The impact of the model structure in social simulations

O. Barthélémy
Centre for Policy Modelling, Manchester Metropolitan University,
O.Barthelemy@mmu.ac.uk

The use of scenarios for planning is quite common, be it for industries, nations, shop chains, or technologies. They represent a specific approach where while dealing with uncertainties, one can either consider the whole (frequently continuous) range of alternatives, or specify particular cases that would capture key properties of this range.

From their appearance in the literature in the 40s, scenarios have been more and more frequent. It was generally extrapolated through past data and relationships, till the 80s, when the studies in innovation and diffusion showed that the future is depending on changes in social and economic systems which paths are multiple, and indeed not fixed, but evolving themselves. The goal of scenarios then became the analysis of some trends within a "possibility space", and eventually the reduction of that space finding potential discontinuities, in order to improve the decision making process.

It is the case for climate change and social behaviour throughout time. Scenarios are used because the future is uncertain, and the ability to adapt to these future changes might have effects upon the longer term (e.g. technological changes).

A multi agent system can be used to represent formally these scenarios and its structure and components can then be analysed in order to evaluate their impact upon the outcome.

The interest in scenarios

This diagram from the CC:DEW report shows the increasing uncertainty as the different components are integrated into a model.

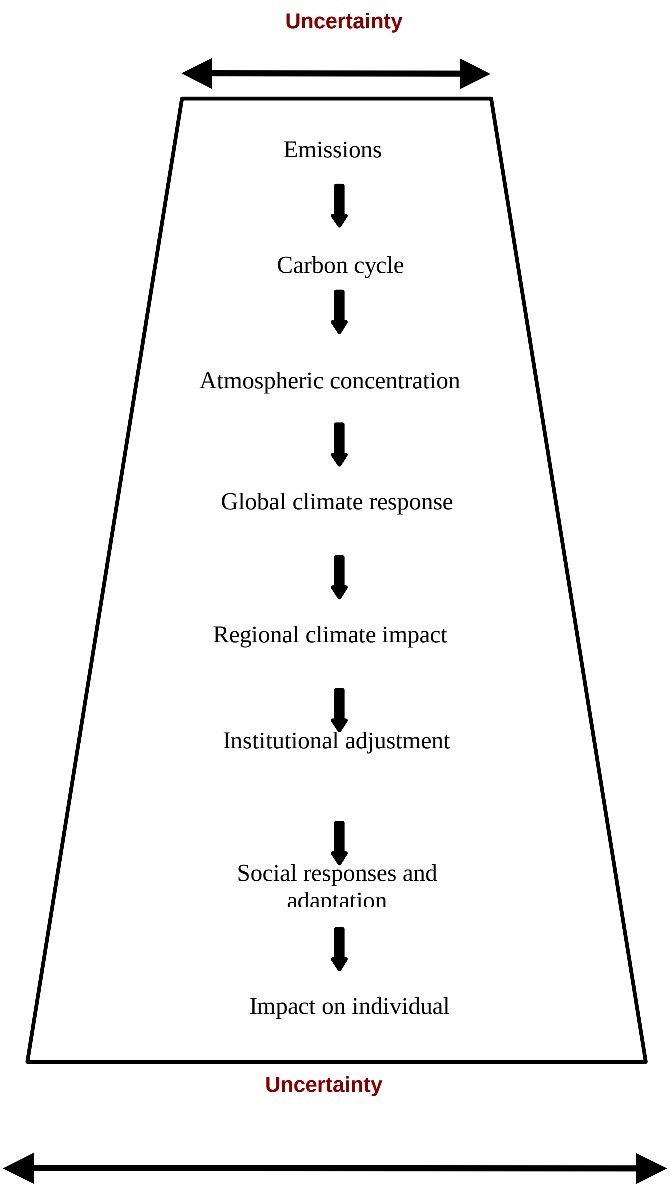

Fig 1: The presence of uncertainty at multiple levels

Multiple scenario frameworks are built on the Environmental Futures scenarios, from the UK Foresight programme. This programme tries to look beyond normal commercial horizons to identify potential opportunities from new science and technologies. It intends to deliver thorough and up to date information and analysis of recent developments in relevant science and technology, vision of the future reflecting the potential impact of science and technology and of forecast social and economic trends, recommendations for actions, and networks of people who recognise the importance of the issues addressed by the project.

The Foresight Future scenarios have been created for the UK Foresights programme, and the project was funded by the Department of Trade and Industry, as well as the Department of Environment, Transport and the Regions. The research was led by the Science and Technology Research Policy for the UK Foresight Programme (SPRU) from the University of Sussex. These scenario represent a tool for foresight, enabling institutions, businesses, and more generally users, to apprehend possible futures, in order to improve their decision making.

Generated via an iterative participatory process, the scenario framework also draw on pre-existing work, such as the scenarios developed by the Intergovernmental Panel on Climate Change (IPCC 2000) that is trying to estimate future greenhouse gas emissions.

The UKCIP scenarios use computer estimations of climate change, and are attempting to assess their impact upon the UK's socio-economic structure. They differ from the Foresight scenarios by being specifically designed for the timescale of the associated climate scenario provided, and by providing details likely to be of use for regional and sectoral studies. For example, they give greater emphasis to the possible changes to regions and to certain types of geographical domain. Classified according to governance system and social values, their denomination is equivalent to the Foresight scenarios, apart from the Provincial Enterprise, renamed National Enterprise. Every scenario describes a plausible future, and the shape of water demand, agricultural trends, future transport, and economic development.

The scenarios presented by the Environment agency are based upon the UKCIP scenarios, themselves based on the Foresight scenarios. The Foresight scenarios were devised taking into account various sectors of the economy. The UKCIP focused on the climate change impact, and the EA focused further on water resources.

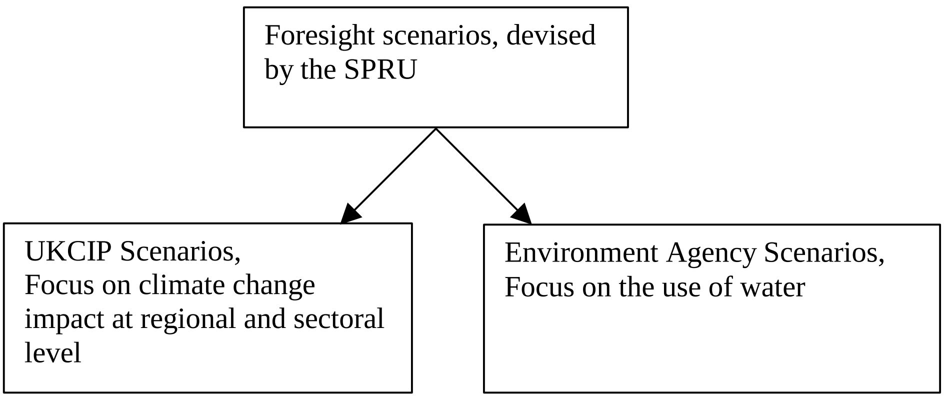

Fig 2: The different focuses of studies originating from the future scenarios

Four distinct Foresight scenarios were retained as typical cases. They are classified according to a couple of main indicators, or drivers of change: the social values of the individuals, and the governance structure in place.

Social values go from individualistic to more community oriented, while the system of governance, dealing with the structures of the government and the decision making process go from autonomy (power remaining to national level) to interdependence (power moves to institutions, e.g. from the EU to regional government).

Governance \ Values	Individual	Community
Interdependence / Globalisation	World Markets (B)	Global Sustainability (C)
Autonomy / Regionalisation	Provincial Enterprise (A)	Local Stewardship (D)

The scenarios have specific general characteristics, presenting the general trends, and more details upon economic and sectoral trends, employment and social trends, regional development, health, welfare and education, and the environment.

The statistical issue

As clearly expressed in Herrington (1996), the statistical results obtained for a given period, and the best goodness of fit for several representations were varying when applied to the following time period, largely reducing the interest of such results in a forecasting perspective. One of the reasons for such lack of success could be the fact that the tools might not be appropriate for the subject of study.

The use of parametric statistics, although very common, is subject to several conditions.

It includes the fact that both variables should have homogeneous levels of variance. Parametric statistics use the knowledge upon the distribution the sample is extracted from as components of the tests that can be undertaken.

Using these assumptions, they can use mathematical properties and simplification that enables them to reach for example confidence intervals, and qualify the generated or observed sample.

While this is sufficient to analyse a finite set of data, the inference from such a finite set of data can be jeopardised by some limits for this method.

In most cases, the statistical treatment of data is done with methods that have for assumption the existence and stability of the mean and the standard deviation for that distribution. But this assumption cannot be taken for granted in multiple cases. As shown in Moss (2001) and Bak (1997), many phenomenon could have underlying distribution that do present these properties.

It seems to be the case for household water house. The data provided by some water companies was analysed, and showed that the relative changes are not normally distributed (i.e. either the mean or the standard deviation, or both, is not stable). The use of tools assuming so is consequently unsound.

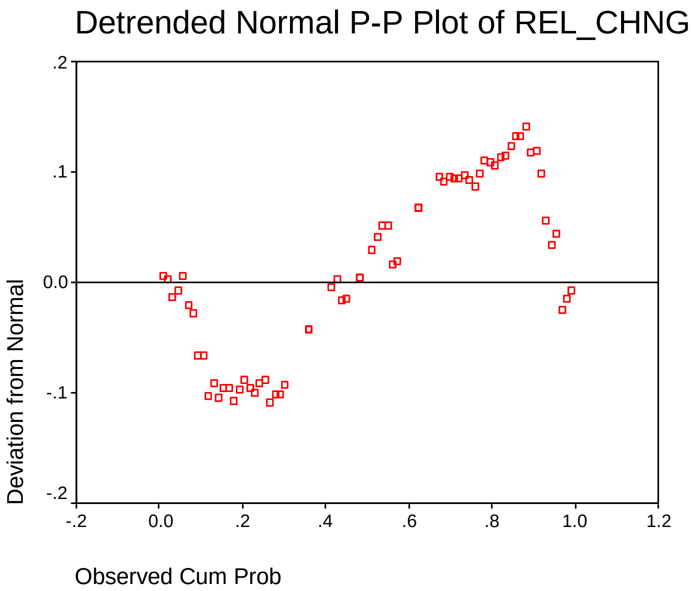

Figure 3: Comparison of detrended cumulative probability with a normal distribution

This figures shows the representation of relative change for household water demand for the Fairlight region. If the relative changes were normally distributed, the dots would be plotted alongside the horizontal line.

As the tests undertaken tend to confirm the assumption that this sample does not suit a normal pattern, further analysis indicate that the property shown, a relatively fat tail, and thin peak, is known as leptokurtosis.

Failing to use normal distributions, even with time-dependent mean and variance considered by economists, physicists like Per Bak (Bak 1997) used the power law devised by Pareto in 1893. If the data observed suit this kind of distribution, the consequences are important. The probability density function of the pareto distribution has two parameters, one, ?, as the peakedness parameter, in the interval (0,2], and the other, ?, as the skewness parameter, in the interval [-1,1]. The issue is that these parameters have critical values. When ? is equal to 2, the characteristic function of the paretian distribution reduces to that of the normal distribution. But for ? < 2, there is no finite variance for the distribution, and for ? less or equal to 1, there is no finite mean.

Moss (2001) has investigated the different means to generate such a distribution. The three mutually exclusive explanations are: a normal distribution with predictable time varying parameters, a stable pareto distribution with infinite variance generated by self organised critical social process, or a non stable distribution generated by a self organised critical social process.

Self organised critical processes can be generated by systems that present social embeddedness. It is defined in Edmonds 1999, as “the extent to which modelling the behaviour of an agent requires the inclusion of other agents as individuals rather than an undifferentiated whole”. It means that formally, t is more relevant to model an agent as a part of the total system of agents and their interactions as opposed to modelling it as a single agent that is interacting with an essentially unitary environment.

The classical statistical approach used is parametric statistics. Another option is to use non parametrics statistics. It cannot really be used for inference, as one cannot actually provide a non parametric model for forecasting, but can be used instead to characterise an already existing data sample.

But as seen earlier, this assumption does not always hold, and as it is likely the case now. Because the assumptions required to use parametric statistics are at most debatable in the current case, it puts the reliability, hence the utility of standard methods in jeopardy.

What can then be used to analyse the samples are nonparametric methods. Also be called “distribution-free” methods, they do not assume the underlying distribution of the variable involved, and consequently, none of their eventual properties. Instead, they are based on ordinal measurements. Consequently, while the nonparametric methods are not as powerful as parametric ones when in the correct situation, they are much more powerful in cases such as this one when data cannot be assumed to be normal).

The overall principle of the nonparametric methods used in this research is that a sample can be compared to another by verifying whether the distribution of their variations is either consistent with a know distribution (that method is used to demonstrate that the data, both observed and generated, are unlikely to match normality assumptions), or similar to one another (that is used to demonstrate that the results obtained by multiple simulations have the same underlying distribution, and that this distribution can be considered as matching the observed data).

The use of MAS and the resulting model

The research into climate change issues and the impact upon household water demand has led to the generation of a model, using Integrated Assessment (Moss, 2001). Multi disciplinary inputs have helped to make the representation as sensible as possible, and multi agent systems were used, in order to represent the behaviour of households in terms of water demand. It is devised as a dynamic representation of a society composed of reactive agents (Ferber, 1999) influenced by their environment, both social and physical.

The model used is based on Moss and al. (2000) and Barthélémy and al. (2002). It incorporates agents representing several households and a policy agent. The households are characterised by their location on a grid, and a set of ownership, volume per use, and frequency of use of appliances. The households can observe and evaluate subjectively their neighbours, their activities, and the appliances. They can therefore rate differently the information depending on its source.

The policy agent reacts to the climatic conditions, and broadcasts messages of water saving in case of dryness. Innovation is also present, as some appliances can break down, and be replaced by newly available substitutes with different characteristics.

Amongst the processes embedded in the model, a particular attention is given to the influence of innovation, its presence and diffusion, as well as the importance of population response to the various signals, from the policy agent or the neighbouring households.

The outputs of such simulations can either be a straightforward analysis of the water demand generated by the simulated households, or a more qualitative analysis of a specific phenomenon, or of the characteristics or patterns (rather than the values themselves) of the water demand. The latter will have our attention, that’s why it is necessary to present the few assumptions that were found or thought to be of importance in the model.

Some formal models are simple enough so that the few parameters are meaningful ones with respect to the object of the modelling. It is for example the case when dealing with the evaluation of weight category for a person with respect to current weight and physical characteristics. There are more complex models, for which the sophistication requires many aspects of a problem to be taken into account. It is then possible that some parameters integrated to the model could influence significantly the results, while not being central to the modeller. Based on simple model, Hales and Edmonds (2003) have given an example of modelling details that, although not really central to their issue, turned out to be decisive for the behaviour of the model, and the observed phenomenon.

During the verification and validation processes, several particularities have been observed. The first one refers to the innovation process, and the diffusion of new technologies. The second one refers to the importance of initial conditions, and the way they are implemented into the model.

In Duboz et al. (2001) for example, the Multi agent system used is tested for boundary conditions, i.e. a change in the algorithms that are involved in the spatial behaviour of agents (namely the way the agent bounces off a wall). Are also tested the distribution algorithms and the size of the space, and the conclusion suggests that the choice of the bouncing algorithm is a more important parameter than the distribution or size of the population of agents.

In the current case, there are many parameters and algorithms. The methods and values used are carefully selected as having appropriate characteristics and (in general a lack of) underlying assumptions.

Innovation

Quite an exhaustive view of innovation diffusion can be found in (Rogers Everett 1995). He defines diffusion as “the process by which an innovation is communicated through certain channels over time among the members of a social system”.

Rogers presents all (or nearly) the aspects of innovation, from its generation to its consequences, through the study of its diffusion through the characteristics of the technology, of the user, and of the underlying network. It is noticeable that the diffusion of innovation depends then a lot on the nature of the innovation. They have specific characteristics that could explain the rate of adoption, i.e. the success or the failure of a given technology: relative advantage, compatibility, complexity, trialability, and observability. Some even display self-reinforced dynamics, when the technology can benefit from network externalities. What is taken in to account then is the global influence of the number of adopters in the system, not only locally (Blume [1993], Ellison [1993]).

These characteristics are obviously tightly depending on the technology itself and hence will not be included extensively in the present study for the aforementioned reasons. The common literature, mainly composed of surveys, is globally presenting these characteristics of the technology along with the characteristics of the individuals to explain the success or failure of some specific cases.

After many studies and debates, a scale and a classification appeared. Proposed by Rogers in 1962, it is based on the assumption that the frequency of adoption follows a bell-shaped curve, and the associated cumulative curve is S-shaped. The adopters are then categorised depending on their time of adoption.

?? The innovators are the first 2.5%
?? The early adopters are the next 13.5%

- ?? The early majority is the next 34%
- ?? The late majority is the next 34%
- ?? The laggards are the last 16%

These numbers are based on the intervals each side of the average time of adoption. The innovators are more than 2 standard deviations less than the average, while it is only one for early adopters, the early majority is situated within a standard deviation less than the average, the late majority is within a standard deviation more than the average, and the laggards are adopting a technology after a period of time that is morethan the average plus one standard deviation. Trondsen (1996), Valente (1996) and Young (2002) amongst others refer to these values, and present results that conform to these categories.

One of the issues with such a theory s that one cannot know beforehand which agent is which, unless the size of the market is known in advance. It then becomes impossible to use this approach in order to represent the diffusion of innovation in markets that could be smaller than the whole population. In this model, the adoption process for innovation is based on endorsements. In this matter, one can argue that the subjectivity of the indicator selected can be such that it will direct the whole pattern of adoption.

It was seen though that with this particular type of representation, when the choice had to be made at random, the bell-shaped pattern emerged in multiple occasions.

Technically, the reason for this random selection is that amongst the endorsements recalled by the agent in order to assess their values and select the highest, most of them were equivalent. In certain cases, an agent looked for a specific type of endorsement, and could not find them. It was then automatically considering every endorsement value as zero.

Initial conditions

The initial conditions for this model are based upon real life observation, and research upon the assumptions made in the different scenarios generated by the Environment Agency.

Amongst the various assumptions, three are of importance in this context.

- ?? The representation of social values for every scenario

The representation of the social values of households does not imply anything in terms of the modelling of the structures and the environment. The implications are concerning the way they see and judge that environment. The argument here is that someone caring about community will put a greater emphasis on the community as a driver of his own behaviour. Selecting the appropriate weights of influence in the already existing model can then represent this indicator. The endorsements can be ranked, from an individualistic (self centred) point of view, to a more citizen (globally influenced). They can therefore be used to represent the concern, and influence, of a particular agent. The link is made here between the fact that an agent is community oriented, and its major influences are in the “community” around him, his neighbourhood. Nevertheless, while is easier to argue that individualism can be linked with the references in the model to the self-centred beliefs and rules, community can be a bit more difficult in the framework of this model. What is called community in the EA approach is actually referred as “community” within the model as the immediate social environment of the agent. As it is expressed in their description, community also seems to have the meaning of “citizenship”, a behaviour in line with the idea of not wasting limited resources.

- The representation of the governance structure through the distinctive characteristics of the scenarios

While the social values can be represented in such a way that various ones can be generated easily, through a simple choice of different ranking and / or values of the endorsements themselves, it is not possible for the governance structure. As expressed earlier, there are issues with the meaning of such an indicator, that prevent from implementing it in a single and specific way. Consequently, unlike the first part of the influences, this classification of the scenarios will be done using the detailed approach. For a given state of social values, the governance structure will be identified (and the scenario defined) by the range of available appliances, their associated values (ownership, frequency, volume, replacement rate), as well as the presence or not of technological regulations.

- The representation of the regulator through the availability of resource saving appliances.

The representation of the technological regulator is simple. Since the regulations are enforced in the scenarios, there is no need for a dynamic adaptive regulation, i.e. the presence in the model of an agent that would evaluate the situation and eventually decide for the need of intervention. Like the emergence of new appliances, which was already implemented, it is present as a constraint upon the appliances. Since the scenarios describe accurately when regulation happens, the influence on the model is that from a given date onwards, some devices are made available, or unavailable for the households.

The layout of the support for the agents can be important, and slightly different properties generate different outcomes. In this case, the agents are situated on a regular grid limits. What has been investigated though, is the impact of the grid structure itself. It can be considered as a bidimensional mapping, or a tridimensional mapping, the latter being equivalent to a toroidal shape, allowing agents to observe more cells when they are located towards the edge of the grid.

The study of both situations tends to show that although there is a significant difference in the links between agents, it does not seem to generate large differences in the behaviours. It can be assimilated to an increased possibility of communication amongst the agents.

Fig 4: Matrix of links for a grid with a toroidal structure: in this case, the 20 agents are situated on a grid of size 8*8.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		■				■						■					■			
2	■			■											■		■			
3								■					■		■		■	■		
4		■					■		■						■					
5							■									■				■
6	■									■		■		■						
7				■	■				■											■
8			■							■			■		■					
9				■			■				■			■		■			■	
10						■		■						■						
11									■					■		■			■	■
12	■					■														
13			■					■							■					
14						■			■	■	■					■			■	
15		■	■	■				■					■							
16					■				■		■			■					■	
17	■	■	■															■		
18			■														■		■	
19									■		■			■		■		■		
20					■		■				■									

Fig 5: The equivalent matrix of links for the non-toroidal version can be displayed as follow:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		■				■						■								
2	■														■					
3								■					■				■			
4									■											
5							■									■				
6	■									■		■		■						
7					■				■											■
8			■							■			■		■					
9				■			■				■			■		■			■	
10						■		■						■						
11									■					■					■	■
12	■					■														
13			■					■							■					
14						■			■	■	■					■			■	
15		■						■					■							
16					■				■					■					■	
17			■															■		
18																	■			
19									■		■			■		■				
20							■				■									

Since the black cells show the existence of an interaction between the agents listed horizontally and vertically, it is easy to notice that the toroidal structure provides more contacts to each agent.

A significant difference could not be proven to result from such changes, as long as the situations were similar enough (i.e. there were not multiple simultaneous parameter changes).

Nevertheless, their influence upon the results of the model needs to be understood, in order to improve the model's comprehension.

Algorithm used

While using power law distributed frequency and volumes for the agents, some peaks of consumption appeared in the outputs. They were initially though to be caused by drought periods, since the model is devised to capture this process. Despite this, the fact that some peaks did not seem to correspond to dry periods lead to a more thorough investigation ofall peaks. The outcome was actually that the particular implementation of the model allowed in some rare cases the agent representing the institutions to broadcast a message encouraging households to use more water than they were.

This phenomenon does not appear in the alternative, where the frequency and volume are normally distributed, but then it does not result in satisfactory outcomes.

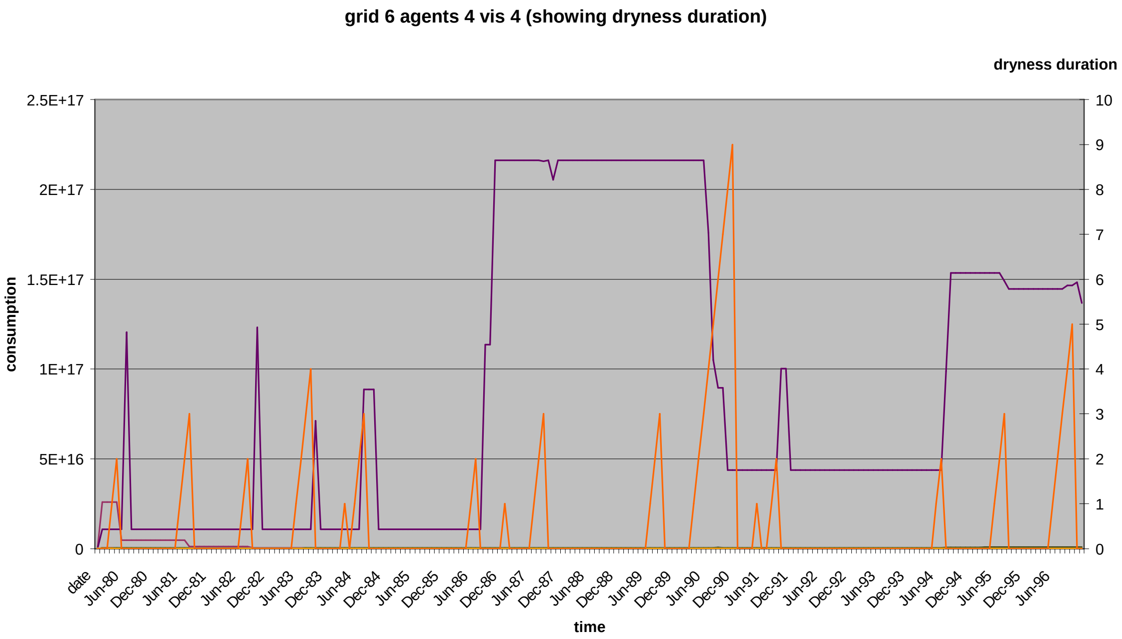

Fig 6: Peaks in demand observed in parallel with dryness duration in the model

One could expect that the effect of dryness would drive consumption down. The matching of these visual indications reveals that the reaction to an exhortation from the policy agent is not always producing the expected effect. Only the major dryness period lasting for 9 months 1991 had an important and significant effect upon the water consumption (as well as the subsequent ones, but on a smaller scale). The other dryness periods actually seem to have no effect while only when the level is already very high, a decrease can be observed.

This demonstrates that either the behaviour of the agents is not implemented properly, or that there can be other method related issues.

Although this behaviour does not seem to affect the vast majority of the runs, it requires investigation to understand what is the cause of such variance within the simulations.

The detailed study of this run shows exactly what is happening. As expressed in the description of the model, the policy agent uses a kind of average of the observed frequency and volume data from the households. Due to the initial conditions, the policy agent could then be biased by some extreme randomised value for the households.

It would therefore broadcast a message that would lead households to adapt by using patterns whose recommended values are higher than those in use by the households themselves.

Also, as one would expect, the different cases of population repartition show that the favourable repartition of the population towards agents that are marginally influenced by their environment tend to generate patterns with significantly higher water demand levels. That could be explained by the shift of influence from a citizen-centred view to a more self centred one. One could then consider that the messages from the institutions are not rated high enough to result in a change of behaviour from the households.

Finally, the global demand for water generated by a set of runs for this model can be displayed as follows:

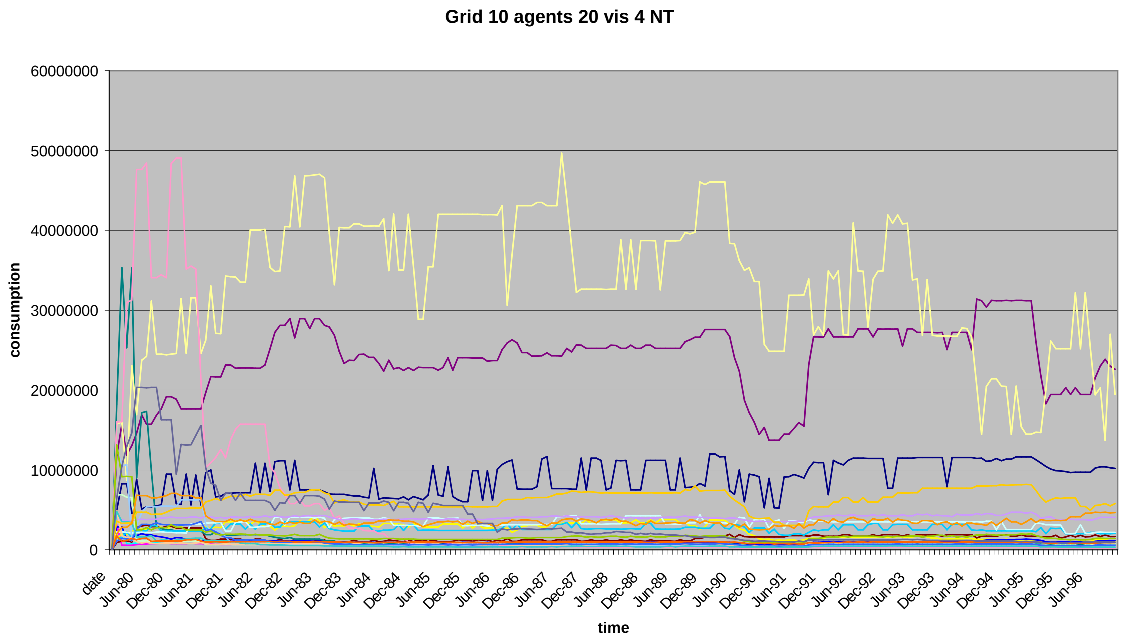

Fig 7: Chart of multiple runs for the same simulation settings

This shows the evolution of water demand for the entire population, i.e. 20 agents in this case, which are located on a grid of size 10, on which they can see what their neighbours are doing up to 4 cells away, without being limited by the edge of the grid.

Due to the unavoidable (at this stage) effects of the power law implementation, some of the runs are not likely to be representative of a standard behaviour. Still, the majority of the runs are similar and could certainly be considered as representative of a scenario.

Conclusion

As a model is devised to analyse the multiple issues surrounding the use of scenarios describing plausible futures, the multi agent system used demonstrates the importance of careful implementation of objects and processes.

The multi agent system can generate patterns that are consistent, and that seem more accurate on a statistical point of view than the traditional parametric approaches used in other studies on the same subject.

While generally the sensitivity to the initial conditions is investigated, it is found that sometimes, trivial choices of modelling, or even coding, can have an important impact upon the validity of the model itself.

During the course of the validation and verification processes, interesting phenomenon could be identified, and demonstrated some interesting properties. Further investigation will be necessary in order to improve the understanding of the reasons for this surprising diffusion process, as well trying to avoid the emergence of extreme scenarios.

References:

Bak, P., 1997, How Nature Works: The Science of Self Organized Criticality (Oxford, Oxford University Press).

Barthélémy O. Moss S., Downing T., Rouchier J., (2002), Policy Modelling with ABSS: The Case of Water Demand Management, CPM report 02-92

R. Duboz, E. Ramat and P. Preux, Towards a coupling of continuous and discrete formalisms in ecological modelling - influences of the choice of algorithms on results, In proceedings of the 13th European Symposium on Simulation, Marseille 10/18/2001-10/20/2001 (p481-487).

Edmonds, B. (1999). Capturing Social Embeddedness: a Constructivist Approach. Adaptive Behavior, 7:323-348

Environment Agency, 2001, A scenario Approach to water demand forecasting, Environment Agency

Ferber J., 1999, Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence, Addison-Wesley Edmonds B, Hales D, M2M Communication, 2003

Hales D, Edmonds, B, 2003, M2M conference, Marseille, 31/03-01/04/2003

Herrington, P. and E. (1996). Climate change and the demand for water. London, Hmso 1996.

Jensen, H., 1998, Self-Organized Criticality: Emergent Complex Behaviour in Physical and Biological Systems (Cambridge: Cambridge University Press).

Moss, S., 2000, Competition in Intermediated markets: statistical signatures and critical densities, CPM Report 01-79

Moss S., Downing T., Rouchier J., 2000, Demonstrating the Role of Stakeholder Participation: An Agent Based Social Simulation Model of Water Demand Policy and Response, CPM Report 00-76

Moss, S., Pahl-Wostl, C. and Downing, T., "Agent based integrated assessment modelling", Integrated Assessment 2: 17-34, 2001

Rogers Everett, M. (1995). Diffusion of innovations. New York ; London, Free Press.

Trondsen T.J., 1996, Some characteristics of adopters of a major innovation in the computer field and its potential use in marketing, INDUSTRIAL MARKETING MANAGEMENT, vol. 25, issue 6.

Valente T.W., 1996, Social Networks thresholds in the diffusion of innovation, Social Networks, vol. 18, pp. 69-89.

Young, P.H. 2002, The diffusion of innovation in social networks, working paper, The Santa Fe Institute