EnviroInfo 2004 (Geneva)
Sh@ring – EnviroInfo 2004

How to assess the Environmental State of EU regions with the global concept of sustainability?

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Abstract

EPSILON[2] project is aiming at assessing sustainability of all European regions to provide a quantitative tool for policy decision making. EPSILON will propose a coherent view of the economic, social, institutional and environmental state of a region, taking into account local as well as relationships indicators. EPSILON provides sustainability maps for monitoring & benchmarking of regions at different levels of aggregation of indicators thanks to a GIS integrated computerized model .

This paper is focused on presenting EPFL modelling of the environmental dimension within the sustainability model. Its particularities are:

- The full use of the DPSIR[3] approach to define relevant environmental indicators at the State level. These indicators are structured across environmental themes (Air, Soil, Water and Land).
- The inclusion of proper environmental interactions across Europe by using results from transboundary fate models such as EMEP.
- The aggregation of environmental indicators according to scientific backgrounds. Whenever possible, this aggregation relies on the recognition of the relative impact of the pollutants on human health using the DALYs[4] parameters. These DALYs have been derived from the IMPACT2002 model, a multimedia fate and exposure model for the impact assessment of toxic chemicals covering all Western Europe (Pennington et al., 2003a).

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[2]EPSILON : Environmental Policy via Sustainability IndicatorsOn a European-wide NUTS-III level. The Nomenclature of Territorial Units for Statistics (NUTS) is a geocode standard for referencing the administrative division of countries for statistical purposes.

[3] Conceptual framework of a system of environmental indicators: Driving Forces, Pressure, State, Impact, Response

[4] DALY: Disability Adjusted Life Years

1. Issues related to model sustainability at a regional level

EPSILON project is aiming at assessing European regional sustainability in order to provide a tool for policy decision making related to the improvement of regional sustainability. EPFL is in charge within EPSILON project to develop the sustainability model. Modelling sustainability is a challenging task and several models have already been defined, each one tackling specific issues. All models provide a collection of sustainability indicators but the difficulty is to propose a coherent conceptual structure easing the making of meaningful composite indexes. The innovative features of the EPFL model relies on the latest socio-economic study at European-wide level concerning the quality of life, the full utilisation of the DPSIR approach, the recognition of links between regions and sustainability dimensions and the integration of explicit relevant impact assessment methods derived from Life Cycle Impact Assessment.

1.1 Relevance of the DPSIR approach

Several attempts to model sustainability with relevant indicators are currently ongoing. Among these models, let us cite:

- The UN Commission on Sustainable Development and Organisation for Economic Co-operation and Development lists of SDI (UN-CSD,2001)
- The Barometer of Sustainability (Prescott-Allen,1999)
- The ESI Index (World Economic Forum, 2002),
- The Structural Indicators (EUROSTAT),
- The EUROSTAT SDI framework (Wolff, 2004),

Most models are based or at least referring to the DPSIR approach which presents strong and fundamental key elements when aiming at modelling sustainability.

The DPSIR model is based on the OECD's PSR model, originally developed as a conceptual framework of a system of environmental indicators. It adopts a circular reasoning which allows to link human activities and environmental degradation. It differentiates categories of indicators in order to explain the modification of the *state* of the environment resulting from the *pressure* put by human activities on the environment and the *impacts* of such changes. It also includes the individual or collective *response* to these impacts.

Various organisations, within the United Nations system (UNCSD) in 1996), as well as research groups (ESI), on behalf of the European Commission, have developed a framework based on such DPSIR approach (Berger-Schmitt and Noll, 2000). The first attempt has been done by the United Nations Commission on Sustainable Development (UNCSD) in 1996. However, most of the time, the indicators are not always defined at the same levels (Driving forces, State level or Response level) and it may change the intended coherence of the structure.

1.2 The EPSILON Model for sustainability

Based on an extensive review of the available models in the literature and previous attempts to construct operational tools, the EPSILON sustainability model (Friot, 2003) has been derived from two major conceptual models:

- The **DPSIR** model which differentiates between levels of indicators (driving-forces, pressures, state, impact and response levels),
- The "**four spheres**" model, from UN-CSD, which is a 4 dimensions view of sustainable development (social, economic, institutional and environmental).

The EPSILON sustainability model depicts a global picture of the regional sustainability. It respects the Bellagio principles (Hardi,1997) and takes profit of both themes and sub-themes structure from UNCSD and the DPSIR framework. The result is a regional description composed of:

1. A static overall view at the *state* level, represented by a 4x4 structure[5]
2. A dynamic view, split in 4 pillars at the *response* level
3. A potential for linkages and interconnections between themes & sub-themes, based on a trans-pillars category (structures and human practices at the *driving-forces* level) and on a *pressure* category.

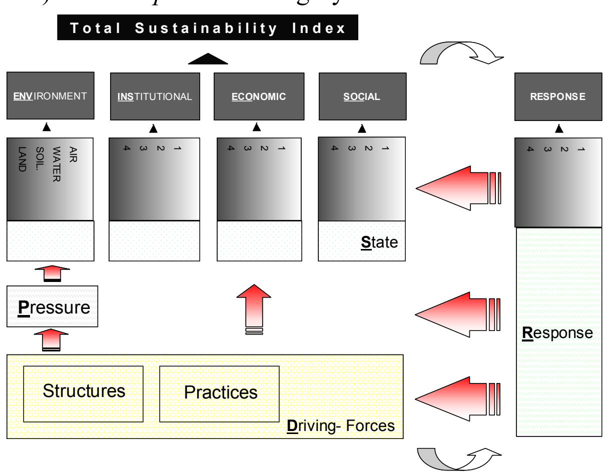

Figure 1: The EPSILON sustainability framework

The 4 pillars are describing features of the quality of life (or sustainability):

[5] 4 pillars (Social, Economic, institutional and Environmental) and 4 themes par pillar.

- The social pillar will look at the **human-being's situation** as well as the **social welfare** for all citizens.
- The economic pillar will examine the **financial prosperity** of the region by assessing economic performance and efficiency.
- The institutional pillar will analyse the **regional governance**, how the whole society is acting and the resulting outputs.
- The environmental pillar will relate about the **state of the ecosystems** and the environment.

2. The environmental dimension within the EPSILON sustainability model

2.1 The environmental pillar structure

Sustainability within the EPSILON model is defined along four dimensions (corresponding to four pillars) and this article is focused on the environmental dimension. The environmental pillar is assessing the state of the ecosystem and the environment. Following the orientation initiated by the EUROSTAT SDI framework, themes and sub-themes have been defined to correspond as much as possible to EU priority policies for sustainable development. However, sub-themes are grouped according to a compartment rationale in four themes: Air, Soil, Water and Land (Table1). To each sub-theme corresponds a variable number of indicators.

Theme Index	Sub-theme index
Air index	Climate change --Local Air quality 1 -Local Air quality 2--Noise
Soil index	Soil degradation - Soil toxicity -- Soil loss
Water index	Water quantity-Surface water quality-Ground water quality -- Ocean quality
Land index	Fragmentation -- Naturalness--Wilderness

Table 1: Environmental pillar: themes and sub-themes index definitions

EPSILON indicators have to conform to the following inherent constraints: be specifically relevant at the regional scale, scientifically sound based and take benefit of existing European data.

2.2 The AIR Theme within the environmental pillar

The theme AIR comprehends issues related to policies protecting human and environmental health from air pollution or damaging conditions transmitted through this media. This theme is to be mainly defined considering the impact on human health. This approach fits the priorities highlighted for the Pan European Region: exposure to air pollution is one of the major sources of human disease (EEA, 2003). See on Figure 2 the Air Index.

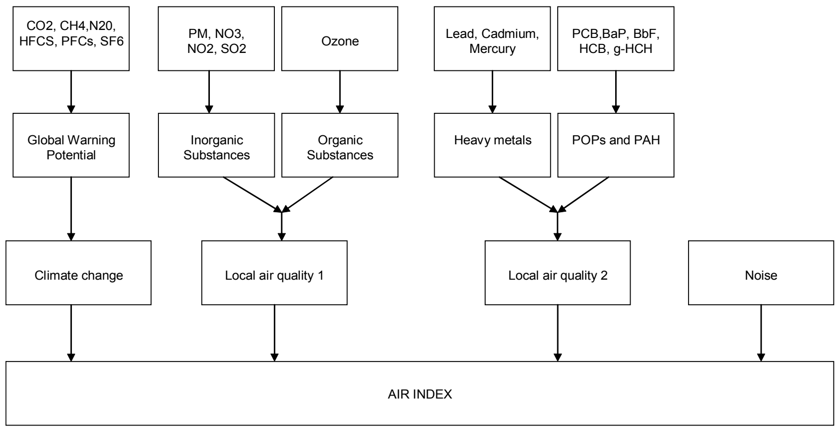

Figure 2: The Air index

2.1.1 Climate change sub-theme

Global warming is related to the global impacts of air pollution. It is the damage to the global ecosystem caused by emissions of GreenHouse Gases (GHG) in the air compartment. Global warming potentially leads to climate change. The indicators will be weighted by their global warming potentials (GWP). The **GWPs** relate to the ability of the different gases to cause global warming in comparison with CO2 GWP set as unit. They are calculated by the IPCC[6]. Indicators are primarily selected at the *state* level (such as gas concentrations) but for this specific sub-theme a *pressure* type indicator has been used (gas emissions) which is a temporary exception in the EPSILON structure.

[6] Intergovernmental Panel on Climate Change

2.1.2 Local air quality 1 sub-theme

Air quality is related to the local impacts of air pollution. These local effects have been split into two categories, according to their effects on human health: respiratory and carcinogenic effects. The sub-theme comprehends air concentrations of pollutants causing respiratory effects to humans. Modelled data of concentrations in air and depositions of main Pollutants, Aerosols (PMs), Heavy Metals and POPs are calculated by EMEP models and provided on a yearly data for the whole EMEP grid (50x50 km^2 or 150x150 km^2).

2.1.3 Local air quality 2 sub-theme

This sub-theme comprehends air concentrations of pollutants causing carcinogenic effects on humans (POPs, and heavy metals concentrations issued from EMEP database). The different environmental concentrations are weighted with a factor linking fate concentration to human damages into a metric expressed in Disability Adjusted Life Year (DALY). This can then be summed up when considering aggregation at the sub-theme level (§3 gives more details on how this factor is obtained).

2.1.4 Noise sub-theme

Noise is a measure of sound emissions in the air. This indicator is related to human health since high noise levels can cause stress, psychological diseases and deafness. Noise emissions levels have been defined in the European noise directive (2002/49/EC). This directive is aimed at requiring competent authorities in Member States to produce strategic noise maps on the basis of harmonised indicators. Up to now these noise maps are not available. As a consequence data corresponding to the noise sub-theme is missing in the current EPSILON database but has been formally identified as a relevant sub-theme within the structure.

3. Aggregation of state indicators into an environmental composite index

3.1 An extensive use of composite indicators

Examples of Environmental composite indicators are numerous: The Environmental Sustainability Index (World Economic Forum, 2002), The Well-being Index (Prescott-Allen), The Sustainable Development Index (UN). Composite indicators have received substantial attention in recent years. A very complete state-of-the-art report has been issued (JRC,2002)[7] enabling to report all possible methodological approaches. Two workshops on composite indicators of country performance[8] have been organized by JRC (JRC,2003 and OECD, 2004). Besides reporting all current development, these workshops focused on reviewing the advantages and disadvantages of composite indicators with a view to developing "quality guidelines" for their construction. These quality guidelines are at the basis for the EPSILON composite indicator strategy. A list of recommendations for best-practice methodologies for composite index (Salzman, 2003) has provided relevant recommendations for EPSILON composite index (Blanc, 2004).

3.2 How to determine a composite indicator

To build a composite indicator requires establishing a ranking among indicators. Most attempts to derive a unique composite indicator from complex systems have clearly shown the difficulties of such exercise as it requires being able to give value to issues where they clearly depend on actors preferences. EPSILON solved this issue by not weighting the four pillars together and provides 4 separate indices, one for each sustainability dimension.

1. However weighting is necessary within each pillar to aggregate the sub-themes corresponding to the 4 themes. A combination of relevant techniques has been adopted within the EPSILON project:

1. Choose to rank indicators only when scientific knowledge is available and recognized (such as the ranking established between the greenhouses gases)
2. Adopt an implicit weighting approach. The corresponding main assumption is that the difference between worst and best region per indicator is equally important among all sub-themes. Such approach enables to avoid specific ranking between indicators with a clever selection of indicators. Real difficulties surrounding the explicit third party determination of weights are to be found and the idea that variables should a priori be weighted equally is a relevant choice (Salzman, 2003).

[7] a complete list is also to be found on http://farmweb.jrc.cec.eu.int/ci/

[8] A composite indicator of country performance is a synthetic indice of individual indicators which compare and rank countries in different performance areas, e.g. competitiveness, innovation, environmental

3.3 Aggregation of indicators into an environmental composite index based on DALY's.

The authors of this paper have focused their research on developing relevant weightings factors linking environmental concentration (State indicators for the environment) to human damages. Impacts on human health are quantified in Disability Adjusted Life Year (DALY), accounting for both mortality due to premature death and morbidity. Such approach allows comparing the environmental state indicators based on a same metric, i.e. their potential damage on human health.

This approach relies on IMPACT 2002[9], a model that provide estimates of the cumulative contribution to the risk of an effect over time and space associated with the air emission of chemicals (Pennington et al. 2003a, 2003b). It is specifically developed for providing risk-based toxicological effect indicators in life cycle assessment (LCA), (Jolliet et al., 2003, 2003a). Generic factors for organic chemicals and heavy metals are calculated at a continental level for Western Europe. Different types of relevant information are needed regarding human toxicity assessment: **fate**, FF (Concentration/Emission), handling transport in the environment, **exposure**, XF (Intake/Concentration), considering where contaminants enter the environment relative to where food is produced and the resulting intake. This is then combined with an **effect factor**, EF (DALY/Intake) characterizing the potential risks linked to the toxic intakes at a population level. The human damage factor (HDF) for chemical i is then calculated as:

$$HDF_i = FF_i \cdot XF_i \cdot EF_i$$

In EPSILON the starting point is slightly different. Instead of relating potential impact for a given mass (kg) of a chemical emitted into the environment, we needed to relate these potential impacts with **concentrations** of chemical (the State environmental indicators). These concentrations are issued from EMEP. Based on IMPACT 2002 framework, starting from these concentrations we determined a factor linking the concentrations to the potential Impacts on human health termed "Concentration to Damage Factors" (CDF) with units expressed in DALYs/year/concentration. These CDF are obtained combining a multi-pathway exposure factor (XF) and effect factor (EF) and are the weighting factors built within the EPSILON sustainability model. Table 2 gives CDF for the indicators corresponding to the AIR theme:

[9] IMPact Assessment of Chemical Toxics which can be downloaded at http://www.epfl.ch/impact together with a more detailed method description

THEME	SUB-THEME	INDICATORS	Sub-INDICATORS (EMEP Concentrations)	Concentration to Damages Factors (DALYs/YEAR)/(kg/m3)
AIR Index	Air quality 1 index	Inorganic substances	PM (TPM, PM10, sec. Particles)	7,87E+13
			NO2	1,42E+14
			SO2	2,36E+14
	Air quality 2 index	Heavy Metals	Lead	1,34E+08
			Cadmium	1,22E+10
			Mercury	3,18E+10
		POPs and PAH	PCB	1,00E+11
			(B[a]P)	1,32E+13
			(HCB)	4,71E+12
			(PCDD/Fs)	2,00E+17

Table 2: CDF for the AIR Theme (from IMPACT2002)

3.4 Illustration of the EPFL DALY weighting approach with the "Heavy Metals" composite index

To build the Heavy Metals composite index within the local Air quality 2 sub-theme, we need lead, cadmium and mercury air concentrations. These concentrations were obtained through EMEP data (available at a 50x50 km^2 scale) which have been converted to NUTS level within EPSILON (Schaller, 2004)[10] .
Two weightings are now compared when building this composite indicator:

1. A plain equal weighting between lead, cadmium and mercury.
2. A "DALY" weighting using the Concentrations to Damage Factors (Table 2)

These two methods have been applied to European NUTS0 data (Results on Figures 3 and 4 annual data concentration – Y2000 with the weightings factors on Table 3:

	Lead	Cadmium	Mercury
Equal weighting	0.33	0.33	0.33
DALY weighting	0.003	0.276	0.721

Table 3: Weighting factors

[10] EPSILON acquired the GISCO GIS DB from EUROSTAT to use this geographical representation of the NUTS regions as standards for the creation of the Geo-Database used in the project.

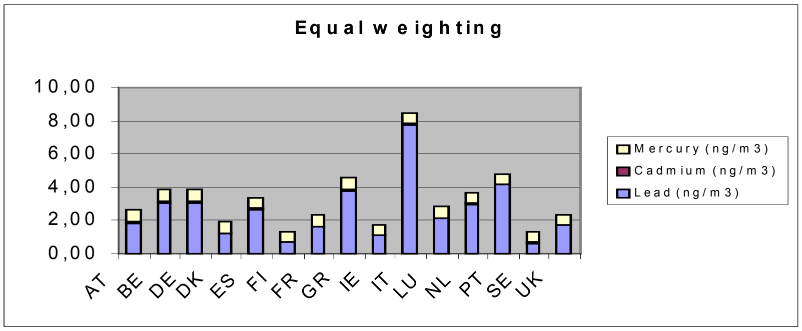

Figure 3: Heavy Metal Index with an equal weighting

Applying the "DALY weighting" to these 3 metals is highly modifying the resulting composite index. Cadmium and mercury have been assessed as 100 times more toxic for human health than lead. Although some countries had high level of lead concentrations such as Italy, they no longer appear with high values for the Heavy Metal Index.

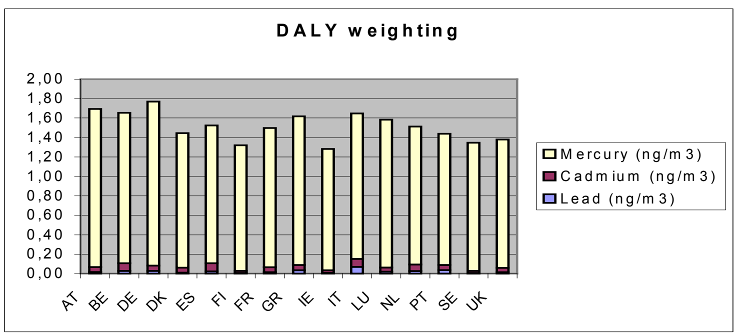

Figure 4: Heavy Metal Index with the DALY weighting

When considering the European benchmarking with these two approaches, we have significant differences between the countries as shown on Figure 5. According to the equal weighting approach, Austria is ranked at the 7th level but with the DALY weighting, it is ranked at the 14th rank as Austrian mercury concentration are quite high compared with the other EU countries (rank n°1 performs best).

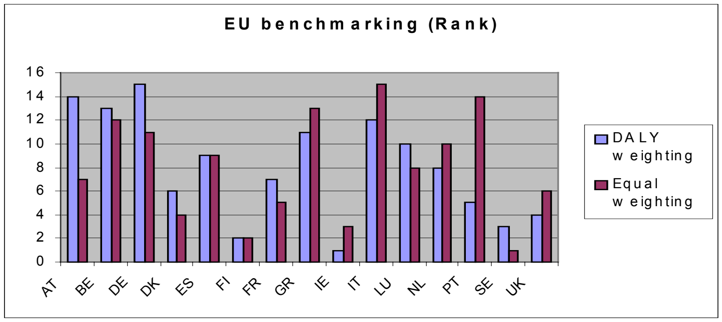

Figure 5: EU benchmarking with the Heavy metal Index

4. EPSILON: an opportunity to linking environmental interactions across Europe

EMEP air concentrations have contributed to assess the **environmental state** of European regions in terms of Heavy metals, PM, POPS, etc…. (Figure 6 shows the Lead air concentration over Europe). The next challenge is now to explain such environmental state by encountering the interactions across Europe. These interactions are not only to be found at the country level but also at the regional level.

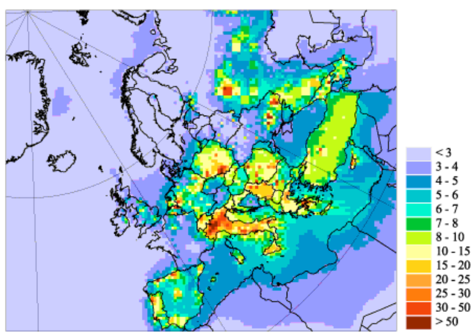

Figure 6: Lead Annual mean air concentrations of lead in 2001, ng/m^3

Based on the DPSIR approach, the EPSILON sustainability model has clearly differentiated the Driving Forces/Pressures from the State level. Assessing the European emissions (considered as pressures) over their sectoral distributions (Energy distribution, Residential/tertiary, Road transport, Manufacturing industries, Agriculture, etc…) and relating these to the concentrations will provide a powerful tool to explain the environmental state and the environmental interactions across Europe between regions.

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