Asian Journal of Chemistry Vol. 21, No. 4 (2009), 3279-3294

A System to Support Policy Development for the Sustainable Production of Biofuels

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The authors present a system that supports the development of policies, in particular those related to food security. It does so by facilitating the communication between policy makers through the explicit computer representation of policy intent, content and rationale. A prototype software system has been implemented as an extension of Compendium (http://compendium.open.ac.uk) and its potential impact as a tool to be used during policy making is explained with the help of a case study on the sustainable production of biofuels in Zambia.

Key Words: Biofuel sustainability, Zambia, *trans*-Disciplinary activity, Issue based information system.

INTRODUCTION

One of the most profound impacts of climate change will be on agricultural productivity, food systems and global food security. Increasing temperatures and a declining and unpredictable main season precipitation over semi-arid regions is likely to reduce the yield of primary crops like wheat, corn and rice in the coming years[1]. External factors can further increase the vulnerability of regions like southern Africa, where already a significant problem of food insecurity exists. The most important of the external factors which can impact long-term food security, both locally and globally, is the rise of oil prices. With the oil futures rising to $ 110/barrel, massive global expansion of biofuel production from sugar crops, maize and oilseeds is taking place. This creates a situation where prices of these essential food items will be determined in part by their value as feedstock for biofuel production rather than by their importance as human food or livestock feed. For 2.7 billion people who live on less than $ 1 a day the effects of rising food prices will be catastrophic[2].

It is expected that while petroleum prices remain high, government policies in major crop producing countries will remain tilted towards the continuous expansion of biofuel production capacity. Hence, a complex energy supply issue which threatens global food security requires the formulation of policies to ensure the sustainable production of biofuels.

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A prototype system that supports the development of policies by facilitating the communication of policy intent, content and rationale between the different stakeholders is presented. It records the decision making process (decision rationale) in a format amenable to computer manipulation thus enabling to recall which decisions were made and why and to explore the effects of a change in a variable on a decision network.

The rest of the paper is organized as follows: in the next section we discuss the objectives of the research and discuss the application of decision support in the formulation of policies in general. Section 3 describes the software used in the implementation of our proposed methodology, in particular the extension to a public-domain tool called Compendium and how they are relevant to supporting decision making in the context of policy formulation. Section 4 exemplifies the methodology and the application of the prototype support system through a case study: the sustainable production of biofuels in Zambia. The limitations of the current work, the proposed future work and the conclusions are presented in the last sections.

The application of decision support software in policy formulation:

Policy formulation is the development of effective and acceptable courses of action to reach explicit goals. However, most of the policies have many layers of hidden intent and complex interrelationships with other issues, which result in misaligned objectives between the various policy makers.

The development of policies for the sustainable production of biofuels and the maintenance of food security is a classic example of a *trans*-disciplinary activity, *i.e.*, the bridging of science and policy in the co-production of knowledge during which different policy cultures interact[3]. Both, biofuel production and food security are vast fields involving experts from a number of diverse disciplines such as economics, social policy, environmental studies, foreign policy and agriculture science. We are using a network representation to characterize the concepts and relations of policy design for food security in the context of a sustainable production of biofuels.

The purpose of present research is to develop a software platform to support the development of policies of a multidisciplinary nature by facilitating the communication between policy makers through the explicit computer representation of policy intent, content and rationale.

In present approach, the development of policy follows a three stage cyclical model:

(1) The development starts with the representation of the policy's intent, *i.e.* the objectives of the policy and the associated criteria against which the alternative policy options are going to be measured.

(2) The policy itself is understood as a set of policy tools (or measures) belonging to 4 possible classes: economic (*e.g.* taxes and subsidies), regulatory, technological and market tools. Policy tools are added to the current state of the policy by the

policy makers with the intention of satisfying the objectives. The policy tools can be selected from an existing library and the policy can be evaluated against a set of weighted criteria representing the objectives.

(3) The policy maker can record the justifications for the decisions taken when developing the policy by means of argumentation structures in the form of Issue Based Information Systems (IBIS) networks.

IBIS was originally developed in the 1970s to model argumentation in social sciences[4]. The use of the IBIS argumentation grammar enables the representation of decision rationale by structuring information in terms of issues (Issue or Question nodes), a number of alternative solutions to each issue (Option nodes) and reasons that support or oppose each of the options (Pros/Cons and Argument nodes), see for example Fig. 1. A record of decision rationale (*i.e.*, of the reasoning behind making the individual decisions) is important for the identification of the impact that changes in the current situation may have on previous decisions, *e.g.* the impact of crop prices on deciding which biofuel crop to grow (if any). A similar methodology has been successfully applied for the design of chemical processes[5] and urban waste-water treatment plants[6].

In present methodology the support decision rationale management is viewed as a type of dialogue mapping, which is a technique to support collaborative problem analysis or, in the words of Conklin[7] "*supporting collaborative intelligence through building shared understanding and shared commitment*". The software that is being used for dialogue mapping is Compendium, a hypermedia concept mapping tool which provides a visual environment for a collaborative, semiformal modelling of argumentation and decision-making; Compendium has been developed by the Compendium Institute[8]. A user of Compendium can create and connect Issue, Position and Argument nodes thus developing an interactive map which, in turn, is the basis for a shared display. In addition to the types of nodes already mentioned, we are also using Map nodes. A Map node groups a set of other nodes permits the representation of decision rationale at several levels of abstraction.

Discussion and rationale can thus be captured and then presented in a structured visual form. Nodes can appear in more than one Map node, providing different contexts for the decisions being recorded.

Compendium's hypertext functionality is a valuable addition to the issue-based notation derived from IBIS and its Java-based open architecture enables interoperability with other database and collaboration technologies.

EXPERIMENTAL/COMPUTATIONAL

Policy development using an extension of Compendium: From the point of view of policy making, Compendium allows for argumentation facilitation between different stakeholders. Argumentation facilitation is carried out by recording the information in a clear and concise fashion such that a shared understanding is created about the problem between different stakeholders and shared commitment to possible solutions can be obtained. The essence of the policy dialogue is captured by dialogue mapping by recording what arguments and what subsequent decisions were made in the process. Stakeholders can decide upon shared meaning for key terms and concepts, thus ensuring that they are about clear in their roles in the combined effort together to reach the requisite policy goals. This capability of Compendium is displayed in the Fig. 1 which shows the overview of a policy development process.

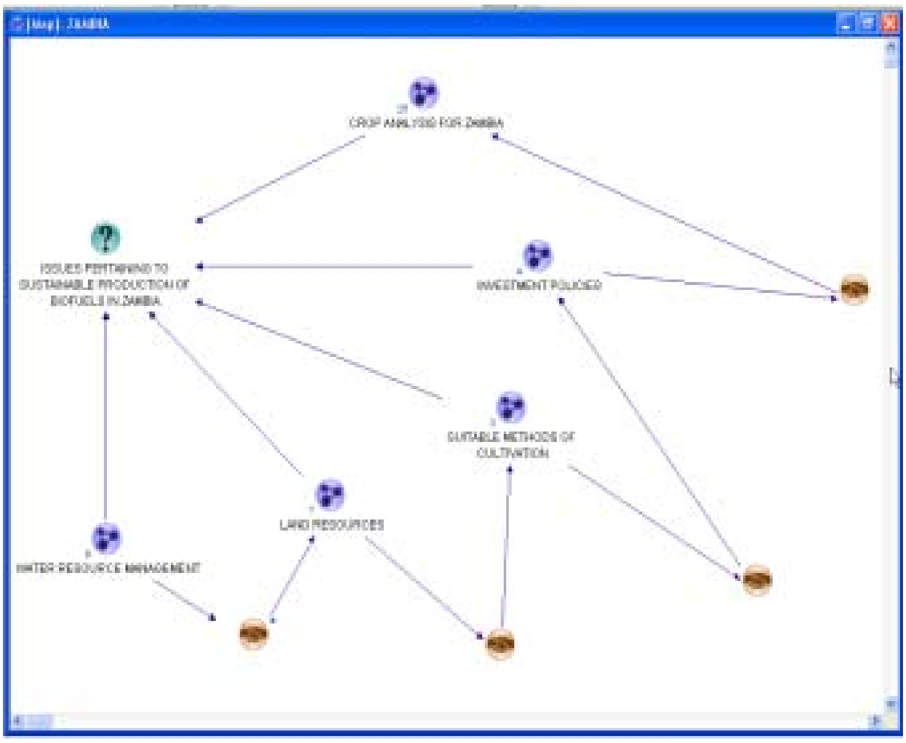

Fig. 1. Argumentation facilitation between different stakeholders

The policy representation in Fig. 1 shows an issue node (Issues Pertaining to Sustainable Production of Biofuels in Zambia) grouping all the issues related to the sustainable production of biofuels. Attached to this Issue node are 5 different Map nodes (*i.e.* water resource management, land resources, methods of cultivation, investment policies and crop analysis), each of them representing diverse stakeholder concerns, but all of related to the main issue of ensuring the sustainable production of biofuels in Zambia. In essence, policy makers have to resolve the set of decisions related to all the different concerns; agreement is represented by the Handshake node (a decision or set of decisions taken). The above representation is a simple representation of the policy cycle in which taking one decision leads to other issues.

Compendium provides a software platform which allows stakeholder concerns as diverse as crop analysis and demographics to be represented, visualized and evaluated together. The entire policy issue is broken up into smaller parts, each evaluated separately and then refitted in the policy paradigm to allow for a complete and coherent decision making process. The breaking down of the large policy issue into smaller sub-issues gives the stakeholders the scope to simplify the policy development process.

An extension to the public domain version of Compendium has been implemented and the results of its application are reported in the rest of the document. The extended version contains as an additional feature an '*Options vs. Criteria*' matrix[9] (shown in Fig. 5), which allows for the quantitative analysis of the information by (a) evaluating the available options with respect to the criteria selected by the policy makers, (b) run sensitivity analyses and (c) perform 'what if' studies.

This functionality facilitates the identification and selection of what may be considered a 'satisfying' option.

The use of an IBIS representation within an extended version of Compendium will be explained using a case study on Zambia, a landlocked country in southern Africa. One of the issues in this case relates to the selection of the most suitable crops for production of biofuels in Zambia (Fig. 2). This question is represented using an Issue node (Study of Biofuel Crop Alternatives for Zambia). The various options, in this case the basic 8 crops grown currently in the country, are represented using Options nodes (Maize, Cassava, Jatropha, *etc.*). Attached to each Option node are the Argument nodes that represent the advantages and disadvantages of each of the options.

The standard version of Compendium enables a user to create and edit the tree structure shown in Fig. 2. It visually represents the issue at hand and the options to be considered, but a mechanism to represent the criteria used to compare the options and to rank such options is unavailable in Compendium.

Our extensions to Compendium allow the users to add their own goals, associate criteria to each of those goals and record the criteria used during the comparison of alternative and competing options.

Creation of criteria: Fig. 3 shows the creation of the 'resistance to droughts' criterion and in the background, a list of some of the other criteria used in the case study. Once a criterion has been created, the user may use it in any of the decisions that are being recorded.

Association of criteria to goals: Fig. 4 shows that several criteria, such as suitability for jatropha and vulnerability to climate change, have been associated to one of the goals (environmental sustainability). Similarly, other criteria such as yield per hectare and international selling price are associated with economic sustainability. Finally, some other criteria may be associated with more than one goal, *e.g.*, presence of pasture land and pesticide usage (environmental and economic sustainability), production of cereals (economic and social sustainability), *etc.*

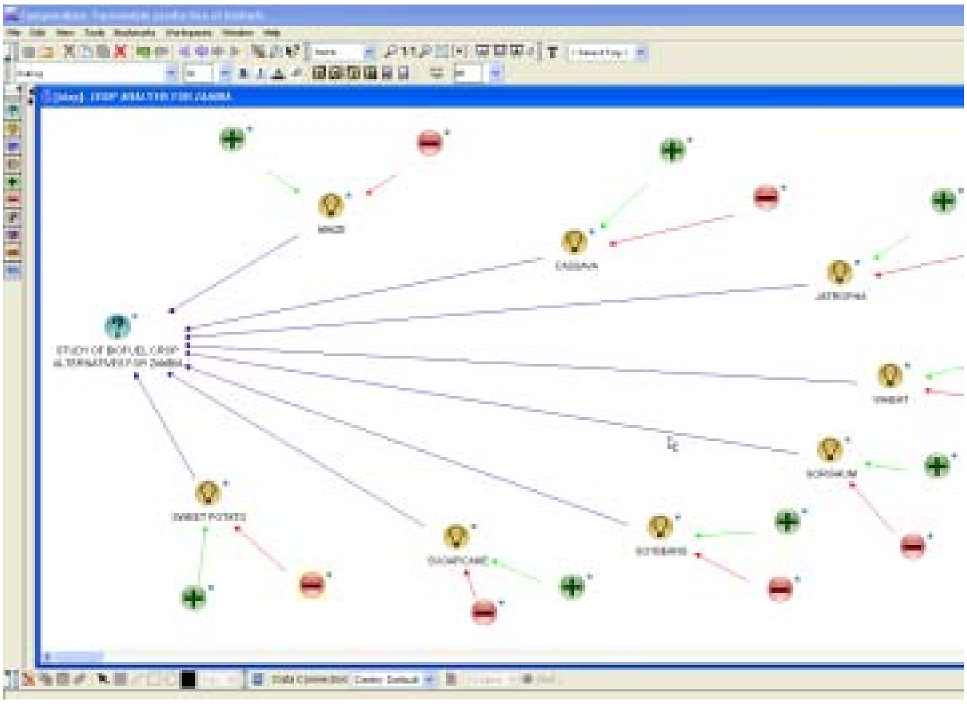

Fig. 2. A simple Compendium map, one of the decisions associated with the sustainable production of biofuels in Zambia

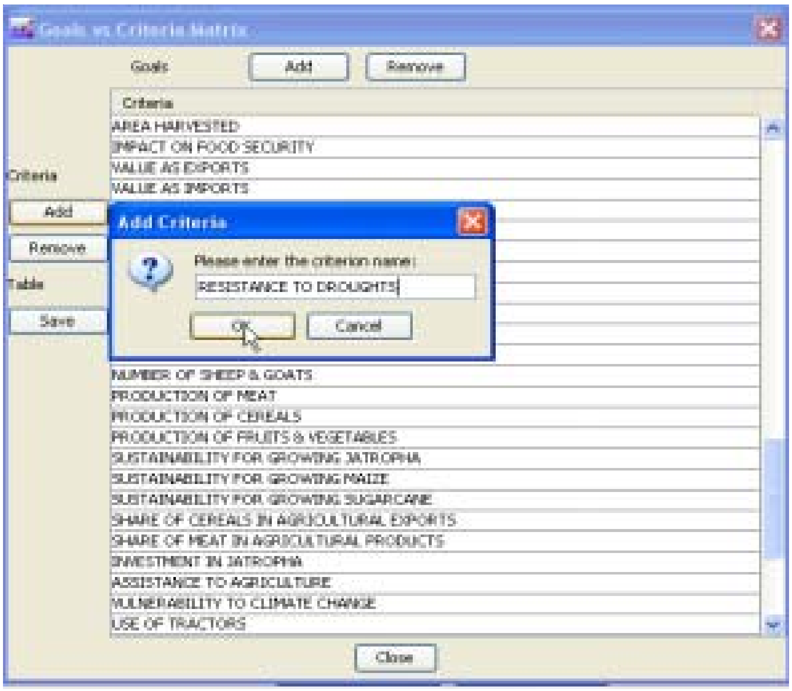

Fig. 3. Adding criteria using the goals *vs.* criteria matrix

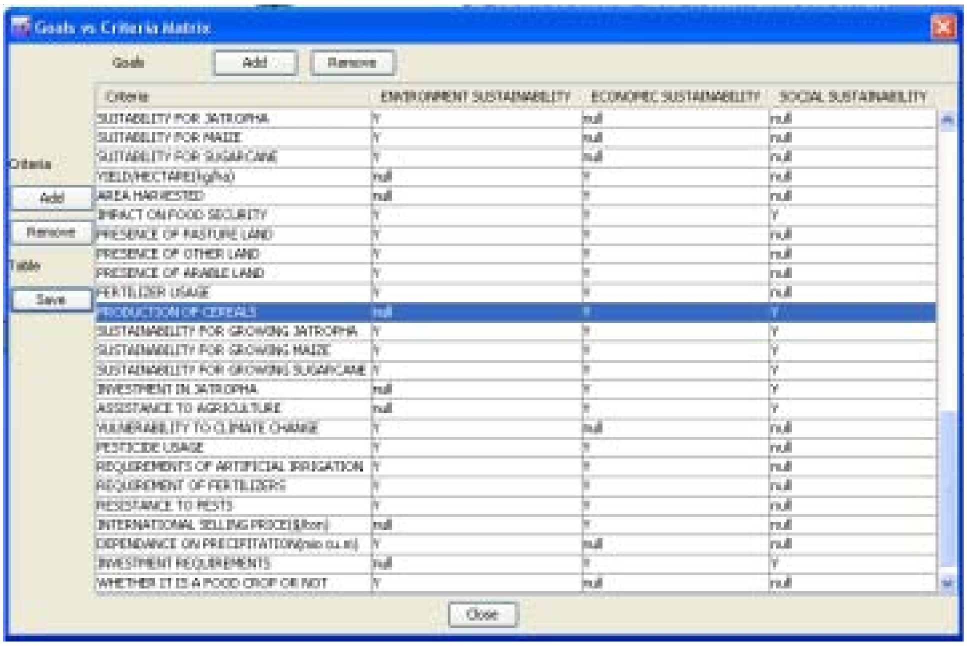

Fig. 4. The goals *vs.* criteria matrix showing the association of criteria to goals

The fact that some criteria may be matched to more than one goal reflects their *trans*-disciplinary nature and the fact that overlapping criteria are needed to measure a specific goal. For instance, the impact on food security criterion is related to all 3 goals of environmental, economic and social sustainability.

Options *vs.* criteria matrix: Furthermore, the extensions to compendium associate automatically an 'options *vs.* criteria' matrix to every existing issue and its connected options. As a result, the template of a matrix such as the one shown in Fig. 5 (but with no rows or values in the cells at the outset) is created for every issue. The user then selects, from a list of the existing criteria, which of them are to be used in the comparison and ranking of alternative options; he/she also has to input the values inside the cells of the matrix.

The resulting options *vs.* criteria matrix is used to compare the options (columns) against the set of weighted criteria (rows). To this end, the quantitative rating of every option is calculated for all the options in the matrix and displayed in the row labelled 'totals'. This information is helpful in the selection of the best option.

In this example, we can see that Jatropha is best suited crop for biofuel production in Zambia. Following Jatropha and ranked in order of suitability, are Sorghum and Cassava. Currently, Zambia does not use either sorghum or cassava for biofuel production, however, given the total production levels of 19,000 kg and 950,000 kg respectively[10], these options could arguably be considered in the future.

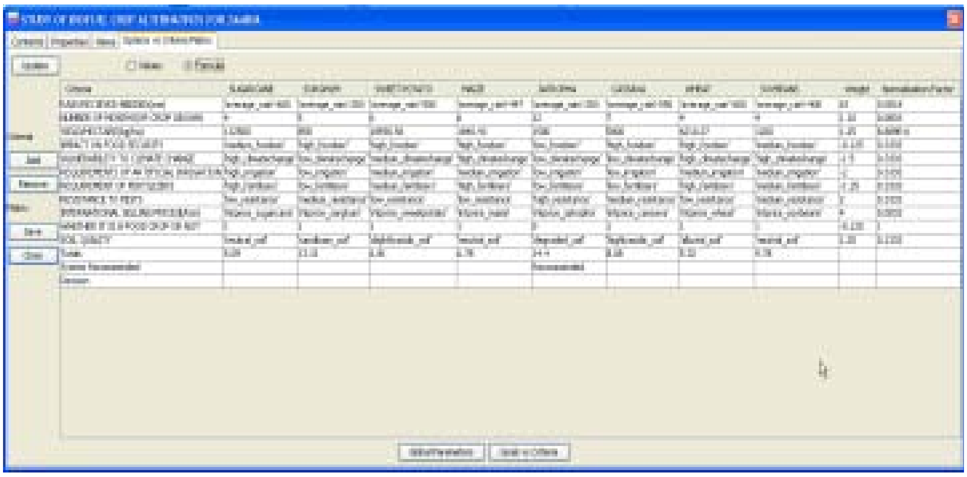

Fig. 5. The 'options *vs.* criteria'matrix associated with the map in Fig. 2 (data taken from http://www.fao.org/statistics/yearbook/vol_1_1/index.asp, last checked on 11/Jan/08)

Global parameters and sensitivity analysis: In the options *vs.* criteria matrix, the degree of satisfaction of each alternative with respect to a criterion (the values in the matrix cells) may be expressed as a function of a set of parameters, for example 'parameter 1' * 'parameter 2'. In present implementation these parameters are known as global parameters and are declared in the global parameters window shown in Fig. 6. Once declared they are available throughout the project. In particular, the system will supply the value of a global parameter to the cells in the options *vs.* criteria matrix (Fig. 5) when a reference is made to that parameter. The importance of global parameters is that a change in the value of any of them in the global parameters table shown in Fig. 6 can be propagated throughout all the decisions where the parameter is present.

For instance, one of the global parameters in Fig. 6 is intprice_jatropha, an abbreviation for the price of Jatropha in dollars, which is $ 125 per tonne. Any change from the value of 125 $/tonne will cause the calculations in the matrices representing the decisions to vary accordingly. This would facilitate, for example, the exploration of which decisions would need to be revised in the event of a given change in Jatropha prices.

The possibility of running sensitivity analyses is also available. It simulates the effect of changing the value of a global parameter above and below a certain percentage over a number of steps and allows the exploration of the effects on previously taken decisions. The result of a sensitivity analysis is shown in Fig. 7. The analysis considered the effect of a 40 % change in the global parameter "intprice_ sorghum"; only starting at this level of variation in the value of the international price of sorghum the originally recommended option (Jatropha) may be substituted in favour of a new recommended crop (Sorghum and Jatropha).

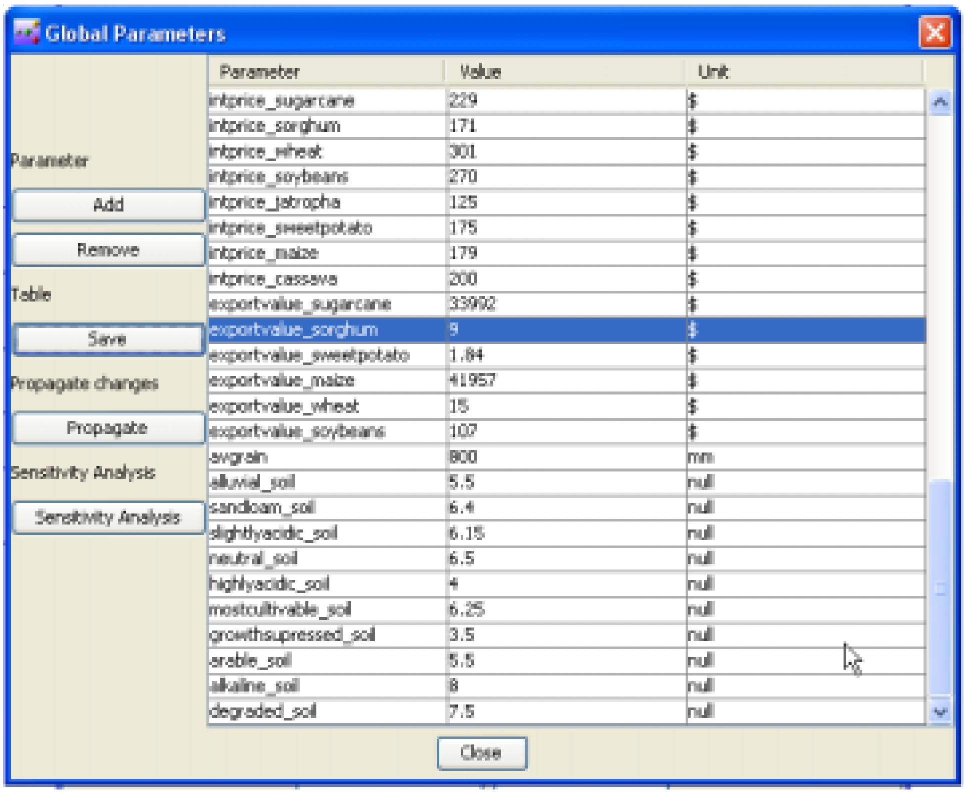

Fig. 6. Global Parameters Table

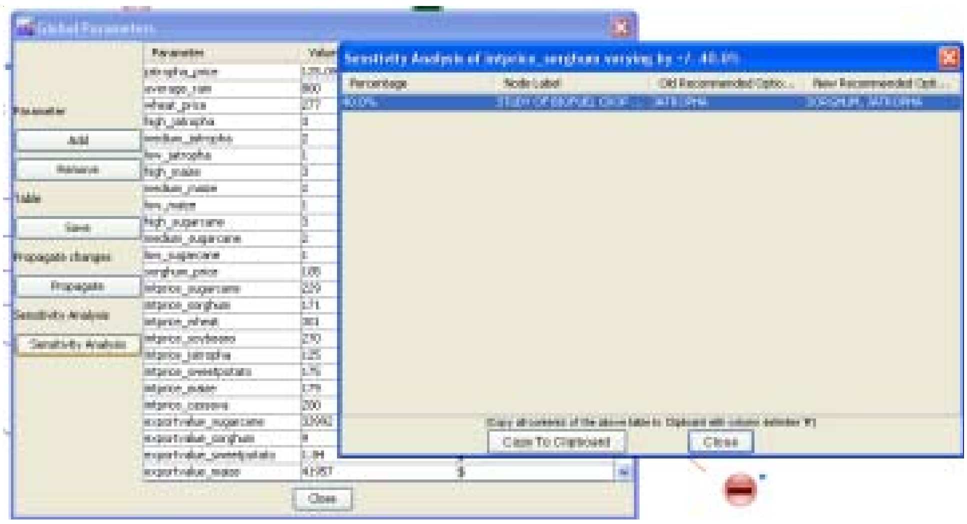

Fig. 7. Sensitivity analysis of the variation in the "intprice_sorghum" parameter

Furthermore, the value of a global parameter may be imported from an Excel file, opening up the possibility of obtaining such value from external calculation packages, such as simulation or forecasting ones. We envisage the use of a simulation package to explore the effect of its inputs on the recorded decisions as follows: (1) The user executes the package with a set of input values. (2). A set of outputs is generated and exported into Excel (most external packages provide this functionality). (3). Each one of these values may be made accessible by reference to one or more decisions in the system, *e.g.*, the expression 'C:\My Documents\FileName.xls; SheetName1;b7' * 3, would retrieve the value found in column B, row 7 of the sheet Sheet Name inside the excel file File Name.xls and multiply it by 3. References to this or other values can be made from any of the options *vs.* criteria matrices in the system, *i.e.* from each one of the recorded decisions (not used in present case study). (4) As the values in the Excel files are updated every time that the external packages are executed, those values are, in effect, propagated through the decision records. (5) The effects of this propagation on the preferred options for all recorded decisions are visualized in a window similar to the one shown in Fig. 8 (not shown).

Hence, the global parameter and the sensitivity analysis functionalities allow the user to explore a number of scenarios and see how they affect the decisions already made. A tool with such functionality may become very important when recording the decisions regarding food security in the context of climate change, given the fact that climate change itself increases the uncertainty of factors such as rainfall and soil quality.

RESULTS AND DISCUSSION

Case study: the sustainable production of biofuels in Zambia

In order to test and showcase the features of the prototype, a case study on the sustainable production of biofuels in Zambia has been developed. The contents of the case study are believed to be representative of the types of issues, options, criteria and weights that a policy developer may want to use, but are not purported to be a recommended policy for Zambia.

Zambia is a landlocked country in southern Africa which in the past years has been facing extreme weather conditions in the form of droughts and unpredictable rainfalls. All of which threaten its food security and are regarded as consequences of climate change. These factors make the consideration of water management issues and the selection of the right crop alternatives, among others, indispensable to policy development for the sustainable production of biofuels.

The network in Fig. 1 illustrates our approach to the task of policy making. To begin with, when the map node representing water resource management is clicked, another window showing the water resources options available for Zambia is opened. As will be explained in water resource management issues section, each of these options (drip irrigation, aquifers, surface irrigation, water harvesting, full/partial irrigation schemes and sprinkler irrigation) was weighed against a set of criteria selected by the user. As a result, the water harvesting option was recommended over the others, as shown in Fig. 8. The arrival to a decision for any of the sub-issues (the Map nodes in Fig. 1) is represented by the handshake nodes. Similarly, a decision pertaining land resources will be described in land resources issues section.

Although not described in detail in the rest of the paper, the sub-issue related to the selection of suitable cultivation methods has been explored. Only 2 options were considered in this case: Extensive and intensive agriculture. Owing to the importance of the agriculture practises on sustainability issues and the influence of land and water resources on agricultural options, these 2 options were considered with respect to several weighed criteria related to the agricultural, social and economic suitability. As a result, the extensive agriculture option was recommended; this agricultural practice was found to be sustainable not only from an agricultural point of view but also from a socio-economic view as it can generate rural employment and requires low investment by the farmer.

The role of the general economic aspects of policy making was then examined in the investment policies sub-issue. Investment policies deal with the economic options available to Zambia that ensure the sustainable production of biofuels. The shortlisted options for Zambia were: government sector investment in the nascent biofuel production program, a joint public-private investment, raising loans from the international market and creating microfinance institutions to enable the availability of funds for farmers. Again, these investment options were weighed against economic and social criteria to enable the formulation of a sustainable and acceptable socioeconomic policy. However, more research needs to be done on the socio-economic aspects of sustainable biofuel policy before any final results can be drawn on this sub issue.

Finally, the last sub issue was crop analysis, *i.e.* the selection of the most suitable crop for the sustainable production of biofuels. This issue has been briefly introduced in section option *vs.* criteria matrix and will be further explained in evaluation of crop alternatives section.

Water resource management issues: One of the steps taken during the course of policy formulation was to select the most suitable irrigation method, *i.e.* one that would meet the sustainability criteria in terms of water resource management.

Fig. 8 shows the use of the options *vs.* criteria matrix to evaluate the options available to Zambia in terms of water resources. Some of the options (drip irrigation and sprinkler irrigation systems) can be effectively used with limited water supplies, but owing to their prohibitive costs they are used exclusively for coffee and wheat cultivation. In turn, water resources available in the form of aquifers and dambos (inland water harvesting lakes), although cheap, yet owing to their extensive dependence on rainfall can be inadequate in drought conditions. The options of surface irrigation and full/partial irrigation schemes stems from the fact that 42 % of Southern Africa's water resources are located in Zambia. Lastly, water harvesting (the recommended option) involves storing rainwater in large tanks and use it during the dry season;

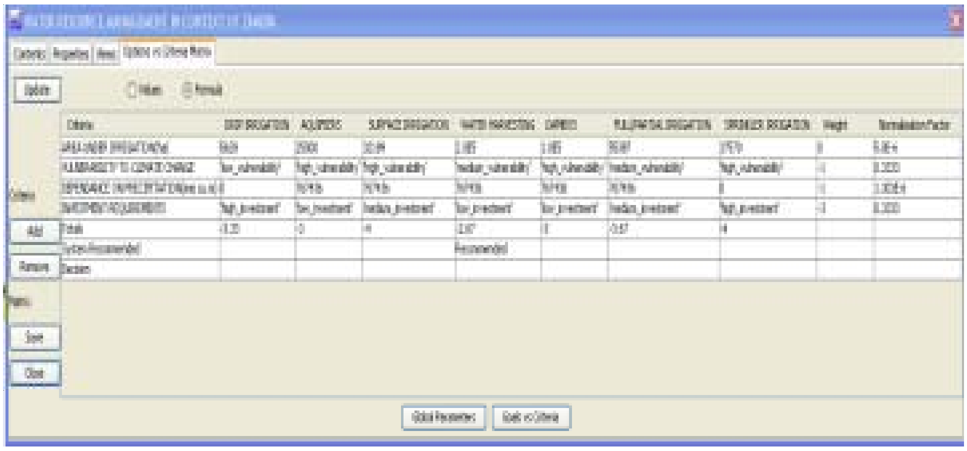

Fig. 8. Decision regarding water resources management options[10] (data taken from http://www.fao.org/statistics/yearbook/vol_1_1/index.asp, last checked on 11/Jan/08)

this method is both cheap and, like in the arid parts of India, has the potential of preventing flooding during periods of excess rainfall and combating drought in the absence of rainfall. The criteria used in the matrix were selected in accordance with generic water sustainability issues such as dependence on precipitation, investment requirements and the ability to withstand extreme weather events.

Evaluation of crop alternatives: The decisions related to water resource management were the first considered in order to address the overall issue of sustainable production of biofuels (as shown in Fig. 1). The next set of concerns presented is related to the selection of the most sustainable crop option for Zambia. The options considered were the major crops being cultivated in the country, *i.e.* sugarcane, sweet potatoes, cassava, sorghum, wheat, corn/maize and soybeans. In addition to the food crops, Jatropha was added to the options because recently Zambia has launched a program to utilize it for biofuel cultivation[11]. Jatropha is a non-food crop which only needs 250 mm of rainfall per annum and can grow on degraded soil. As shown in Fig. 5, the analysis through the options *vs.* criteria matrix recommends Jatropha as the most sustainable of the crop options. This recommendation seems sensible, but it should be stressed that it depends strongly on the limited amount of data used for the case study and the particular selection of criteria and their corresponding weights.

Land resources issues: As mentioned previously, Zambia already suffers from a threatened food security which makes the selection of right land resources critical for ensuring the sustainable production of biofuels. The options available to Zambia are pasture lands, arable lands, land with permanent crops, land under irrigation and other land resources. These options were compared against different weighted criteria such as their suitability for growing Jatropha, soil quality and vulnerability to climate change (on the land resource). Fig. 9 shows that the analysis of the land resource options recommends the use of Pasture land for Jatropha.

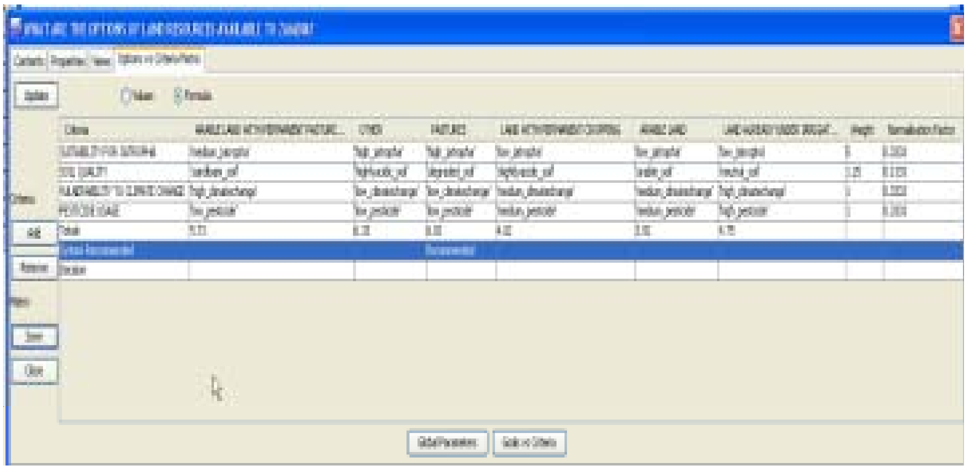

Fig. 9. Options *vs.* criteria matrix for evaluation of land resource options

A sensitive analysis was carried out to see how much variation in the selected global parameter would tilt the decision. The global parameter selected in this case was 'degraded_soil', abbreviation for the level of degradation of the soil quality. A degraded soil arises out of regressive evolution process associated with loss of equilibrium of a stable soil system. Formation of degraded soils is different from the normal process of soil evolution and related to local climate changes and soil erosion. In quantitative terms, the level of soil degradation is measured using the pH of soil water which depends on the activity of hydrogen ions in the soil water solution.

For the purpose of sensitivity analysis, the value of degraded soil was varied by 80 % (given the severity of soil degradation in Zambia and rest of southern Africa such a variation in degraded soil quality is plausible).

The "degraded_soil" global parameter is present in 2 different decisions: one related to the usage of land resources and other to the selection of suitable crops for biofuels in Zambia. Hence, the variation in this global parameter is propagated throughout all the decisions (in this case 2 different matrices). This has caused 2 of the originally recommended options (pastures and Jatropha) related to land resource usage and crop selection, respectively, to be discarded in favour of new recommended options, *i.e.*, other (land resources) and sorghum.

In the same fashion the remaining stakeholder concerns, represented by the map nodes in Fig. 1 can be addressed with the help of the options *vs.* criteria matrix, global parameters and sensitivity analysis to reach a satisfysing biofuels policy.

In summary, the prototype provides a visual representation of the policy development decision process and has the potential to improve the engagement and communi-cation between stakeholders. More importantly, it provides different mechanisms to explore the effect of a change in the world, such as the price of a commodity or the tax rate, on decisions previously made.

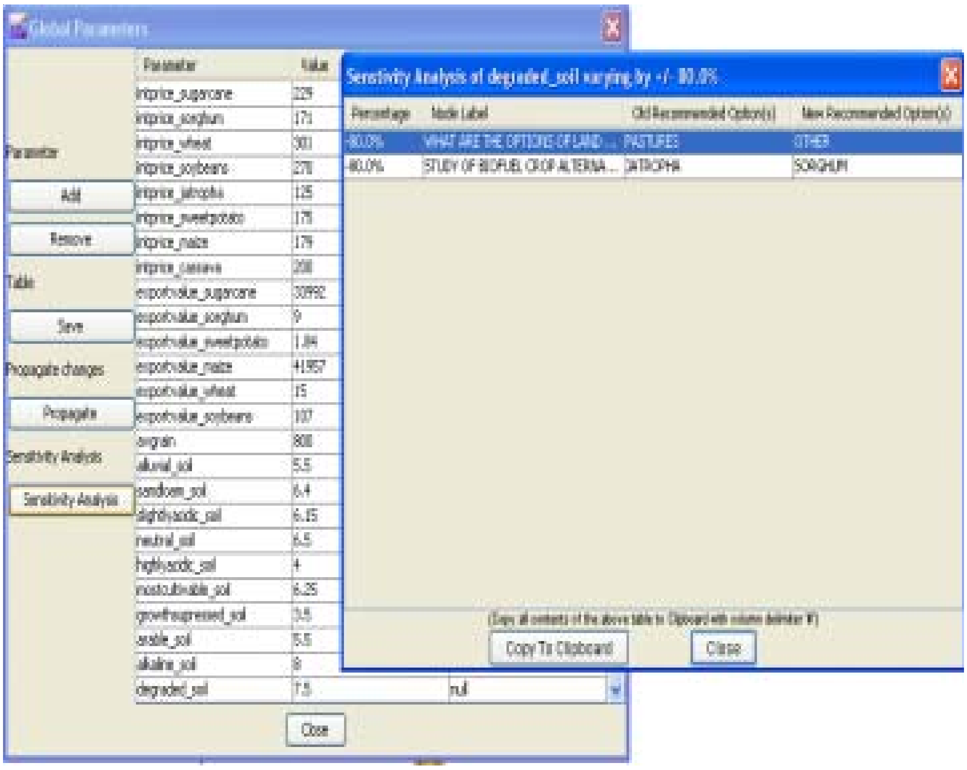

Fig. 10. Sensitivity analysis showing changes in two decisions

Limitations and future work: A number of limitations have been identified through the application of the extended version of Compendium to the case study. These limitations can be grouped in the following areas: (1) Treatment of qualitative values. (2) More sophisticated methods of multi-criteria decision analysis. (3) Provision of connectivity to external databases calculation packages.

Perhaps the most important limitation of the current version of present system is its limited ability to deal with the qualitative evaluation of options with respect to criteria, *i.e.* those options whose compliance with respect to a criterion cannot be quantified numerically. Examples of these types of criteria are those related to the social impact of bio-energy crop cultivation. The present (very limited) approach maps the low, medium and high qualitative values to an arbitrary numerical scale of 1 to 3 in order to combine qualitative and quantitative criteria. We are currently implementing another extension that uses fuzzy values and logic to categorize the extent to which an option satisfies a criterion in terms of linguistic values, *i.e.* low, medium high.

Another extension being considered is the addition of more sophisticated multi-criteria decision analysis methods on top of the weighted and normalized summation used at present, such as the ones discussed[12].

Apart from the above, we are seeking to provide connectivity to external databases and external calculation packages, *e.g.* to models that forecast the effect of a variable on the rest of the system.

Conclusion

Policy development for the sustainable production of biofuels is an example of *trans*-disciplinary activity, *i.e.* the bridging of science and policy in the co-production of knowledge during which different policy cultures interact[3]. Both, biofuel production and food security are fields involving experts from diverse disciplines such as economics, social policy, environmental studies, foreign policy and agriculture science.

A prototype system that supports the formulation and development of policies of a *trans*-disciplinary nature has been presented. It supports policy developers by facilitating the communication of policy intent, content and rationale between the different stakeholders. The prototype system embodies a 3-stage cyclical model of policy formulation, *i.e.* one in which (1) the objectives and the criteria to evaluate compliance are declared first, then (2) diverse issues are explored by proposing and analyzing alternative solutions for each and finally (3) decisions are made in terms of selecting the most appropriate option for each issue using the information available at the time.

This decision making process can be recorded in a format amenable to computer manipulation such that this record, or decision rationale, enables the user not only to recall which decisions were made and why, but also to explore the effects of a change in the value of a variable on the current network of decisions. These effects can be investigated in three different fashions in the proposed system: (1) by changing the value of any of the global parameters and propagating this new value to all the decisions where it is present, (2) by re-executing one or more external calculation packages and importing their outputs from an Excel file, or (3) by performing sensitivity analyses. In all cases the system will return a list of the decisions that may have to be revised because a more favourable option than the one originally recommended has been identified.

ACKNOWLEDGEMENT

The authors wish to thank the Compendium Institute for developing and providing public access to Compendium.

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(*Received*: 1 December 2008; *Accepted*: 24 January 2009) AJC-7187