REPORT on WORKSHOP
'Towards a science of global systems'

Introduction
The workshop took place in Brussels on 15 and 16 December 2009. It was organized by the coordination action Global Systems Dynamics and Policy (GSD), in collaboration with DG INFSO's Future and Emerging Technologies program and DG RTD's unit on Sustainable Development.

The aim of the meeting was to explore research questions responding to the needs identified by GSD relating to the modelling of global systems dynamics and its impact on decision processes in society. These questions were focused on the use of dynamic systems modelling for policy across many areas of critical importance. How can dynamic systems science help us tackle the big challenges we currently face in Europe and the wider world?

Executive summary
The study of global systems is particularly urgent today because humankind has reached a situation where existing policy instruments are clearly unable to provide sustainable outcomes on a global scale. Global coordination is needed, grounded in a new type of science that links data, models and social decision processes. Present academic knowledge of systems and current practice in the public and private sectors must be radically reconsidered in the light of global intertwined challenges like global climate change or the current financial crisis that need system-wide coordinated action. A science of global systems must pay special attention to, and critically reflect on, its interface with policy in order to make a pertinent contribution to challenges ranging from climate change impact to systemic economic failure.

Information technologies will play a key role in establishing an interface between science, policy and society. Comprehensive advances in information science (software engineering, model specification, formal methods) and in the ways it is applied are required in the years to come. Models will rely on the gathering and managing of large-scale, heterogeneous sets of diverse data and will require large computing capacity. ICT will help to establish new communication channels between policy, science, and society.

The challenge for science is therefore two-fold: to advance modelling of global systems and to engage with novel forms of interaction with policy, with regard to problems that span from local to global decision–making. There is a need for a research initiative fostering bold experiments and new techniques of developing models in diverse global contexts. In addressing concerns about how to best arrive at decisions, global public support and legitimacy must cohere with science and policy to set the agenda and to determine the issues to be tackled, the scientific questions to be asked, the data to be collected, and the models to be implemented.

These challenges are genuinely trans-disciplinary — they move across the academic community, the modelling community, the policy community and the business

community, and the knowledge needed to tackle them exists in the natural and life sciences, the social sciences, and the humanities.

We need to integrate in novel ways the four cornerstones of research in global systems science – i) people ii) data iii) models iv) policy. The challenges ahead are, broadly: how can scientific modellers communicate better with citizens, business, politicians, government officials and NGO representatives? How can they make sure they are gathering and transmitting the right data? What tools and concepts should they develop to integrate their models better across different systems and into the decision processes? In particular, as decisions are triggered by and trigger the need for a systemic view, how can the policy link be consolidated within models rather than bolted on at the end?

Participants and structure of the workshop
Deputy Director General (DG INFSO) Zoran Stančič opened the workshop with the political framework of the discussions, invoking the need for concrete policy actions built on sound science and a move away from looking at isolated systems, all within the context of exit from economic crisis, sustainable development, and the enhancement of European citizenship.

Opening statements were made by Julian Hunt and Carlo Jaeger. Ralph Dum then gave the EC perspective. Other participants (see appendix for list) made five minute presentations, with some discussion. These were followed by break-out sessions. Different parts of the workshop were chaired by Ralph Dum, Prabat Agarwal from DG INFSO and Nicole de Wandre from DG RTD. The rapporteur was Giles Foden.

Mario Campolargo, director of the 'Infrastructures and Emerging Technologies' Directorate of DG INFSO, made closing remarks on behalf of EC. He emphasized the need to ground sound policies in sound data.

Orientations

What is modelling of global systems dynamics?
Modelling system dynamics is a significant current research direction in information science directly relevant for business, policy, and a large number of academic disciplines. It is concerned largely with depicting and analyzing the changing relationships within and between systems, considering in particular system-wide patterns and dynamics. Dynamic systems modelling has gained importance since 1990 with recognition of the importance of network effects such as globalization and technical connectivity.

'Global' refers to the current situation in which global issues dominate and the tension between local and global action is a major challenge to policies. But it also implies the need for integrated approaches to modelling, from a systemic point of view. Governance needs to be enacted on all spatio-temporal scales, and global actions need to interact positively with local initiatives.

Models of dynamic systems tend to develop on multiple scales in space, time and systems aggregation. Often, models of dynamic systems involve identification of previously unseen connections between patterns on different scales. This connectivity aspect of dynamic systems is one of the reasons why they have ramifications for complex policy actions in an often uncertain and rapidly changing global context. High system interconnectivity is also why a key aspect of global systems is the role of uncertainty and instability.

Relevance of global systems dynamics models
Modelling of dynamic systems – social, political and economic - is of particular relevance to decision making in the political and corporate arenas. The French utility company Veolia uses system models to discuss policy options with city authorities, for example. In that context, a demand for integrated civic policies points to the need for integrated system models. System modelling tends to provide outputs that are widely distributed, but it is often in their nature that they need to be adapted according to the user/receiver needs and questions. Typically, again, the actions of the user/receiver become significant information that is fed back into both the system and the model. The usefulness of the model is often concerned with how flexible it is in accommodating the new information.

The role of Information and Communication Technologies (ICT)
ICT plays a very prominent role in a research agenda, and in the deployment of dynamic systems models generally: provision of large-scale computing infrastructures for real-time modelling; collective and interactive web infrastructures enabling stakeholder participation and interaction between stakeholders in society; large-scale data infrastructures and data mining, and sensor networks to gather data on various aspects of ecological and social systems. Those applications which seek to identify, predict and avert crisis, through a process of online monitoring with feedback from individual citizens, will play an increasing role in dynamic systems modelling. ICT progress needs to be guided: at present there is a lot of ICT supply 'push' instead of demand 'pull'.

The need for an inter-disciplinary approach
Part of the task ahead (and an important reason for adopting a systemic approach) is to see in how far such an authentically holistic, discipline-neutral approach can actually help us overcome the current predicaments that are themselves in large part due to the silo-style organization of our science and our decision processes.

EC funding context

Various complementary options were presented on how the EC might support initiatives relevant to the themes discussed in the meeting. Among them were: the possibility of a joint action between DG RTD and DG INFSO (acknowledging the complementary constituencies and synergies of goals of these two directorates); the upcoming action in the e-government unit that emphasizes online tools for policy and models; and possible actions in the Future and Emerging Technologies Programme of DG INFSO, in particular the new instrument of Flagships mentioned by J. Fernandez-Villacanas-Martin.

Several ongoing research efforts funded within the EC are relevant to, but by no means identical with, the science of global systems as envisioned in these discussions. In particular: complex systems research as funded by Future Emerging Technologies (DG INFSO FET) and the NEST unit in DG RTD; sustainable systems research, funded by DG RTD; modelling research currently supported by the environment and social sciences directorate of DG RTD; policy relevant ICT tools funded by the e-government unit of DG INFSO, and Internet science that studies the interaction between society and the Internet as part of the future networks programme. In addition, the e-infrastructures (GEANT) program could provide the basis for the large scale computing and data facilities necessary for the modelling component of global systems science research.

Research agenda

(1) System thinking

This is the foundational study that needs to be undertaken in global systems science. There is a critical need to enhance understanding and effective operation of the distributed multilevel control processes that characterize global systems.

Among other things, we need to:

- Develop techniques, tools and concepts for an integrated system model in order to arrive at a system-wide view (rather than using linked sub-systems). Produce ways of verifying the results of integrated models by establishing an over-riding systemic-view model to ensure that all interactions between sub-models are configured at the right level. This would build on existing work in the environmental and health sciences.
- Understand how a multilevel system is acting on different spatio-temporal scales and how these scales interact and constrain each other (following the lead of research in complex systems).
- Improve our understanding of the role of patterns in systems. Identify macro-/meso-level patterns in systems from underlying mechanisms at the micro-level, both spatial (as in urban shape and growth) and non-spatial (as in scaling networks). Link such patterns to system properties such as (in)stability, resilience, vulnerability, and tipping point/regime shift tendencies.
- Better understand the boundaries between models; what are the implications of linking existing models of systems into a co-ordinated whole? How far do we need to move beyond integration of current models towards conceptualization of truly holistic models that not only combine but actually fuse knowledge from different domains, points of view and disciplines? What are the dangers of such fusions?
- Learn about coherent model interfaces and how to make adaptable models. This may involve new software for a flexible conceptual analysis that enables users to examine problems across a variety of systemic domains. Useful policy interfaces require for instance the capability to modify conceptual structures in the course of negotiation processes.
- Create a dynamic ICT-enabled lexicon of systems thinking to avoid inter-disciplinary interference.

(2) Model/data pragmatics. Models and the data supporting them should answer questions of relevance to the challenges faced and the decisions to be made. This requires:

- New methods of better user-centred modelling techniques for gathering and incorporating user pertinent data into models.
- Novel ICT-enabled methods to use and interact with data and models (eg visualisation, online access etc)
- The development of formal methods and ICT tools to reduce/simplify models in ways that address their application/use in a decision-support and/or training context, rather than the scientific description of the phenomena involved.
- Investigating the feasibility of setting up data listings centres in Europe as now exist in US. These would contain updated information on where data is held across different systems and in what form. Large-scale data structures are inherent in the development of large models and many kinds of decision-making. For the moment, access to such structures is very localized; we need to develop ways to promote local accessibility
- Understanding what it means to use 'other people's data'; what are the dangers to watch out for when data is consolidated or transferred or recalibrated?
- Development of infrastructures for big models used for ongoing questions about output (e.g. changing rainforests, changing CO_2 emissions), where the whole model is run for each scenario/decision on a GRID infrastructure, and the models must be able to deliver scenarios in real time.

(3) Science of foresight

We need to better understand how to use data, models and knowledge from the past to help us find appropriate ways to choose between options for the future. This requires that we

- Find ways to represent uncertainty in data and models, recognizing the divergent sources of uncertainty.
- Improve our understanding of the relationships between cognitive models of the past (ex-post, 'closed' cause-and effect models which reduce the number of dimensions of reality to represent it) and cognitive models of the future (ex-ante, 'possibilistic' models that encompass unknown dimensions of reality by assuming indeterminacy)
- Develop a coherent approach to narratives and analogies as they apply to models, which provides chains of causality from models and data to outcomes for use in socio-political negotiation and decision–making processes. ICT tools can help us to construct and interpret such narratives, whose imaginative effectiveness needs to be linked to the formal aspects of scenario building
- Understand the relationship between volatility and predictability, and how there are different levels of probability at different scales

(4) The people link. Identifying socially accepted data relevant to policy decisions requires:

- Developing a theory of social and economic experiments (how to set them up, what data to gather, etc.). Developing theories of the determinants of perceptual change in societies. Understanding the role of present ICT in this process.
- Setting up continual people–based monitoring, for example in networks of focus groups that are maintained over time and allow us to study the changes in social values that hinder or facilitate specific policy solutions.
- Studying the use of Web 2.0 based opinion dynamics Developing individualised models adapted to individual citizens and focused according to the interest of the user. In limited ways this is already being exploited commercially.
- Developing non-aggregated data: information (e.g. warnings) more closely related to the needs of the recipient (e.g. health, farming), whether for individuals, specific social groups, geographic localities, or regions

(5) The policy link: the relation between scientific models and the decision process in society. In order to make existing scientific insights and models more useful for decision-making, it will be necessary to analyse how to incorporate human decision-making in the models ('agent-based') and how to validate their representation. This entails, inter alia:

- A 'mathematics of social entities' to capture underlying social processes
- Understanding problems of agency and the social acceptance of scientific reasoning, including models. For example, experimenting with decision-making processes in different individual and group contexts.
- Understanding the dynamics of conventions and conceptual structures
- Strengthening existing and developing new forms of participatory modelling and model analysis (decision theatres, online web-based games, etc)
- Improving the study of the role of conflict in decision-making, notably by using models of such situations

Issues in implementing the research agenda

In order to focus on the issues concerned, we need participants from all the domain-specific academic disciplines involved, as well as from the modelling, policy-making and business communities. ICT is crucial both in the model and data aspects of the challenge and in the need to communicate model results and to involve stakeholders in the data and model elaboration. This combination of factors seems best served by a joint initiative between the ICT program (for the new information technologies and information science approaches), the sustainability program (for the knowledge of the domain that needs to be innovated), and other schemes with domain knowledge.

Case studies to illustrate the research challenges

It was suggested that both high and low level case studies be undertaken, in order to reflect the multi-dimensionality of dynamic systems and build on existing programs.

i. City systems
ii. Systems of violent co-ordination
iii. Water and food securities
iv. Climate change impact
v. Dynamics and control of the financial system

The workshop: How the research agenda emerged during the two-day workshop

Opening the workshop, Zoran Stančič referred to the 2020 strategy of President Barroso that is rooted in sound science advice to policy makers. Present challenges such as global climate change and the financial and economic crisis are a challenge to policy makers but equally to science. There is a strong need to build sound policies on sound data. To build integrated policies, we will need a better understanding of how to integrate models and create system-wide models in particular in the context of sustainable development. Science will be challenged in its findings, as happened for instance in the Copenhagen summit, and needs to be prepared for that.

Stančič congratulated the GSD coordination action for its strenuous pursuit of this question over the last two years and said it would have a clear role to play in setting an agenda for how science modelling can influence governance. The crucial role of ICT in this process is also evident, he added.

Systems thinking: from science to policy and back

At present there are different communities of practice within modelling. While there is some shared meaning, each community has its own ontology[1]. Part of the difficulty here relates to a tension between pragmatic approaches, which deal with particular cases within a domain, and normative approaches, which identify those situations when patterns seem to operate across a large number of scales (David Lane/Geoffrey West). An appreciation of this tension is itself at the heart of systems thinking. The ideal systems thinker is able to accommodate this tension, mentally encompassing both particularity and typicality. Decision makers too have their own ontologies, though these are often actualized in behavior rather than stated as precepts; successful systems modelling takes account of the decision maker's ontology.

Between the scientific systems modeller, in whatever his or her discipline, and the political decision maker, from presidents to members of the public, lie all sorts of uncertainties, hitches and traps. Many of these are as much related to rhetoric – that is, the science and art of articulate persuasion – as to the relevant scientific and political context. This is why all models, whether integrated or not, need to lead to coherent narratives, in the hope that these in turn will lead to sound actions based on sound science.

Many scientists lack the skills and motivation to come up with such narratives, while the scientific community as a whole undervalues such skills (Julian Hunt). Prabhat Agarwal identified agency as being at the heart of the wider discussion of systems thinking. Who has the authority to act, to whom can agency be delegated, and what role can science play in the policy process? How can one achieve a shared political will that supplements scientific facts? (Bert de Vries). Who is telling the story and why should we believe them?

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[1] In philosophy an ontology is a set of basic beliefs and their relations. This translates in information science to a formal representation of relations between elements in a domain – both these meanings are relevant to systems thinking.

Policy challenges could be met in the spirit of what Carlo Jaeger called 'the spirit of Athens' (opening up knowledge networks in the spirit of the Greek polis) or in 'the spirit of Luxor' (where knowledge just informs and reinforces the power of an 'elite'). These are two concepts of governance that need not be as contradictory as they sound. To both approaches, science input will be crucial. New forms of interaction between science and policy makers and the citizen (e.g. Web 2.0) will help enhance this interaction and make it more lively. But is knowledge democracy based on well-communicated science even possible?

The workshop identified the need for a science of global dynamic systems to enhance communication between systems thinkers from different disciplines and between policy makers. The way that both top-down and bottom-up constraints produce marked and often unpredictable alterations of behaviour in different parts of a system needs to be reflected in the way models are constructed (David Lane). This new science would inform that process, laying the groundwork for flexible, multi-level governance.

This new science would also take account of recent social developments. Dynamic systems thinking is actually itself part of the new paradigm of 'sustainable development', as pointed out in the workshop by Nicole Dewandre from DG Research. Conceptually, both 'sustainable development' and 'dynamic systems thinking' touch on resilience, an idea which is increasingly defining human subjectivity in the wake of the security, environmental and financial shocks of the past decade (one of the uses of dynamic systems models is in disaster/emergency planning).

Consensus building is itself a complex dynamic process that might deserve to be analyzed as such (Julian Hunt gave the example of European fishery policies). The dynamics in systems is often underestimated in both modelling and policy level efforts. This is why GSD has put a clear emphasis on dynamics (global system dynamics and policies). Hunt also made the point that depending on the speed or through-put of information, dynamic systems – from traffic to management – can behave predictably and smoothly. Unpredictable shocks arise when the control mechanism of dynamic systems cannot cope with the flow of new information.

Sander van der Leeuw added that we have to revise our notions of 'crisis' as an externally caused phenomenon. Crises are inherent in the dynamics of a society and are often due to the incapacity of society to deal effectively with available information.

Model integration
The workshop agreed that integrated approaches to decisions are triggered by and trigger need for model integration. A distinction was drawn by Michel Morvan of Veolia between systems that are already integrated, however imperfectly (ie cities), and the models which currently dealt with sub-domains (electricity, water, waste, transport etc). Veolia as a company has up to now been divided in different 'silos' (water, transport, energy etc). There is a need, he said, for an integrated approach and for system-wide models that would catalyse such an approach.

Looking at the question from the policy side, it was agreed that integrated decision-making should determine the extent and form of integrated models. Rather than simply accumulating models, it was thought that consolidation of system models could help overcome fragmentation in decisions processes. Hunt insisted that integrated decision-making should take a global view from the start.

Peter de Smedt from DG RTD (directorate for research) pointed out that DG RTD is currently struggling to integrate models across different systems. The big models that ensue from model integration can be used directly for policy questions, with the whole model being run for each scenario/decision. However, there are often semantic output difficulties when big models are used in this way, which is one of the reasons for simplification of models. There are some projects attempting to do that (e.g. one that integrates models of land-use with models of forestry and economy) but there are still fundamental challenges ahead.

One is the need to have common model interfaces to better integrate models (this is addressed in one upcoming call in DG RTD). Other issues include how to ensure that such integrated models deliver clear messages. A particular challenge, according to de Vries, is the integration of socio-economic models with ecological models. This is of course at the heart of the challenge of measuring climate change impact. Van der Leeuw contended that although scientists have for historical reasons distinguished between natural and social phenomena, and have developed different analytical tools and modelling strategies – in reality there is only one indivisible system, the socio-environmental one. Hence, overcoming the current difficulties will require a thorough re-conceptualization of our thinking, with the development of new strategies and methods, as well as new techniques and tools.

Model simplification and pragmatics

The workshop agreed there was a need to simplify or reduce models for policy purposes and user customization. Is there a systematic way in which we can analyse the processes that lead us to take particular options (the taking of options is not based exclusively on empirical facts)? This is essential to evaluate the consequences of past actions, to better understand the biases in our decision-making, and to improve our anticipation of 'unintended' consequences. Though scientists do these things at least to some extent, this is generally not reflected in policy decisions.

Narrative, analogy and interactive communicative technology have been identified as important factors in increasing the applied potential of systems modelling. Ideally this research would link to the science of systems thinking topic. The workshop agreed that as an extension of model simplification, model construction needed to be objective and user-related and that there was much work to be done in model pragmatics in this regard (pragmatics is a sub-field of linguistics concerned with how meaning is defined by context). It was suggested by Giles Foden that an ICT thesaurus tool for analysing narrative and analogy processes could be developed — this could also be used to look at 'regime shift' contingencies by connecting scales to concepts.

This aspect of the discussion also considered ways to involve stakeholders, focusing on problems of agency and social acceptance of the model. ICT has a further role here. Vittorio Loreto described active research into a number of potential applications on these lines. Maria Geronymaki, from the EU's ICT unit for Government and Public Services, explained that a new line of research was launched in FP7 that focuses on use of data and models in government decisions and that explores the role of new forms of ICT in societal behaviour. Steve Bishop emphasized the role of ICT in enhancing the interaction between models, data and public decision processes, for example with new ways to visualize data and model results. The availability of, and legal framework round, non-commercial data is a factor here (cf Freedom of Information Act requests for raw climate data in UK and also arguments over Ordnance Survey geospatial data there, which was subject to a newspaper 'free our data campaign').

Lane mentioned the crucial role of narrative in involving stakeholders, and Diana Mangialagu emphasised the issue of metaphor choice in communicating complex issues. Jeffrey Johnson drew attention to the design cycle as an example of user-focused adaptation, in which there is co-evolution between the design and the end result. There was wholesale agreement that the model-policy link works best when models are extremely visual and that modelers need to show policy-makers what is important for them.

There was general interest in Arizona State University's decision theatre: a quasi-cinematic experience in which policy makers could run through options within a model, discuss them, make decisions, and be observed while doing so, so that the theatre also helps our understanding of decision-making processes.

Hunt and de Vries said that to convey model results well, various tools and approaches are useful. These include mental maps and games (in particular, and with the help of ICT, web-based games). This fits with what we know: common analogies currently used in explaining model options to policy-makers and the public include maps and games. Betting, biology and machine analogies are also employed. This is a lexicon that could be extended and put on a better linguistic footing (metaphor choice is a highly developed area of study in literature departments). It was Foden's view that Roman Jakobson's metonymy-metaphor model could be integrated into the ICT-enabled thesaurus application referred to above.

But there are also other ways of simplifying models, including by formal logic. These need to be looked at closely, as does the whole question of what it is entailed in simplification and reduction of complex problems. How far can we develop a coherent theory around this?

Data issues

The workshop agreed that data was as significant as structure in systems modelling and this also had relevance for the policy link. Systems modelling relies on large-scale data structures but these are often inaccessible or not envisaged as important until after the event. Systems modelling will rely more in the future on forms of data gathering involving individual agents moving across system domains. Calibration of data is a significant issue.

Johnson emphasized that every policy ought to be tested with data. While there is indeed an obsession in governments with assessing their policies with data (impact assessment), there is a problem of gathering data on the right level and of the right type. Often there is a mismatch of scale and type. Data play a crucial role in refinement of models, said Hunt, citing the work of the Hungarian philosopher of science, Imre Lakatos. Science looks at the data and corrects its model (see for example the modelling of climate change at the beginning of the 1990s where a mismatch between models and data led to introducing aerosols into the equations that led to a far better match). Hunt also mentioned data-info centres springing up in the US, saying we needed to have them here: places that tell you, citizen or scientist or policy-maker, where to find the data you need.

Loreto made the point that data is essential in any policy debate. New ways of gathering and communicating data, enabled by ICT, produce new forms of involving the public. Sensor-based gathering of temperature and noise-level information, for example, allows collection of data on totally new scales. Use of mobile phones for this seems a particularly powerful way of getting ordinary people involved, as it could integrate subjective data (moods, opinions) as well as scientific readings. Data gathered in this way could, if socially accepted, induce widespread opinion dynamics leading to changes in behaviour. However, as Diana Mangalagiu warned, trust in data can result in overly superstitious beliefs on how to interpret the data. De Vries pointed out the difficulties of local actions based on misinterpreted data hindering scientifically well-founded policies operating on a larger scale.

List of participants
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Bert de Vries, Utrecht University, NL
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David Lane, University of Modena, IT
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