Sustainability science: a possible strategy to enhance resilience to climate and rural ecosystem changes

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ABSTRACT

Sustainability Science is an increasing internationally recognized field that combines together social, natural, technical and health scientists as well experts in the humanities, decision makers and private enterprises to find solutions and strategic planning to deal with the huge challenges facing human societies.

1. INTRODUCTION

Improving the sustainability of humanity's relationship with Planet Earth is firmly established as a societal goal for the 21st Century. To achieve it we need a better understanding of how to govern ''the process of moving towards greater sustainability'', with a new style of governing, called *governance*, which is more pluralist and decentralized than the conventional state-centered government style.

With climate change, biodiversity loss, global water and energy crises, the growing problem of desertification, the phenomenon of massive urbanization and many other manifestations of global environmental change becoming more and more evident, there is a widespread and increasing feeling in the society at large that the concept of sustainability is not sufficient to counteract the complex and problematical situations.

As it is known, *sustainability* is a concept dealing with the way how humans should act towards environment and how they are responsible each other and towards future generations. The use of the word *sustainability* exploded in academic, professional, and public communication in the last decade of the 20st century.

Sustainable development has been defined in many ways, but the most frequently quoted definition is from *Our Common Future*, also known as the ***Brundtland Report*** [1]:

[1] World Commission on Environment and Development (WCED). (1987) *Our common future.* Oxford: Oxford University Press.

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

It contains within it two key concepts:

- the concept of *needs,* in particular the essential needs of the world's poorest population, to which main priority should be given;
- the idea of *limitations*, imposed by the state of technology and social organization on the environment's ability to meet present and future needs."

All definitions of *sustainable development* intrinsically require that we see the world as a system, a system that connects *space* (all continents); a system that connects *time* (what we do now has an effect in the future); a system that is strongly influencing the *quality of life* of all humans.

It is evident that *sustainability* is based on a simple principle: everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions, under which humans and nature can co-exist in productive harmony, that permit satisfying the social, economic and other requirements of present and future generations. A *sustainable approach* is a systems-based methodology that request to understand the interactions among the ***three pillars*** (*environmental*, *social*, and *economic*) in an effort to better understand the consequences of our actions. Ideally, research that seeks sustainable solutions to protect the environment also strengthens our communities and promotes prosperity.

Sustainable development was fundamental to the conventions on climate change and biological diversity agreed at the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992; the Desertification Convention (UNCCD) agreed afterwards, including sustainable development in the crucial way to fight desertification.

However, emerging recognition of ***two fundamental errors*** characterizing past polices for natural resource issues is an indication of understanding of the need for a worldwide fundamental change in thinking and in practice of environmental management.

The ***first error*** has been an implicit assumption that ecosystem responses to human use are linear, predictable and controllable. The ***second one*** has been an assumption that human and natural systems can be treated independently. In fact, evidence that has been accumulating in diverse regions all over the world suggests that natural, economical and social systems behave in nonlinear ways, exhibit marked limits in their dynamics, and that ecological-social-economical systems act as strongly coupled, complex and evolving integrated systems [2].

At the beginning of the 21st century, we face significant new challenges including rapid climate change, the degradation of fresh water resources, the massive use of non renewable primary energy sources (that is fossil and nuclear fuels), the globalization of diseases, the economical crises, the massive immigration with evident social consequences, and the more complicated question of long term environmental security. The foot print of human activity continues to expand to the point that is having a significant impact on nearly all of Earth's environmental systems. We are participating in and increasingly becoming designers and managers of the complex relationships among people, their necessities, ecosystems and biosphere. Human and environmental health are highly complex and human well-being is inextricably linked to the integrity of local, regional and global ecosystems. Environmental research and education are therefore key elements of local, national, regional and global security, health and prosperity.

We will analyze some very complex systems as agriculture, climate change, and desertification as examples of non linear relationships between *development* (which is not the same that *economic growth*), *sustainability*, *environmental policy making*, *ecosystem quality* and *human well-being.*

2. AGRICULTURE

Agriculture as developed in the recent decades is not a sustainable activity but it is becoming an area of problems. Agriculture is the first, most intensive user of non renewable land, water, primary energy sources, ecosystems and biodiversity. It is generally recognized that in 2050 we will need more food, more water and more energy and that is a real challenge.

In fact, we don't have any more new land to use for food production. The suitable land is reduced. Only 10% of land is utilized for human activity but the competition among industrialization, energy uses (biofuel cultivations), civil activity (roads, houses, resorts) and many others strongly reduces the amount of land suitable for food production. It has been

[2] Folke Carl, Steve Carpenter, Thomas Elmqvist, Lance Gunderson, C. S. Holling, and Brian Walker (2002) Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations. AMBIO: A Journal of the Human Environment, pg(s) 437-440

estimated that out of $13x10^9$ available ha only $1.5x10^9$ ha are utilized for crops, while 3.30 $x10^9$ are dedicated to pasture. The rest is marginal land, rocky, too dry, too wet or too cold. So only the 12% of valuable land is utilized for food production. The amount of cultivated land per person decreased significantly from 1960, when each person had 0.44 ha, to the actual value of 0.22 ha. It has been estimated that in 2050 it will drop to 0.15 ha per person. The competition between food and biofuels production certainly will not alleviate the trend even in the near future.

2.1 Agriculture and water

One third of water used in Europe goes to the agricultural sector. As a matter of fact, agriculture affects both the quantity and the quality of water available for other uses. In some parts of Europe, pollution from pesticides and fertilizers, used only in agriculture, remain a major cause of poor water quality[3]. Our industries and lifestyles together with the personal needs of our growing populations are also nature's rivals for the use of clean water. Climate change adds an additional element of uncertainty to the availability of water resources. In southern European Countries, such as Greece, Italy, Portugal, Cyprus, Spain and southern France, the arid or semi-arid conditions necessitate the use of irrigation. In these areas, nearly 80% of water used in agriculture currently goes to irrigation[4].

Agricultural practices may also have negative impacts on water quality: improper agricultural methods may elevate concentrations of nutrients, fecal coliforms, and sediment loads. Increased nutrient loading from animal waste can lead to eutrophication of water bodies which may eventually damage aquatic ecosystems. Animal waste may also introduce toxic fecal coliforms which threaten public health. Grazing and other agriculture practices may intensify erosion processes, by raising sediment input to nearby water sources[5]. The increased incidence and severity of flooding could mobilize sediment loads and associated contaminants and exacerbate impacts on water systems, while more severe droughts may reduce pollutant

[3] Moss B. (2008). Water pollution in Agriculture. Philos Trans R Soc Lond B Biol Sci; 363(1491): 659–666.

[4] European Environmental Agency (2012) European waters - assessment of status and pressures. EEA Report 8/2012

[5] Thornes John B. (2007) Modelling Soil Erosion by Grazing: Recent Developments and New Approaches. Geographical Research. Volume 45, Issue 1, 13-26

dilution, thereby increasing toxicity problems. But whatever the impacts on water systems, the task of achieving water quality objectives in agriculture will become more difficult in the coming years as a result of climate change, although this is a poorly understood and researched aspect of climate change science to date[6].

2.2 Agriculture and energy

In recent years the overall world consumption of primary energy sources ranges around 13,5-14 Gtoe (billions of **t**ons of **o**il **e**quivalent), including biomass and other non commercial energies[7]. Up to 85% of such a total amount comes from *non renewable sources* (fossil and nuclear ones), while 80% are also *non sustainable,* in terms of climate change effects, due to the massive greenhouse gasses production caused by the combustion.

Direct final energy consumption for agricultural and agro - industrial uses reflect such a critical data: both for direct energy uses and for indirect ones (mainly water and heat) rural areas are in appropriate energy starvation and critical aspects are both the surviving and the quality of life. 2.500 millions of people (94% in rural areas) depend on biomass fuel, while death for pulmonary problems deriving from the unsafe burning of biomass for cooking and/or heating is the second most diffused social cause of death, after AIDS[8]. Finally, 1.700 millions of people have no access to electricity, 92% of them living in rural areas.

2.3 Agriculture and biodiversity

Agricultural land use affects large parts of terrestrial area, so its contribution to biodiversity is critical for successful conservation in the future[9]. A landscape vision is needed to understand why agricultural land use has the well known negative and less known positive effects on biodiversity and related ecosystem services. Agricultural land use and biodiversity conservation have been traditionally viewed as incompatible. Ecologists and conservationists often focus on unspoiled or little intervened habitats to save the remains of wild nature.

[6] OECD (2012). Water Quality and Agriculture: Meeting the Policy Challenge. Organization for Economic Co-Operation and Development - Directorate for Trade and Agriculture

[7] International Energy Agency (2013), World Energy Outlook

[8] World Health Organization (2013) Data and Statistics.

[9] Thrupp Lori Ann (2000) Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture. International Affairs 76, 2, 265-281

Only recently there has been an increasing recognition that such a conservation focus is of limited value. Intensive land use in agriculture and forestry is irrefutably the main cause of global change and biodiversity loss, but low-intensity land-use systems may be important elements of large-scale programs on biodiversity conservation. In fact, the importance of biodiversity in multifunctional agriculture and for ecosystem services, such as pollination and biological control, is well known. During the last decades, worldwide losses of biodiversity have occurred at an exceptionally increasing rate and agricultural intensification has been a major driver of this global change[10]. The modernization of traditional agro-ecosystems, that in tropical regions are still much under traditional management, strongly affected biodiversity[11].

The dramatic land use changes include the conversion of complex natural ecosystems to simple managed ones and the intensification of resource use, including application of more agrochemicals and a generally higher input and output, which is typical for agro-ecosystems as relatively open systems. Not only the biodiversity of unspoiled habitats and traditional, low-intensity, agro-ecosystems, but also the biodiversity of intensively used agro-ecosystems has been greatly reduced during the last decades.

The main biodiversity losses are due to the post-war transformation of traditional to modern, high-intensity landuse systems in simple landscapes. The decline of biodiversity may affect ecosystem functioning and yield, although the functional role of biodiversity is not yet completely understood[12]. More recently, the focus on biodiversity in undisturbed habitats has also been challenged. Attention has been called to the fact that 95% of contemporary terrestrial ecosystems are managed ones, including agricultural systems[13]. The conventional view is that agro-ecosystems are at best insignificant with respect to biological diversity, and at worst reduce diversity to negligible levels.

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[10] Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R. et al. (2001). Forecasting agriculturally driven global environmental change. Science, 292, 281–284

[11] Perfecto I., Vandermeer J., Hanson P., Cartiâ V. (1997) Arthropod biodiversity loss and the transformation of a tropical agro-ecosystem. Biodiversity and Conservation 6, 935±945

[12] Daily, G.C. (1997). Nature's Services: Social Dependence on Natural Ecosystems. Island Press, Washington, DC, USA

[13] Western, D. and Pearl, M.C. (eds) (1989) Conservation for the Twenty-®rst Century. NewYork: Oxford University Press

Although no one would affirm that a modern agro-ecosystem may have as much biological diversity as a rain forest, it is doubtful that certain agro-ecosystems indeed have a very high diversity of plants[14] [15].

2.4 Agriculture and soil

Unlike air, water, and biota, which are mobile systems, soil is site-specific, and although more stable than the other three systems, it shows great variability in space and time.

Soil is the Earth's living skin, essential for life on our planet. Nevertheless, increasing areas are being covered with impervious materials as a result of urban development and the construction on new infrastructure. This 'soil sealing' causes an irreversible loss of the soil's natural functions and can lead to floods as water can no longer seep and drain away. Soil sealing can also affect human health as well as medium- and long-term economic development and food security. Soil is a non-renewable resource: its health is important for world’s sustainable development and therefore needs to be preserved and managed carefully.

Soil can be affected by physical, chemical and biological degradation. Soil health, biodiversity, and soil resilience are severely limited in extreme environments and are more sensitive to anthropogenic disturbance[16]. Agricultural activities contribute to these negative effects. Land use practices such as deforestation, overgrazing, some agricultural cultivation practices, removal of vegetative cover or hedgerows can exacerbate physical degradation of the soil due to agriculture. The increasing demand for water, the sometimes excessive mechanization and ploughing are further causes of such degradation.

However, it must borne in mind that industry, urbanization, road construction, fire, other human activities and, more generally, anthropic and demographic pressure and climate changes are also major factors. Dramatic is the current rate of soil loss by sealing through urban expansion and infrastructure in Europe, like in Germany (120 ha per day), Italy (100 ha per day), Austria (35 ha per day) and Switzerland (10 ha per day). This urban expansion

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[14] Paoletti, M.G. and Pimentel, D. (eds) (1992) Biotic Diversity in Agroecosystems. Amsterdam: Elsevier

[15] Hawksworth, D.L. (ed) (1993) The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture. Oxon, UK: CAB International

[16] Doran J. W. and Zeiss M. R. (2000) Soil health and sustainability: managing the biotic component of soil quality. Applied Soil Ecology 15, 3–11

increases the costs of urban infrastructure, traffic in urban areas, and energy consumption; and has negative effects on the quality of the countryside and the environment. This development is in direct competition with agricultural land uses and is threatening valuable agricultural soils all over Europe[17].

3. CLIMATE CHANGE

The changing climate impacts society and ecosystems in a broad variety of ways.

For example climate change can increase or decrease rainfall, influence agricultural crop yields, affect human health, cause changes to forests and other ecosystems, or even impact our energy supply.

Climate-related impacts are occurring across regions of the country and across many sectors of our economy[18]. Many state and local governments are already preparing for the impacts of climate change through "adaptation," which is planning for the changes that are expected to occur.

Starting from the beginning of the XIX Century, people worldwide began burning more coal and later oil for homes, factories, and transportation. Massively burning these fossil fuels releases carbon dioxide and other greenhouse gasses into the atmosphere. These added greenhouse gasses caused Earth to warm more quickly than it has in the past. The rising of temperature is having many side effects at the planet level, as changes in rainfall pattern, melting of glaciers, and sea ice, sea level rise and increased intensity and/or frequency of extreme events. These changes in physical processes have impacts on biological and socio-economic factors such as shifts in crop growing seasons; changes in disease vectors; increased rates of extinction for many species; severe water shortage and heavy deluges and flooding.

[17] Scalenghea, R. and Ajmone Marsanb F. (2009) The anthropogenic sealing of soils in urban areas. Landscape and Urban Planning, 90, 1-10

[18] Parmesan C. and Yohe G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. Nature, Vol 421, 2, January, 37-42 |

Moreover, climate change plays a significant role on people health, leading to more frequent, more severe and longer heat waves in summer time[19].

How much warming has happened? Scientists from around the world within the Intergovernmental Panel on Climate Change[20]. us that during the past 100 years, the world's surface air temperature increased an average of 0.89° Celsius, while the CO_2.percentage in the atmosphere raised up to the values of 395 ppm (never reached in past 400.000 years[21]). This may not sound like a great change, but even such increasing can meaningfully affect the Earth's equilibrium. The IPCC Report is supposing that the number of cold days and nights has decreased at the global scale between 1951 and 2010. It is probable that, since 1950, the number of heavy precipitation events over land has increased in more regions than it has decreased. Regional trends vary, but confidence is high for North America with trends towards heavier precipitation events. On the other hand, there is solid conviction for the occurrence, during the last millennium, of droughts of greater magnitude and longer duration than observed since 1900 in many regions.

4. DESERTIFICATION

Desertification is often triggered by initial conditions of environmental fragility. Causes are linked to several underlying factors (of both natural and anthropic nature) that act as a complex system of interactions.

People cause desertification by cutting trees, logging, and diverting river water to cities for human consumption.

Another consequence of desertification at local and global levels is the reduction in biodiversity, since it contributes to the destruction of the habitats of animal and vegetable species and micro-organisms. It encourages the genetic erosion of local livestock and plant varieties and species living in fragile ecosystems. It is extremely difficult to put a figure on

[19] USGCRP (2009). *Global Climate Change Impacts in the United States* . Karl, T.R., J.M. Melillo, and T.C. Peterson (eds.). United States Global Change Research Program. Cambridge University Press, New York, NY, USA.

[20] IPCC (2013). Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis

[21] Rohde D. L., (2008). Environmental values and behaviors- GLOBAL WARNING ACT, Heinonline.

this loss because of our inadequate familiarity with the features, the sitting and the economic importance of the biodiversity of the dry zones. The destruction of the natural grass and woody vegetation cover in dry areas affects the topsoil temperature and the air humidity; consequently it influences the movements of atmospheric masses and rainfall. Furthermore, the drying of the soils and the destruction of soil cover encourage air erosion.

The primary reasons for desertification are overgrazing, over-cultivation, increased fire frequency, water impoundment, deforestation, over use of groundwater, increased soil salinity, and global climate change. Climatic changes are both a consequence and a cause of desertification. In this context, climate change makes ecosystems even more sensitive and fragile because it increases the pre-existing climate aggressiveness. Instead, the socio-economic causes are generated from the impacts of anthropic pressure linked to urban expansion and economic activities, especially when the above factors involve an unsustainable exploitation of natural resources.

Each of these environmental hazards, even if not producing immediately observable desertification effects, can create instability in the ecosystem equilibrium[22].

5. THE SUSTANABILITY SCIENCE APPROACH

How to manage the difficult global socio-economical-environmental changes?

It is readily evident that we are facing many urgent sustainability challenges, including poverty, epidemics, violent conflicts, economic crisis, beside climate change, aggressive agriculture and biodiversity.

These problems range in scale from global to local and are expected to affect future generations[23]. We considered all the changes that are currently occurring in our environment and in our society in a sectorial way. Promoting sustainable development requires research on wide range of social, economic, institutional and environmental issues. The aim to understand

[22] Perini L., Ceccarelli T., Zitti M., Salvati L. (2009) Insight Desertification Process: Bio-Physical and Socio-Economic Drivers in Italy. Italian Journal of Agrometeorology 45-55 (3)

[23] van der Leeuw S., Wiek A., Harlow J., Buizer J. (2012) How much time do we have? Urgency and rhetoric in sustainability science. Sustain. Sci 7 (Supplement 1) 115-120

the dynamics of coupled social-ecological systems stimulated an innovative, problem driven research that has been called ***Sustainable Science***.

Sustainability Science has emerged over the last two decades as a vibrant field of research and innovation[24]. Today, this field carried out a basic research agenda, an increasing production of results, and a growing number of researchers committed to teaching its methods and findings. Like "*agricultural science*" and "*health science*" , Sustainability Science is a field defined by the problems rather than by the disciplines it employs. From its core focus on advancing understanding of coupled human–environment systems, Sustainability Science has reached out with focused problem-solving efforts based on urgent human needs. As most recently delineated by the World Summit on Sustainable Development (Rio +20), these efforts include improving access to water supplies of adequate quality and quantity, enhancing agricultural production and food security, developing cleaner energy and manufacturing systems, mitigating the human health impact of pollution and environmentally mediated disease, encouraging governance of rapid urbanization, and more generally making more effective use of environmental and natural resources to promote poverty alleviation. Similarly, Sustainability Science is being applied to devise practical protections for the earth's key life-support systems. Special attention in recent years has been paid to mitigating pressures on the global climate, conserving ecosystem services, and protecting biodiversity. Finally, and most ambitiously, Sustainability Science is seeking to support the integrative task of managing particular places where multiple efforts to meet multiple human needs interact with multiple life-support systems in highly complex and often unexpected ways[25].

Generally research relevant to the goals of sustainable development has been carried out from diverse disciplines as geography and geochemistry, agriculture and heath, ecology and economics, or physics and political science. But its research programs should transcend the knowledge of its foundational disciplines and focuses instead on understanding the complex dynamics that arise from interactions between human and environmental systems[26]. The

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[24] Clark WC, Dickson NM (2003) Sustainability science: the emerging research program. Proc Natl Acad Sci USA 100:8059–8061

[25] Dodds Felix and Michael Strauss with Maurice F. Strong (2012) Only one earth: the long road via Rio to sustainable development. Routledge Publishing.

[26] Clark, W.C., 2007. Sustainability science: a room of its own. Proceedings of the National Academy of Sciences 104, 1737–1738.

participatory, interdisciplinary research can contribute to the solution of complex persistent problems. This is the transdisciplinary research that is, essentially, team science. In a transdisciplinary research attempt, scientists contribute their unique expertise but work entirely outside their own discipline. They make every effort to understand the complexities of the whole project, rather than one part of it. Transdisciplinary research allows investigators to transcend their own disciplines to inform one another's work, capture complexity, and create new intellectual spaces[27].

Brandt et al.[28] identified five key themes to adopt transdisciplinary approaches to sustainability science.

The first theme is the ***lack of coherent structure*** between scientists and stakeholders due to different prospective and the ***lack of interaction***. Sustainability science could be the right attempt to increase the exchange and integration of different disciplinary and non-academic knowledge, allowing mutual learning between scientists and stakeholders.

The second is the ***integration of methods to use in the transdisciplinary research*** as a crucial point in the establishment of efficient and coherent research frameworks.

The third theme is ***research and knowledge production*** due to the fact that transdisciplinary projects need a collaborative identification of the problem, its analysis with the co-creation of solution-oriented and transferable knowledge and the implementation of the results into practice.

The fourth theme is the crucial element of ***link between stakeholders and scientists***. Is this an information, a consultation, a collaboration or empowerment? It is evident that the involvement of stakeholders is a vital goal for transdisciplinary projects but it is not clear to what extent this goal could be reached within published transdisciplinary research.

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[27] Hadorn Gertrude Hirsch , Holger Hoffmann-Riem, Susette Biber-Klemm, Walter Grossenbacher-Mansuy, Dominique Joye, Christian Pohl, Urs Wiesmann, Elisabeth Zemp (Eds) (2008) Handbook of Transdisciplinary Research. Springer Link

[28] Brandt Patric , Anna Ernst , Fabienne Gralla, Christopher Luederitz, Daniel J. Lang, Jens Newig, Florian Reinert, David J. Abson, Henrik von Wehrden (2013) A review of transdisciplinary research in sustainability science. Ecological Economics 92, 1-15

The fifth theme is related to the ***impact of transdisciplinary research at global level***. In fact, much of transdisciplinary research originates from developed countries but the sustainability problems are global and not local or regional.

6. CONCLUSION

It is readily evident that there is a need to develop a systematic approach that allows the integration of knowledge across disciplines, ecosystem health, economic development and social needs. We should understand how integrate the dynamic interactions among the Earth system, social and economic development, and sustainability, and how long term trends can remodel the interactions nature-society. Science and technology could be more effectively bound to reach sustainability and research should be addressed to the factors that limit the resilience, enhancing the vulnerability, of the nature-society interactions. The implementation of sustainability requires a considerable scientific and technical knowledge, coupled with a constructive political will. Sustainability without the scientific-technological and political ability to complete it, is meaningless.

However, it is not clear how trasnsdisciplinary approaches will integrate in the future scientific research and how the boundary among scientific research, political decision making and societal organizations will further evolve. Active interaction and effective debates are taking place on the necessity, adequacy and capability to bridge science and political decision to make the link nature-society sustainable.