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Sustainability Assessment in Switzerland: a sub-national approach

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Abstract

Four different methods to account for complex relationships between regional and local viability/sustainability and vulnerability have been investigated. The ecological footprint technique, emergy analysis, natural capital evaluation and compensation areas methods are used to infer and synthesize different sustainability/viability aspects of the Swiss territory. The results of this study and assay suggest coherency and complementarity of the multiple methodology used. Furthermore, bio-geographical, bio-physical and economic particularities of Switzerland, that differ largely from canton to canton, determine an important variation of local sustainability levels and capacity of response to climate forcing in action. We thus propose next to a general Swiss approach of sustainability, a subsequent differential treatment of cantons, based on spatial inequalities that are linked to primary physical, biological and economical structures and potentials. Despite of a unifying, global and federal approach, the implementation of sustainability measures and laws should be afterwards modulated in the case of each canton, by accounting for all these physical, biological, and anthropogenic disparities (equity treatment).

Keywords: *cantons, Switzerland, sustainability, vulnerability*

Résumé

Quatre méthodes différentes pour estimer la relation complexe entre la viabilité/soutenabilité et la vulnérabilité régionale et locale ont été examinées. La technique de l'empreinte écologique, l'analyse émergétique, l'évaluation du capital naturel et la méthode des surfaces virtuelles de compensation ont été utilisées pour déduire et construire les différents aspects de la soutenabilité/viabilité du territoire suisse. Les résultats de cette étude et essai montrent la cohérence et la complémentarité des différentes méthodes utilisées. De plus, les particularités biogéographiques, biophysiques et économiques de la Suisse diffèrent largement de canton à canton, et déterminent une importante variation du niveau de la soutenabilité locale et de la capacité de réponse face au forçage climatique en action. Nous proposons ainsi, à côté d'une approche générale de la soutenabilité en Suisse, un traitement différentiel subséquent des cantons, fondé sur les inégalités spatiales, liées aux potentiels et aux structures primaires physiques, biologiques et économiques. En dépit de l'approche fédérale globale et unifiante, la mise en œuvre de mesures et de lois en vue d'améliorer la soutenabilité devrait être, après coup, modulée dans le cas de chaque canton, en tenant compte dans chaque cas des disparités physiques, biologiques et anthropogéniques (traitement équitable).

INTRODUCTION

The regional and local transformation of the planet by the human activity is in fact a very old process (Neolithic waste bins; flooding of plains following deforestation of watersheds; desertification of forested areas due to intensive tree cutting for boat construction, overgrazing, etc.). These local processes gradually extended at the regional scale, affecting over time the entire planet, and produced, since the 19th century, a significant change of amplitude and scale, namely the perspective of a global, thermic and chemical pollution, likely to modify our climate significantly (Diamond 2005; Farvar and Milton 1972; IPCC 2001; PNUE 1999, 2006; Turner et al. 1990; Weart 2003). This generalized transformation of the natural environment by our economic activities and cultural ways of life is supplemented by another one, more discreet, affecting the composition of human organisms (isotopes, various pollu-

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tants and their derivatives, etc., in very low dose certainly, but corresponding in every organism to a mirror of the environment as modified by our activities; another probable aspect concerns some epigenetic and biochemical modifications).

The heterogeneity of our planet, offering shelter and protection to approximately 200 different nations, determines however many difficulties in searching for a global, viable and dynamic balance, and sustainable development (Bell and Morse 2000; Moffat et al. 2001; Moldan et al. 1997). The additional anthropic climate forcing (~3,7 10^{22} J/yr), constantly increasing for the moment, and superposed on the existing natural forcing (~2,8.10^{24} J/yr), determines an acceleration of the natural climate evolution by activating positive climate feedbacks (10 - 15x faster, in comparison with the multi-secular trend), and generating changes of state which progressively exceed the evolutionary homeostatic balance and could disrupt a certain natural dynamic climate stability on quaternary geological scales (Crowley and North 1991; Greppin et al. 1998, 2000, 2002, 2003 ; Magny 1995). Each nation contributes in a diverse, specific manner to this increase of the generalized greenhouse effect, both in absolute value and per capita; less than 15 countries are responsible of ~ 80% of the climate forcing by GHG emissions, and it exists an important per capita variation: Quatar – 2.6 times USA; 8.5 times Switzerland; 18x China; 47x India; 52x Sierra Leone. Additionally, the economic capacities and financial means to answer this challenge differ widely; the geographical position on the planet will mainly determine the amplitude of climate impacts, as well as new climatic effects, independently of each country's real responsibility in the evolution of this phenomenon (Beniston 2004; Haurie and Viguier 2005; IPCC 2001; Priceputu et al. 2005a,b). The solution to this global crisis with major regional and local effects is inevitably a viable and sustainable adjustment of the human activity integrating simultaneously the global, regional and local scales, namely the three different levels of heterogeneity and governorship (Froger et al. 2001, 2002).

According to this perspective, Switzerland constitutes an interesting microcosm with three levels of political decision; Switzerland is a federal State comprising up to 26 States (Cantons and Half-cantons) and many Communes, variously involved in managing their environment and modulating in an open market their economies within certain limits. Three integrated levels of responsibility, decision, law and regulation, taxes collection, etc. may be observed within the Swiss territory (Federal, States and Cities Governments). These are associated with a semi-direct old democracy and possible control of political institutions by complementary popular rights, such as obligatory or facultative referendums and initiatives. The territory planning and land management are under the responsibility of States, also associating some delegations from Cities. But the Federal Government (3 different offices) exerts a certain overall control (envelopes effect), maintaining the coherence of the system. The distribution of the GDP (2003: 3.57 10^{11} SFR) is variable: a ratio of 1 to 125 pro State, 1 to 40 per km^2, 1 to 2 per capita. This economic diversity also determines a heterogeneous capacity of adaptation towards global and local sustainability, because of the non-uniformity of the vulnerability at the regional and local scale, and probability of different local evolution patterns of climate change effects during this century (Beniston et al. 1994, 2004; Gyalistras 2003; Priceputu et al. 2005a, b, c; Rebetez 2002; Schmid et al. 2003; SwissRe 2005). Economic vulnerability is partially compensated by some financial redistribution by the Federal Government (financial "perequation" between States).

The Swiss space, situated in the heart of Europe (41295 km^2: 0.027% of the emerged world surface, 0.4% of the European one), is characterised by a highly compartmented and structural configuration, with important altitudinal gradients and a local mosaic structure (relief, climate, biosphere, economy; 4 official Cultures and an important presence of foreigners). The Swiss territory is constituted by an orographic triad: Alps (~60% surface, highest point: 4634 m; ~1/8 population, ~23% GDP), Plateau (~30% surface, between 400 and 500 m; ~3/4 population, ~66% GDP), and Jura (~10% surface, highest point: 1680 m; ~1/8 population, ~11% GDP). Globally, 15% of the territory is situated between 193 and 500 m altitude; 32% between 500 and 1000 m; 29% between 1000 and 2000 m, and 24% exceed this last limit. These characteristics determine a semi-continental type of climate with great variations of both thermic and pluvial patterns. These particularities are reinforced by multiple external climatic influences, originating outside the European continent: oceanic from the West, continental from the East, boreal from the North, and Mediterranean from the South. The oceanic character is preponderant, and Switzerland remains the water-works of Europe (annual water flux: ~ 1.219 10^6 t/km^2). The Swiss biomass corresponds to ~0.018% of the world's biomass, and the annual net primary productivity to ~0.027% of the world's productivity (human population: 0.11% of the world's population producing 0.2% of the global CO_2 emissions of anthropogenic origin, and essentially produced by consumption of fossil energy). The extension of this per capita rate of GHGs emissions to the entire world's population (6.4 10^9 H) would generate ~1.6 10^{10} t atmospheric CO_2 per year (~600 ppm; +3°C). The current Swiss biomass levels correspond to ~60% of the wilderness situation (i.e. virtual situation without human pressure) (Flüeler et al. 1975; Lauber and Wagner 1998; Pfister and Messerli 1990; Racine and Raffestin 1990).

We propose here an analysis of the situation (vulnerability) in Switzerland, by applying four different evaluation methods related to and accounting for the interactions between economic activities and nature (physical and biological environment) in 26 different Swiss states. The results emphasise the complementarity between these four approaches, and in some cases, large similarities.

Data sources and methods

Four different methods to estimate the degree of sustainability of Swiss cantons were employed in this study. The Ecological Footprint approach originates in early studies by Wackernagel and Rees (1996), and is described in and developed by Chambers et al. (2000) and Wackernagel et al. (1999, 2002, 2005). The Energy/Emergy-based analysis was first established by Odum (1996), and later developed by Brown and Ulgiati (1998 and 1999), Pillet and Odum (1987), and Pillet (1993, 2004, 2006). Costanza developed an economy-based methodology for quantifying, in monetary terms, the total value of ecosystem services (Constanza 1991; Constanza and Daly 1992; Constanza et al. 1997). Furthermore, Greppin et al. (2000, 2002) and Priceputu (2006) elaborated a broad approach to estimate Virtual Compensation Areas of human activities. All these methods were used to account several sustainability factors and applied to each Swiss political/administrative unit (canton).

Ecological Footprint

Planetary and bioproductive land area is one of the most important and scarce natural resources on Earth. In using the land, humans compete with most other species for space, water, oxygen, and trophic energy. An approach which has received a lot of attention in recent years, because it captures in simple, yet comprehensive way, humanity's draw on nature and terrestrial physical surface, is the ecological footprint. The ecological footprint casts a strictly utilitarian view on society–nature interaction by comparing the amount of bioproductive area available to the amount required to maintain the resource flows of a defined human population (sustainability). More specifically, ecological footprint studies evaluate how much planetarian and bioproductive area (global ha per capita) is needed to produce the biomass consumed as ecological services, to host the buildings and infrastructure, and to absorb the wastes (above all, CO_2) generated by a human population. The evaluation is based on equivalence and yield factors that take into account local, regional and global technological levels; the evolution of technology produces significant changes of these factors (progress or regression of sustainability), that are calculated on a yearly basis. Depending on technological progress and adaptation, as well as on our cultural goals and ways of life, these factors could be recalculated, allowing a better estimation of the footprint value. On a global level, the interpretation of a footprint calculation is straightforward: if humanity consumes more resources and surfaces than the planet and biosphere can regenerate (food, energy, matter) this must lead to the depletion of natural capital and cannot be sustainable in the long run.

A sustainability/vulnerability indicator may thus be constructed by analysing the ratio between the local biocapacity (biological potential) of a given territory, total biocapacity (local and imported utilized biocapacity) of the human population occupying the same territory, and total ecological footprint (biocapacity consumption). A ratio of Local Sustainability Index LSI ≥ 1 means that we are in a sustainable configuration with nature, according to both local biocapacity and ecological footprint. Additionally, if the Total Sustainability Index TSI ≥ 1, then there exists some imported biocompensation for the local situation, depending on the vulnerability of outside territory (foreign countries) sustaining the local sustainability. The annual observation of the positive or negative evolution and structure of the local and total sustainability index (biocapacity/ecological footprint) could assist the decision making process (political and economic). The following 'equations' show the calculation of the above mentioned indicators:

1. Local Biocapacity = bioproductive surface (ha) x equivalence factor (gha/ha) x annual yield factor
2. Ecological Footprint = area of local consumption (ha) x equivalence factor (gha/ha)
3. Local Sustainability Indicator = Local Biocapacity/Ecological Footprint
4. Vulnerability Indicator = 1 - Local Sustainability Indicator
5. Total Biocapacity = Local Biocapacity + Imported equivalent biocapacity x equivalence factor (gha/ha)
6. Ecological Deficit = Total Ecological Footprint – Local Biocapacity
7. Total Sustainability Indicator = Total Biocapacity (local and imported)/Ecological Footprint

Emergy-based approach

Another reliable indicator in sustainability evaluation is drawn on the concepts and methods of emergy accounting (embodied energy). The emergy methodology aims at accounting for the environmental perturbations caused by our way of life, directly and indirectly related to anthropic energy use patterns and fluxes (renewable and non-renewable) in comparison with all the natural energy fluxes issued directly and indirectly from solar energy. At a process scale, an energy balance may be enough to define the efficiency of a process. However, if the system utilizes, transforms and produces different kind of energies, different energy qualities should be accounted for. Using a convenient algorithm, the emergy methodology aims at expressing the total energetic cost of every action in the same unit (solar emjoules, sej). The principle is to sum properly (from nature to economy) all the energy of one kind required to provide the different resources of considered systems according to the causality adopted for the model (thermodynamical loss included): for example, the summation of all the energy fluxes necessary to produce human proteins, from light absorption by plants to animals and then to human anabolism. Since the solar energy is at the origin of most of the energy we use, most of emergy studies are expressed in Solar Em-Joules (i. e., solar joules properly accounted). Emergy accounting traces the 'energy history' upward a certain process, from nature to economical products and services by adding all the energy inputs successively required to obtain the final product, and expressing them in a common energy unit and form, i.e., solar energy. The application of emergy methodology allows us to obtain information about the dimensions and qualities of flows through systems, and account the whole system behaviour and its dynamics in exploiting resources. This approach helps to evaluate the economic pressure on the environment sustained by natural energy fluxes, and allows modulating an optimal pattern in the economical energy use and regulation by normative rules (Pillet and Odum 1987; Pillet 1993, 2004, 2006). The efficiency of a given system in using available resources may be synthesised by a composite indicator, the so-called 'sustainability ratio':

1. Environmental Yield Ratio (EYR) = Total Emergy Used / Imported Purchased Emergy
2. Environmental Loading Ratio (ELR) = (Imported Purchased Emergy + Indigenous Non-renewable Emergy) / Local Renewable Emergy
3. Sustainability Ratio (SR) = EYR / ELR
4. % Renewable energy to the total.

Natural Capital

Another approach focuses on the evaluation of ecosystem services and natural capital attempts to apply economic metrics to services that are not accounted in commercial markets. The methodology was developed by Constanza et al. (1997), who propose various methods to estimate market and non-market components of the value of ecosystem services. In their analysis, a synthesis of previous studies based on a variety of methods has been made. The majority of the valuation techniques used is founded on attempts to estimate the 'willingness-to-pay' of individuals for ecosystem services. The total global value of ecological services and the value per unit area of each ecosystem service for each ecosystem type are therefore estimated. Mean global values provided by Costanza's study have been afterwards employed in order to account for regional and local ecosystem services' values in each of the 26 Swiss cantons. The mean global value per unit area for each ecosystem type ($/ha) has been multiplied by the total area that the ecosystem considered occupies within the canton's limits. Imported ecosystem services are primary ecosystem services used by importing forest and agricultural products. Imports (quantity) are transformed in equivalent surface of mean global productivity, and the resulting surfaces are quantified in monetary terms by using Constanza's mean global values of agricultural and forest surfaces ($/ha). The relationship between imported and local ecosystem services is an important factor determining the degree of sustainability of Swiss cantons.

Virtual Compensation Areas

Virtual Compensation Areas of CO_2 emissions are broad estimates of additional areas of mean primary productivity that would be necessary to capture excess CO_2 emissions at the sub-country level. Global mean carbon intake of different types of ecosystems has been used to infer the mean regional and local C intake (Priceputu et al. 2005a; Schlesinger 1991). The mean global value per unit area for each ecosystem type (t CO_2/km^2) has been multiplied by the total area that the ecosystem considered occupies within the canton's limits. By summing these values, and dividing the totals obtained by the total area of the canton/country, we obtain mean regional and local CO_2 intakes at the local (cantonal) level. 'Virtual Compensation Areas' are afterwards calculated by dividing excess CO_2 emissions at the cantons' level (non-compensated CO_2) by the mean CO_2 intake level for each canton (t CO_2/km^2) (Priceputu 2006).

Calculation methods

Calculations are based on a top-down, 'compound' approach, mainly using disaggregated national data (OFS 2005). International data sources were also used for filling some data gaps at national level. Where data were not available at cantons' level, estimates of desired variables were made by proxying Swiss national data (as appropriate), and adjusting for population and/or area size. Detailed national data (imports, exports, production, and yield) for a large range of agricultural and forestry products were primarily collected from international data sources (FAO, http://faostat.fao.org, WRI, etc.). By emphasising a so-called 'geographical responsibility principle', each canton's imports in terms of biocapacity, emergy flows, eco-services, and additional areas to compensate the actual amount of CO_2 emissions are computed; the final balance between imports, exports and local resources shows the overall degree of both environmental and economic sustainability and vulnerability.

For each of the Swiss cantons, local data included: population, surface/land use, CO_2 emissions, GDP (total, per capita, per km^2), local production and yields, imports and exports. As many of the local data were not available (particularly those related to detailed imports/exports categories, local yields, etc.), approximations were made using per capita and/or per km^2 proxies. The use of such proxy data does tend to mask regional differences in consumption, and this should be borne in mind when considering the figures presented hereafter. The analysis presented in the following sections may thus be significantly improved by amending the access to detailed local statistics. Another aspect is the metropolization of Switzerland (Bassand 2004) that imposes different territory utilization and economical effects in comparison with the political official structure (26 States).

Several limitations/weaknesses of the above mentioned approaches might be described. The 'compound' approach does not give any revolutionary new information for the municipalities. Analyses at cantons' level may thus be biased by this general lack of local details (e.g. Zürich county and its urban agglomeration). Energy is another problem: the consumption of fossil energy has become a major question for society, but most of the analyses do not differentiate between different types of non-renewable energy sources (e.g., nuclear energy assimilated to fossil fuel burning). Particular aspects of water and soil pollution are also ignored. Some of the concepts lack several major dimensions of sustainable development (e.g. do not include social/economical aspects, the question of poverty, etc.) and only account for specific sustainability issues, ignoring the others. By combining results of all four approaches, some of these limiting aspects may be overcome.

Despite these problems related to specific calculation methodologies and sustainability factors taken into account, the results do not only tell us what the balance between local demand and existing resources is, but also in which direction we should be moving, in order to achieve sustainable/viable equilibria between natural environment and economic and social development (locally, regionally, global). Results also illustrate strategies for change by presenting key components of (un)sustainable consumption patterns, and therefore potential for change by different efforts in different directions. The effectiveness of changes in energy sources, production systems, transportation, dematerialisation, bio-production, etc., becomes visible. The concepts may be successfully adopted by policy-makers, and integrated in the perspective of defining economically, environmentally and socially reasonable development strategies. By the annual observation of these indicators (+ or -, quantitative variations, space phase, etc.), it becomes possible to know if we are going in a more or less sustainable way, according to the economical market and political decisions.

Results

Sustainability (Artiola et al. 2005; Jakubec 2004; Moffat et al. 2001; Pearce and Atkinson 1998) is a characteristic of dynamic systems that maintain themselves over time; it is not a fixed endpoint that can be defined and depends on the society's vulnerability potential (IPCC 2001; Priceputu 2006; Sen 1993, Turner et al. 2003). Environmental sustainability refers to the long-term maintenance of valued environmental resources in an evolving human context. The best way to define and measure sustainability is contested. Economists often emphasize an accounting approach that focuses on the maintenance of capital stocks. Some in the environmental realm focus on natural resource depletion and whether the current rates of resource use can be sustained into the distant future. Our emphasis is broader, in the sense that it tries to account for numerous sustainability factors. Sustainability in this broader sense is the dynamic condition of society that depends on more than the protection and management of environmental resources and stresses. It is also necessary to have economic sustainability, balanced capital accounts, and wealth-generating investments. The ultimate sustainability of human society also depends on education, through which knowledge, science, culture, values and the accumulated experience that we call civilization are transmitted from one generation to the

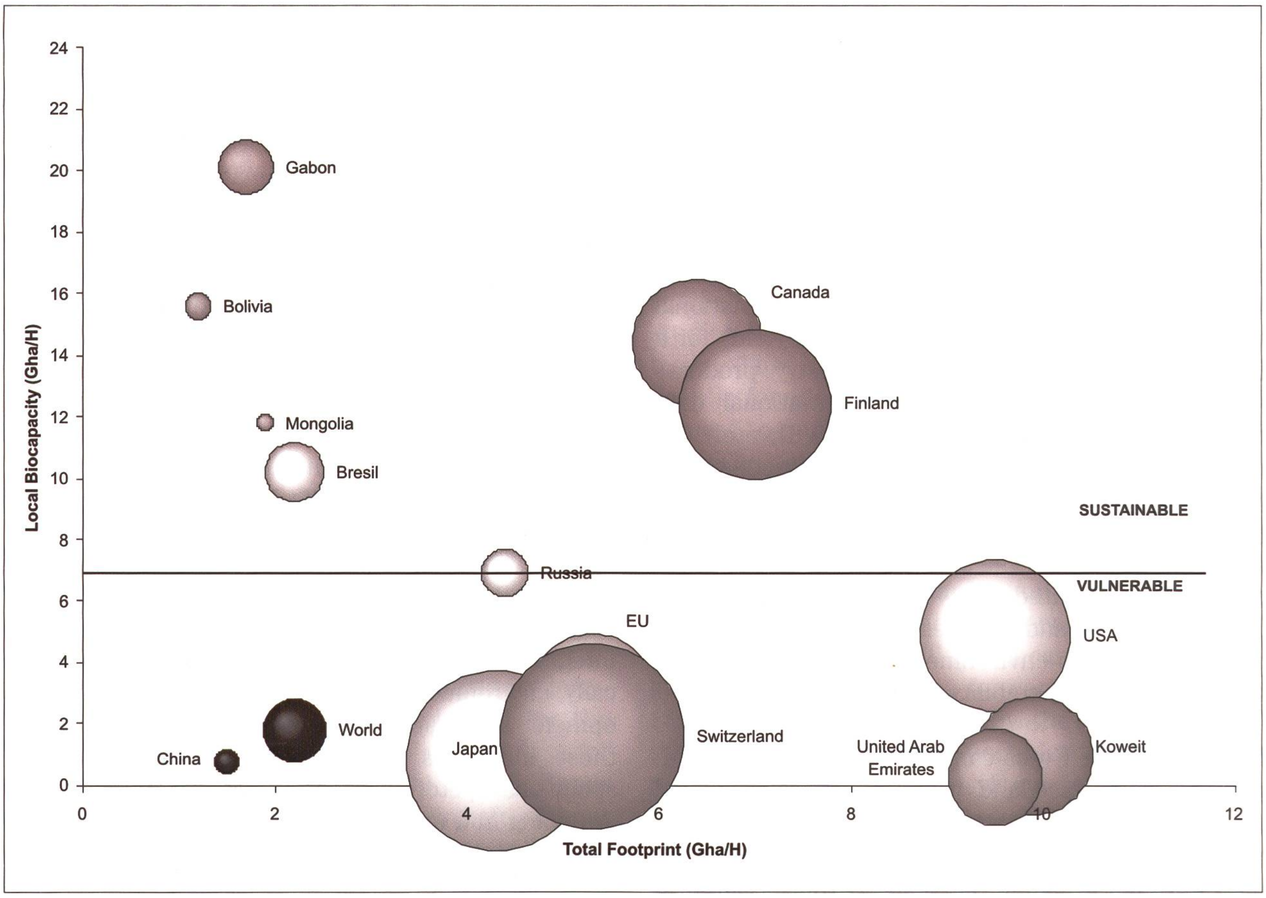


Fig. 1. Ecological Footprint and Sustainability at the global planetary level. Diameter of circles proportional to GDP per capita. Color is function of population: black: > 500 10^6 H, grey: 50 – 500 10^6 H, white: < 50 10^6 (from Wackernagel et al. 2005, modified). The line on the graph corresponds to the frontier between sustainable situation versus vulnerable one (i.e. mean value of years 1960-1970 considered as sustainable).

next. The complex interactions between the economic, social, and environmental dimensions of the human system are the main factors guiding society's way towards sustainability.

This section presents Switzerland's sustainability indices based on the approaches described above, and provides a composite profile of the environmental and economic situation at sub-national level. By facilitating comparative analysis across sub-national jurisdictions, these metrics provide a mechanism for making environmental management more quantitative, empirically grounded, and systematic. These comparative analyses do not imply that only one way towards sustainability exists. Cantons face an array of issues and policy questions when trying to improve their environmental performance. The answers that make sense will depend on their specific environmental, economic, and social circumstances, internal factors such as the priority given to environmental issues, cultural and social circumstances, as well as a multitude of external factors such as international environmental policies. The approach proposed in this study may assist in policy evaluation processes by identifying the most significant issues a canton faces and the trade-offs that can be expected as a result of appropriate environmental choices.

Fig. 1 presents the global situation of Switzerland (local biocapacity and ecological footprint) in comparison with other countries (LSI: Gabon 11.8; World 0.8; Switzerland 0.3; Kuwait 0.03). Between 149 countries in the World, 58 are sustainable (LSI ≥ 1) and 91 are vulnerable (LSI < 1) (Wackernagel et al. 2005). The dimension of the planet is insufficient (~20% deficit) to support the present economical and cultural ways that we have developed. With such figure, we have an image of the overshoot (LSI < 1) and so an indication concerning the potential vulnerability and ecological deficit of Switzerland (according to these criteria), because the Swiss consumption exceeds by approximately 70% what local nature can regenerate on a continuous basis, without ecological import. If the latter permits to achieve a nearly complete compensation of the ecological deficit at the global level, direct and indirect local effects of such environmental interactions cannot be totally smoothed.

Canton	1. JU		2. UR		3. GL		4. GR		5. IA		6. OW	
	LSI	TSI	LSI	TSI	LSI	TSI	LSI	TSI	LSI	TSI	LSI	TSI
Sust.	1.14	1.20	1.0	1.28	0.95	1.17	0.94	1.17	0.86	0.97	0.82	1.12
Canton	24. ZH		25. GE		26. BS		CH		LSI: local biocapacity/ecological footprint. TSI: total biocap./ecol. footpr.			
	LSI	TSI	LSI	TSI	LSI	TSI	LSI	TSI				
Vuln.	0.09	0.90	0.05	0.89	0.03	0.88	0.36	0.97				

Table 1

Canton Sust.	1. JU	2. IA	3. GL	4. GR	5. UR
EYR	3.90	3.56	3.44	3.44	3.23
ELR	0.37	0.39	0.41	0.41	0.45
SR	10.52	9.08	8.35	8.29	7.15
% renew.	74%	72%	71%	71%	69%

Canton Vuln.	24. ZH	25. GE	26. BS	CH	World 1995	1975	1950	1900
EYR	1.32	1.16	1.01	1.37	1.44	1.50	2.34	9.20
ELR	3.24	6.69	10.68	2.84	2.56	1.60	0.50	0.10
SR	0.41	0.17	0.09	0.48	0.56	0.94	4.67	92.15
% Renew.	24%	13%	1%	27%	28%	40%	62%	90%

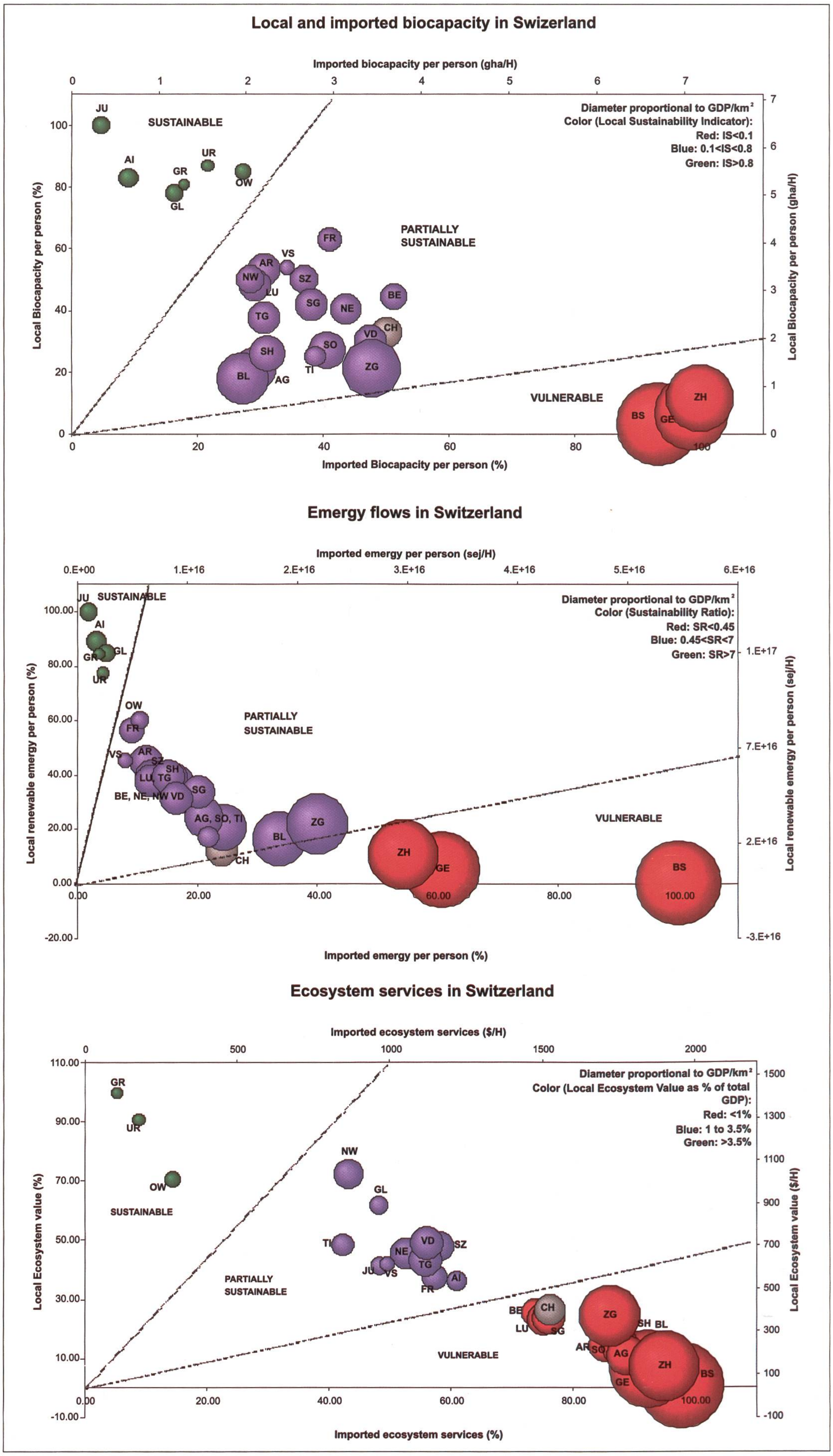
Table 2

Table 1. Comparison between sustainable and relatively vulnerable situations in Switzerland (2003). Jura, Uri, Glaris, Grisons, Inland Appenzell, Obwald: 5% population, 25% surface, 4.5% GDP, 5.3% fossil energy consumption. Basel Stadt, Zürich, Geneva: 25% population, 5% surface, 32% GDP, 22.6% fossil energy consumption. CH: Switzerland. Total biocapacity: local + imported biocapacity.

Table 2. Comparison between sustainable and relatively vulnerable situations in Switzerland (Emergy). Jura, Inland Appenzell, Glaris, Grisons, Uri. Zürich, Geneva, Basel Stadt. CH: Switzerland. Environmental Yield Ratio (EYR); Environmental Loading Ratio (ELR); Sustainability Ratio (SR). World : Brown and Ugliati (1998).

Our ranking provides a relative gauge of sustainability in 26 Swiss cantons. Fig. 2 and tables 1 and 2 compare the results obtained by applying three approaches to sustainability: the Ecological Footprint approach (Wackernagel et al. 2002, 2005), Emergy Analysis (Brown and Ulgiati 1999; Odum 1996), and Ecosystem Services and Natural Capital Evaluation (Constanza et al. 1997). Per capita values of selected parameters (biocapacity, emergy, value of ecosystem services) are standardized on a 0 to 100 scale, in order to insure easier interpretation of results. We observe a great dissimilarity between the 26 cantons (LSI from 0.03 for BS to 1.14 for JU; mean value for Switzerland 0.36. TSI between 0.88 for BS and 1.28 for UR; mean value for Switzerland 0.97 – nearly global ecological balance). The role of imported capacity is very important to maintain a global sustainability, with a low local biocapacity according to such cantons as BS, GE and ZH, for example. This situation, out of local equilibrium, requests an acute examination of all the aspects related to the environment's evolution (possibility of acceleration of ecological and social risks), as well as impacts on foreign biocapacity that our importation policy may have (outside risks). In all the three examined cases, some similar configurations are obtained (Fig. 2a,b,c). The sustainability/vulnerability hierarchy of cantons' distribution remains virtually about the same (emergetic analysis, SR index: from 0.09 for BS to 10.52 for JU; mean value for Switzerland 0.48), regardless the method used for quantifying human impacts and pressures. In relation with the criteria utilized, cantons are classified in three main categories: 'sustainable', 'partially sustainable' (highly depending on imported biocapacity), and 'vulnerable' (versus a general planetarian viability). Wackernagel and Odum methods make conspicuous a high degree of similarity because the first corresponds to an evaluation of the ecological situation on the field, as driven by human actions, and the other to indirect consequences of nature and energy use by anthropogenic actions that generate environmental modifications (GHG effects), not directly measured by this method, but indirectly, by a detailed energy fluxes analysis (import-export; renewable, nonrenewable), and in relation with economical and financial fluxes (monergy). Some discrepancies exist with the third economical technique because of the difficulty to endogenize and integrate in the usual economic vision the effects of natural physical and biological specific logics. But these three approaches could help in various degrees to the research and policy towards an efficient and simultaneously global and local way to a continuous sustainability (Biosphere – Society – Environment) (Greppin et al. 1998, 2000, 2002; Priceputu et al. 2005 a,b,c).

Agricultural cantons (mainly those where mountain agriculture and tourism are developed), Jura, Grisons, Glaris, Uri, etc. occupy the top ranks. These cantons are moderately developed at the general economic level compared to other Swiss regions, but endowed with natural resources and low population densities; they face relatively low environmental stresses and generally manage these environmental challenges well. At the bottom of this hierarchy, Basel-Stadt, Geneva and Zürich, are cantons with environmental stresses, high population density and economic demand exceeding local capacities, but also, for the moment, with relatively poor policy


Local and imported biocapacity in Swizerland
Imported biocapacity per person (gha/H)
Local Biocapacity per person (%)
Local Biocapacity per person (gha/H)
Imported Biocapacity per person (%)
Diameter proportional to GDP/km²
Color (Local Sustainability Indicator):
Red: IS<0.1
Blue: 0.1<IS<0.8
Green: IS>0.8
SUSTAINABLE
PARTIALLY SUSTAINABLE
VULNERABLE
JU
AI
GR
UR
OW
GL
FR
VS
AR
NW
LU
SZ
SG
NE
BE
TG
CH
VD
SO
SH
TI
ZG
BL
AG
BS
GE
ZH
Emergy flows in Switzerland
Imported emergy per person (sej/H)
Local renewable emergy per person (%)
Local renewable emergy per person (sej/H)
Imported emergy per person (%)
Diameter proportional to GDP/km²
Color (Sustainability Ratio):
Red: SR<0.45
Blue: 0.45<SR<7
Green: SR>7
SUSTAINABLE
PARTIALLY SUSTAINABLE
VULNERABLE
JU
AI
GR
GL
UR
OW
FR
VS
AR
SZ
SH
LU, TG
BE, NE, NW VD
SG
AG, SO, TI
BL
ZG
CH
ZH
GE
BS
Ecosystem services in Switzerland
Imported ecosystem services ($/H)
Local Ecosystem value (%)
Local Ecosystem value ($/H)
Imported ecosystem services (%)
Diameter proportional to GDP/km²
Color (Local Ecosystem Value as % of total GDP):
Red: <1%
Blue: 1 to 3.5%
Green: >3.5%
SUSTAINABLE
PARTIALLY SUSTAINABLE
VULNERABLE
GR
UR
OW
NW
GL
TI
VD
SZ
NE
TG
JU
VS
FR
AI
BE
CH
LU
SG
ZG
SH BL
AR
SO
AG
ZH
BS
GE

Total GNP*	Agricult. GNP**	Forest GNP**	Tourism GNP***
ZH (LSI :*0,09*) (SR:0,41) BE (LSI :0,44) (SR:2,30) VD (LSI :0,37) (SR:1,69) AG (LSI :0,39) (SR:0,96) GE (LSI :*0,05*) (SR :0,17) SG (LSI :0,51) (SR1,93) *LU (LSI :0,65)* (SR:2,39) *BS (LSI :0,03)* *(SR :0,09)*	BE (LSI :0,44) (SR:2,30) *GR (LSI :0,94)* *(SR :8,29)* VD (LSI :0,37) (SR:1,69) VS (LSI :0,63) (SR:2,98) SG (LSI :0,51) (SR:1,93) FR (LSI :0,64) (SR:4,14) LU (LSI :0,65) SR:2,39) *ZH (LSI :0,09)* *(SR :0,41)*	*GR (LSI :0,94)* *(SR :8,29)* BE (LSI :0,44) (SR:2,30) TI (LSI :0,37) (SR:0,73) VS (LSI :0,63) (SR:2,98) VD (LSI :0,37) (SR:1,69) SG (LSI :0,51) (SR:1,93) *ZH (LSI :0,09)* *(SR :0,41)* AG (LSI :0,39) (SR:0,96)	*GR (LSI :0,94)* *(SR :8,29)* VS (LSI :0,63) (SR:2,98) BE (LSI :0,44) (SR:2,30) ZH (LSI :*0,09)* (SR :0,41) VD (LSI :0,37) (SR:1,69) TI (LSI :0,37) (SR:0,73) *GE (LSI :0,05)* *(SR :0,17)* LU (LSI :0,65) (SR:2,39)
68,8% GNP CH	59% GNP CH	63,9% GNP CH	60,3% GNP CH
64 %CO_2 Emission	*69,8% agriGNP CH*	*70,7% forestGNP CH*	*70,9% tourGNP CH*
65,4% Pop.CH 39% Surface CH 297,2 H/km^2	59,2% Pop.CH 68,7% Surface 152,7 H/km^2	63,1% Pop.CH 71,4% Surface 156,6 H/km	59,8% Pop.CH 67,4% Surface 157,2 H/km^2

*-***: sensitivity degree to the climate forcing (Priceputu et al. 2005 a et b; Priceputu 2006).

Table 3. Situation of the first eight cantons on 26, producing ~ 2/3 global GNP, CO_2 Emission, Agriculture, Forestry and Tourism GNP. LSI: local sustainability Index. SR: sustainability ratio.

responses to existing environmental challenges and perspectives for the future (climate forcing), despite some good adaptive reactions. Their presence at the bottom of the ranking suggests that the level of economic development does not exclusively determine environmental performances. While it is clearly possible to identify leaders and laggards and to pose hypotheses on the reasons for their positions at the high and low ends of the ranking, it is more difficult to analyze the middle ranks. This 'partially sustainable' category also relies on 'moderate' use of outside sources. This fact seems to indicate that environmental sustainability challenges come in multiple forms and combinations. The diversity of underlying institutions – including economic and regulatory systems – adds to the complexity of the picture. On the

Fig. 2. Swiss Sustainability analysis (2003) – per capita values. 2a: Local and imported biocapacity. Local biocapacity represents net local biological potential. Imported biocapacity corresponds to the total surface necessary for producing imported goods (fossil fuel, CO_2: export - import, balance not included), and expressed as mean global capacity. Diameter of circles proportional to GDP/km^2. Colour depends on Local Sustainability Indicator values: red LSI < 0.1, blue 0.1 < LSI < 0.8, green LSI > 0.8. 2b: Local and imported emergy resources. Local emergy values consider renewable energy sources within the country/canton. Imported emergy equals to emergy stored in imported goods, materials and fuels. Diameter of circles proportional to GDP/km^2. Colour depends on Sustainability Ratio values: red SR < 0.45, blue 0.45 < SR < 7, green SR > 7. 2c: Local and imported ecosystem services. Local ecosystem values take into account all natural and semi-natural ecosystems within the country/canton. Imported ecosystem services are basically primary ecosystem services used by importing forest and agricultural products. Imports are transformed in equivalent surface by using mean global yields, resulting surfaces are quantified in monetary terms by using mean global values of agricultural and forest surfaces. Diameter of circles proportional to GDP/km^2. Colour depends on the part (%) of ecosystem services in total GDP: red < 1%, blue 1 to 3.5%, green > 3.5%.

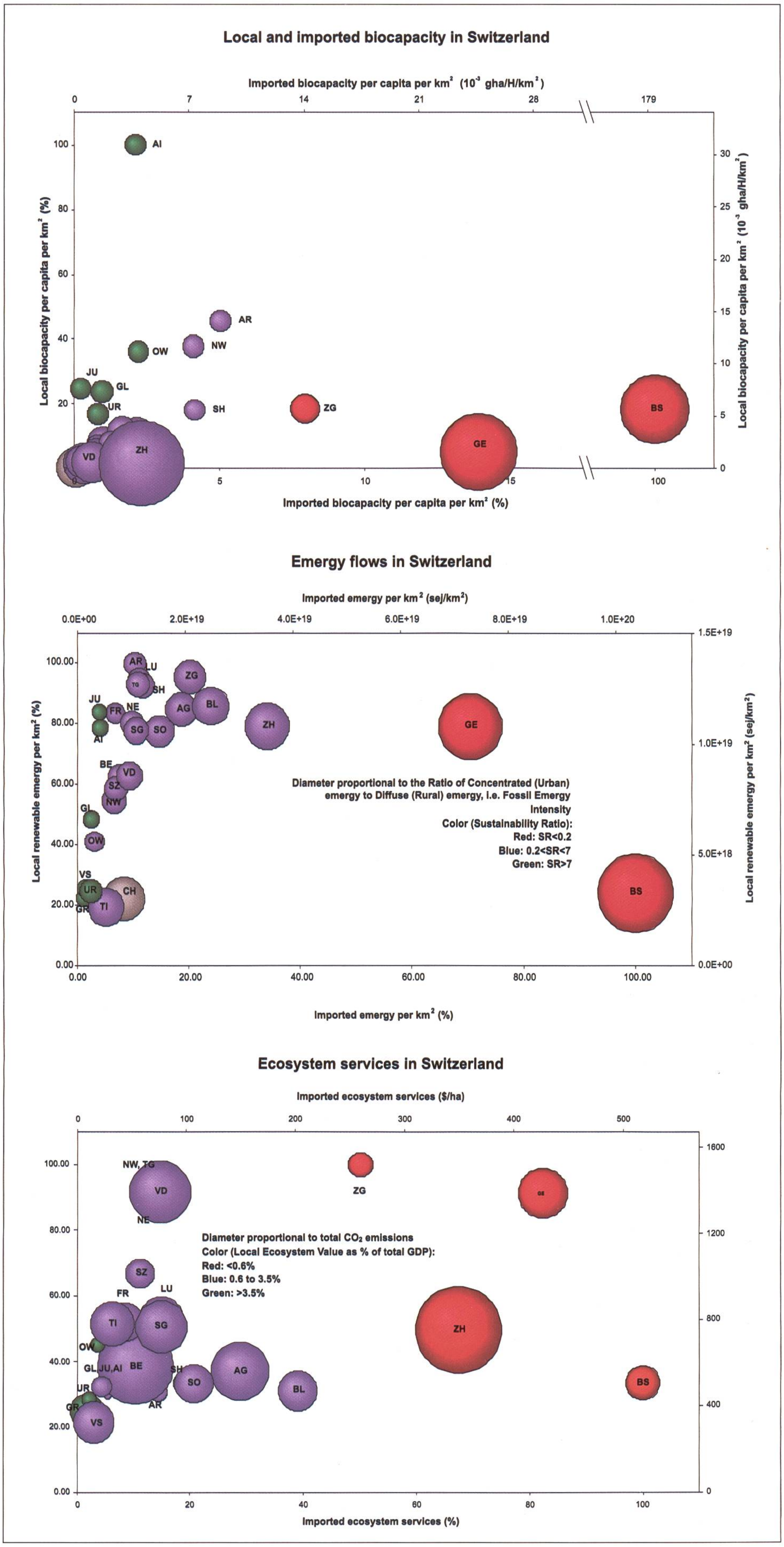


Fig. 3. Sustainability analysis – per km² values. 3a: Local and imported biocapacity. Diameter of circles proportional to Energy Consumption Footprint. Colour depends on Local Sustain-ability Indicator values: red LSI < 0.1, blue 0.1 < LSI < 0.8, green LSI > 0.8. 3b: Local and imported emergy resources. Diameter of circles proportional to the ratio of Concentrated (Urban) Emergy to Diffused (Rural) Emergy (i.e., Fossil Emergy Intensity). Colour depends on Sustainability Ratio values: red SR < 0.2, blue 0.2 < SR < 7, green SR > 7. 3c: Local and imported ecosystem services. Diameter of circles proportional to total CO_2 emissions. Colour depends on the part (%) of ecosystem services in total GDP: red < 0.6%, blue 0.6 to 3.5%, green > 3.5%.

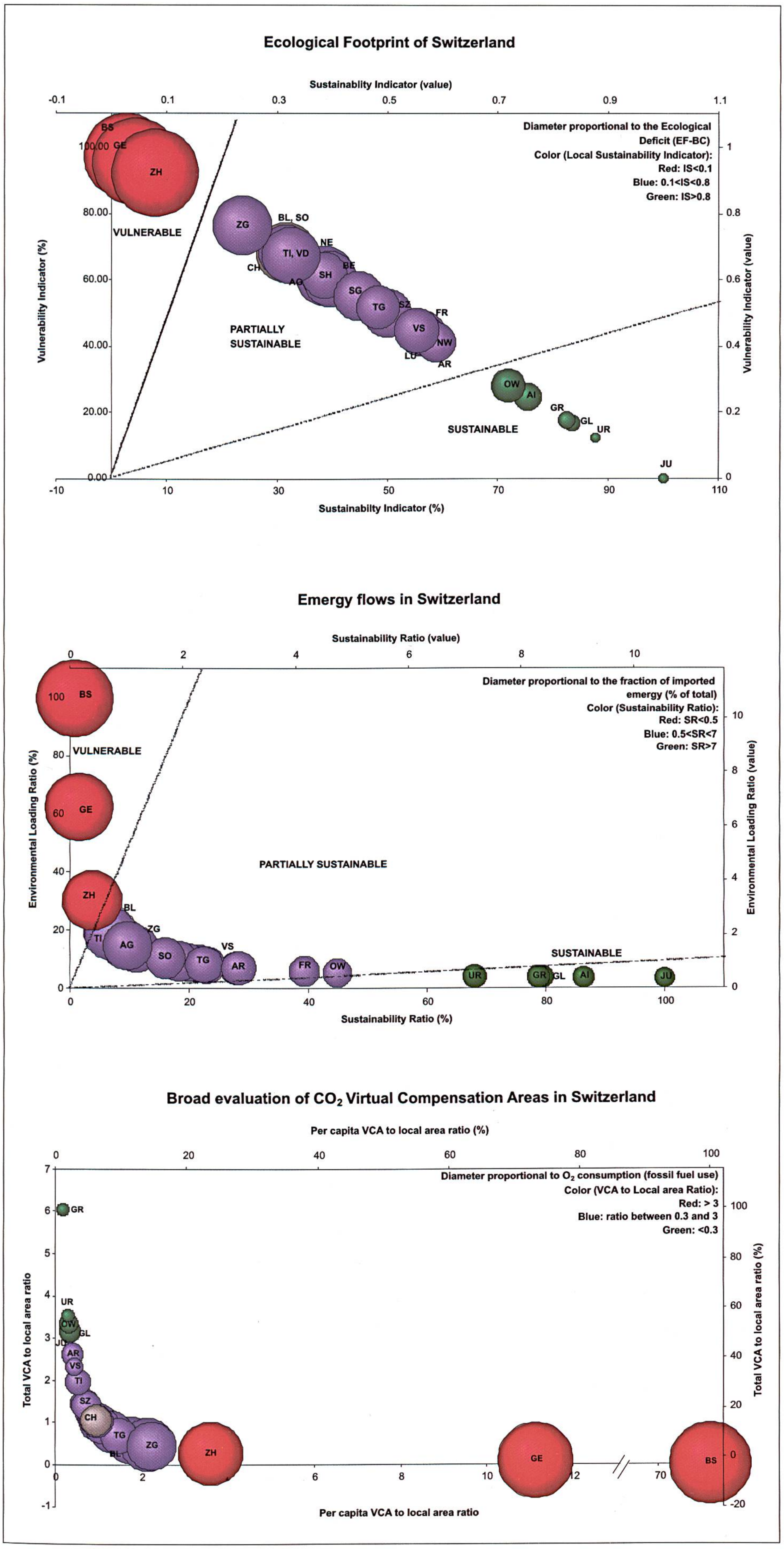


Fig. 4. Relationship between sustainability and vulnerability in Switzerland. The Local Sustainability Indicator (LSI) is the ratio between local biocapacity (LBC) and ecological footprint (EF). The Vulnerability Indicator is calculated as 1 – LSI. Diameter of circles proportional to Ecological Deficit values (EF-LBC). Colour depends on Local Sustainability Indicator values: red LSI < 0.1, blue 0.1 < LSI < 0.8, green LSI > 0.8. 4a. Sustainability Indicators vs. Vulnerability Indicator. 4b. Sustainability Ratio (SR) vs. Environmental Loading Ratio (ELR). SR is the ratio between the Emergy Yield Ratio (EYR) and Environmental Loading Ratio (ELR). EYR is the ratio between total emergy used (local and imported) and imported emergy flows (of goods, materials, fuels and services). ELR is the ratio between imported and local non-renewable emergy flows, and local renewable emergy inputs. Diameter of circles proportional to the fraction of imported emergy (% of total inflows). Colour depends on Sustainability Ratio values: red SR<0.45, blue 0.45 < SR < 7, green SR > 7. 4c. Broad evaluation of CO_2 emissions' Virtual Compensation Areas. VCAs equal to additional areas of mean local primary productivity necessary to capture 80% of total local CO_2 emissions. The remainder (20%) is considered already stored by existing vegetation. Diameter of circles proportional to photosynthetic oxygen consumption by fossil fuel us. Colour relates to the VCA to Local Area Ratio: red > 3, blue between 0.3 and 3, green < 0.3.

Population (2100) SRES A2 estimation		11782560	
GDP 2100 (10^6 CHF) SRES A2 estimation		874516	
ECOLOGICAL FOOTPRINT (E.F.) [gha/H]	Forest	0.16	
	Crops	0.35	
	Animal breeding	0.54	
	Built-up land	0.25	
	Fossil energy	2.20	
	Biodiversity	0.48	
E.F. TOTAL [gha/H]	without biodiv.	3.53	
	with biodiv.	4.01	
BIOCAPACITY (BC) [gha/H]	BC local (a)	4.52	
	BC imported (b)	4.82	
	a+b	9.34	
	% import	51.6	
	Ecological deficit	EF-a	-0.51
		EF-(a+b)	-5.33
SUSTAINABILITY INDICATOR (SI)	EF/a (LSI)	1.13	
	EF/(a+b) (TSI)	0.43	

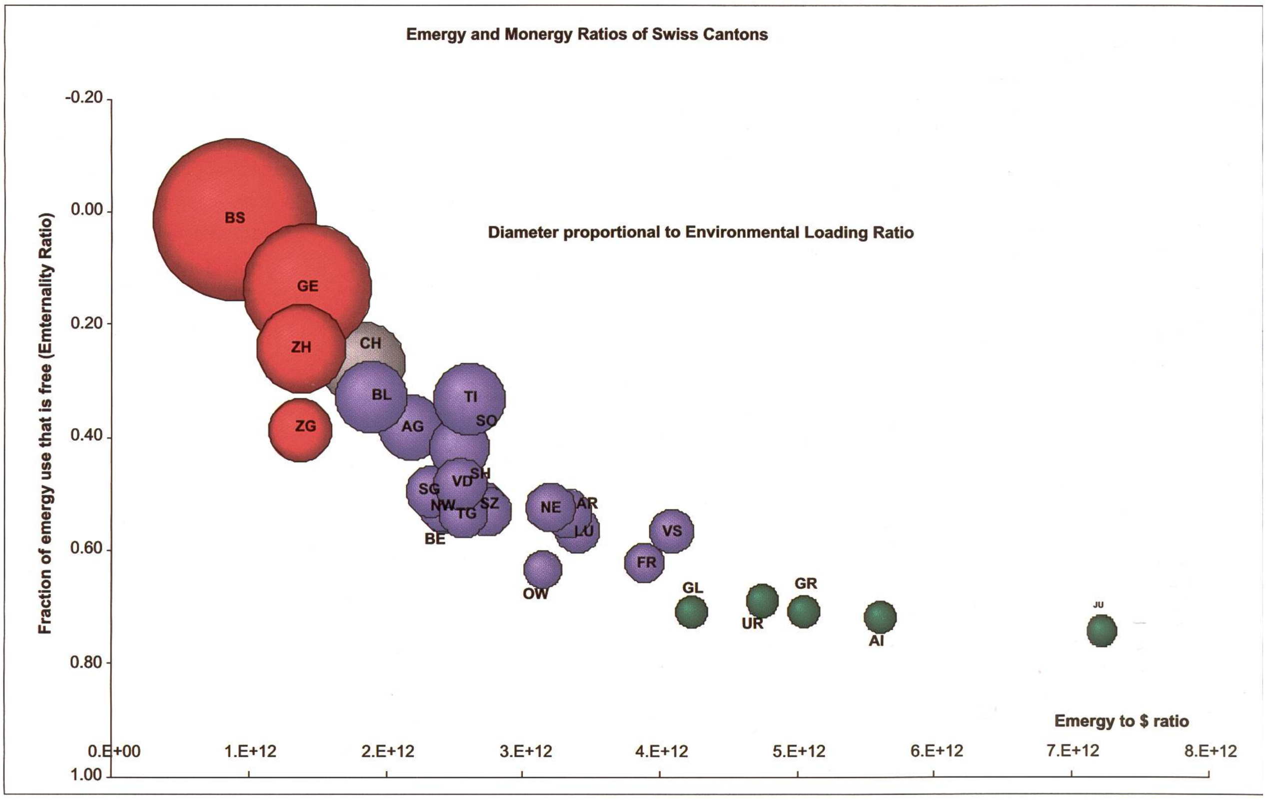
Table 4. Ecological Footprint and biocapacity in Switzerland in 2100. IPCC SRES A2 scenario (reduction of per capita CO_2 emissions at 3t/yr, namely –50.9% of the present emission level) (Priceputu 2006).

and biocapacity components, emergy use per sector, etc.). For example, if cantons (table 3) wanted to improve their environmental performance (and their sustainability score), they should focus on their lagging indicator components, such as high levels of greenhouse gas emissions, vulnerability index (forests, crops, cattle, tourism, biodiversity, etc.), sectorial GNP, sensitivity to climate change (flooding, drought, forest fire, landslide, environmental stresses, etc.) (Beniston 2004; Haurie and Viguier 2005 a,b,c; Priceputu et al. 2005; Priceputu 2006).

Figure 3a, b and c presents a similar comparison of cantons' sustainability levels, in terms of imports and local resources per real physical km² of the cantons. The diameter of circles representing the cantons relates in all cases to fossil energy consumption. Unsustainable positions are in majority consequences of high rates of energy consumption and/or unsustainable energy schemes. Cantons' distribution in the resulting 'sustainability space' follows a differ-

other hand, because sustainability indices are aggregated indicators, the search for policy models is best conducted at the variable level rather than at the level of the total sustainability score (e.g., footprint

Fig. 5. Relationship between emergy and economic output (GDP and financial fluxes in relation with energy fluxes: monergy). Diameter of circles proportional to the Environmental Loading (Pressure) Ratio.



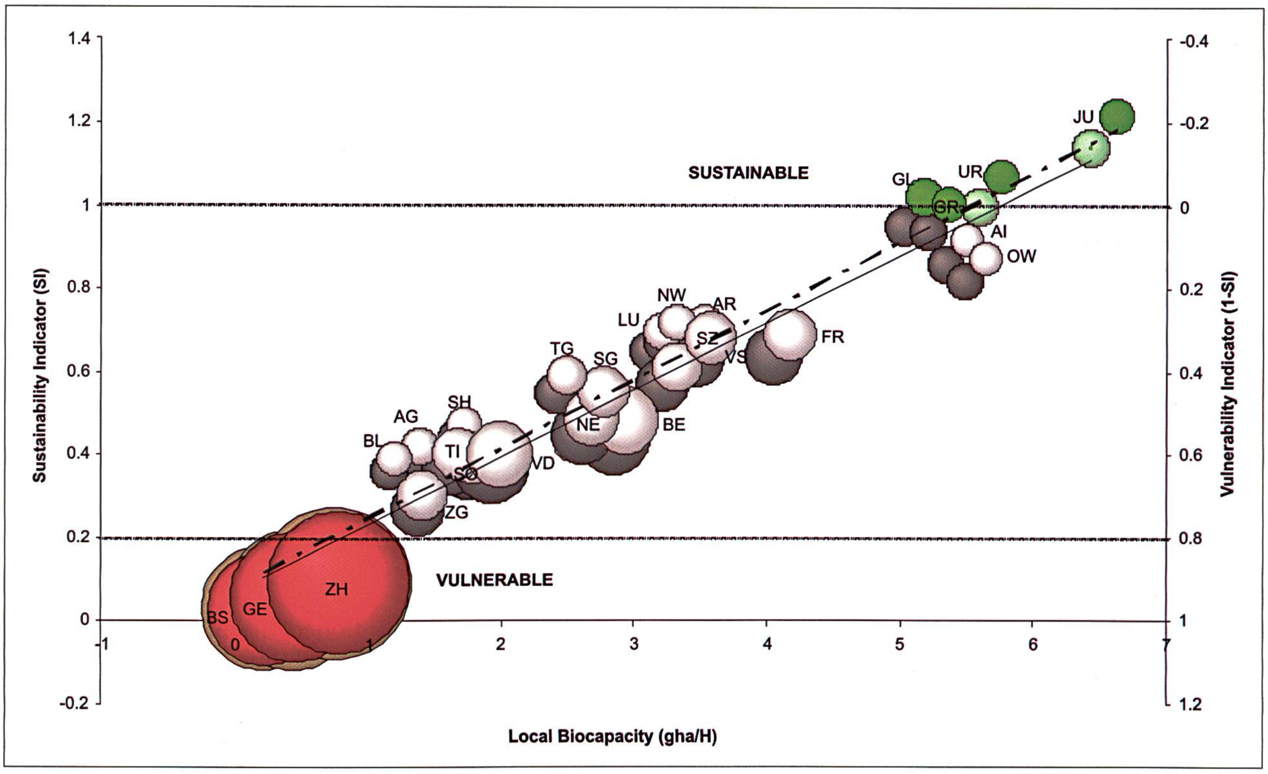


Fig. 6. Sustainability/vulnerability and ecological footprint of Swiss cantons. Present situation: rose, dark grey, light green. Virtual situation (Kyoto –8% of the actual CO_2 emission level until 2012): red, grey/white, green. The circles represent Swiss cantons. Diameter proportional to the fossil energy footprint. (CO_2 law: –10%, 1990 level; –15% combustible; –8% motor-fuel).

ent configuration than in the previous case, which only considered per capita distribution of footprints, biocapacities, emergy and ecosystem values. When calibrating sustainability levels according to real surface values, a dilution (example: Zurich) or concentration effect on areas is also accounted (balance between areas necessary to sustain effective consumption and the real surface occupied by the population, and indications of GNP/km²). Thus, the total environmental pressure may be extreme even if per capita levels are relatively low. The consistency between the results obtained by applying the three approaches is maintained in this case too. Vulnerability (un-sustainability) is associated with consumption levels that largely surpass local potential to cover human demand. BS, GE, ZH are thus vulnerable from Wackernagel's point of view; only BS and GE are considered vulnerable by the Odum/Brown approach (lack of the metropolis effect); finally, Constanza's approach on estimating ecosystems' value also considers ZG as ecologically vulnerable, aside BS, GE, and ZH.

These two approaches (per capita and per km²) provide two complementary views of real environmental pressure that need to be considered for adaptation purposes. Actions to reduce vulnerability should thus take into account two different criteria: per capita distribution of resources and demand, and total environmental pressures function of existing compensatory surfaces (per km²).

The formal relationship between sustainability and vulnerability indicators, ratios, and compensation areas is analyzed in Fig. 4a, b and c. Vulnerability is directly related to environmental pressures. A negative balance between local natural resources and high levels of consumption has direct effects on the local environment, and consequently on the level of vulnerability. The quantitative classification of Swiss cantons into 'sustainable', 'partially sustainable' and 'vulnerable' depends on this fundamental relationship.

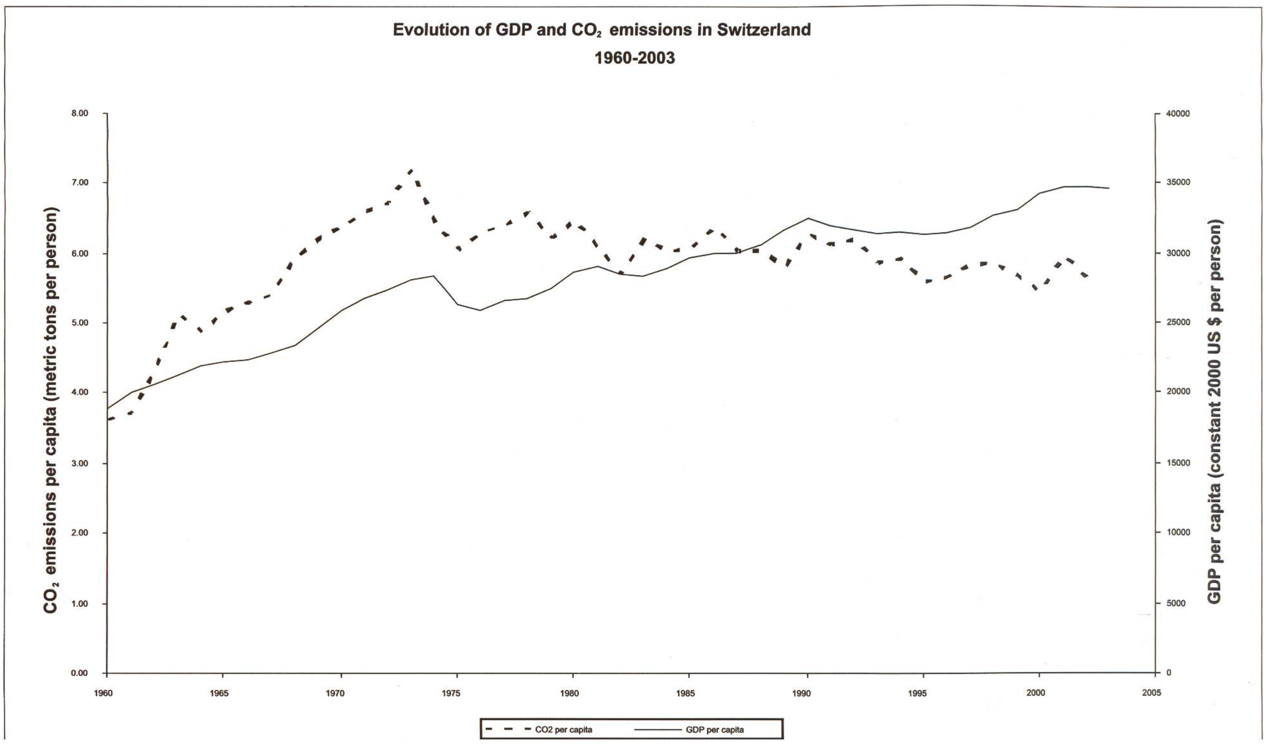
Virtual compensation areas (VCAs) account for supplementary surfaces of mean primary productivity, necessary to completely balance CO_2 emissions at national level (Fig. 4c). VCAs are represented in relation to the surface of each canton (per capita and total). High emission levels generally correspond to limited local capacities of CO_2 fixation (BS, GE, ZH). The cantons that are largely disposing of important environmental resources (particularly forests and pastures) are the most sustainable ones. The cantons of Grisons, Uri, and Glaris have the largest areas covered by forests and pastures, susceptible of capturing an important amount of their CO_2 emissions. The difference between low and high values of cantons' VCAs is considerable: the additional area of mean primary productivity necessary for complete fixation of CO_2 emissions is ~70 times higher than the real canton surface in BS, and represents only 16% of the Grisons' area. The output of this broad approach has a similar pattern as the emergy flow classification (Fig. 4b), because it is linked to CO_2 emissions and energy consumption patterns.

The environmental, social, economic, and cultural diversity at sub-national level is also highlighted by Figs. 1-4. Each canton's position (± sustainable, ± vulnerable) is the result of a particular combination of environmental and economic drivers, determining a unique 'signature', particular sustainability niches being occupied by particular cantons. Therefore, improving cantons' sustainability conditions requires specific solutions for each case. The policies generally applied at the national level should properly consider this diversity. Results obtained by applying uniform policy measures will evidently produce lower sustainability scores than measures that are fully based on specific local baseline conditions and needs, and could induce in the future some indirect effects and inconveniences on the local economy.

Most of the cantons that are considered sustainable by our analyses are also privileged by an important access to unpaid natural resources (externalities, emternalities; see Fig. 5). The emergy to GDP ratio (monergy) is considerably higher in the case of JU, GR, GL, UR, etc., illustrating a greater fraction of 'free emergy' use (emternality; Pillet and Odum 1987; Pillet 2004, 2006). Since most of the emergy inputs used by vulnerable cantons (BS, GE, ZH) are imported, and thus paid for, the monergy (amount of GDP produced by using one emergy unit) is higher, as well as the emergy yield. This situation implies that an emergy unit is used more economically efficient in those cantons having limited local resources, and needing to import the majority of the goods and services consumed by their population. On the other hand, the economic structure (I, II, III) of cantons influences on the total economic output (i.e., cantons that developed to a larger extent their tertiary sector obtain more significant value added outputs).

We have already mentioned the importance of particular aspects of sustainability in decision-making processes. Decision making related to climate change is a crucial part of making decisions about sustainable development simply because climate change is one the most important symptoms of 'unsustainability'. For instance, several of sustainability-related actions and measures would have implications for the climate change issue by either influencing the degree of vulnerability/resilience to climate change or by changing the level of emissions of GHGs. Additionally, climate change impacts would, in turn, relate to sustainable development

Fig. 7. Coupling between Swiss GDP and CO_2 emissions (1960-2004).



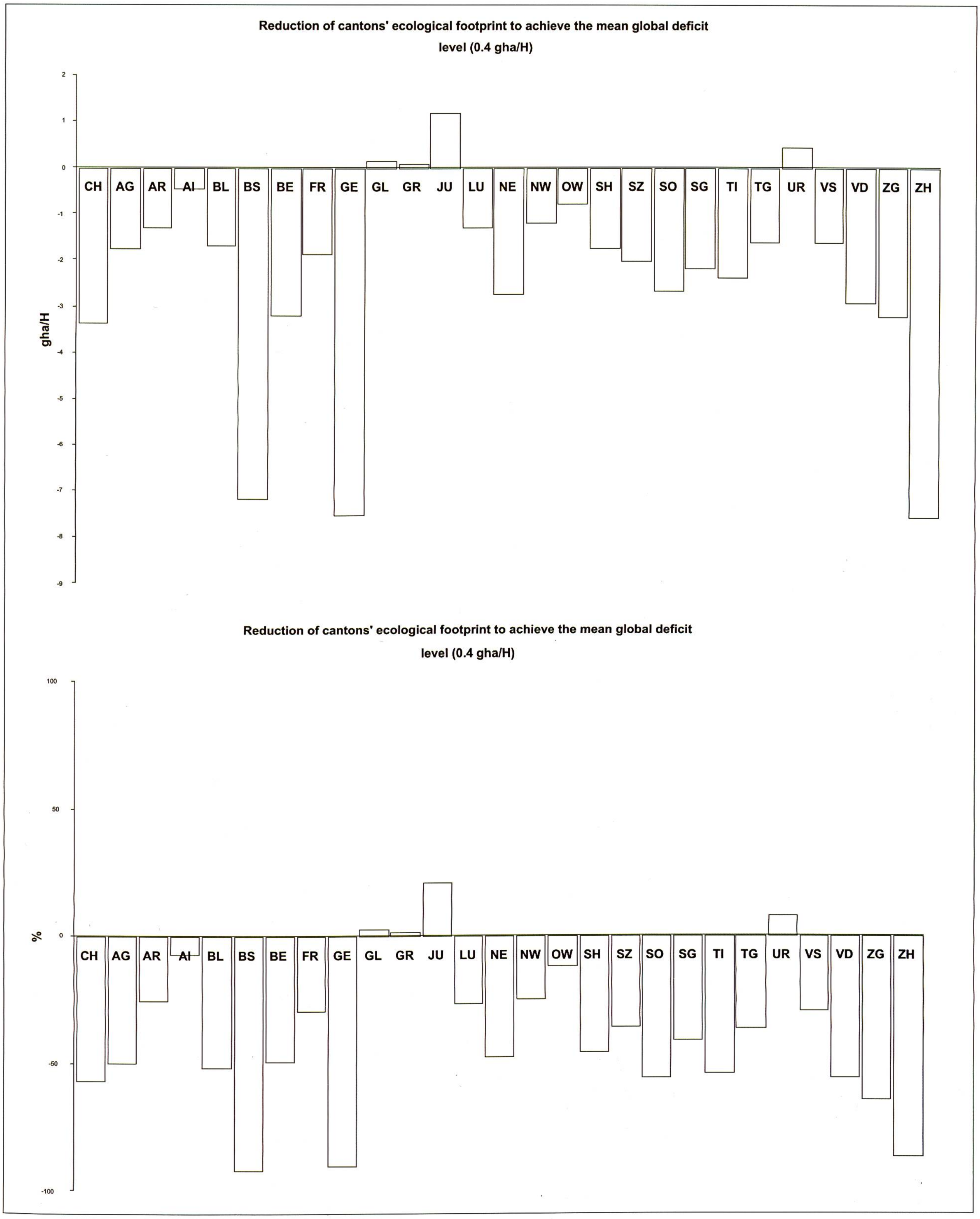


Fig. 8. Reduction of cantons' ecological footprint to achieve the mean global deficit level (0.4 gha/H). 8a. Footprint reduction calculated as gha/H. 8b. Footprint reduction calculated as % of the local value.

largely through their implications on the opportunities for economic development (and for development planning), on access to resources, and on distributional effects.

In 1997, after numerous negotiation sessions, the Kyoto Protocol, whose goal is a progressive reduction and stabilisation of GHG emissions (industrialized countries) has been drawn up, and entered into

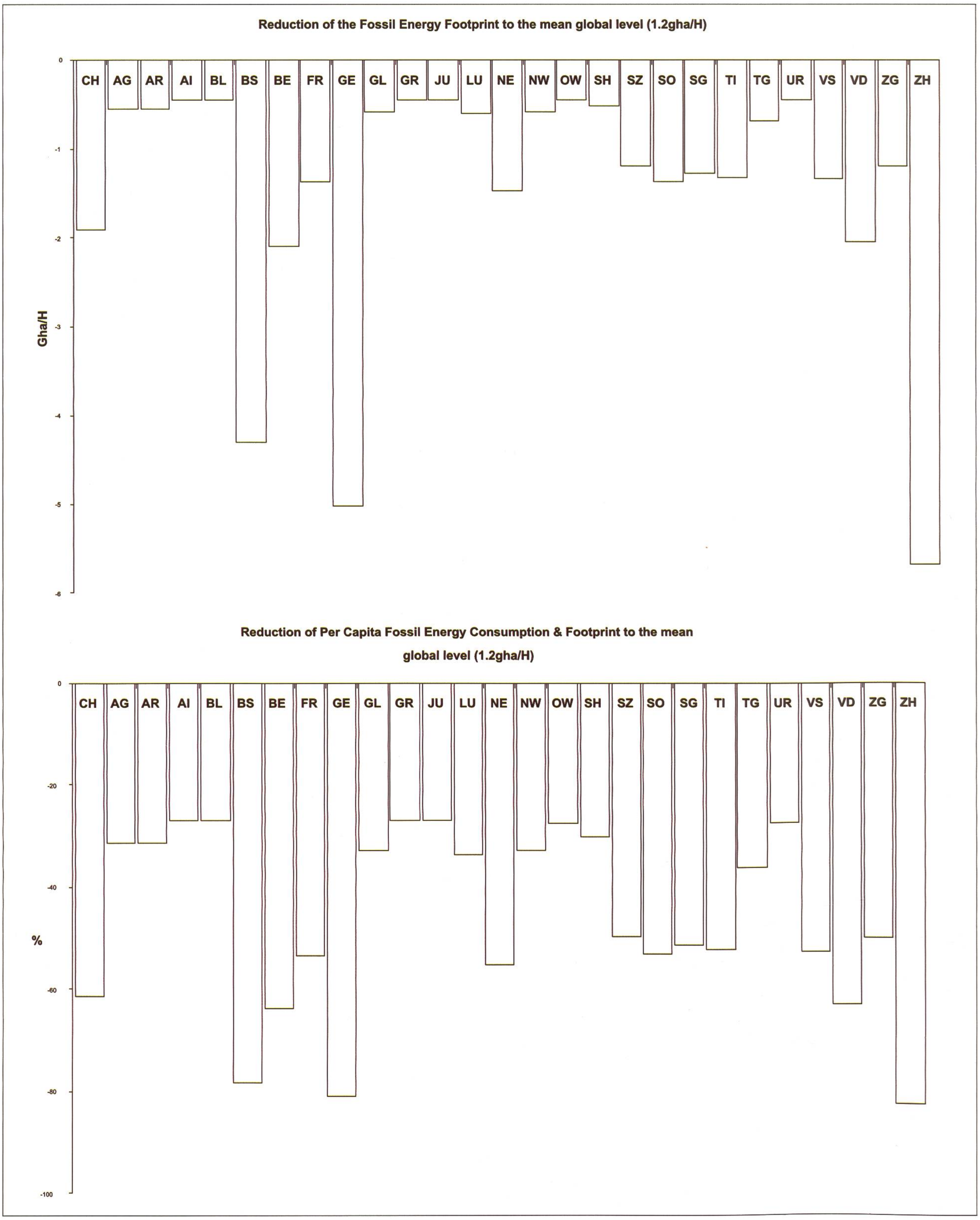


Fig. 9. Reduction of Per Capita Fossil Energy Consumption & Footprint to the mean global level. 9a. Calculated in terms of gha/H. 9b. Calculated as % of the current local value.

force only since February 2005 (Priddle 2001; Kintisch and Bückheit 2006; http://www.industrie.gov.fr/energie/developp/serre/textes/se_kyoto.htm; http://www.effet-de-serre.gov.fr/; http://www.radio-canada.ca/nouvelles/dossiers/kyoto2-page7.html).

Fig. 6 presents the actual situation of sustainability/vulnerability in Switzerland (Wackernagel method) and the effect of the above-mentioned GHG

Canton	%GDP	%CO2	Relative Coupling +/-	Rank +/-	CHF/tCO2	Rank	LSI/SR
AG*	7.49	9.86	+2.36		6,246		0.39/0.96
AR°°	*0.65*	*0.52*	*-0.13*	*7*	*10,305*	*7*	*0.67/2.96*
AI	0.17	0.44	+0.27		3,210		0.86/9.08
BL	3.73	4.16	+0.42		7,375		0.36/0.71
BS°°*	*3.86*	*2.51*	*-1.35*	*3*	*12,617*	*3*	*0.03/0.09*
BE*	11.35	13.36	+2.01		6,978		0.44/2.30
FR°°	*2.64*	*2.05*	*-0.59*	*6*	*10,555*	*6*	*0.64/4.16*
GE°°*	*6.16*	*3.63*	*-2.53*	*2*	*13,934*	*1*	*0.05/0.17*
GL	*0.57*	*0.54*	*-0.03*		*8,607*		*0.95/8.35*
GR	2.30	2.62	+0.32		7,214		0.94/8.29
JU	0.68	0.81	+0.12		6,965		1.14/10.52
LU°°*	*4.12*	*2.79*	*-1.33*	*4*	*12,120*	*4*	*0.65/2.39*
NE	1.99	2.99	+1.01		5,451		0.45/2.27
NW	*0.61*	*0.55*	*-0.07*		*9,198*		*0.67/2.30*
OW	0.34	0.46	+0.13		5,942		0.82/4.72
SH	1.04	1.04	0.00		8,254		0.44/2.11
SZ	*1.88*	*1.87*	*-0.01*		*8,245*		*0.57/2.42*
SO	3.02	3.47	+0.44		7,170		0.36/1.19
SG*	5.55	6.40	+0.85		7,123		0.51/1.93
TI	3.26	5.51	+2.25		4,861		0.37/0.73
TG	2.78	3.23	+0.46		7,057		0.55/2.37
UR	0.43	0.50	+0.06		7,198		1/7.15
VS	2.87	3.95	+1.08		5,971		0.63/2.98
VD*	8.72	8.86	+0.14		8,087		0.37/1.69
ZG°°	*2.21*	*1.44*	*-0.78*	*5*	*12,650*	*2*	*0.27/1.03*
ZH°°*	*21.56*	*16.45*	*-5.12*	*1*	*10,770*	*5*	*0.09/0.41*
CH	**35.7 10^{10} fr**	**44.7 10^{6} t**			**7985.96**		**0.36/0.48**

*: 8 cantons cumulating 68.8% GDP, 63.8% CO_2 emissions.
°°:7 uncoupled cantons: 41.2% GDP, 29.4% CO_2 emissions.

Table 5. The coupling degree between GDP and CO_2 emissions shows dependency on fossil fuels and GDP/tCO_2 levels. Negative coupling (uncoupling) shows higher energy efficiency levels and elevated GDP/CO_2 ratios: development of the tertiary sector is the main reason of cantons' efficiency and negative coupling. The relationship with LSI and SR is also given for these cantons.

reduction programme on these indicators until 2012. Table 4 illustrates necessary sustainable conditions that should be met by the year 2100 (-50.9% of the present CO_2 emissions level), according to the SRES A2 scenario. By comparing these two situations, we measure the great difference between the expected output and immediate results of Kyoto Protocol (an important political and cultural event), and the reality to be reached. The climatic, economical and political constraints will probably accelerate in time the process of reorientation of the energy policy (yield, GHGs sequestration, substitution, economical redeployment and technological innovation, etc.).

At the world's level, since the 18th until the 20th century, there is a regular increase of per capita CO_2 emission correlated (broad coupling) with per capita GDP (gross national product). But since 1950 until now, some stabilization following even a reverse trend (uncoupling) is appearing in high-developed countries (Edwards et al. 2005; Schmalensee et al. 1990). There are several reasons behind this ± stable situation: amplification of the tertiary economic sector, progress in technology and energetic yield, energy substitution to renewable sources, etc. We present in Fig. 7 and table 5 the evolution of both CO_2 emissions and GDP for Switzerland, and the actual relative broad coupling or uncoupling degree in 26 cantons. We observe a great disparity with respect to the financial/energy yield, from IA 3210 CHF/tCO_2 to GE 13934 CHF/tCO_2; seven cantons (uncoupled) produce 41% GDP for 30% CO_2 emissions (GDP mean value: 12119 CHF/tCO_2), and 19 (broadly coupled) produce 59% GDP for 70% CO_2 emissions (GDP mean value: 6903 CHF/tCO_2). This aspect (economical and ecological consequences) should be considered in determining adaptation measures and orientations towards a sustainable Biosphere-Society-Environment relationship at both the local and global level.

The environmental Kuznet Curve (IBRD 1992) is often utilized as a reference for the relationship between the environment and economic growth. This empirical proposal is an inverted U-shaped function of income per capita versus an indicator of environmental degradation. It means that in the early stage of economic growth, environmental degradation and pollution increase, but beyond some level of income per capita, this trend reverses and the environmental indicators improve with structural changes in the economy, development of better and new technologies, changes in the fuel mix, and enforcement of stricter environmental regulation. This is not evident in Switzerland for the time being, despite a high GDP value per capita (table 5).

Figs. 8 and 9 show possible regional efforts to achieve sustainability in Switzerland. Firstly, we look at the potential to reduce cantons' ecological footprint in order to diminish their ecological deficits at a mean global level of 0.4 gha/H (global equity). Several cantons may still increase their consumption footprint: Jura +21%, Grisons +1.5%, Glaris +3%, Uri +8%. The remaining cantons should focus on reducing their footprints: Basel-Stadt –92%, Zurich –87%, Geneva –89%, etc. This implies radical changes in consumption patterns, particularly those of fossil energy use (renewable energy substitution, technical innovation, yield, economical and lifeway adaptation), and adequate management of limited local resources. Another partial solution would be to maintain fossil fuel importation, with some progressive reduction and counterpart measures sustaining the economical and ecological situation of the foreign countries representing the sources of imported biocapacity and energy.

Fig. 9 details related energy reduction targets for each canton. The strategies to be pursued by Switzerland to achieve sustainability in the energy sector should be positioned in relation to local, regional, national and global 'market' arenas. Addressing the issue of sustainability for each arena and for each canton will yield a suite of transitional strategies that will require differential application measures and targets. Each canton represents a singular entity, with specific levels of interaction between environment, society and economy. The measures applied in order to reduce CO_2 emissions, improve sustainability and reduce vulnerability have to take into account this biophysical and economical diversity at cantonal level by considering and proposing different application schemes.

Conclusions

Sustainable development will continue to mean different things to different people (socio-economic and cultural problem), but the goal of integrating viable and efficient ecological and economic concerns in decision-making remains one of the invariables of this concept. The Brundtland Commission's definition of sustainability (WCED 1989) has helped to provide a consistent definition that has been difficult for many to grasp in theory or practice. However, the definition of sustainability does not offer any conceptual framework or methodology – no how-to information or guidelines that can help communities move toward sustainability. It merely offers a very broad vision or goal but no set of approaches to get there. We have tested four different qualitative and quantitative approaches that were later developed within this conceptual framework.

This evaluation of data and methods used to estimate current sustainable/vulnerable conditions for each canton in Switzerland demonstrates compatibility and complementarity between different perspectives on sustainable development. Wackernagel's approach to sustainability relies on the difference between local consumption and supply and integrate import and export of biocapacity; Odum, Brown and Pillet apply essentially an energy-based approach to quantifying system inputs and outputs and the relation with financial fluxes (monergy); Costanza et al. use common monetary metrics (internalisation of externalities); finally, we propose a broad approach to estimate virtual supplementary areas for GHGs emissions' compensation. Even if each of these methods is based on totally or partially different criteria, applying different units of measurement, the results show the analogous 'sustainability configuration' of present conditions in Switzerland, and similar sustainability ranking of cantons, especially for local sustainable structures. Furthermore, the differences between the overall levels of sustainability of Swiss cantons are quite large, and based on different levels of interaction between local communities and their environment, different economic structures, different bio-physical potentials/capacities, etc., and these will be accentuated by the climate change in action (Beniston 2004; Priceputu and Greppin 2005b). When considering the application of sustainable policy measures in Switzerland, these environmental and economic discrepancies should be taken into account; we thus conclude to a 'canton-by-canton' modulation of sustainability-related measures in the global envelope of general decisions at the Swiss national level. For example, CO_2 emissions reduction targets and measures should be implemented at cantonal level in function of local emissions and potentials for photosynthetic fixation. The application of a unique CO_2 target for the entire Swiss territory could be afterwards modulated by differential taxes and targets for each canton, calculated with respect to their concrete emission levels, economic potential and structure, and overall sustainability conditions. We plead for a differential treatment of cantons, based on general sustainability criteria, of which, most importantly, equity-based criteria; these suppose the examination of both temporal and spatial inequalities that are linked to primary physical, biological and economical disparities at the planet's level, and usually hidden by an averaging approach, for example at the country level.

Uniform regulation measures do not properly consider existing environmental, economic, and social diversity at sub-national level, which in the case of Switzerland are shown to vary by large factors between the cantons. The progress toward a sustainable economy, society and environment, as well as the adoption of sustainable development as a general public policy objective, requiring articulation of many different environmental, social and economic growth policy agendas, would have to be based on various implementation schemes of sustainability measures and laws, that account for all these physical, biological and socio-economic and decisional disparities.

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