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Environment

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Abstract

Many environmental problems are large scale in terms of geographical units and long-term with regard to time. We therefore find a coincidence of different causes and impacts that qualify the interplay between humans and nature as highly uncertain ("transparency challenge"). In consequence we see a need for innovative analytical methods and modelling approaches to supplement the traditional monitoring-based approach in environmental policy. This should allow capturing different degrees of uncertainty which in general is out of power of any monitoring activity. Moreover, with regard to the design of monitoring approaches it requires collecting and connecting data from different fields of social activities in regard of a divergence of natural and social systems' boundaries. This requires the provision of sufficient, frequently huge data sets ("availability challenge") that need to fit with each other ("compatibility challenge"). Even if these challenges are met data processing remains a very complex and time-consuming task which should be supported by a user-friendly infrastructure. We here see a comparative advantage in using the GIS technology and a nested structure for data provision supporting the up and down scaling of information and the access of data from different perspectives ("connectivity challenge") - a polluters, a victims and a regulators point of view.

Keywords: Coincidence of causes and impacts, transparency challenge, availability challenge, compatibility challenge, connectivity challenge, GIS technology, nested structure of data provision

1. Research questions

At present, various data sources indicate that human interferences in nature have reached dimensions as never before (e.g. Vitousek et al. 1997; Nelson et al. 2006). Disturbances of ecological systems have increased in magnitude and have impacts not only on the ecosystem functions but also on the vulnerability of human wellbeing which has become increasingly unpredictable (e.g. IPCC 2007; MEA 2005). In consequence this created doubts on the appropriateness of applied management strategies. In order to deal with these developments new monitoring approaches and strategies are required that more adequately capture the interplay between humans and nature with regard to different degrees of uncertainty and unpredictability.

The fact that many environmental problems today are large scale in terms of geographical units and long-term with regard to time – which often leads to irreversible impacts on the environment – challenges the design of data provision (henceforth including the gathering, processing and accessibility of information). Reasons are: (1) In face of multiple environmental problems being long-term in nature it is frequently impossible to separate the coincidence of different causes and impacts from each other. (2) There are many environmental problems characterized by "true uncertainty" meaning that neither sufficient knowledge about expected damages and costs nor a probability for the occurrence of these damages and costs exists. In turn, (3) this hampers the control of policy intervention by changes in relevant state variables and (4) undermines the measurement of policy success or failure. Hence, any monitoring activity aiming at capturing complex environmental change phenomena is doomed to failure and the critical questions to answer are: How to monitor complex environmental change phenomena characterized by human interference and human-nature feedbacks? How to control the success of policy interventions when large scale and long-term environmental problems require solution?

To answer these questions we see a need for innovative analytical methods and modelling approaches that supplement the traditional monitoring-based approach. While traditional monitoring delivers valuable information, inter alia, for indicator-based environmental assessments, caused by a single (often well-known) source or pollutant that leads to a specific impact of the ecosystem, analytical methods and modelling approaches are required in order to better understand correlations between multiple interferences of natural and societal system as well as the interplay of different sources and pollutants. We call this the "transparency challenge" – it is the challenge of separating multiple interferences at different levels of interplay (e.g. the level of drivers and responses). As a prerequisite for defining policy responses addressed to halt and redirect undesired environmental changes, these innovative methods and approaches require feeding with descriptive information on units of the natural system (esp. on pressures on nature affecting the state of the ecosystems) but also on behaviour of individuals and relevant societal groups creating human pressure on the ecosystems (the human drivers of environmental change: consumers, producers, sectors of the economy, local planning bodies etc.). We label this the "availability challenge" – it is the challenge of delivering sufficient information on different facets of a problem for researchers, policy-makers and the public. Here problems may arise if data are not existent or not accessible. In this regard it is important to note that environmental problems are very special by nature: they are characterized by problems of fit, interplay, and scale (Young 2002). The notion of fit refers to the natural and socio-economic boundaries of an environmental problem. While the natural boundaries are determined by the "natural properties" of an ecosystem, e.g. the boundaries of a river basin, the socio-economic boundaries are mainly administrative ones, e.g. national, regional or local governmental units. From the perspective of providing adequate data this leads to a misfit so that the environmental problem under concern cannot be adequately captured in quantitative dimension. We call this the "compatibility challenge" – it is the challenge of avoiding a mismatch of available data sets. Problems of interplay refer to the fact that many environmental problems are cross-cutting by nature so that data from several policy fields have to be combined. Making proposals for alternative land use requires information from, e.g. agriculture, urbanization, the water sector, and other environmental media. In most cases the existing data base was not developed for cross-cutting research questions like this so that major adjustments with respect to data processing have to be made. Finally, problems of scale refer to the need of up-scaling and down-scaling data. Many environmental data are gathered on a scale, which differs from the scale where policy recommendations are usually been given. This leads us to formulate a fourth challenge, the "connectivity challenge" – it is the challenge of combining the available data sets in a way that information is accessible from different perspectives (e.g., a victims and a policy makers point of view).. The identified challenges require new and innovative ways of data management.

2. Status Quo: Data Bases and Access

Over the past years considerable progress on the provision of both natural and social science data related to environmental issues has been made. Today, it is undisputed that social and behavioural science data are supplementary and complementary to natural science data. At international level four major approaches came on the spot (Ohl et al 2008):

1. The media approach – based on considering the major environmental components, such as air, land, water and human made environment;
2. The stress-response approach – focused on human impacts on the environment and subsequent transformation ("responses") of environmental systems;
3. The resource accounting approach – focused on the natural resources flow from extraction via different resource uses in the lifetime of a product to the final return of the resources (e.g. as emissions, wastewater) into the environment;
4. The ecological approach – based on using models, monitoring techniques and ecological indices. This approach, with regard to data organization, draws on the notion of pressures, state, and response (PSR), but applies these concepts only to ecological zones within a country (Geographical Information Systems – GIS use the ecological approach, for example).

Different combinations of these approaches are used on all scales of environmental statistics (local, regional, national) (cf. Ohl et al. 2008):

- FDES – A Framework for the Development of Environmental Statistics – developed by the United Nations Statistical Office;
- PSR – Pressure-State-Response framework – developed by the Organization for Economic Cooperation and Development (OECD);
- DSR – Driving forces-State-Response framework – developed by the Commission of Sustainable Development;
- DPSIR – Driving forces-Pressure-State-Impact-Response framework – used by the European Environment Agency (EEA) and the Statistical Office of the European Communities (Eurostat).

The use of these approaches and frameworks led to a comprehensive data base on all kinds of environmentally important topics, not only in Europe but all over the world. To some extend these approaches are supplementary to each other, emphasizing different issues of an environmental topic. The differences in viewpoint, however, are sometimes confusing: For example, data gathering on drivers and pressures separately from each other is only supported by the DPSIR framework – the other frameworks do not differentiate between them.

Despite this confusion, the overall experience in environmental information and reporting gathered since the 1970s led to the development of several useful environmental indicators, which allow reporting on, e.g., states of the environment, environmental performance and progress towards sustainable development. These indicators are judged as cost-effective and powerful tools for tracking environmental progress, providing policy feedback and measuring environmental performance (OECD 2003). Their development has catalysed fruitful cooperation among a great number of countries and international organisations, for example between OECD and the United Nations Statistics Division (UNSD), the UN Commission for Sustainable Development (UNCSD), the United Nations Environment Programme (UNEP), the Commission of the European Communities, Eurostat and the European Environment Agency (EEA).

In addition, considerable progress has been made regarding the development of a System of Integrated Environmental Economic Accounting (SEEA) at UN level, and at the respective national levels, e.g. in Germany with regard to the Umweltökonomische Gesamtrechnung (UGR). The UGR was developed in the 1990s and delivers the most comprehensive framework for capturing the relationships between environment and economy today. Both approaches, the SEEA and the UGR, are characterised by an integrative perspective that makes use of common concepts, definitions and classifications in order to allow for direct observation of links between economic and environmental development and serve as a basis for indicator based information for policy makers and the public. Moreover the integrated accounting approaches allow drawing conclusions regarding the macroeconomic costs of policy measures by supporting the econometric modelling of sector-specific economic and environmental behaviour under certain policy constraints. These approaches are therefore currently evaluated and revised by UNCEEA – the UN Committee of Experts on Environmental Economic Accounting and Statistics – in order to serve as a statistical standard at the international level.

Against this background deficits in data provision are hardly found on the macroeconomic level. What is rather missing is a provision of adequate data sets on the microeconomic level which needs to be linked with the already available data sets on the macroeconomic level. Combined micro- and macroeconomic data could, e.g., enhance our understanding of the vulnerability of individuals and social groups in the course of environmental change on the level of small scale regional units.

3. Future Developments

3.1 Data provision

Besides the information provided by statistical institutions and other organisations, there are several networks in charge for data provision. Within the next decade the Global Earth Observation System of Systems (GEOSS), for example, is expected to provide a further large amount of new data sets; several products like maps on river systems, infrastructure, land cover and land use are expected for common use. To interpret and use these products for societal benefit the earth observation data need to be linked to social science information on human related drivers and consequences of change. Currently, there are two problems associated with data provision in GEOSS: firstly, socio-economic data providing this kind of information is very often on administrative scales, which differ from natural scales, so that there is a problem of fit (see above). Secondly, the socio-economic data and indicators are rarely delivered and visualised in maps, although progress is made in the technical support of this kind of data provision, especially since GIS[1] technology has improved the effectiveness and analytic power of traditional mapping.

Today, in several field of application, GIS not only provides maps on socio-economic developments in space and time, it also supports analyses of social science data for decision making. To give just a few examples: For marketing purposes, demographic information is used to determine how many individuals with a certain socio-economic characterization (e.g. age, sex or income) live in a given spatial area (e.g. a street block). The CompStat approach used in New York City uses GIS for crime mapping and analysis (e.g. crime forecasting and geographic profiling) to formulate strategies and target resources but also to evaluate crime reduction programs. Data held by GIS may also be used as spatial decision-support system. In the U.S. time-specific population data, delivering insight in humans' daily routines, are used to track and model patterns of commuter behavior. Projecting these data forward into future is helpful in assisting the local planning bodies in analyzing and testing different types of policy decisions.

In the field of the environment the most prominent example is the use of GIS to understand the impacts of global climate change. So far, however, the focus was mainly on the combination of various maps and satellite information sources to simulate the interactions of complex natural system phenomena (e.g. the impacts of climate change on coastal areas, including flooding due to sea-level rise and storm erosion). According to these data the

1 GIS application tools support users in analyzing spatial information (i.e. data that refers to or is linked to a specific location), in editing data, and in visualising the results of operation in maps. GIS can for example be used for urban planning, resource management and environmental impact assessment.

exposure of individuals, societal groups or regions to climate change risks and impacts can be visualized. A challenge for future development is the inclusion of anthropogenic factors in order to better understand the coping-capacity of the considered entities. Which individuals or social groups are affected by global change, what is their regional distribution (e.g. within the boundaries of an urban agglomeration)? What are the housing conditions? Are individuals able to protect their houses against flooding or to cope with flooding events? Is it possible to combine global change data with data on social segregation? Can changes in lifestyle or socio-economic adaptation measures been captured? The final goal of adding these data to the existing global change data is to get a deeper understanding of the vulnerability of individuals, social groups, societies, or regional units. This includes data on both the exposure of “elements at risks” as well as coping capacities.

A further aspect is to measure the success of policy responses: How is a new type of regulation expected to feed back in the state variables of both the natural and the social system? Who are the current and future addressees of regulation and what are relevant transmission channels? Answering these questions should deliver the blueprint for building the infrastructure of modern data provision. And, of course, an update of the infrastructure is required as soon as a new policy problem shows up. Here, the challenge is that for the observation of newly emerging environmental problems the roadmap of the existing infrastructure needs to be flexible enough to adapt to and be merged with the newly emerging claims on data provision. A second important challenge is to identify overlaps with other impacts in the natural and social system (esp., with regard to the social entities affected) – this aspect is related to the problem of interplay (see above) as well as correlations between the new and the past chain of causes and impacts.

3.2 Data usage

The most important deficit in the field of data usage is an improper provision of information for the implementation of policy responses. The provision of data does not take sufficiently into account the needs of the users of the data. This holds primarily to *transboundary* and *global* environmental change phenomena (Neßhöver et al. 2007), but also for regional and local phenomena. To overcome this shortcoming the design of monitoring activities need to start more stringently from the policy perspective and the needs of the users. Which information is required for which purpose, at which point in time and by which user (e.g. at which governmental level)? Very often, data collection, processing and publication are driven by the providers, the “supply side”. It is indispensable to strengthen the interests of users in the process of collecting and proceeding data and indicators in order to strengthen the "demand side".

Provision of environmental data often remains insufficient not only for policy evaluation but also for public communication purposes. One important goal of the collection and distribution of environmental data is that the "general citizen" should be informed. In order to achieve this goal the information has to be prepared in a way that stakeholders, who are not experts in a particular environmental field, are able to understand and interpret the data.

However, public participation and the involvement of user groups can even go a step further: To foster public involvement in policymaking as well as to promote the goals of nongovernmental organizations, grassroots groups and community-based organizations the data infrastructure should broaden its view to public participation. In this regard Public Participation GIS (PPGIS, Sieber 2006) can be used as a supportive tool. Ghose (2001) reports a case study where residents of an inner city neighborhood became active participants in building a community information system. The participant learnt to access public information and create and analyze new databases derived from their own surveys and so became engaged in city management and in the formation of public policy. The use of PPGIS is motivated by the expectation that access to information is the doorway to more effective government and community empowerment. As a top-down approach PPGIS could also be used to analyze the spatial differences in access to environmental services (e.g., with reference to the social and economic background of relevant actors) and thus support making adjustments and improvements in environmental management.

3.3 Data access

The vast amount of data provided by institutions and organisations is easily accessible via the internet. However, the data sets are often dispersed and disconnected and thus inconvenient to handle by the users. In cases where data sets are centrally held, e.g. at the homepages of the United Nations Framework Convention of Climate Change – UNFCCC or the Convention on Biological Diversity – CBD, the amount of information often blows up the scarce time constraints of the users seeking for particular information.[2] The progress in computer technology and related widespread internet access together with the complexity of the problems under consideration (esp., if they affect worldwide) is one of the reasons why

2 As just one example the reporting of CBD signatories on measures taken for the implementation of the CBD and their effectiveness in accordance with article 26 of the Convention can be mentioned. So far there are 191 CBD parties from which 143 delivered the third national report (NR3) (see http://www.cbd.int/reports/, accessed 11-30-08). Going through all these reports to find country-specific information on a particular measure is an extremely time-consuming task.

desired information is not accessible in reasonable time. This holds true not only for third party users (public users seeking information with no official responsibility for data analysis), but also for the persons responsible for the provision and analysis of the data sets. Hence, it is not at all astonishing that relevant data suffer from time lags in provision and do not qualify as up to date.

Thus, although data provision considerably improved in recent years due to technological development in the information sector, the limiting factor for information processing is human. Limits in cognitive capacity, the handling of complexity and time constraints of the users are the bottleneck. To deploy and process the information provided by administrative accounts to a higher degree it is thus necessary to assist the users with improved search functions and an infrastructure that allows for individual ways of data connection. One promising route to follow in this regard is again the development of a GIS based system of data storing and processing.

To fully deploy the societal benefits of environmental data provision, data sharing across administrative boundaries within a nation and across the nations is a further decisive prerequisite. In this regard the GEOSS data sharing principles could work as an archetype for future developments in national and international data sharing. In recognition of relevant international instruments and national policies and legislation, GEOSS will support full and open exchange of data, metadata, and products not only within the GEOSS community but also beyond. For research and education all shared data, metadata, and products will be provided free of charge or charged with no more than cost of reproduction. For other users this will be provided at minimum cost. And the use of data or products needs not necessarily imply agreement with or endorsement of the purpose behind the gathering of the data which will be made available with minimum time delay.

Considering the local level, data security can still be a problem for social sciences in the field of environment. While data collection on a very small scale is usually not a problem for the natural sciences, the collection of such data in the fields of socio-economics can become a problem if persons, households or companies can be identified due to the small number of elements in the sample. Here the legal protection of the private sphere of considered persons, households or companies may lead to conflicts with research interests.

4. Future Developments: European and International Challenges

Despite important progress in the field of international environmental statistics, differences among countries remain. In order to make progress in the policy relevance of environmental data provision there is a need to establish closer links between the data sets gathered from the natural system and the data sets gathered from the social system on different scales. In this respect linking the national accounts with international data sets seems to be most important. A nested structure of data provision seems appropriate that provides the data sets from different points of view:

- Polluters point of view (focusing on e.g., consumption behaviour and production processes).
- Victims point of view (focusing on e.g., the consumption of harmful goods, or vulnerability of specific sectors in the economy due to climate change).
- Regulators point of view (focusing on an inventory of policies affecting e.g., environmental pollution behaviour and reducing social vulnerabilities).

Coordinated data management of national and supra-national governments should centre on environmentally *relevant core activities*. Determination of these core activities requires an approach that includes the interests of (national) users. The outcome of such an approach could be an agreement on the objectives of data gathering and sharing as a pre-requisite for developing a common data infrastructure. Guiding questions in this regard are:

- What are the most important environmental problems that need to be solved on a supranational level (climate change, biodiversity loss, water scarcity, deposition of nuclear waste etc.)?
- Which state variables describe the problem under consideration (e.g., emission levels, damage costs, stock of resources)?
- What are the key variables that require monitoring and policy control (e.g., sectors, inputs, outputs)?
- What are the most important channels for transferring impacts from one administrative unit (governance level) to another (e.g. import and export of goods, unidirectional or reciprocal externalities etc)?
- Within which time horizon need the problems be solved and a policy phase-out take place (considering delays in time as well as persistence and irreversibility of causes and impacts)?

- Which policy measures already affect or are expected to affect the problem under consideration?

With regard to organizational infrastructure an improved systematic horizontal and vertical integration of data sets from different types of administrative, research and business units is urgently required. The key aim of horizontal integration is to develop standards for the integration of important private (business) and project-related research data in the official accounts at all administrative levels. The key aim of vertical integration is to come to a strict derivation of national accounts data from the data sets of the lower (sub-national) administrative units and vice versa. This requires developing ways of combining electronic surveys with new sampling techniques and/or algorithms which are capable of exploiting data at different levels of generalisation (i.e., cross-linking of statistical data, including its combination with text and image based information available from different sources if adequate). This also includes development of a sophisticated infrastructure for data storage and provision (e.g., development of statistical and machine learning algorithms that have the capacity to cope with massive amounts of data, development of ontologies and semantics for statistics, integrated with metadata construction and retrieval systems to handle statistical requests and improve the access to datasets; see EU call *SSH-2009 - 6.3.1. Data management for statistics*). Future will show how far improvements will here be made.

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