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Research article

A structured participatory method to support policy option analysis in a social-ecological system

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A B S T R A C T

In this study we demonstrate how to support policy option analysis for a problematic Social-Ecological System (SES) with the help of stakeholder participation. SES sustainability problems 1) are highly complex, 2) may lack reliable data, 3) encompass conflicting interests and 4) may require contradictory management interventions. Our approach uses a structured participatory method combining the Driver-Pressure-State-Impact-Response (DPSIR) model together with Fuzzy Cognitive Mapping (FCM) to capture the complexity of the system and simplify its representation for simulation and policy option analysis. Using this novel mixed-method was useful in dealing with above-mentioned characteristics of the complex SES problems. The method was applied in a case study of water scarcity in Rafsanjan, Iran. FCMs were produced for 60 individual farmers and 40 individual researchers and policy makers. Our mixed-method analysis reveals similarities and differences of stakeholder knowledge and problem perception, and simulates the impacts of alternative policy options according to each group's perception. The final result of our case study indicates that farmers in Rafsanjan strongly believe in the impact of economic diversification on reducing water shortage, but they have a low level of trust in the ability of the government to regulate and control water usage, whereas the policy makers and researchers still believe in the role of government control and monitoring policies to deal with water scarcity in Rafsanjan.

1. Introduction

There is a general insight that decision making in complex environmental problems requires an integrated consideration of both social and ecological systems and their interactions: the Social-Ecological Systems (SESs) (Berkes et al., 2000; Folke, 2006; Ostrom, 2007, 2009; Binder et al., 2013). SESs are dynamic systems for which states are constantly changing through the interactions among social and ecological factors (Berkes et al., 2000; Holling and Gunderson, 2002). Due to the dynamic and complex nature of such systems, the environmental management of SES has to deal with four main characteristics: 1) complexity, multi-variability and multi-disciplinarily, 2) ill-formulation of problems because of lack of or conflicting knowledge, 3) the large number of stakeholders with conflicting values and different views about problems and solutions, and 4) large number of management options and unanticipated consequences of each intervention for the whole system (Xiang, 2013; Olazabal and Reckien, 2015; Vasslides and Jensen, 2016). These four characteristics of SES problems make it difficult for policy makers to use standard dynamic modelling methods to represent and analyse such problems.

The aim of this study is to introduce a structured participatory method to support policy option analysis for a complex SES problem with the help of stakeholder perception. For this objective we use a combination of a Problem Structuring Method, i.e. Driver-Pressure-State-Impact-Response (DPSIR), with a participatory modelling method, Fuzzy Cognitive Mapping (FCM). The advantages of mixing this two methods is two-fold: methodological and structural. In methodology, DPSIR provides a structuring framework for a complex, multi-variable problem and FCM aids to 1) collect data via experts in data-scarce or poor data environments, 2) involve different interests of stakeholders and 3) simulate the impact of different interventions to the entire system (Reckien et al., 2013; Reckien, 2014; Singh and Chudasama, 2017). Therefore, the mix-method of DPSIR and FCM provides a modelling

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platform covering all the characteristics of SES problems mentioned earlier: complexity, multi-stakeholder and conflicting interests, data scarcity and unintended consequences of interventions. The structural advantage of DPSIR-FCM method is the use of DPSIR framework for condensation and simplification of multi FCMs outcomes which will be explained further in section 2.3.2. The final point of our objective is using the stakeholders' perception for modelling the complex SES problems. In our vision successful policy making should consider multiple stakeholder views and their perceptions and reactions to policies. Therefore, policy makers need to be able to assess the local knowledge and perceptions of different stakeholders which might be missed or be in conflict with official data in a SES problem.

1.1. The Driver-Pressure-State-Impact-Response (DPSIR)

DPSIR, adopted by the European Environment Agency (EEA, 1999), is widely used as a problem structuring method to capture and structure the complex causal interactions of human-environmental systems (Bell, 2012; Gregory et al., 2013). This framework categorizes the complex indicators of an environmental problem into social-ecological *driver* indicators that exert *pressures* on the system and consequently affect the *state* of the environmental problem indicators, leading to *impacts* on the system and triggering societal *responses* that may in turn feed back to the drivers, pressures, state, or impact variables. Although DPSIR can help to structure and analyse complex SESs problems, it cannot capture trends of change in a dynamic system, as it builds a snapshot of the current situation of a system in the form of causal chains but not its causal networks (Svarstad et al., 2008; Maxim et al., 2009; Atkins et al., 2011; Gregory et al., 2013; Gari et al., 2015). Thus, DPSIR itself does not have the capacity of modelling a complex SES, while its combination with other tools such as FCM can create more valuable outcomes to overcome DPSIR's limitations (Bell, 2012; Lewison et al., 2016).

1.2. Fuzzy cognitive mapping

FCM is a participatory modelling method recently used in very different disciplines including SES modelling (Fairweather, 2010; Wildenberg et al., 2014; Gray et al., 2015). Structurally, it is a directed graph with feedback, consisting of nodes and weighted interconnections. It is a useful method in eliciting data from experts and stakeholders in data-scarce or poor data cases (Reckien, 2014, 2016); it helps to capture stakeholders' perceptions and communicate their knowledge in decision making processes (Papageorgiou and Kontogianni, 2012), and, moreover, by representing the semi-quantitative cause-effect relationships of a system, it can simulate the unanticipated impact of an intervention on different components of a complex SES. But combining a large number of cognitive maps can result in very complicated maps with too many nodes and connections, making the understanding and analysing of the maps very difficult. According to graph theory, an effective way to better understand the structure of complex FCMs is to condense them. However, the process of condensation is not well-documented nor standardized (Gray et al., 2014). By combining the structuring capabilities of DPSIR with the analysis and simulation capacity of FCMs we demonstrate a potentially fruitful method for FCM condensation.

1.3. Case study

We used our methodology in the case of water scarcity in Rafsanjan, Iran; a major producer and exporter of pistachios in Iran (see Fig. 1). Being in an arid and semi-arid region, pistachio farmers

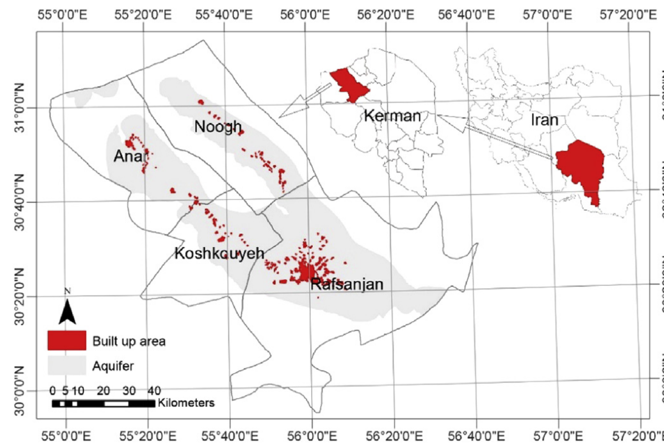

Fig. 1. Rafsanjan Township in Kerman province and in Iran.

in Rafsanjan are dependent on ground water for orchard irrigation. Rapid agro-economic development of the land and unsustainable water management have led to a high water demand of pistachio lands and overexploitation of groundwater. Frequent droughts and climate change are also contributing to the depletion of the area's aquifer.

Water scarcity in Rafsanjan is a tightly intertwined social-ecological problem. Water is almost free of charge, the energy for pumping groundwater is subsidised and the government has shown little control on the growing number of wells and their extraction limits. While pistachio farmers' associations have cooperated in the management of shared wells, they are not generally involved in policy and decision making about water management. Pistachio associations also have little contribution in water demand reduction activities since their main concern is the increase of production and export capacity of pistachio. This situation indicates a complex SES where various variables from social, economic, ecological and political disciplines are interdependently affecting the state of ground water in Rafsanjan.

Lack of data and their unreliability are challenges too. Besides conflicting data from different reports, government data are inaccessible due to the high sensitivity of the water crisis in Iran and its political and societal implications.

Currently, there is an "every man for himself " situation in Rafsanjan: farmers maximize water extraction for their remaining lands or move the pistachio orchards to other regions once they can no longer make the desired profit in Rafsanjan. Attempts to manage groundwater reserves at a sustainable level are not adopted. There are many different actors and institutions with conflicting interests that complicate the decision making process related to groundwater and pistachio production in Rafsanjan.

There are alternative strategies for monitoring and limiting water use: applying advanced irrigation technologies, regulating water supply and demand provisions, and educating farmers, but their effectiveness in this complex SES of Rafsanjan is unclear. Most of these strategies are either new or have not yet been applied. Even when some water is saved, it is often used for the expansion of pistachio cultivation (Mehryar et al., 2015, 2016).

Considering the sustainability challenges of water scarcity in Rafsanjan, a tool to help policy makers in assessing the impact of their policy options is potentially useful. The tool should be able to deal with complexity of various changing factors, conflicting interests of stakeholders, the lack of reliable data and also the unanticipated consequences of the policy interventions in the whole system.

2. The methodological framework

The methodology is designed to support policy options analysis in a multi-interest system with poor data or conflicting knowledge about system behaviour among the stakeholders and scientific studies. This methodology comprises four steps.

Step 1: Provide a preliminary problem structuring DPSIR framework of the SES problem indicators based on literature and statistical data to set objectives and system boundaries.

Step 2: Create different stakeholders' FCMs which together present the collective knowledge of participants helping to define indicators of the system and their relations when there are not enough reliable objective data.

Step 3: Use the DPSIR framework (step 1) to condense and structure the set of FCMs (step 2) through an iterative adjustment process producing a perception model for each stakeholder group.

Step 4: Simulate with the perception models the impact of different policy alternatives and assess their effectiveness on the state of system.

Each step is described in more detail below.

2.1. Step 1: project objectives and system boundaries via DPSIR

To model the most important indicators of a complex SES it is important to define the exact problem and the related project objectives (Jetter and Kok, 2014). Otherwise, there is a danger that the model will be too general to be analysed (Mourhir et al., 2016). To do this, we created an initial DPSIR framework to structure the problem components based on scientific studies, reports and statistical data which are mostly used in environmental decision making. The advantage of using an initial DPSIR model is threefold: 1) it helps to focus on particular information and data needed to be derived from participants later and also identifies useful questions for appropriate knowledge elicitation; 2) the modeller's initial understanding of the problem domain can serve as a stimulus in respondent surveys in a later stage (Jetter and Kok, 2014), although it should not be imposed in the process of stakeholder knowledge elicitation (step 2); 3) the content of this step is useful to check stakeholder inputs versus accepted scientific facts (Jetter and Kok, 2014).

2.2. Step 2: stakeholders knowledge modelling via FCM

In this step FCM was applied to model the perceptions and knowledge of stakeholders about problem indicators and their relationships. A participatory elicitation process ensured that all important variables of a system, in spite of lack of measurable quantitative data, were captured, as well as the different and sometimes conflicting interests of stakeholders to bring about a joint decision. (Malena, 2004; Buruzs et al., 2015; Mckenzie, 2005).

Table 1
Interview questions and DPSIR categories that each question aims to find concepts related to them.

Interview questions	Related DPSIR category
1. How is the current water situation in Rafsanjan (your specific region for farmers)?	Sate
2. What do you think has influenced/caused the current water situation in the region?	Driver & Pressure
3. What have been the impacts of the new water situation in the region?	Impact
4. What have been the adaptive actions to this new situation?	Response

FCM, by its structure, is a fusion of a neural network and fuzzy logic (Carvalho, 2013). It contains a signed and directed graph with feedback, consisting of nodes and weighted interconnections (Kosko, 1993). Each node represents a concept of the system which can be either a tangible object such as 'resource quantity' and 'quality', or an abstract object like 'public trust' (Vasslides and Jensen, 2016). The weighted connections represent the causal relationships between concepts. The individual or group participants identify the important concepts and then link them with weighted and directed arrows.

To develop the FCMs, we used the individual face-to-face interview technique (Gray et al., 2014). FCM data collection was done by adapting the suggestions of Özesmi and Özesmi (2004), Jetter and Kok (2014) and Gray et al. (2014), as explained in following sections.

2.2.1. Stakeholder groups

The first step was to determine the right groups of stakeholders. The main aim of involving different stakeholders in this methodology was to gather various kinds of knowledge and views about the problem domain. Different stakeholders were categorized based on their knowledge and experience of the system. For example, there are many stakeholders in Rafsanjan involved in causes and impacts of water scarcity, including policy makers for water, agriculture and environmental sectors, NGOs, researchers, and farmers. While doing the interviews we learnt that both the policy makers and researchers in Rafsanjan have similar perception of the system problem, probably because both of them have their knowledge based on official studies and scientific data while the farmers have the local knowledge based on their own experience. Consequently, we formed two groups: policy makers and researchers (P&R), and farmers to address the most conflicting perceptions. More information about the difference of group and individual interviews in this case study as well as defining the sample size is explained in Supplementary 1 & 2.

2.2.2. Interviews and questions

In order to keep the variety of voices and reduce "elite bias", all the mind map production during the interviews were done without any predetermination of concepts from preliminary step of research. Rather, the interviews were conducted with open-ended and free style questions where the interviewees were free to choose their own concepts. However, the questions were following the predetermined categories of DPSIR framework (Table 1).

Defining the concepts by stakeholders helped us to capture most possible aspects of the SES problem. This method of collecting data is useful specifically in such cases where the problem itself is ill-formulated. Yet, having a preliminary understanding of the research area through DPSIR framework increased the theoretical sensitivity of the interviewer and also supported the focus and scope of our interviews.

Talking about the questions required long discussions lasting from 30 min to 3 h per interview. During the discussions the networks were drawn on paper by the interviewer who regularly validated these with interviewees. The concepts and the directed links between these were drawn at the same time to establish causal connections. On several occasions during the interviews we needed to specify the exact period of time for the questions. It has to be noted here that FCM is suitable for short-term time series analysis and prediction (Buruzs et al., 2015). FCM by its nature is not capturing the episodic events or temporal sequence of a system. It only represents the recently experienced events which have caused the current state. Therefore, the exact period of time for each question should be identified for the variables with different sequences of state. For example, when we are talking about the variable "agriculture land area", there is a period of expansion because of agro-economic growth in Rafsanjan followed by a period of shrinking because of water scarcity. So we asked participants about their latest experiences of agriculture land area change.

2.2.3. Weighing the connection linguistically and numerically

After defining the whole network, the interviewees were asked to weigh the connections to show the degree of influence of concepts on each other. It was important to explain that the connections reflect causal relations among variables meaning the increase or decrease of one variable causes the increase or decrease of another variable (Carvalho, 2013).

Causal weight can be either a number in the interval [-1,1], or a linguistic value such as "very low", "low", "average", "high" and "very high". In a later stage these linguistic values can be translated into numerical values in the range of [-1; 1]. During the interviews we noted that some people, especially farmers, provide a linguistic judgment (Abdullah and Khadiah, 2011), while policy makers and researchers tend to give a scale number. Therefore, a five-point numerical of linguistic scale was shown to the respondents and during the weighing they used the one that was most understandable to them.

2.3. Step 3: FCM post-processing using DPSIR framework

After creating all individual FCMs, each map was transformed into an adjacency matrix. For each map all the concepts were listed in the horizontal and vertical axis of a square matrix and the weights of connections are placed in the intersecting cell of the respective concept, which is a value between −1 and 1 (Carvalho, 2013; Olazabal and Reckien, 2015). Before transferring maps into the matrices, the different wording concepts in individual maps should be converted into a common terminology or code (Reckien, 2014). It means the variables with similar meaning are coded with one concept name, e.g. 'dry climate' and 'lack of precipitation'. To avoid a biased terminology coding, we went back to the respondents to check the validity of the standardized concept names.

2.3.1. Network aggregation

All individual cognitive maps can be mathematically augmented using matrix addition to create a social (i.e. multi-stakeholder) cognitive map (Özesmi and Özesmi, 2004). The entries of the new augmented matrix are the average of the connection weights assigned by individuals. Aggregating the individual maps was done very carefully. In addition to using standardized terms, sometimes concepts and dis-concepts were used in different maps (e.g. optimal farming and non-optimal farming). In such cases one of them was modified and the sign of any relationships was also reversed to maintain effect consistency.

2.3.2. Quantitative and qualitative condensation

Aggregated maps contain more concepts and connections than any of the individual maps. Since maps with more than 20–30 variables look overcomplicated for gaining insights (Özesmi and Özesmi, 2004), condensation is used to simplify the complex cognitive maps. Two types of condensation were used in our case: quantitative and qualitative condensation. In quantitative condensation the concepts with the least influence in the system, i.e. the nodes with a centrality number less than 1, have been eliminated. In qualitative condensation the variables were combined and nested into the upper level encompassing categories. Each new larger subgroup consists of a group of variables connected to other variables outside the subgroup. The new connections' weights of the subgroup is the average of all connection weights of variables inside the subgroup. But the connections inside the subgroup have not been kept, following the accepted argument that causality is not self-reflexive, i.e. a concept cannot cause itself (Carvalho, 2013).

In FCM technical studies, the process of defining the main subgraph themes is not yet clear. In some applications subgroup themes emerge with the help of participants, which is very difficult and confusing with individual-FCMs. In other studies, the subgroups emerge from the relevant larger theoretical framework of the studied issue (Nakamura et al., 1982; Özesmi and Özesmi, 2004; Kontogianni et al., 2012). Here we used the principles of "directed content analysis" method in which the analysis of collected data starts by using prior research findings as guidance for identifying key concepts as initial coding categories (Hsieh and Shannon, 2005). Considering the setting in Rafsanjan the preliminary concepts of DPSIR conceptual model helped us to define the different subgroups of the system. Any concepts of FCM findings that could not be categorized within DPSIR subgroups were given a new subgroup. Moreover, data analysis with prior research guides the discussion of findings which might be contradictory with such preliminary researches or might extent and enrich that (Hsieh and Shannon, 2005). In our case, having the DPSIR model allowed comparison of the literature data captured by the DPSIR model with knowledge-data captured by the FCM model in later steps.

2.3.3. Calibration of the model

The FCM model approach does not represent the absolute truth of a system, rather it models the stakeholders' perceptions of a system. Therefore, it cannot be verified using quantified or historic data that are accepted as truths (Penn et al., 2013; Jetter and Kok, 2014). Moreover, the summation of all individual perceptions may eventually show different dynamic properties from what an individual may infer from his own knowledge. Therefore, the aggregated social FCM may not necessarily represent the perception of each individual and thus cannot be validated by individual stakeholder members. Following the suggestion of Jetter and Kok (2014) as applied by Olazabal and Pascual (2015), we used a simple bivalent nodes cognitive map that expresses the very well-known dynamics captured from respondents during the interviews. For example, based on farmers' perceptions it was very well-understood that an increase in "irrigation system modification" has caused an increase in "pistachio production" and also an increase in "groundwater depletion", or an increase in "small holding" has caused an increase in "unregulated ground water use". These three examples were checked and were matched with the basic behaviour of the modelled system.

2.4. Step 4: assess the impact of different policy options

Having the current state model of the system perceptions, one could also ask "what-if" questions to understand the impact of different policy options. This simulation shows us 1) the effectiveness of each policy option based on the stakeholders' knowledge of the system and 2) the acceptance of each policy options by two selected groups of stakeholders, farmers and policy makers/researchers.

For running the policy options simulations, the steady state of the model was first calculated. The steady state shows where the system would go if nothing changed, based on the stakeholders' view of the system. For calculating the steady state, all the initial values of the concepts were set to 1, assuming they are all equally active. Then, matrix multiplication yields new values for each concept. These new values are then normalized, using a so-called squashing function, to return to values between 0 and 1 (Reckien et al., 2013). This procedure is repeated until all concepts reach a steady state representing the baseline. Theoretically, resulting values can go into a limited cycle or into a chaotic pattern (Dickerson and Kosko, 1994). In our analysis, all the concepts reached a steady state within 30 iterations.

In the second step the results of a manipulated system, i.e. representing different policy options through the "what-if" analysis, are calculated. It explains where the system (perceived by stakeholders) would go if one or more policy options were to be implemented (Kontogianni et al., 2012). In our study we separately simulated impacts of four policy options for the case of water scarcity in Rafsanjan. Among many possible policy options we chose the ones that significantly change the influence of one or more of the main drivers in our model, i.e., *mono-economy*, *lack of government control*, *traditional agriculture/irrigation system* and *small-holding,* using the FCMapper program. The four policy options are explained in Table 2. To simulate the implementation of policy options, in each policy option run one or more concepts are clamped as continually high or low (Kosko, 1986; Özesmi and Özesmi, 2004; Gray et al., 2015) to a value of 0 or 1 (Singh and Chudasama, 2017). If the policy option increases a concept, it is clamped to 1 and if it permanently decreases a concept, it can be clamped to 0 (Reckien, 2014). For example in the *economic change* policy option the two concepts of *Mono-economy* and *Agriculture area expansion* are clamped as permanently low (Table 2). The value of clamped concepts remains fixed in each time step of matrix multiplication and the change of other concepts was calculated under the new policy implementation. This was repeated until the unclamped concepts reach a steady state. The simulation process is done by using the FCMapper program.

Lastly, the final values of the concepts in the non-manipulated system (baseline steady state) are compared to the final values of concepts in the adjusted policy scenario. Comparing the results of different policy options to the baseline scenario determines the desirability level of each scenario by two stakeholder groups of farmers and P&R (section 3.4).

3. Results

The main research question deals with the likely impact of alternative policy options on water scarcity in the complex, dynamic social-ecological system of Rafsanjan. To answer this question, we developed and applied our structured participatory method to simulate SES behaviour without and with new policy regimes.

3.1. Analytical DPSIR based on literature study and field data

The output of step 1 of the methodology, i.e. the analytical DPSIR framework of water scarcity in Rafsanjan, has been developed and described in an earlier paper (Mehryar et al., 2016). This framework input is based on spatial data-sets, statistical data, scientific studies on quantitative-data and governmental reports which are basically the policy makers' input data. Fig. 2 represents the causal network generated by the DPSIR framework. More information about each category of this framework can be found in Supplementary 3.

3.2. FCM model structured by DPSIR framework

After generating and aggregating all individual FCMs, the two stakeholders' maps, so-called social FCMs, were composed and condensed through applying the preliminary DPSIR framework (Figs. 3 and 4).

3.3. DPSIR-FCM analysis

Having two different DPSIR-FCM models gives us the possibility to have threefold comparisons: 1) comparing knowledge data versus available literature/statistical data, 2) comparing different stakeholders' perceptions, 3) comparing inter-layers DPSIR categories.

3.3.1. Knowledge data versus literature data

There are many concepts in stakeholders' FCMs that are not considered by research studies and government reports that are based on quantitative and statistical data mostly. These missing concepts in scientific studies indicate that the problem itself may not be well formulated for policy makers due to a lack of knowledge of the system's complex structure and behavior.

Among the main *drivers* of water scarcity, *small holding* and *mono-economy* are new concepts mentioned by stakeholders but less studied in researches and reports. Small land holding emerged after the 1963 land reform in Iran. The consequences of reform not only replaced the Qanat collective management system with individual pumping well systems (Mehryar et al., 2015), but also resulted in suboptimal irrigation and wells over-exploitation comparing to the large size lands. A costly new irrigation system for small lands is an obstacle for changing the traditional irrigation system of small holders. On the contrary, *climate change* and *population growth* have been mentioned among the less important driving forces in both P&R and farmers' FCMs whereas these are usually mentioned as the main causes of water scarcity in reports and studies.

In the part of *pressures*, often the wells construction and growing number of wells are mentioned as the main causes of ground water over-exploitation (Mehryar et al., 2015). But from the stakeholders' perception, the "unregulated wells water consumption" puts a much higher pressure on the system than the "number

Table 2
Policy options, the clamped concepts and their values in each policy option.

Policy option	What-if question	Clamped concepts and their clamped values
1) Economic change	What if the economy of the region changes from agriculture to other sources of economy like industry and service production?	Agriculture area expansion = 0 Mono-economy = 0
2) Irrigation/Agriculture system change	What if the decision making focuses on modification of the irrigation/agriculture system by using advanced technology to improve production?	Agriculture area expansion = 1 Traditional Agriculture/irrigation = 0 Irrigation system modification = 1
3) People participation and integrated landowning	What if the decision making focuses more on participatory management methods? Integrated landowning for optimized irrigation and agriculture is one of the main solutions that needs farmers' high involvement.	Lack of people participation = 0 Small holding = 0 Community based organization = 1
4) Government control, monitoring and limitation	What if the government implements appropriate controlling and monitoring policies?	Subsidy = 0 Lack of government ctrl = 0

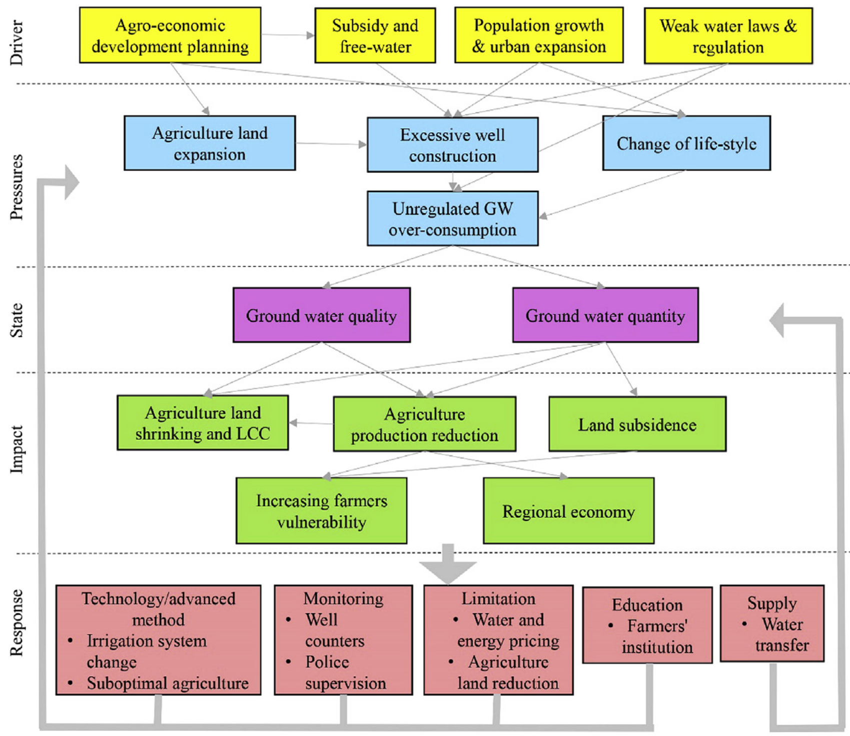

Fig. 2. Preliminary DPSIR framework of water scarcity in Rafsanjan, based on literature and statistic data. Indicators are categorized in 5 different layers (driver, pressure, state, impact and response) and the causal relations are shown with directed arrows. The concept and connections have no value or degree.

of wells". According to the farmers' knowledge the growing number of legal wells was more relevant than the number of illegal wells. So the problem is not excessive well construction without the governmental permission, but rather the weakness of water authority control and supervision that leads to excessive groundwater exploitation via legal wells. In the relatively chaotic situation after the Islamic Revolution in 1979, corruption and populistic water governance were considered as the main components leading to the weak wells control and supervision.

Although official reports and researches emphasize *land subsidence* in Rafsanjan Township (Dehghani et al., 2014; Rahnama and Moafi, 2009; Motagh et al., 2008; Solaimani and Mortazavi, 2008), this issue is not perceived as an important *impact* of water scarcity by farmers. Some farmers have experienced fractures in their buildings and infrastructure (as the symptoms of land subsidence) and P&R know somehow about it from scientific studies but because land subsidence is hidden and slow it is almost ignored, though in the long run the loss of aquifer capacity due to subsidence may reduce the likelihood of aquifer recharge even if precipitation increases.

And finally among the responses derived from the scientific studies and reports, the informal adaptive responses from lay people are not addressed. Here *pistachio land transfer*, *desalination* and *integrated land owning* are among the farming community's responsive actions that are not yet considered. Most of the large land owners are planting pistachio in other regions with better access to water and gradually abandoning their lands in Rafsanjan. Farmers believe this trend is resulting into "water scarcity transfer" to those places where the pistachio land is intensified.

3.3.2. Different stakeholders' perceptions

An interesting difference between the two stakeholders is that the P&R group perceives *lack of government control* as the main driver of water scarcity whereas farmers see the pistachio dependent economy or *mono-economy* as a more important driver (Figs. 3 and 4). *Traditional agriculture/irrigation system* is among the most important drivers for both groups. Yet, there are driver variables mentioned by one group but not the other, e.g. the *lack of land document* is recognized by farmers as the main cause of *traditional irrigation system.* For switching from flood to drip irrigation farmers can get government loans if they have a land title document. However, after the 1963 land reform and the 1979 revolution, many farmers do not have such a document and therefore have less interest in changing their traditional irrigation system. This is an example of a driver that is not perceived as important by the P&R group. Moreover, the *subsidy* and *free water* are drivers only noted by the P&R group and not by farmers.

Another noteworthy difference is that the P&R group perceives *farmers' vulnerability* as the most important (highest centrality) *impact* of water scarcity, whilst the farmers themselves perceive the decrease in *agriculture production* as the most important *impact,* higher than their *vulnerability*. The much higher in-degree value of the *agriculture production* concept than its out-degree in both groups (Fig. 5) indicates that the decrease in pistachio production has not yet influenced other concepts like poverty and migration much. However, both groups mentioned that the visible social-ecological impacts of agriculture production change like immigration, poverty and desertification will be revealed in the very near future.

Considering the *response* category of variables, the most important responses for P&R are *irrigation system modification* and *pistachio land transfer,* whereas *deepening and transferring wells* is the most important response from farmers.

3.3.3. Inter-layers DPSIR categories

We can also compare the structure of FCMs in DPSIR categories via the graph theory to define the category of variables influencing the system more. Based on the graph theory, the variables with

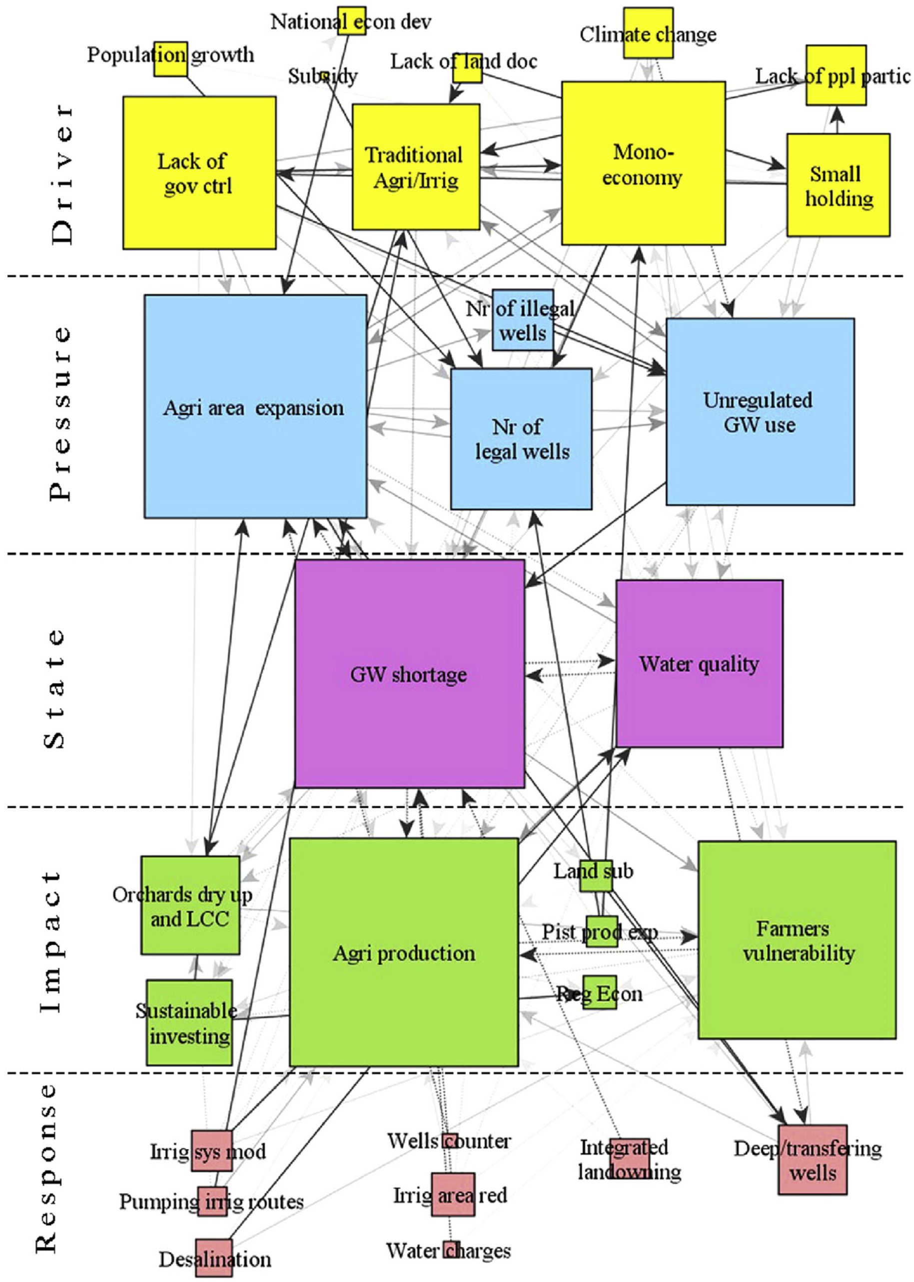

Fig. 3. Farmers' Social Fuzzy Cognitive Map of current state in DPSIR framework. The size of the nodes refers to the centrality of impact, i.e. the weighted sum of input and output connections. The thickness of the connections shows their weight value. Connections with positive weights are straight; and with negative weights are shown in dashed line.

higher density are the more important ones, but the variables with higher out-degree than in-degree are the ones that can better initiate a change to the system than receive the change from system dynamics (Supplementary 5). In both FCMs the important *impact* and *pressure* categories have a higher in-degree than out-degree (Table 3, Fig. 5), meaning these are more influenced by system dynamics. So a change in their behaviour is highly related to a change of input they receive from other categories, i.e. *driver*, *state* and *response* categories, whereas all *driver* and *response* concepts have a substantial higher out-degree than in-degree, meaning a change in their value may easily and more effectively change the behaviour of the system than other categories. However all the response concepts have very low centrality, which means that they have a relatively low impact on the system as a whole. This situation indicates the low effectiveness of adaptations and solutions made so far.

On the basis of the graph theory analysis of the two FCMs, the higher density of the P&R social FCM (Table 3) indicates that they perceive a higher level of complexity within the system than farmers do. Generally speaking, the P&R group has a more diverse and broader view about various aspects of the system than farmers, while the farmers' knowledge of the system is limited to fewer variables.

3.4. Simulation and what-if analysis results

Currently there are different policy alternatives being considered by policy makers in Rafsanjan. As an example we simulate the

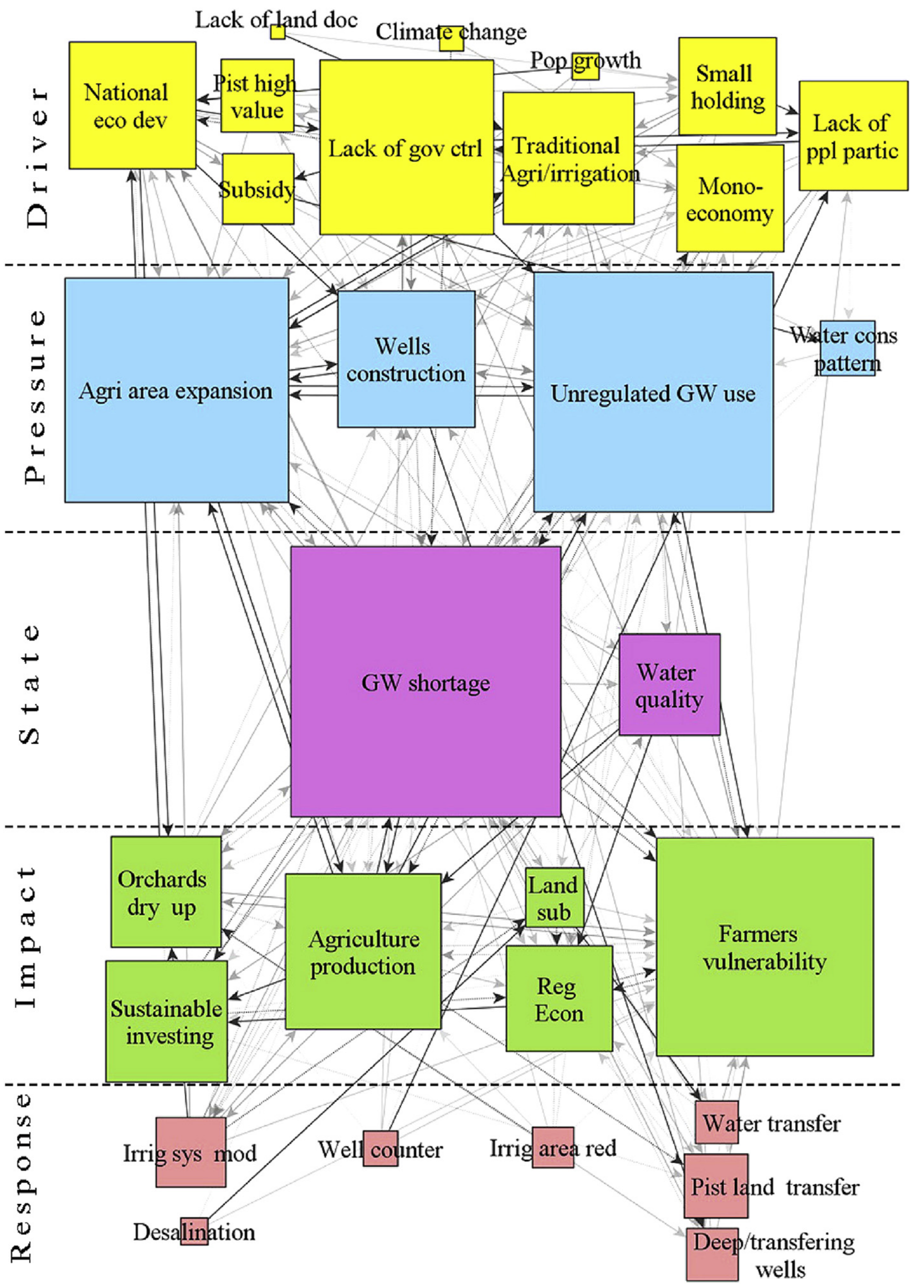

Fig. 4. Policy makers' and researchers' Social Fuzzy Cognitive Map of current state in DPSIR framework.

impact of the four different policy options that have been explained in section 2.4. After running each policy option the end values of each option were compared with the end value of the baseline steady state. Fig. 6 indicates the positive and negative changes of various concepts for each policy option. Concepts without change are not shown in Fig. 6.

Policy option 1: The *economic change* policy has the largest influence on decreasing water shortage in the farmers' model. Although this policy decreases agriculture production as well, eventually it results into sustainable economic development in the region. This interesting result indicates that farmers have a high acceptance in a change of regional economy from agriculture to other source of economies.

Policy option 2: The *irrigation and agriculture system modification* policy has a large influence on a pistachio production increase according to the farmers' model, but it does not help the water scarcity problem that much. It explains that the current agriculture/irrigation system is one of the main drivers of water shortage, but the policy for its modification only works as a short-term solution to palliate the symptoms of the problem, i.e. pistachio production, without removing the main cause. This policy does not have any significant influence on the P&R model except increasing the drying up of orchards.

Policy option 3: The *people participation and integrated land owning* also has a large influence on pistachio production growth in the farmers' model, but it has the lowest positive impact on water shortage in both models. From the farmers' point of view the policy of *people participation and integrated land owning* can highly improve government control.

Policy option 4: Although the farmers perceive lack of

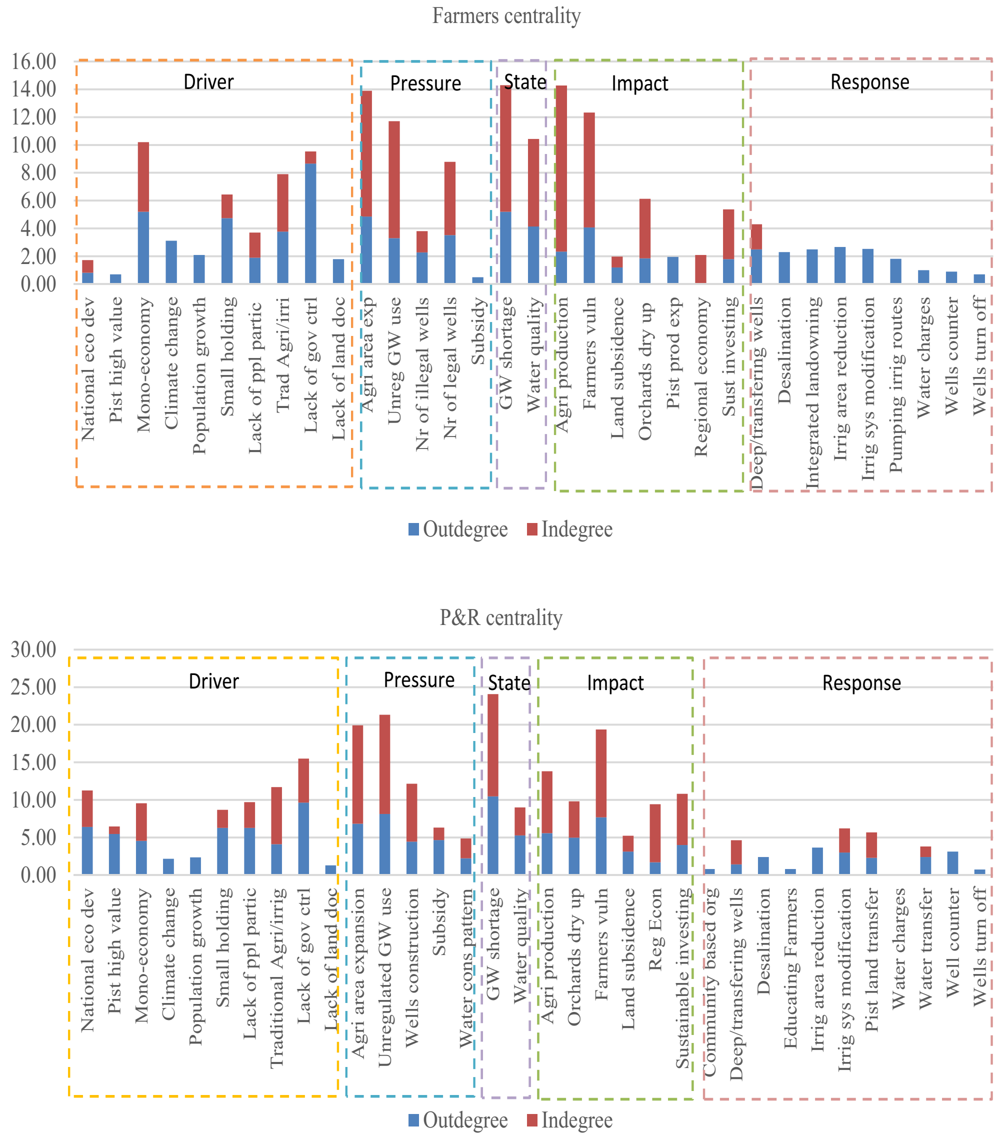

Fig. 5. In-degree, Out-degree and Centrality of variables in Farmers and P&R social map. In-degree and out-degree of each variable indicate the sum of all connections' values entering and exiting that variable respectively. Centrality is the summation of the in-degree and out-degree of a variable.

Table 3
FCM graph theory analysis per Farmers and P&R.

	N[a]	C[b]	T[c]	R[d]	D[e]	ID[f]	OD[g]	IP[h]	OP[i]	IS[j]	OS[k]	II[l]	OI[m]	IR[n]	OR[o]
Farmers	33	124	14	1	0.11	1.44	3.28	4.85	2.89	7.67	4.67	4.42	1.89	0.20	1.88
P&R	34	209	10	0	0.18	3.1	4.85	7.66	5.26	8.67	7.87	5.91	3.98	1.12	1.99

[a] Number of nodes.
[b] Number of connections.
[c] Number of transmitters.
[d] Number of receiver.
[e] Map density.
[f] Mean in-degree of Driver.
[g] Mean out-degree of Driver.
[h] Mean In-degree of pressure.
[i] Mean Out-degree of pressure.
[j] Mean in-degree of State.
[k] Mean out-degree of State.
[l] Mean in-degree of Impact.
[m] Mean out-degree of Impact.
[n] Mean in-degree of Response.
[o] Mean out-degree of Response.

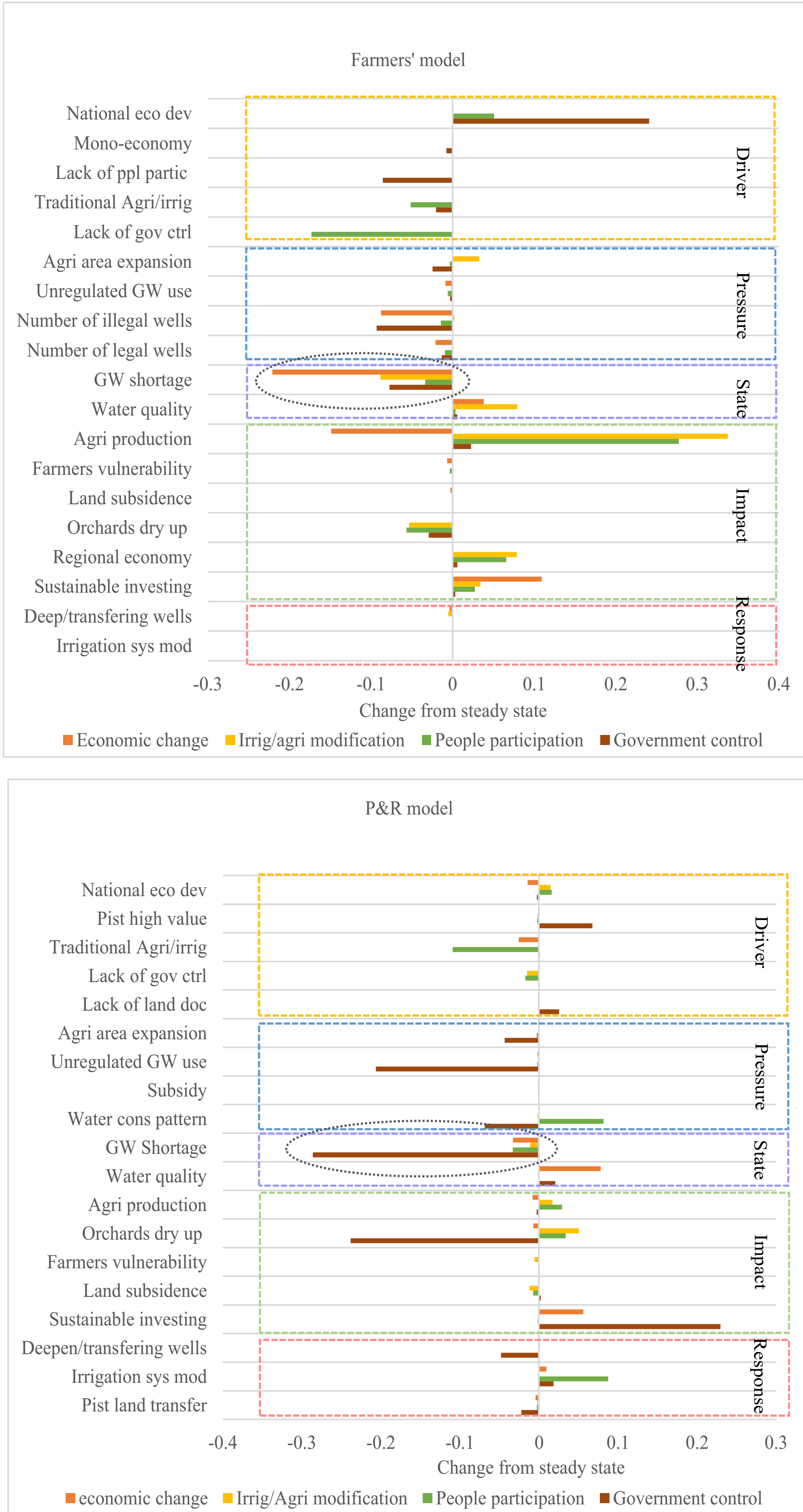

Fig. 6. Simulation results of four policy options and their impact on each indicator compared to the baseline steady state for P&R and farmers' models. The horizontal values represent the change in value of each variable for each policy scenario. Negative value.

government control as one of the main drivers of water shortage, they do not believe that *control and monitoring policies* decrease the water shortage of the region as much as economic change and irrigation modification policies. It does not have any influence on impact concepts as well. On the contrary, *the government control and monitoring* is the most effective policy option in P&R perceptions. It has a much larger positive impact on water shortage than other policy options, as well as on unregulated ground water use and orchards dry-up. Additionally, this policy option dramatically increases sustainable investment of the region according to the perception of the P&R group.

To conclude, the *economic change* and *government control and monitoring* policies are considered to be the most effective policy options fighting water scarcity. However, farmers do not perceive current government policies to control, monitor and constraint water use as very effective.

4. Discussion

4.1. Related work

Some studies use causal networks rather than causal chains in an Enhanced-DPSIR to represent inter-relations of complex systems and to indicate the importance or priority level of concepts based on stakeholder opinions, statistical data and literature (Niemeijer and de Groot, 2008; Namaalwa et al., 2013). Yet, as the degree of causal links is not described in this model, it cannot capture trends but only provide a snapshot picture of a constantly changing system. Other studies use a Bayesian Belief Network (BBN), a probabilistic graphical modelling technique, in DPSIR to quantify causal relationships (Langmead et al., 2009; Lowe et al., 2014). While BBN is a directed acyclic graph it does not incorporate feedback cycles, which are a crucial part of SES (Carvalho, 2013). In our methodology we proposed to use FCM in combination with the DPSIR framework to overcome these limitations.

Mourhir et al. (2016) also introduced an environmental assessment mix-methodology using DPSIR and FCM. Our approach differs from theirs in several ways. Mourhir et al. (2016) used DPSIR to predefine and frame concepts via a stakeholders' workshop and data analysis, and then used the standardized concepts for FCM generation via individual experts. For a SES setting like Rafsanjan, we found it difficult and confusing to structure the problem through defining the variables of DPSIR with stakeholders. Rather, we used a free-style interview for FCM to capture as diverse a range of concepts as possible and then used DPSIR to reduce and structure the complexity of the resulting FCMs. Further, unlike Mourhir et al. (2016), we used the DPSIR framework in later steps of our methodology, for condensation, and as a means to structure the analysis and simulation.

4.2. Applicability of method

The aim of this research was to incorporate stakeholder perception in policy option analysis in the context of a SES problem. The proposed mix-method was easy to use for the acquisition of knowledge from a large group of stakeholders and understanding and analysing the impact of different policy alternatives. For future studies our structured participatory method is applicable in cases where there is 1) a heterogeneous group of stakeholders with strong conflicting interests, and 2) divergent knowledge of problem indicators among stakeholders and scientific studies. In this respect mere reliance of policy makers on available scientific objective data may result into non-effective policy options for stakeholders. Therefore, our structured participatory method is applicable in SES problem settings having the two earlier mentioned characteristics. Application of our method requires the following conditions: 1) ability to identify and categorize groups of stakeholders with different interests, 2) willingness of stakeholders to provide their perceptions in a comprehensive survey, and 3) availability of literature data to categorize each of the DPSIR indicators. If that is the case, the proposed mix-method allows for simulation of different policy options.

The inherent limitations and constraints of each method define the context and extent of its application. An important applicability feature of our method is related to the kind of participatory data collection technique that is used in FCM and makes it different from the knowledge engineering methods (Jetter and Kok, 2014). Unlike the latter, which focuses on capturing the knowledge of recognized experts and presenting it to other people (Jetter and Kok, 2014), the former tries to extract the knowledge of as many stakeholders as possible in an equivalent manner (Papageorgiou and Kontogianni, 2012). The outlier concepts, though these might be important variables but just not perceived by many respondents, are eliminated in condensation or given little weight in social maps. Although there are methods for scaling respondents' contributions or assigning credibility weights to experts (Kosko, 1987), in our view, participatory FCM does not aim to represent reality itself but the most dominant perception of reality. In this way it is a good tool to simulate the general *acceptance* and *suitability* of policy options based on stakeholders' perceptions and experiences. It might happen that policy concepts with strong engineering and technical support of success do not receive positive perception from some of the important stakeholders. In such cases our method will identify stakeholders' perceptions and recognize discrepancies in perceived policy impacts that might be valuable in reconsidering policy options in order to achieve more support from stakeholders.

4.3. Non-applicability

Nevertheless, there are three main shortcomings in the participatory FCM method that need future study:

1) In the case study we noted that some part of the system cannot be observed/perceived by people but there might be accurate scientific data about them, e.g. land subsidence or ground water level which are known as hidden problems. This deficiency of participatory FCM may require a mixed-method that combines local-knowledge-based and scientific-knowledge-based FCMs.

2) The method relies on realities that have been experienced and perceived by respondents. Therefore, only impacts of policy options that have already been experienced or have been well explained can be assessed. The impact of a "water transfer project" is an example of a policy option that cannot be assessed with this method, if the consequence is not well presented and made known, because there is no experience yet with importing (highly priced) water to the region. For using FCM as a policy making tool more modifications and enhancements are required.

3) Since the perception of the different stakeholders is taken, mapped and aggregated by the mediator/interviewer, his/her skill on this also plays a very important role to the final results. It may cause the biased and subjective results especially in the cases that interviewer is not involved enough in the stakeholders' communities.

5. Conclusions

This study introduces a method to model a complex SES problem and to assess impacts of different policy options. It has been applied on a SES setting related to water scarcity in Rafsanjan, Iran.

Combining the problem structuring method of DPSIR with a participatory modelling method of FCM gives us the opportunity 1) to structure the system problem and avoid over-complexity of the participants cognitive maps, 2) to elicit data in cases with lack of reliable data, 3) to involve different stakeholders with conflicting interests and develop perception models, and 4) to simulate impacts of policy interventions on different components of the SES.

The case of Rafsanjan clearly needs two types of strategies to increase its resilience in dealing with water scarcity. First, the quick and short-term actions to fix the most urgent problems, like losing pistachio lands, and to keep the region a place for farmers to stay and invest. Second, the longer-term solutions to secure the sustainable groundwater management in Rafsanjan. The results of a policy option impact analysis indicate that *change of economy* and *government control and monitoring* are perceived as being the most effective water scarcity policy options by farmers and P&R respectively. However, the modelling clearly showed that the farmers have a low level of trust in the ability of the government to regulate and control water usage. The current water crisis appears to justify such a view. A crucial issue for effective water management in Rafsanjan would therefore be an equitable engagement of all major stakeholders so that a multi-stakeholder approach to sustainable groundwater management can be pursued.

Finally, the outcome model of this study can only be used for deliberating and comparing the acceptability of different policy options' impacts, and is not meant to give definitive answers to the problem nor accurate forecasts of policy impacts.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2017.04.017.

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