variables under the natural dynamic scenario.

Scenes 2 and 3 allow to simulate different policy intervention scenarios (Fig. 9). In our example, as emerges from Fig. 9, in Scene 2 we simulated the enforcement of an “agri-environmental-climate” payments by clamping the relate value at 1 (see the value in cell C9). Scene 3 simulates a policy

Table 1
The list of variables.

| N. | Name | Category |
|----|-----------------------------------|------------------|
| 1 | Population | Policy objective |
| 2 | Income | Policy objective |
| 3 | Quality of Life | Policy objective |
| 4 | Agri-environment-climate | Policy driver |
| 5 | Producer groups and organisations | Policy driver |
| 6 | Farm and business development | Policy driver |
| 7 | Knowledge transfer | Policy driver |
| 8 | Co-operation | Policy driver |
| 9 | Quality schemes | Policy driver |
| 10 | Information technology | Policy driver |
| 11 | Input costs | Context variable |
| 12 | Low quality products | Context variable |
| 13 | Lacking human Capital | Context variable |
| 14 | Credit crunch | Context variable |
| 15 | Fragmentation | Context variable |
| 16 | Environmental risks | Context variable |
| 17 | Bargaining power | Context variable |
| 18 | Price volatility | Context variable |

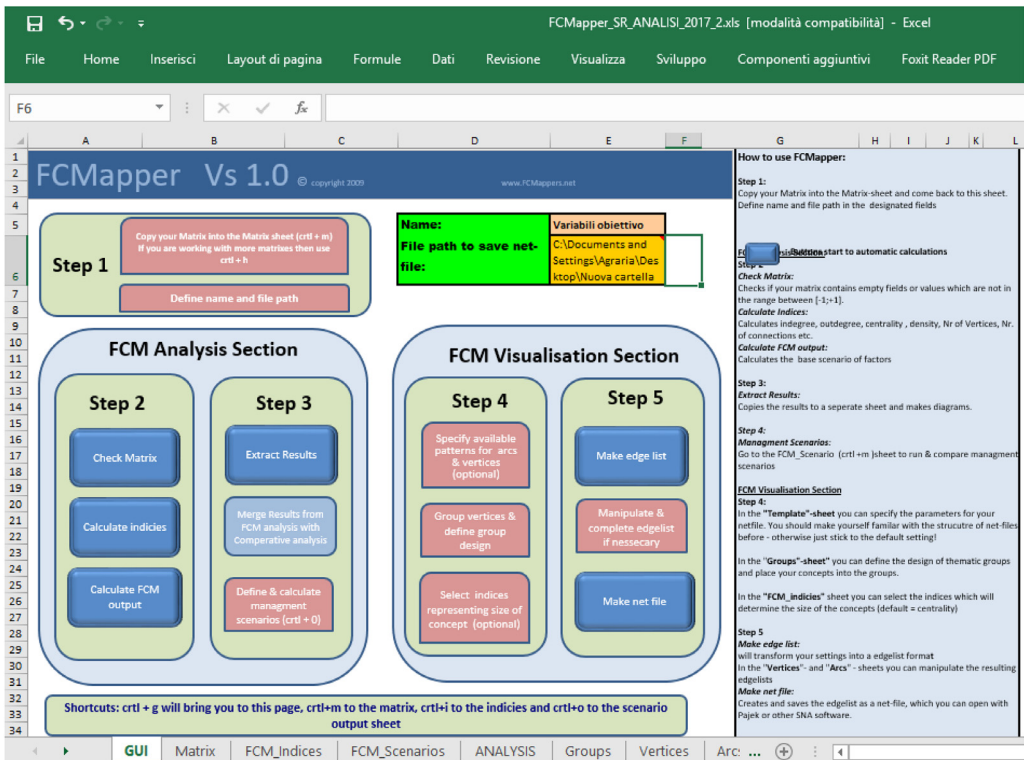


Fig. 6. The GUI interface of the FCMapper excel tool (<http://www.fcmmappers.net/joomla/>)

Table 2
The connection matrix

| Variables | Pop. | Inc. | Qual. | Agri-e. | Prod. | Farm | Know. | Coop. | Qual. | Inf. | Inp. | Low | Lack. | Credit | Fragm. | Envir. | Barg. | Price |
|-----------------------------------|-------|-------|-------|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|-------|-------|
| Population | 0,00 | 0,33 | 0,22 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | -0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Income | 0,56 | 0,00 | 0,59 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | -0,11 | 0,00 | 0,00 | 0,00 | 0,00 |
| Quality of Life | 0,44 | 0,44 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Agri-environment-climate | 0,00 | 0,26 | 0,67 | 0,00 | 0,11 | 0,22 | 0,00 | 0,00 | 0,15 | 0,11 | -0,11 | -0,19 | -0,11 | -0,11 | -0,15 | -0,19 | -0,11 | -0,11 |
| Producer groups and organisations | 0,26 | 0,81 | 0,22 | 0,00 | 0,00 | 0,00 | 0,04 | 0,00 | 0,22 | 0,00 | -0,26 | 0,00 | -0,07 | -0,33 | -0,52 | 0,00 | -0,41 | -0,19 |
| Farm and business development | 0,22 | 0,59 | 0,22 | 0,37 | 0,00 | 0,00 | 0,07 | 0,00 | 0,11 | 0,00 | -0,19 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | -0,07 | -0,07 |
| Knowledge transfer | 0,44 | 0,33 | 0,22 | 0,00 | 0,41 | 0,33 | 0,00 | 0,19 | 0,41 | 0,00 | -0,04 | -0,04 | -0,44 | 0,00 | 0,00 | 0,00 | -0,04 | 0,00 |
| Co-operation | 0,19 | 0,22 | 0,00 | 0,00 | 0,11 | 0,07 | 0,11 | 0,00 | 0,11 | 0,11 | -0,11 | -0,11 | -0,07 | 0,00 | 0,00 | 0,00 | -0,07 | 0,00 |
| Quality schemes | 0,00 | 0,37 | 0,07 | 0,11 | 0,00 | 0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | -0,26 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | -0,11 |
| Information technolgy | 0,19 | 0,26 | 0,30 | 0,00 | 0,00 | 0,07 | 0,11 | 0,11 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Input costs | 0,00 | -0,22 | 0,00 | 0,00 | -0,11 | 0,00 | 0,00 | 0,00 | 0,00 | -0,11 | 0,00 | 0,11 | 0,00 | 0,33 | 0,22 | 0,00 | 0,00 | 0,00 |
| Low quality products | 0,00 | -0,11 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | -0,37 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Lacking human Capital | -0,44 | -0,26 | 0,00 | 0,00 | -0,30 | -0,15 | -0,11 | -0,04 | -0,11 | -0,19 | 0,00 | 0,15 | 0,00 | 0,07 | 0,11 | 0,00 | 0,00 | 0,00 |
| Credit crunch | -0,30 | -0,56 | -0,07 | 0,00 | -0,33 | -0,33 | -0,11 | -0,11 | -0,41 | -0,15 | -0,11 | -0,11 | -0,11 | 0,00 | -0,11 | -0,11 | -0,11 | -0,11 |
| Fragmentation | -0,22 | -0,41 | 0,00 | -0,11 | -0,11 | -0,11 | -0,11 | -0,07 | -0,07 | 0,00 | 0,07 | 0,00 | 0,07 | 0,00 | 0,00 | 0,00 | 0,26 | 0,11 |
| Environmental risks | 0,00 | -0,26 | 0,00 | 0,00 | 0,00 | -0,11 | -0,11 | 0,00 | 0,00 | 0,00 | 0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,19 |
| Bargaining power | -0,22 | -0,70 | -0,07 | 0,00 | 0,07 | 0,00 | 0,00 | 0,00 | -0,11 | -0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,11 | 0,00 | 0,00 | 0,00 |
| Price volatility | 0,00 | -0,48 | 0,00 | 0,00 | -0,07 | -0,11 | 0,00 | 0,00 | -0,11 | 0,00 | 0,11 | 0,11 | 0,00 | 0,11 | 0,00 | 0,00 | 0,00 | 0,00 |

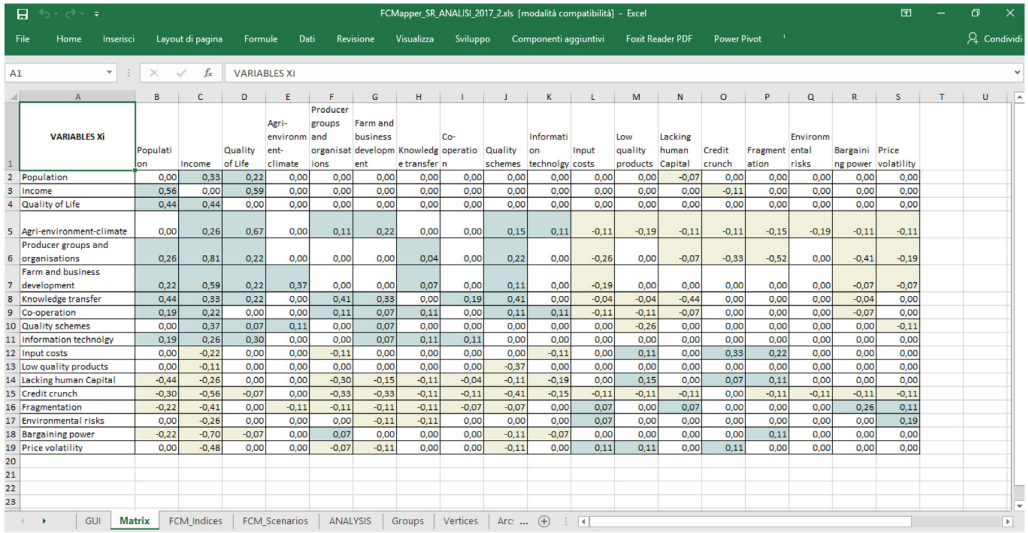


Fig. 7. The connection matrix as it appears in FCMapper (<http://www.fcappers.net/joomla/>)

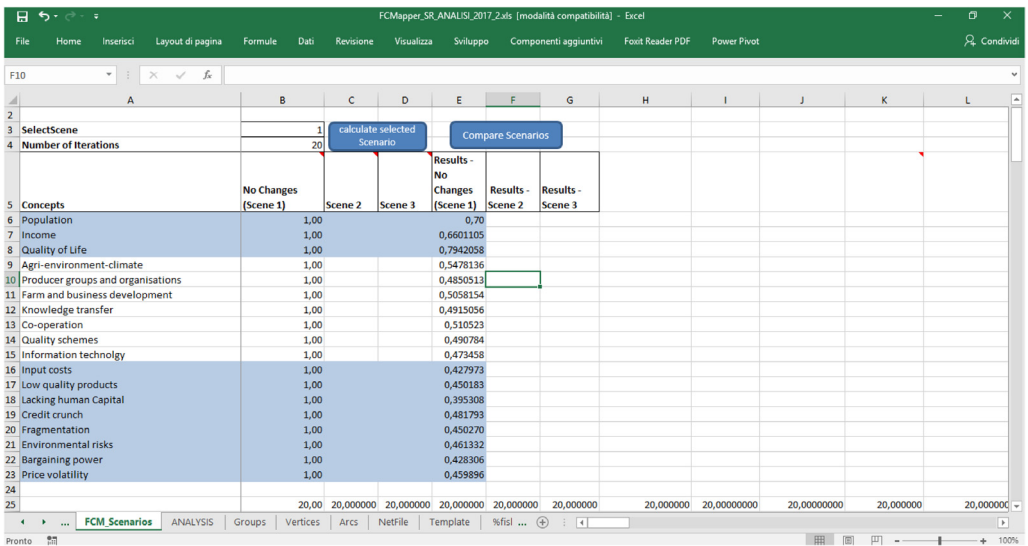


Fig. 8. The natural dynamic simulation with FCMapper (<http://www.fcappers.net/joomla/>)

intervention based on the combination of “farm development” and “knowledge transfer” measures. When Scene 2 or Scene 3 are selected, the “calculation selected scenario” button (corresponding to eq. [6]) is applied and p_{ij} – i.e. the effect of the policy i on the variable x_j – is calculated, where i and j are defined respectively by the row corresponding to the cell containing the value 1 in columns F or G, and the row corresponding to the policy objective under analysis. In our example, if i = “agri-environmental-climate” payments and j = “quality of life”, the related p_{ij} is contained in cell F8 and is equal to 0.846. The method presented here eases the comparison between

| Concepts | No Changes (Scene 1) | Scene 2 | Scene 3 | Results - No Changes (Scene 1) | Results - Scene 2 | Results - Scene 3 |
|-----------------------------------|----------------------|---------|---------|--------------------------------|-------------------|-------------------|
| Population | 1,00 | | | 0,70 | 0,72 | 0,79196364 |
| Income | 1,00 | | | 0,6601105 | 0,7120247 | 0,79215855 |
| Quality of Life | 1,00 | | | 0,7942058 | 0,8463152 | 0,8490502 |
| Agri-environment-climate | 1,00 | 1,00 | | 0,5478138 | 1 | 0,59503604 |
| Producer groups and organisations | 1,00 | | | 0,4850513 | 0,5013251 | 0,5452363 |
| Farm and business development | 1,00 | | 1,00 | 0,5058154 | 0,5353311 | 1 |
| Knowledge transfer | 1,00 | | 1,00 | 0,4915056 | 0,4945922 | 1 |
| Co-operation | 1,00 | | | 0,510523 | 0,5120314 | 0,53534318 |
| Quality schemes | 1,00 | | | 0,450784 | 0,515070 | 0,56737213 |
| Information technology | 1,00 | | | 0,473458 | 0,487977 | 0,47989645 |
| Input costs | 1,00 | | | 0,427973 | 0,412633 | 0,395248 |
| Low quality products | 1,00 | | | 0,450183 | 0,427113 | 0,434807 |
| Lacking human Capital | 1,00 | | | 0,395308 | 0,382526 | 0,338758 |
| Credit crunch | 1,00 | | | 0,481793 | 0,464543 | 0,467637 |
| Fragmentation | 1,00 | | | 0,450270 | 0,430548 | 0,437290 |
| Environmental risks | 1,00 | | | 0,461332 | 0,441075 | 0,459551 |
| Bargaining power | 1,00 | | | 0,428306 | 0,413080 | 0,406705 |
| Price volatility | 1,00 | | | 0,459896 | 0,444497 | 0,444611 |

Fig. 9. Policy interventions simulation with FCMapper (<http://www.fcmmappers.net/joomla/>)

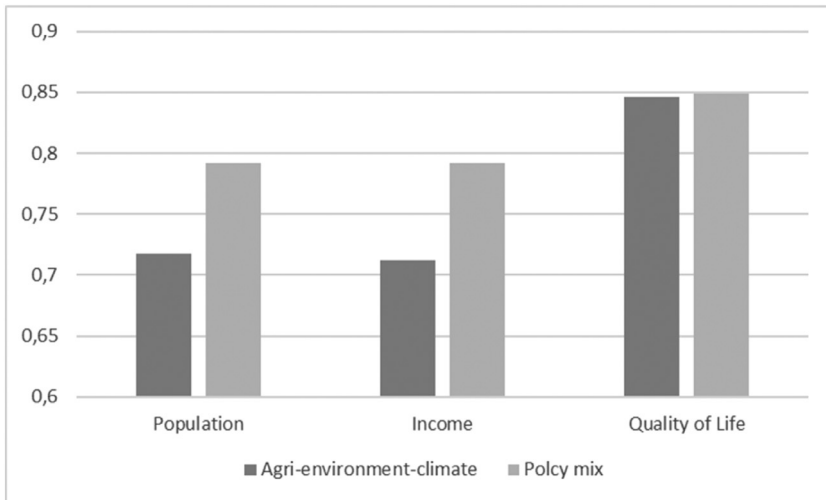


Fig. 10. Policy intervention effect: changes of policy objectives from steady state

policy interventions providing specific values comparison terms. In this example, the effect of “agri-environmental-climate” payments on the “quality of life” is similar to the one produced by “farm development” and “knowledge transfer” mix (0.846 and 0.849 respectively), while the latter policy is more effective as far as the other two policy objectives. When presenting results, p_{ij} values are typically represented by means of bar diagrams as in Fig. 10

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Additional information

The excel macro used in section 1.4 to perform the method validation is called “FCMapper” and has been developed by Michael Bachhofer and Martin Wildenberg. It is available upon request on the web portal: <http://www.fcappers.net/joomla/>

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