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Meta-Modelling the European Environmental Information Space

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Abstract:
In this paper a conceptual Meta-Model is presented with the aim to structure environmental information, relevant for the environmental part of sustainable development. It is focused on crucial environmental information flows handled in the discipline of Environmental Informatics. The introduced structure is a conceptual systems dynamics type model which describes the natural environment (air, water, soil, climate etc.), the private sector (industry, trade, transport etc.) and households. It uses the input-output presentation where cause-effect chains and information feedback paths are considered. The Meta-Model brings together substantial information about environmental indicators from different areas and organizations, the knowledge about levels of action, and grades of spatial resolution. The systems model drafted here is new in establishing a connection between IT applications and sustainable development. It provides a basic structure for interlinking complex, time dependent information flows, aiming to support semantic interoperability in environmental research. Now the Model is applied as organizing principle in the 7th European Framework Programme in the project ICT for Environmental Sustainability Research (ICT-ENSURE).

***Keywords**: Environmental modelling; SISE (Single Information Space in Europe for the Environment); ICT-ENSURE*

1. ORGANIZING ENVIRONMENTAL INFORMATION

1.1 Generic Models for Environmental Matters

Early developments of methodologies to organize environmental statistics were taking place in the 70es. The Stress Response Environmental Statistical System STRESS was proposed by Anthony Fried and David Rapport at Statistics Canada. The PSR model was initially used and further developed by the OECD to structure its work on environmental policies and reporting. The PSR model has the advantage of being one of the easiest frameworks to understand and use (Towards Sustainable Development, 2000). Similar to this is the Source-pathway-response (S-P-R) Model, also addressed as S-P-R-C model, where consequences were included.

A way commonly used to describe environmental stress and human responses is the Driving force-Pressure-State-Impact-Response (DPSIR) model. It is frequently used by the European Environment Agency (EEA) and by international organizations dealing with environmental information, e.g. Eurostat. It allows the classification of the cause-effect relationships between economic activities, environmental pressure and selected social conditions (EEA core set of indicators 2005; assessment 2010). This framework structure is more intuitive, and therefore satisfactory for presentations and publications.

Looking more in detail one will need a considerably more IT related model structure. To describe the systemic effects in the environment, a basis should be provided for the development of a Single Information Space in Europe for the Environment (SISE) (Pillmann, Hrebicek 2009). In compliance with currently developed EU working documents and new research programmes, this concept will continuously be adapted, from workshops and conferences. Prominent examples are the EnviroInfo conferences and the conference "Towards e-Environment (Prague 2009). European solutions for an integration of environmental relevant information are the PortalU www.portalu.de and various environmental information systems based on Service Oriented Architectures and e-Services in general.

1.2 Models related to environmental issues

Since the early 1970es, interdisciplinary and integrated models have been used to describe complex systems in nearly all scientific fields. The application of the so-called „System Dynamics“ for environmental studies is closely connected to names like N. Wiener, J.W. Forrester, E. Pestel, D.L.&D.H. Meadows, H. Bossel, F. Vester and M. Mesarovic. The modelling approaches can be ordered at least in the following categories (Pillmann, Simon D2.2, 2010):

Dynamic models. In this group process models can be found based on differential/difference equations with closed loops and feedback relationships between environmental compartments (Richardson 1991, Meadows D.H. 2009). Simulation software packages are prominent representatives for ICT applications in this modelling segment. The cybernetic approach built on this "philosophy" tries to include dynamic interrelationships to focus on the mutual influences in complex systems. The meta-modelling approach below is based on the System Dynamics idea.

Static models are used in life cycle assessment ("eco balances") and evaluation schemes (hierarchically ordered evaluation criteria).

Integrated models are now applied in several environmental studies that deal with complex problem areas, like sustainability strategies or environmental problems caused by interplay of processes in natural and human systems. Examples are problems like air quality, forest ecosystem dynamics, biodiversity, waste management, environmental effects of tourism etc. For several of these problem areas a thorough analysis of the components and interrelationships exists, which can be further included in the Meta-Model framework.

With respect to the meta-modelling approach the idea of sectoral models to be combined under a common umbrella and the relevance of human activities is here introduced and seems from the authors' point of view of high importance for further implementation in IT supported form.

1.3 Modelling Criteria

Models are used to represent the essential characteristics of an area under investigation. The following requirements are taken into consideration for designing the model framework:

Simplification – As with modelling exercises in general the representation is far more abstract than the phenomena considered. Phenomena, here, does not only mean the man-made sphere and environmental facts but also the information, represented in scientific texts and diagrams.

Comprehensiveness – On the other hand, the relevant information must be included, also on a structural level. Therefore, the openness of the system is of great significance – relevant information must be allowed to be added. Also the layers defined as the Meta-Model should comprise the crucial aspects of the problem situation – especially connecting natural science information with information about human activities.

Dynamics – The Meta-Model must represent the interconnectedness of several compartments and sectors as well as their dynamic interactions. As it is the case with other requirements, also the dynamic characteristics are to be represented on a rather high abstraction level.

Technical support – As well as for the integration of the mentioned elements (sectors, facets) as for the system diagrams the existence of approved measures for implementation would be helpful.

2. COMMUNICATION FOR ICT IN ENVIRONMENTAL SUSTAINABILITY RESEARCH

2.1 The ICT-ENSURE Project

In line with the 7th European Research framework programme the EC Directorate DG-INFSO commissioned the project ICT-ENSURE - "ICT for Environmental Sustainability Research". The project extends scientific networks, provides scientific IT related environmental surveys and set up two Web based information systems: a Literature database and a Research Programmes Information System.

In ICT-ENSURE a multi-scale, multi framework Meta-Model is introduced, that tries to integrate concepts from the approaches above for fulfilling the demands for a Meta-Model usable for environmental science and sustainability aspects in politics.

To foster a 'Single Information Space in Europe for the Environment" (SISE), ICT-ENSURE provides also synoptic views in selected sustainability relevant areas (Pillmann et al. D7.1 and D7.2). In the project a generic Meta-model of the environmental information space was developed, including ICT-Tools for structuring knowledge and research activities which are supposed to circulate freely in the European Research Area (ERA).

2.2 The EnviroInfo Community

Concentrating on environmental matters, **Environmental Informatics** has become a thematic group in applied informatics and computer science. Two nuclei of the upcoming field of "computer application for environmental protection" exist: Symposia on this topic started in 1986 and the foundation of the Technical Committee "Informatik im Umweltschutz" (Environmental Informatics). The growing interest in informatics applications in all fields of environmental protection led to an unbroken series of annual, today called "EnviroInfo" conferences in Europe. Environmental Informatics constitutes an extensive scientific community with nearly 400 members, building a stable research communication platform (Pillmann, Geiger, Voigt 2006).

Over the years, special interests in the EnviroInfo Community led to the establishment of specialized Expert- and Working Groups. This includes the branches

- Corporate (or Industrial) Environmental Information Systems
- Modelling and Simulation in Environmental and Geo-Sciences
- Modelling und Simulation of Ecosystems
- Environmental Information Systems
- Municipal Information Systems and
- Risk Management

Quantitative results of the work of the Technical Committee Environmental Informatics are about 3.300 referenced papers in 23 EnviroInfo conferences documented on approximately 30.000+ pages. Roughly half of them have been included now in the ICT-ENSURE project Literature Information System (http://lit.ict-ensure.eu).

In addition to the EnviroInfo conferences (since 1986), other conferences dealing with ICT research and applications in environmentally relevant areas are e.g. iEMSs (since 2002), ITEE (biannual since 2001), EnviroSoft (1989-2004) and Towards eEnvironment (2009). Also the IFIP groups 5.11 "Computers and Environment" and 9.9 "ICT and Sustainable Development" is dealing with environmental informatics.

3. MODELLING THE EUROPEAN ENVIRONMENTAL INFORMATION SPACE

3.1 Meta-Modelling

Environmentally relevant information can be gathered ubiquitously in all spheres of human activities and natural phenomena. Due to this unmanageable amount of information sources, all persons and organisations involved in environmental protection are faced with the need to reduce complexity. By introducing main sectors of concern, systemic interrelations can be identified to which information (data, facts, journal articles, models) is associated and which define access procedures to relevant knowledge. More or less specific sectors are identified, to select a sample of this paramount space, like research, engineering, industrial information, legal instruments, etc., where ICT services support the organisation within this incredibly huge information space.

Sectors in Environmental Sustainability
Such a selection process is supported by environmental science and sustainability science that work with certain clearly defined areas, concerning air and climate, water, soil ("environmental media") as well as problem areas like transport, waste, degradation and critical areas, dealing with hazardous substances risks, and disasters. More and more these branches of research or scientific subjects include interdisciplinary elements, but due to the lack of standardisation rarely in a systemic manner.

Meta-view on the Environment
General access to this information space can be found through keywords. Such language-based access can be managed by asserting terminologies, thesauri, and ontologies. In ICT-ENSURE it is suggested to follow a more systemic approach that allows for a "holistic" approach in organizing and retrieving information. The approach is to propose an adequate meta-model that represents the relevant pieces of information and knowledge in a comprehensive and effective way. Such a meta-model aims at a final state of an information system that helps to get specific information and knowledge about problem solutions (sustainability, environmental problems) by entering an information level where only the most important issues are presented (Pillmann 2007).

Meta-model
A model is usually a "simplification of reality that is constructed to gain insights into select attributes of a particular physical, biological, economic, or social system". In our approach, the term meta-model is applied to characterise a simplification (or abstraction) of models to describe the essential components and relationships within an environmental area. With such a meta-model a twofold effect is achieved: it can help to identify gaps in information about particular environmental or sustainability problem descriptions, and it helps in accessing information from a more holistic view on problems and problem solution measures.

Hence, the term meta-model is used in this paper to build a structure to provide access to the information space. This definition identifies a use of model in the sense of systems dynamics, opposed to types like process models, (meta-) models in software engineering, business models in eCommerce or linguistic models. However, the proposed meta-model may include elements of the approaches above.

3.2 Systemic view of the Meta-model

To analyze the role of ICT in environmental information and communication, a systems diagram is used. In this model main sectors are characterized as processes, represented as (dynamic) multi-input/multi-output systems. Fig. 1 outlines a draft of such a meta-framework for the environment and man-made sectors in environmental sustainability research, where ICT and Environmental Informatics play a relevant role.

The main parts are the (natural) environment and the production/distribution/transport sectors including agriculture, forestry and public and private households. These sectors are coupled with "the environment" with material flows (resources and pollution). This model separates artificially the economic/societal environment (industry, households) the environmental system, to better illustrate the effects of production, consumption and resource depletion on the natural environment.

The input/output presentation should reveal that this is a highly dynamic system with a multitude of discrete and continuous-time elements, feedback/feed forward loops, disturbances, uncertainties, nonlinearities and unstable processes. This model representation below is chosen as a basis for a tentative further computer assisted integration of the environment and sustainability relevant information space.

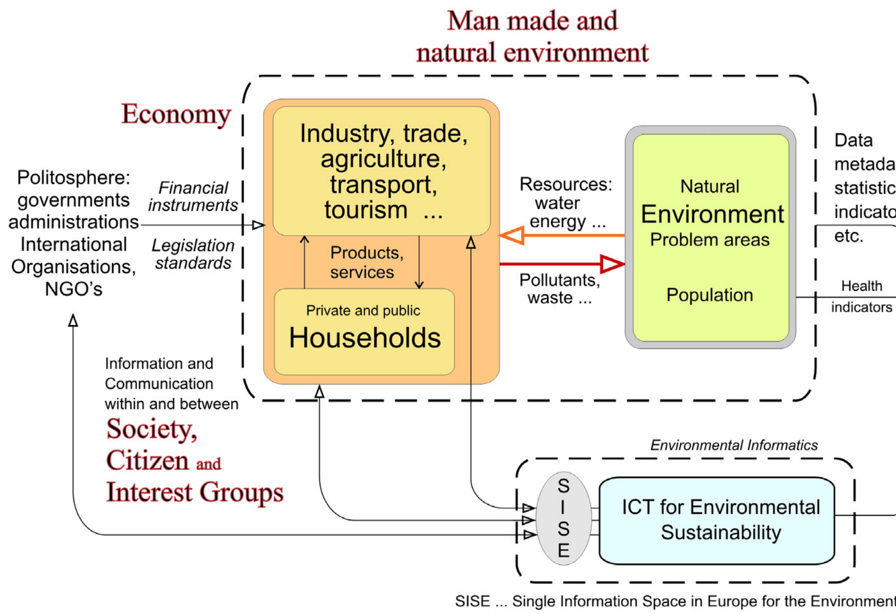

Figure 1: Conceptual Meta-model for ICT for Environmental Sustainability (simplified)
(Source: Pillmann D2.2, modified)

The lines within the diagram are highlighting the origin, the transfer and/or the exchange of environmentally relevant information, which can be characterized by a set of basic dimensions.
These dimensions are

1. the field of interest/application area (natural/built environment, economic activity, society relevant data, regional structure, material balances, resource conservation, legislation etc.)
2. the spatial dimension (coordinates of point sources, local areas, regions, river basins, states, continents etc.)
3. the temporal dimension (time, date, observation interval, time series etc.)
4. the representation of information (written material, formulation of political demands and objectives from decision makers, teaching, personal communication, digital information: databases, images, multimedia material, Web sites; etc.)
5. the sender and receiver of information (scientists, environmental agencies, governments, NGOs, companies, consumer protection agencies, citizens etc.)

The left hand side of the diagram indicates some addressees of environmental information in politics, administrations and organisations. Environmentally related goals (e.g. pollution reduction, national environmental action plans, Agenda 21, Eco Management and Auditing Scheme - EMAS) are influencing politics, administrations and enterprises. Legislation and other measures (taxes, fostering environmentally friendly technologies, information, research, international agreements etc.) should represent the indirect impact of environmental information on industry and the public at large[1].

In the kernel of the model the interaction between the natural environment and the anthroposphere is arranged. The kernel "Human activities" can be specified by including e.g. public and private households, industrial activities, agriculture and the transport sector. The

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[1] The idea for a Meta-Model of Environmental Informatics dates back to 1990. In the proceedings of the conference "Informatik für den Umweltschutz" a forerunner of EnviroInfo conferences, an early regulatory concept for assigning the papers to subject areas was published (Informatik für den Umweltschutz 1990). A general framework structure for the scientific contributions to the EnviroInfo conference proceedings can be found in Pillmann (2002).

natural environment with air, water and soil may also reflect problem areas like waste, land-use changes, energy balances, or climate change. Several "communication channels", influencing primarily driving forces or conservation strategies, have their origin in information processing with ICT.

The main modelling task is to organize the access to and the distribution and communication of information, relevant for sustainability (Pillmann 2000). Therefore, in the concrete examples, the determinants and influences of economy, social processes and dynamics, and on individual behaviour has to be specified. Thus, the following components are of particular relevance.

1. Analysis of data and knowledge about the environment (Pillmann 2009)
2. Systematisation of this information in ICT
3. Communication and distribution of information via media (publications, the Web, conferences, mass media etc.), (Pillmann 2000)
4. Inquiries about the effectiveness of information in decision processes
5. Design of influences on socio-political processes (legal measures, incentives, taxes).

The following chapter provides an example how a systems view in the environmental sector "air quality" can be deduced from the conceptual general model with the focus on ICT for environmental sustainability.

4. MODELLING AIR QUALITY CONTROL AND MANAGEMENT

Monitoring of air quality is one of the fundamental activities for environmental protection. In the course of time, different gasiform substances have attracted the interest of researchers, governments and the public. So, several periods during the development of air quality management and the effects of pollutants can be distinguished:

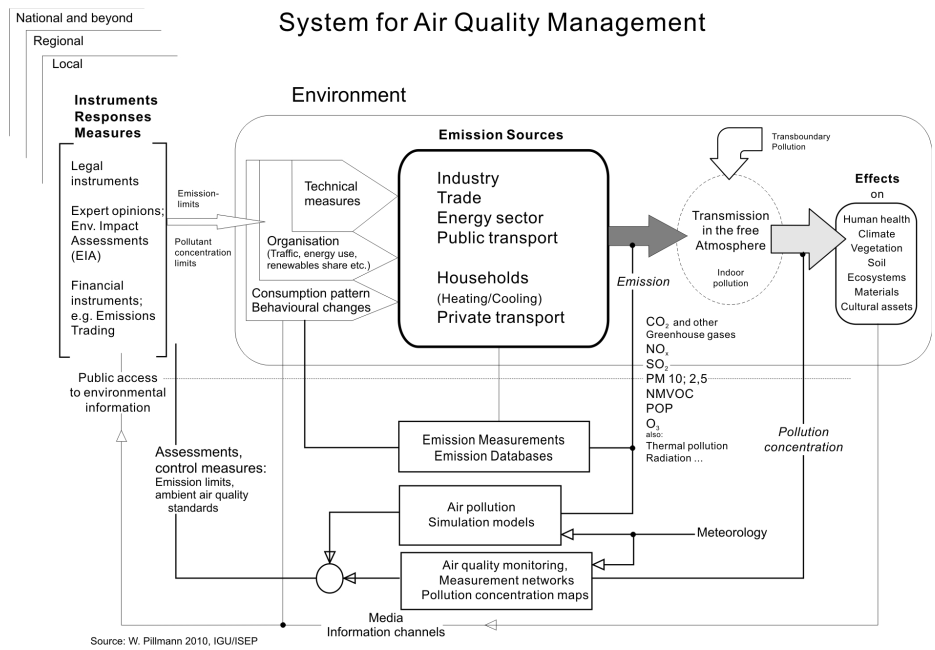
- SO_2, NO_x, relevant for health effects, acidification and forest decline
- hazardous substances (health effects caused by disasters)
- biological materials (allergens)
- stratospheric ozone ("ozone hole") and ground-level ozone (health effects) and
- particulate matter (chronic obstructive pulmonary disease).

Today greenhouse gases measurement and inventories are in the focus of air quality management activities.

A multitude of research programs, administrative tasks and especially environmental protection requires to refer to reliable data. Air quality information is used in environmental and epidemiological research, for policy decisions integrated in all relevant areas, environmental impact assessments and for public information on pollutants concentration, forecasting and civil protection. Within the approximately 120 EU Directives, Regulations and Decisions in environmental legislation, air quality monitoring plays an important role (Handbook on Implementation of EC Environmental Legislation 2008). Based on national legislation, emission inventories and measurement networks are today standard in the environmental protection efforts of the European countries.

An example of such a systemic view on measures to improve air quality is depicted in fig. 2. The Meta-model in the field of "Air Quality Management" conceptualizes the general structure of the main tasks in air pollution abatement and tries to provide a structured approach to information sources. Derived from the conceptual Meta-model in fig. 2.1 the air relevant topics were pointed out. Information about the emission sources in the middle of the diagram was available from a multitude of databases from companies specific for the regional national and international level (e.g. Eurostat). Air pollution networks are measuring locally the concentration of gaseous substances. A diffusion model provides a prognosis of local to trans-boundary dispersion of contaminants also e.g. of sand, isotopes or volcanic ash. In studies the analysis of air pollutants on health, ecosystems and climate are carried out. The feedback of knowledge about impacts of air contaminants provokes measures in the legislation, the fiscal system, in traffic organisation. It forces the development of environmental technologies and slowly changes the behaviour of the population.

The common point of these references is that they are mainly describing more or less precisely feedback cycles from an organisational, administrative and/or political point of view. Very few efforts have been made to describe effects of air pollution from a holistic, respectively generic point of view in order to support monitoring of environmental resources in



the scope of the vision of SISE (Single Information Space for Europe for the Environment).

Figure 2: Meta-model in the field of "Air Quality Management" (Source: Pillmann D2.3 2010)

Multiple efforts are existing dealing with air quality management. A few examples on a European scale are enumerated, comprising the following:

- Emission inventory report 1990-2007 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP) http://www.eea.europa.eu/publications/lrtap-emission-inventory-report-1990-2007
- CAFÉ Clean Air for Europe (http://ec.europa.eu/environment/archives/cafe/general/keydocs.htm)
- EMEP/EEA Air pollutant emission inventory guidebook - 2009 http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009
- A comprehensive source of air quality and climate change reports can be found in the European Topic Centre on Air and Climate Change ETC/ACC http://air-climate.eionet.europa.eu/reports. In the Centres workplan 2010 the following task is envisaged: "Analyse the full causality chain (as encapsulated in the DPSIR framework) in order to appraise the legitimisation of environmental policies (impact on human health and ecosystems), the sectoral contributions and to identify the dynamics of the system." The conceptual Meta-model "Air" in fig. 2 offers such a systemic, closed loop control framework.
- Simulation Models: Rains http://scenarios.ew.eea.europa.eu/fol079729/copy_of_fol615122/model_inventory.pdf/download
- Satellite air quality observations in GMES (GENESIS Air Quality State of the Art Document) http://genesis-fp7.eu/download/52)
- Use of the GEOSS Common Infrastructure to register, discover, and access datasets relevant to air quality management. https://sites.google.com/site/geosspilot2/air-quality-and-health-working-group/aq-engineering-report

- Access to earlier European urban air quality research projects can be found on http://www.nilu.no/clear/ (state 2006)

From the building block "Natural Environment-Problem area" as mentioned in fig. 1, air quality monitoring is only one of many others. More examples can also be found in Pillmann et al. (D2.3 2010).

Abbreviations

DG-INFSO	Directorate-General for the Information Society and Media
DPSIR	Driving forces-Pressure-State-Impact-Response
EEA	European Environment Agency
ICT-ENSURE	ICT for Environmental Sustainability Research
PSR	Pressure-State-Response
SEIS	Shared Environmental Information System
SISE	Single Information Space in Europe for the Environment

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References

Full text retrievals of EnviroInfo Conference Papers (1997-2009) are possible from the ICT-ENSURE Literature Database http://lit.ict-ensure.eu

Towards Sustainable Development (2000): Proceedings of the OECD Rome Conference. http://www.oecd.org/dataoecd/36/39/33703694.pdf

EEA core set of indicators (2005): EEA Technical report No 1/2005. http://www.eea.europa.eu/publications/technical_report_2005_1/at_download/file Latest assessment: http://themes.eea.europa.eu/IMS/CSI

Meadows D.H. (2009): Thinking in Systems A Primer. Earthscan Publisher, London

Handbook on the Implementation of EC Environmental Legislation (2008): available on http://ec.europa.eu/environment/enlarg/handbook/handbook.htm

Pillmann W. et al. see ICT-ENSURE http://www.ict-ensure.eu → Downloads & Resources → Deliverables
- D2.2 (2010): General Model View (together with Simon K.-H.)
- D2.3 (2010): System Model Applications for Information Access to Environmental Information
- D7.1 (2009): Analysis of Information Sources for an Integrated Environmental Information Space
- D7.2 (2010): Conceptual Detailing of a Single Information Space in Europe for the Environment

Pillmann W. et al. see EnviroInfo Conference Proceedings http://lit.ict-ensure.eu
- 2009 Information Sources for a European Integrated Environmental Information Space (together with Hrebicek J.)
- 2007: Environmental System Models: from Technical Models to World Models
- 2002: Modelling European Environmental Communication - Information Flows Supporting Decisions towards a Sustainable Development
- 2000 Environmental Communication - Systems-Analysis of Environmentally Related Information Flows as a Basis for the Popularization of the Framework for Sustainable Development. http://enviroinfo.isep.at/UI%20200/PillmannW270700.el.ath.pdf

Pillmann, W., Geiger, W., Voigt, K. (2006): Survey of environmental informatics in Europe. Environmental Modelling & Software, 21, 1519-27.

Richardson G. P. (1991): Feedback Thought in Social Science and Systems Theory. University of Pennsylvania Press, Philadelphia

Towards eEnvironment. Opportunities of SEIS and SISE (2009): Conference Proceedings Hrebicek J. et al (eds.) ISBN 978-80-210-4824-9. http://lit.ict-ensure.eu