18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Models of Sustainability

Todorov, V.I. [1,2] **and D. Marinova** [2]

[1] *University of Forestry (UF), Sofia, Bulgaria*
[2] *Curtin University of Technology, Western Australia*
Email: vtodorov@ltu.bg and d.marinova@curtin.edu.au

Abstract: The paper presents a general classification of the models being developed in the area of sustainability arguing that the existing models represent the historical conceptualisation of sustainability starting from environmental constraints and moving towards economic valuation and social behaviour and policies. Coupled with computer power, sophisticated models with a varying levels of complexity have also been developed (static/dynamic; local/global; specific/general). However as any model is a simplification of the complex reality, the main purpose of any sustainability modelling should be to allow for co-evolution to be represented, including the role of humans as sustainability guardians.

Keywords: *sustainable development, sustainometrics, co-evolution, classification*

1. INTRODUCTION

According to Franck (2002: 5–7), the ten main general characteristics of scientific models are that they:

(1) provide a simplified representation of the reality;
(2) represent what is considered to be essential to this reality;
(3) are testable;
(4) under the scientific approach, the models themselves become the object of study;
(5) are conceptual;
(6) allow the possibility of measurement and calculation;
(7) allow explanation of the reality;
(8) are a fictive representation of the reality;
(9) represent systems;
(10) are isomorphic (in fact, also homomorphic) to the systems that they represents.

Some of these characteristics (e.g. 1, 2, 5, 7 or 8) are more general than others (e.g. 3, 4, 6, 9 and 10). On the other hand, some types of models represent some of these characteristics better than others. The aim of this paper is to discuss a range of methodological problems related to models of sustainability. It is an attempt to comment on the conceptual frameworks behind the models, their applicability and capacity to generate knowledge.

The analysis of models used to describe sustainable development is also related to the proposed new area of research, namely sustainometrics (Todorov, 2006; Todorov and Marinova, 2009). We present a general typology of models used for the representation and study of sustainability along five major categories of models, namely quantitative models (including mathematical, statistical, data-based, econometric and computer simulation), pictorial visualisation (including the Venn diagram, graphic representation, pictures and drawings), conceptual models (representing particular concepts and theories), standardising models (including indicators, benchmark values and targets) and physical models (a smaller or larger physical version of the object/system that allows visualisation and further investigation). Each category generally satisfies Franck's requirements for a model to be scientific; however the implications from using a particular category are very different. For example, a purely theoretical model can be very strong as a conceptual tool but lack the fully developed tools to be testable and measurable. Alternatively, a system of indicators can play a very valuable role as a fictive representation of the reality which allows measurement and calculation but lack the depth in conceptualisation and explanation of the phenomena that they represent. Moreover, such a system of indicators are likely to also become management targets and detract from the real phenomenon in favour of its model. It is often the case that the modelling of a particular phenomenon or system is done through a combination of models from the above categories as each category serves a different purpose and a different audience.

From a policy perspective, Boulanger and Bréchet (2005: 339) outline five most important methodological criteria that need to be taken into account for modelling the challenging issues of sustainability, namely: C1 – interdisciplinary approach; C2 – managing uncertainty; C3 – a long-range or intergenerational point of view; C4 – global-local perspective; and C5 – stakeholders' participation.

Against this background of achievements in the art of modelling and expectations as to what it can deliver for facilitating a move towards a more sustainable human presence on the planet Earth, the paper comments on the types of models that sustainometrics needs to develop in its capacity of information-based co-evolutionary theory that deals with global virtual realities with a time horizon span larger than a century in order to allow for global intelligent systems to emerge.

2. REVIEW OF SUSTAINABLE DEVELOPMENT MODELS

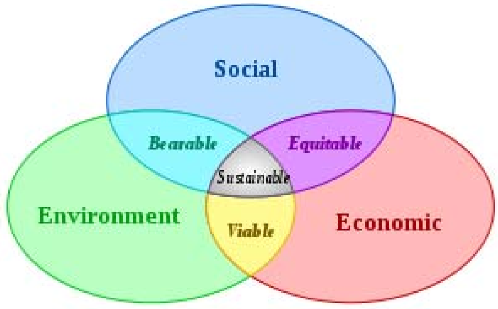
There have been numerous ways of representing sustainable development in a model that captures this extremely complex concept and a new way of thinking. This section is an attempt to briefly capture some of these efforts while the section to follow expands on what we perceive to be the major features of any modelling that would be in a position to properly reflect the essence of sustainability.

2.1. Pictorial Visualisation Models

According to the World Conservation Union (IUCN, 2006), the three dimensions of sustainability (economic, social and environmental) are represented either as pillars, embedded circles or in the popular Venn diagram of three overlapping circles. The latter model stresses the importance of the intersection between the three areas (see Figure 1). These models clearly emphasise the need for interdisciplinary and transdiciplinary (e.g.

Marinova and McGrath, 2005) approach to understanding sustainability but their explanatory power is much weaker in relation to the other four criteria put forward by Boulanger and Bréchet (2005). Generally, these are popular static models with limited informative value but powerful in terms of reaching a broad audience.

For example, Newman and Kenworthy (1999)



IUCN (2006)

Figure 1. Examples of the Venn diagram

2.2. Quantitative Models

From a policy-making perspective, describe six types of quantitative models, namely "macro-econometric models, computable general equilibrium models, optimization models, system dynamics models, probabilistic or Bayesian network models (this category also includes risk assessment models based on influence diagrams) and multi-agent simulation models" (Boulanger and Bréchet, 2005: 340–341).

Economic models represent a special sub-class of the quantitative models. In fact, this area has been extremely active in academic pursuit generating models representing various economic concepts, ranging from neo-classical, evolutionary, ecological economics to neo-Ricardian (Faucheux et el., 1996). These models have attempted to find ways of embracing uncertainty and dealing to a various degree of success with long-range perspectives. Despite this, they have been poorly equipped to accommodate a holistic perspective, address the local-global perspective or acknowledge the need for stakeholders' participation.

A common characteristic of the quantitative models is the fact that they remain dominated by the discipline from where they have originated, be it environmental science, engineering or economics.

2.3. Physical Models

The use of physical models for sustainability has been restricted mainly to its environmental component. They have been applied for water (e.g. Hellström, 2000), energy, buildings, in urban design, for recreation of habitat (Levings, 2004), for handling of pollution, CO2 (e.g. New Zealand's zero emissions housing, http://www.zeroplus.net.nz/) and toxicity (e.g. Karlsson, 2008), in implementing industrial ecology, to mention a few examples.

Physical models are very specific and predominantly local. The purpose of their construction is to reduce the uncertainty; however their time span is quite restricted. They allow for a participatory approach and interdisciplinary perspectives, but by nature are only a fragmented part of the global sustainability system and can rarely serve to main purpose of modelling for sustainability.

2.4. Conceptual Models

This category of models is very broad and is linked to humanity's waking up to the limits of its natural environment and the negative impacts that population and its "development" have been having on it. They started with the work of the Club of Rome (Meadows et al., 1971), went through the conceptualisation of the implications from the use of nuclear weapon ("nuclear winter", see Turco et al., 1983) and from ozone depletion and the ozone hole (Litfin, 1994) to go through the various futurist scenarios such as the ones developed by the World Business Council for Sustainable Development (e.g. Speth, 2004), to the work on global warming and climate change (e.g. IPCC, 2007). Another example of a powerful theoretical idea that has crossed the boarders of many disciplines and is also contributing to understanding sustainability is the evolutionary concept (Costanza et., 1993).

The long-term and intergenerational perspective has been an important trigger for these models and the majority of them contain a warning element and signals for alertness, in some cases threats and fears. Many are also ideologically laden and have been plaid heavily on the political agenda, occasionally allowing stakeholders' participation. With emphasis on the global, concrete solutions for local problems have been difficult to find within the theoretical models and some implied consequences have been the cause of despair and ideological wars.

The inability of these models to manage uncertainty has been their weakest point and this has allowed for wide differences of opinion to emerge. A recent example of this is the so-called climate change denialism (Begley, 2007). On the positive side of things, they have generated wide debates and triggered policy responses.

2.5. Standardising Models

The development and application of sustainability indicators is an area of active research and practice that has received a lot of attention. It has produced a variety of lists and descriptions such as the 2006 United Nations list of Indicators of Sustainable Development which includes a total of 96 indicators (http://www.un.org/esa/dsd/dsd_aofw_ind/ind_index.shtml) or sets applicable at community (Hart, 1999), corporate, national, state or local government level. They can also cover particular activities, such as sustainable consumption or production. There have also been attempts to develop a holistic or aggregate indicator to measure sustainability, such as the genuine savings indicator (Hamilton et al., 1997), gross national happiness (Brooks, 2008) or ecological footprint (Rees, 1992).

The aim for the majority of indicators is to somehow assign a value or a number against that describes the complexity between social, environmental and ecological health. According to Yunis (2004: 2), "(t)hey are signals of current issues, emerging situations or problems, need for action and results of actions". They allow to gauge the performance of the system (Bell and Morse, 1999). These models can accommodate a very specific local–global perspective and the process of their development can be participatory. Despite the intention for a long-term perspective, the practicality of all indicators is such that they represent a good snapshot for the particular moment and only if records are kept and data processed can they provide longer trends. Representatives of different disciplines can be drawn into the process, however the desired outcome has to allow for crossing borders between the disciplines and the three areas of immediate interest.

Irrespectively as to how much progress is made towards measuring and assessing sustainability or unsustainability, there are many signs just in front of human eyes that can perfectly capture what the situation is. As Donella Meadows said: "We can learn at least as much about sustainability by turning our eyes away from numbers and noticing the soil washing down the streams, the clearcuts where forests once stood, the changing climate, the smell of city air, the places on earth too contaminated to live in or too desperate to be safe in, and the hectic emptiness of our lives. Some day we may have numbers to measure these blatant signals of unsustainability. In the meantime we can admit that we already know" (http://www.grist.org/article/sustainability/).

This acknowledgement of the severity and pervasiveness of the problem requires a new perspective and a new way of thinking about sustainability. It requires a stronger focus on the process itself rather than centring attention on its components, states, outcomes or aspirations. This is not to say that all of the above are unimportant; they are useful guiding tools but the nature of the sustainability puzzle at the moment lies in the processes that will generate a different way for humanity to relate to its hosting planet Earth and fully embrace its stewardship role.

3. APPROACH TO MODELLING SUSTAINABLE DEVELOPMENT

According to Murcott (1997), and later adopted by the OECD, sustainable development can be understood within interaction conceptual frameworks that describe the interactions between the pairs of the humanity–economy–nature triad as well between all three of them. This approach as well as the bulk of the models referred to in the previous section reveal some inherent difficulties associated with what we describe as methodological eclecticism. It is not in a position to serve the needs of sustainable development because of the following considerations:

- the approach is based on shorter trends than the long-range intergenerational needs;

• the fragmentation (often representative of the Western science approach) does not allow for a holistic view and understanding.

The approach that is needed requires simultaneous integration of economic, social and ecological knowledge in order to understand development not in an antagonistic way but as human evolution within a constantly changing and evolving natural world. Hence, we need a co-evolutionary paradigm in order to grasp the global problems of humanity which at the moment present themselves as antagonist relationships and contradictions. In fact, this is the first time in human history that we are witnessing problems of such a scale as, for example, climate change. Its origin and causes show that the human race has become such a mighty power that is capable of bringing out of balance what have been for millennia self-regulating geo- and bio-systems. Many see the Apocalypse approaching and believe that humanity is opening the seven seals itself.

Sustainable development is the new emerging area of hope against these doom and gloom projections. It is likely to become a fundamental feature of the global development processes and a point of reference for joint consideration and interpretation of the unity in the development of nature and society.

Based on the co-evolutionary paradigm (e.g. Norgaard, 1997), it is possible to model the interactions within the global "humanity–global economy–nature" system. The important point is that all three should be modelled and analysed simultaneously in terms of their global interactions. In other words, a model: (1) should not be representing only one of the components (e.g. the economy) against the other two; and (2) should allow a study of the conflict and risk factors together with the resulting changes of transformation and co-adaptation that shape the co-evolutionary process. Hence, sustainable development is not only a macroeconomic concept, it is not only nature conservation either. It can be social advancement but again cannot happen in isolation from nature and the economy. Sustainable development is a development that synchronises and harmonises economic, social and ecological processes.

Figure 2. A buffer model of the global system; Giannetti, 1993

An adequate model of sustainable development cannot build on the existing understanding of society and nature. Humans have also created what can be described as "second nature", i.e. the human-made material world which by size and importance has become comparable to the global natural systems. It not only acts as a buffer between humans and nature (see Figure 2) but has also become the main objective of human development. Following its own developmental logic and laws, this "second nature" ironically is now threatening the planet's nature.

Since the 20th century, globalisation has become a distinctive feature of development affecting the economy (and making it global), society (with emerging global consciousness and shared global problems) and the environment (with the effects of pollution, for example, becoming of global importance). In fact, sustainable development is becoming a "globalising" development which does not contravene but reinforces and synchronises these processes. The planet Earth can only support such development.

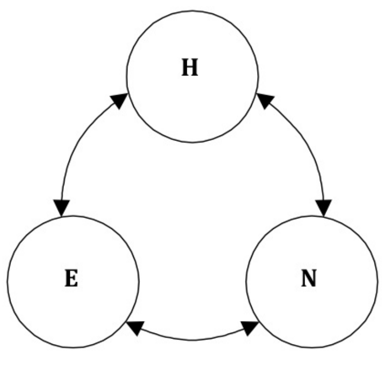


Figure 3. Co-evolutionary model

A model of this global sustainable development is that of a meta-system ① which is in a state of dynamic balance ⊕:

$$\mathbf{GS = H \oplus E \oplus N} \qquad \textcircled{1}$$

where H is humanity; E –global economy and N – the global natural environment (see also Figure 3).

The following three characteristics, informed by the co-evolution principles, are important for model ①**:**

(1) Heterogeneity – i.e. difference in nature and aims in these three components. In fact, the aims can also be contradictory. At the local scale, heterogeneity is expressed in specific socio-ecological systems in which ecological, social and cultural elements are represented as a whole through the complex and intricate interactions of geographic, biological and anthropomorphic factors. Therefore the global system is not just a complex of global phenomena of a different nature, but complex and mutually dependent arranged in pace separate socio-natural agglomerates.

(2) Equality – i.e. need to holistically integrate different priorities. It emphasised the deep connection and direct and multilateral interaction between each of the components and the rest. Examples of this are any of the global problems that society currently faces, e.g. climate change.

(3) Human stewardship – i.e. the leading role that humanity has in transforming, maintaining and/or sustaining the planet Earth.

4. A PROCESS CLASSIFICATION OF THE MODELS OF SUSTAINABLE DEVELOPMENT

Below is a possible typology of models of sustainable development based on the approach described in the previous section.

1. **Time-related** (*t-models*):

- Static (t_s-*models*);
- Dynamic (t_d-*models*).

Criterion: They model (analyse/forecast) the state of sustainability or assess/predict the processes of sustainable development.

2. **Place-related** (*s-models*):

- Global (s^g-*models*);
- Regional (s^r-*models*).

Criterion: They model the state of sustainability/sustainable development processes depending on their scale and/or the localisation. The global closed models are insignificantly affected by the scale of the system, while the regional models are open and reflect the specifics of particular regional systems.

3. **Scale-related** (*r-models*):

- General (r^C-*models*);
- Specific (r^P-*models*).

Criterion: They model sustainable development of systems which differ according to composition and structure.

The type of models that serves the purposes of sustainometrics (Todorov and Marinova, 2009) are those that can be described as: <*Dynamic*-t_d, *Global*-s^g, *General*-r^C >. The development of such models, for example, can assist in creating a GIS-based global virtual model of the Earth which will not only allow forecasting and predicting, but will also assist in building scenarios and trajectories in the opportunity spaces of a future global virtual reality.

5. CONCLUSION

According to Costanza et al. (1993: 547), "(m)odels are analogous to maps… they have many possible purposes and uses, and no one map or model is right for the entire range of uses". The presented brief analysis of the models of sustainable development clarified the need for a new type of models that can fit very well in the domain of sustainometrics. These models are only possible with the current advances in information technology and information theory. Their purpose will be to create a map that not only presents the co-evolution of the global system but also charges humanity with the ability to fulfil its stewardship obligations on this stunningly beautiful planet that we and future generations call home.

ACKNOWLEDGMENTS

The authors wish to acknowledge the financial support of the Australian Research Council for making this research possible. The first author is also grateful for the feedback received from the participants and referees of the International Scientific Conferences on Management and Sustainable Development, Yundola, Bulgaria where some of the original data and related findings were first presented.

REFERENCES

Begley, S. (2007), Global warming: The truth about denial, Newsweek, 7 August, http://www.newsweek.com /id/32482 (accessed 08.09.2009).

Bell, S, and Morse, S. (1999), Sustainability Indicators: Measuring the immeasurable?, Earthscan, London.

Boulanger, P.-M., and Bréchet, T. (2005) Models for policy-making in sustainable development: The state of the art and perspectives for research, *Ecological Economics*, 55, 337–350.

Brooks, A.C. (2008), Gross National Happiness: Why Happiness Matters for America – and How We Can Get More of It, Basic Books, New York.

Costanza, R., Wainger, L., Folke, C., and Mäler, K.-G. (1993), Modelling complex ecological economic systems, *BioScience*, 43(8), 545–555.

Faucheux, S., Pearce, D., and Proops, J. (eds) (1996) Models of Sustainable Development, Edward Elgar, Brookfield, Vt.

Franck, R. (ed.) (2002), The Explanatory Power of Models, Springer, Berlin.

Giannetti, E. (1993), Vícios Privados, Benefícios Públicos? A Ética na Riqueza das Nações, Companhia das Letras, Lisbon.

Hamilton, K., Atkinson, G., and Pearce, D. (1997), Genuine Savings as an Indicator of Sustainability, CSERGE Working Paper GEC 97-03, www.uea.ac.uk/env/cserge/pub/wp/gec/gec_1997_03.pdf (accessed 08.05.2009).

Hart, M. (1999), Guide to Sustainable Community Indicators, 2nd ed., Hart Environmental Data, North Andover, MA.

Hellström, D., Jeppsson, U., and Kärrman, E. (2000), A framework for systems analysis of sustainable urban water management, Environmental Impact Assessment Review, 20(3), 311–321.

Intergovernmental Panel on Climate Change (IPCC) (2007), Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Karlsson, S. (2008), Closing the technospheric flows of toxic metals: Modeling lead losses from a lead-acid battery system for Sweden, *Journal of Industrial Ecology*, 3(1), 23–40.

Levings, C.D. (2004), Knowledge of fish ecology and its application to habitat management, In Groulx, B.J., Mosher, DC., Luternauer, J.L., and Bilderback, D.E. (eds) Fraser River Delta, British Columbia: Issues of an Urban Estuary, Geological Survey of Canada, Bulletin 546: 213–236.

Litfin, K.T. (1994), Ozone Discourses: Science and Politics in Global Environmental Cooperation, Columbia University Press, New York.

Marinova, D., and McGrath, N. (2005) Transdisciplinarity in teaching and learning sustainability, in Banse, G., Hronszky, I., and Nelson, G. (eds) Rationality in an Uncertain World, 275–285, Edition Sigma, Berlin.

Meadows, D., Meadows, D. L., Randers, J., and Behrens, W. (1971), The Limits to Growth, Universe Books, New York.

Murcott, S. (1997), Sustainable development: A meta-review of definitions, principles, criteria indicators, conceptual frameworks and information systems, Annual Conference of the American Association for the Advancement of Science, IIASA Symposium on Sustainability Indicators, Seattle, WA.

Newman, P., and Kenworthy, J. (1999) Sustainability and Cities: Overcoming Automobile Dependence, Island Press, Washington, DC.

Norgaard R.B. (1994), Development Betrayed: The End of Progress and a coevolutionary revisioning of the Future, London; New York: Routledge.

Rees, W. (1992), Ecological footprints and appropriate carrying capacity: What urban economics leaves out, *Environment and Urbanisation*, 4(2): 121–130.

Speth, J.G. (2004), Red Sky at Morning: America and the Crisis of the Global Environment, Yale University Press, New Haven and London.

Todorov, V. (2006), System sustainability and development sustainability: Modelling problems (Is E-conometrics of sustainable development possible?), *Management and Sustainable \Development*, 18(*3*-4), 136–140 (in Bulgarian).

Todorov, V., and Marinova, D. (2009), Sustainometrics: Measuring sustainability, MODSIM 2009 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, in this issue.

Turco, R.P., Toon, O.B., Ackerman, T.P., Pollack, J.B., and Sagan, C. (1983), Nuclear winter: Global consequences of multiple nuclear explosions, *Science*, 222(4630), 1293–1300.

World Conservation Union (IUCN) (2006), The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century, http://cmsdata.iucn.org/downloads/iucn_future_of_ sustanability.pdf (accessed 08.05.2009).

Yunis, E. (2004), Indicators to measure sustainability in tourism, 7th International Forum on Tourism Statistics, Stockholm, www.tourismforum.scb.se/papers/PapersSelected/SD/Paper37WTO/ Stockholm_ Indicators_June04.doc (accessed 08.05.2009).