Carbon Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tcmt20

Benefits of soil carbon: report on the outcomes of an international scientific committee on problems of the environment rapid assessment workshop

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To cite this article: Steve Banwart, Helaina Black, Zucong Cai, Patrick Gicheru, Hans Joosten, Reynaldo Victoria, Eleanor Milne, Elke Noellemeyer, Unai Pascual, Generose Nziguheba, Rodrigo Vargas, Andre Bationo, Daniel Buschiazzo, Delphine de-Brogniez, Jerry Melillo, Dan Richter, Mette Termansen, Meine van Noordwijk, Tessa Goverse, Cristiano Ballabio, Tapas Bhattacharyya, Marty Goldhaber, Nikolaos Nikolaidis, Yongcun Zhao, Roger Funk, Chris Duffy, Genxing Pan, Newton la Scala, Pia Gottschalk, Niels Batjes, Johan Six, Bas van Wesemael, Michael Stocking, Francesca Bampa, Martial Bernoux, Christian Feller, Philippe Lemanceau & Luca Montanarella (2014) Benefits of soil carbon: report on the outcomes of an international scientific committee on problems of the environment rapid assessment workshop, Carbon Management, 5:2, 185-192

To link to this article: http://dx.doi.org/10.1080/17583004.2014.913380

WORKSHOP REPORT

Benefits of soil carbon: report on the outcomes of an international scientific committee on problems of the environment rapid assessment workshop

Carbon Management (2014) 5(2), 185–192

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A Scientific Committee on Problems of the Environment Rapid Assessment (SCOPE-RAP) workshop was held on 18–22 March 2013. This workshop was hosted by the European Commission, JRC Centre at Ispra, Italy, and brought together 40 leading experts from Africa, Asia, Europe and North and South America to create four synthesis chapters aimed at identifying knowledge gaps, research requirements, and policy innovations. Given the forthcoming publication by CABI of a book volume of the outcomes of the SCOPE-RAP in 2014, this workshop report provides an update on the global societal challenge of soil carbon management and some of the main issues and solutions that were identified in the four working sessions.

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Background: the global challenge for soil carbon

(Table 1) By 2050 the world's population is expected to reach 9.6 billion [1]. This will create four major global challenges for the earth's soils over the next four decades:

- A need to double worldwide food supply.
- A need to double worldwide fuel supply (including fuel from renewable biomass).
- A need to increase the supply of clean water by more than 50%.
- A need to mitigate and adapt to climate change and biodiversity decline regionally and worldwide.

The demographic drivers of environmental change and the demand for biomass production are already putting unprecedented pressure on the earth's soils [2]. An urgent priority for action is to ensure that worldwide soils will cope with these multiple and increasing demands [3].

Drawing on the concepts of ecosystem services within the millennium ecosystem assessment, the following services arise from soil functions [10]:

- **Supporting services** are cycling of nutrients, retention and release of water, formation of soil, provision of habitat for biodiversity, exchange of gases with the atmosphere and degradation of plant and other complex materials.
- **Regulating services** for climate, stream and ground water flow, water and air quality and environmental hazards are sequestration of carbon from the atmosphere, emission of greenhouse gasses, filtration and purification of water, attenuation of pollutants from atmospheric deposition and land contamination, gas and aerosol emissions, slope and other physical stability and storage and transmission of infiltrating water.
- **Provisioning services** are food, fuel and fibre production, water availability, non-renewable mineral resources and as a platform for construction.
- **Cultural services** are preservation of archaeological remains; outdoor recreational pursuits; ethical, spiritual and religious interests; and identity of landscapes and supporting habitat.

Soil carbon plays a key role in all the four classes of soil ecosystem services. The flows arising from environmental processes depend on ecosystem structure, where soil carbon is a key component, along with the environmental conditions and human interventions that can strongly influence the services, goods and benefits produced (Figure 1) [11].

Table 1. Global soil carbon fact sheet.

Amount of carbon in top 1 m of earth's soil [4]: 2/3 as organic matter organic C is around times greater C content than earth's atmosphere	2,200 Gt
Fraction of antecedent soil and vegetation carbon characteristically lost from agricultural land since 19th century [5]	60%
Fraction of global land area degraded in last 25 years due to soil carbon loss [6]	25%
Rate of soil loss due to conventional agriculture tillage [7]	~1 mm year^{-1}
Rate of soil formation [7]	~0.01 mm year^{-1}
Global mean land denudation rate† [8]	0.06 mm year^{-1}
Rate of peatlands loss due to drainage compared to peat accumulation rate [9]	20 times faster
Equivalent fraction of anthropogenic greenhouse gas emissions from peatland loss [9]	6% annually
Soil greenhouse gas contributions to anthropogenic emissions, in CO_2 equivalents [101]	25%

†Rate of land lowering due to chemical and physical weathering losses.

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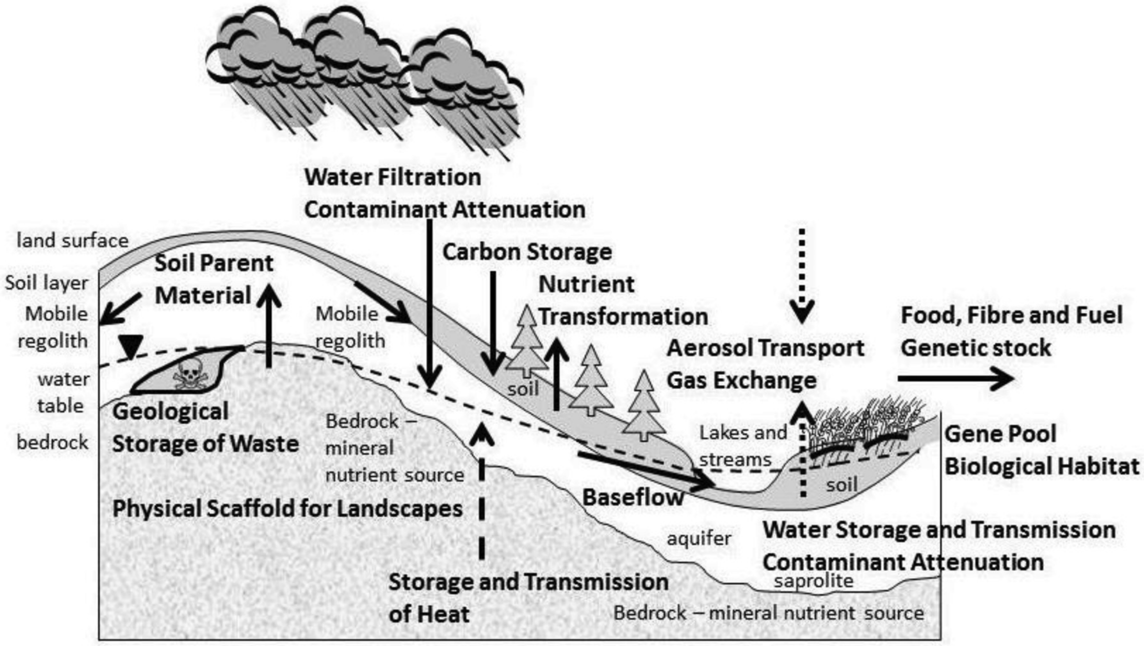

Figure 1. Soil functions and ecosystem services are at the heart of Earth's critical zone. Reproduced with permission from [12].

Outcomes

■ Working session 1 – soil carbon, a critical natural resource: Wide-scale goals, urgent actions

There are many goals and actions that must be addressed to meet the growing human demands for food, water, energy, climate change mitigation and biodiversity in the coming decades. Soil organic carbon (SOC) is central to these being a potentially important determinant of the maintenance, buffering and enhancement of the supply of many ecosystem goods and services under changing socioeconomic and environmental conditions (Figure 2).

We must learn from the past where a focus on single services led to significant reductions in the supply of other services [13]. Focusing land management on a range of benefits rather than a single one can minimize trade-offs and maximize the synergies. Thus restoring, increasing or protecting SOC could play a major role in buffering ecosystem goods and services in the future.

One view of interactions is that each essential service has an optimal operational range of SOC (Figure 3). The 'window for a sustainable livelihood' is defined by the optimum range of soil carbon adequate to supply all essential services. Currently, we are operating at SOC levels far below these windows, as demonstrated by global losses of biodiversity and problems with water quality and quantity [14].

In the next few decades, an increase in SOC has the potential to improve the five essential ecosystem services (Figure 2). However, this potential is dependent on time and is constrained by varying factors (Figure 4). It is known that under given climatic, substrate, relief and hydrological conditions there are biophysical limits to how much carbon a soil can store. However, there is little information on the inherent capacity of many soils to sequester carbon since native reference soils no longer exist. In contrast, economic drivers may rapidly change the crops being grown or the land use type (e.g., forest to grassland) with potentially grave consequences for the soil carbon balance. In view of the various constraints, a research management plan must be implemented along with management actions to monitor and adapt practices and goals according to site-specific conditions at different spatial and temporal scales. Therefore, there is a need to create a global research programme to reduce the uncertainty associated with SOC management across terrestrial ecosystems.

The overall priority is to stop losses of SOC in terrestrial ecosystems, especially in ecological hotspots and carbon-rich soils. First, we need to better understand recovery rates of soil carbon as these are usually non-linear (i.e., have hysteresis effects) making it difficult to forecast the future effects of a decision/management made today. Second, research efforts

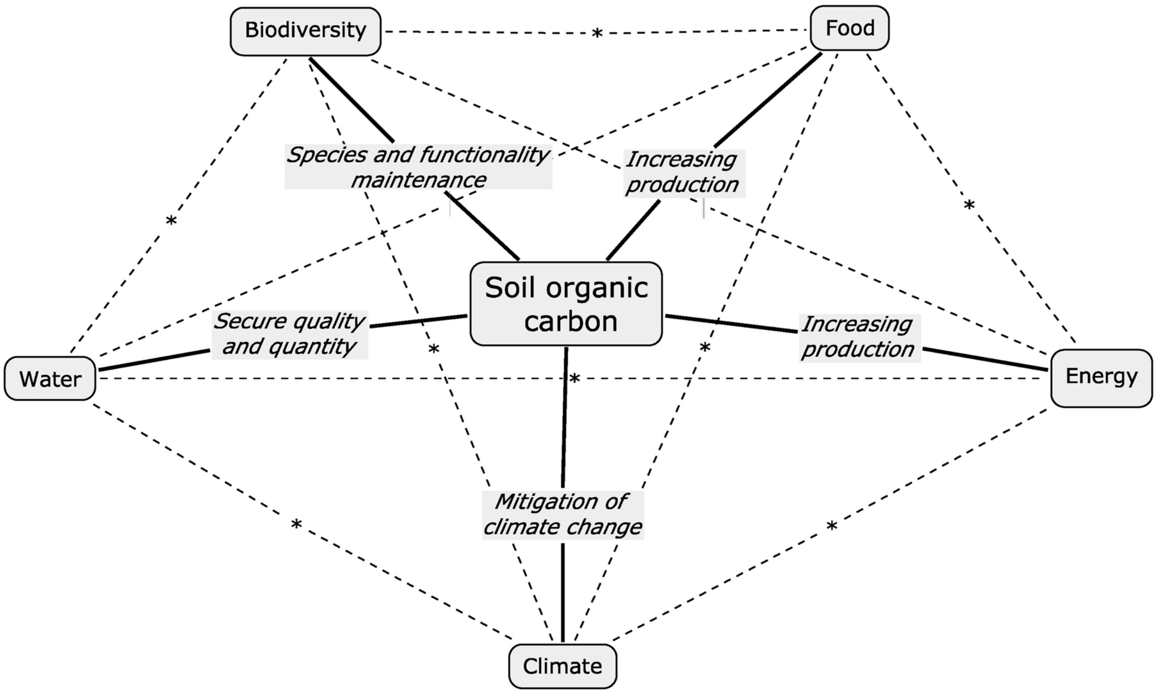

Figure 2. Interactions between soil organic carbon and the five essential services. Reproduced with permission from [21]

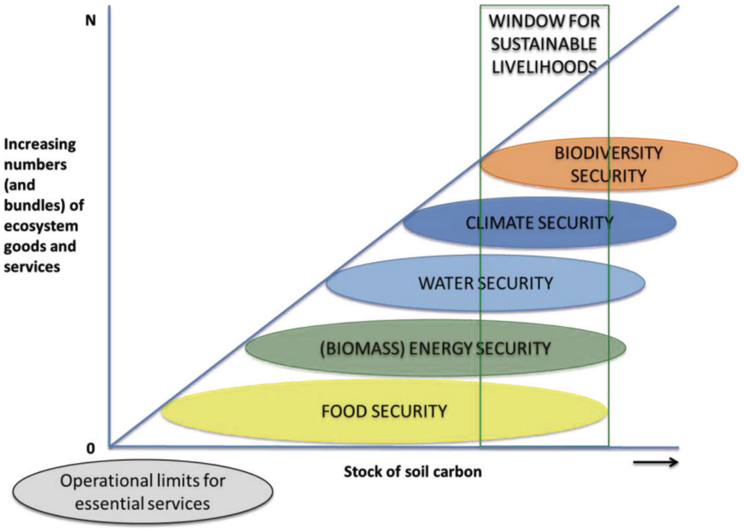

Figure 3. Conceptual representation of operational ranges of essential ecosystem services in relation to soil organic carbon stocks. The axes represent the potential maximum capacity for soil carbon or ecosystem goods and services as these are finite. Reproduced with permission from [21]

should focus on how to optimize the benefits of soil carbon across various spatial scales where management strategies vary at the farm/plot-, catchment-, and global-level. Third, there is a need to identify the critical ranges/thresholds of SOC losses and recoveries for management purposes and to include the ability to estimate the economic value of investments in soil carbon. All these fundamental research priorities must inform public and economic interests and provide information for policy and actions towards reducing soil carbon losses. Finally, the realization of these priorities will not be possible without committed long-term funding and support from national research agencies and international organizations (e.g., World Bank through the CG funded programmes).

■ Working session 2 – reversal of land degradation through management of soil organic matter for multiple benefits

Worldwide there are two situations which have the highest potential for sequestering carbon in the soil. The first situation is degraded agricultural lands in semi-arid climates that were originally grasslands, savannahs or tropical dry forests. The second situation is tropical wetlands or peats that have been drained and cultivated. For example, in the semi-arid agricultural lands of North America, the SOC content diminished by on average 50% during the arable agriculture period. Similar consideration is valid for arid land in China, Mongolia, Russia, Africa and South America. Despite the inherently low carbon contents of their soils, dry lands represent 41% of the global

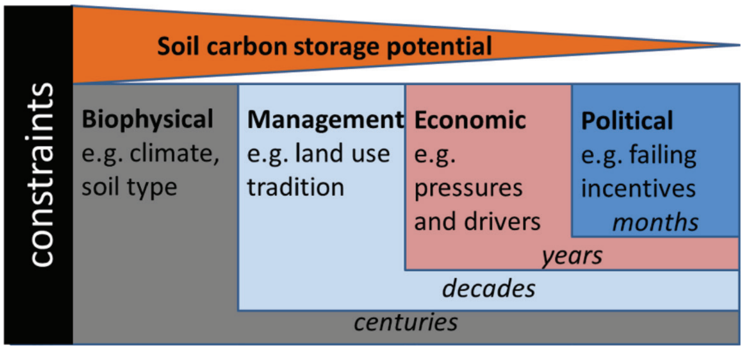

Figure 4. Main constraints to soil carbon accumulation and the timeframes over which these may be addressed. Reproduced with permission from [21]

land area. These regions therefore collectively represent the highest potential for carbon sequestration, and good agricultural practices are at the core of realizing the potential to sequester carbon in semi-arid arable lands.

Organic matter plays a catalyzing role for the maintenance of soil structure, nutrient turnover and other soil functions. The fundamental strategy of restoring soil functions is based on agro-ecological land care practices that entail carbon additions. These additions can be either through aboveground vegetation or through inputs from urban and industrial organic waste. Typically, soil ecosystems are restored naturally unless they have passed a tipping point. However, this process can take decades [15] or centuries [16]. Reversing the degradation trend and enhancing soil ecosystem services requires significantly higher additions of organic matter and in most cases the process of restoration will not achieve the original level of carbon stocks [15].

The ‘yield gap’ is the difference between the theoretical plant physiological maxima for production in the absence of environmental limitations and that which is achieved with help of the best available technology. Current climate-adjusted yields for rice in southeast Asia, rain-fed wheat in central Asia and rain-fed cereals in Argentina and Brazil are all in the order of 60% of the theoretical maxima [17]. To address resultant food security issues, increasing SOM while adapting crop technology and production methods offers multiple synergistic benefits: the benefit of enhanced nutrient supply to crop plants; improved water use and water quality management; energy and carbon inputs to support soil biodiversity; the buffering role to help mitigate negative impacts of fluctuations in environmental conditions such as extreme weather events and pest infestations; reduced soil erosion; and the co-benefit of storing carbon thereby sequestering CO_2 from the atmosphere.

■ Working session 3 – from potential to implementation: an innovation framework to realize the benefits of soil carbon

Figure 5 presents a conceptual model of the change of SOC through time based on the so-called ‘soil carbon transition curve’ showing the soil carbon decline during conventional agricultural land use and its restoration using carbon sequestration techniques.

Despite the knowledge we have about how to technically enhance SOC in different land systems, why such knowledge is not being sufficiently put into practice? The key reason could be the mismatch between private and social benefits and the costs of SOC management across temporal and spatial scales. Most of the SOC benefiting management actions at the local scale are complementary at national and global scales and can simply be aggregated. If all single farms are prosperous, the catchment and the nation are also prosperous and vice versa. However, some soil ecosystem functions become meaningful only at a larger scale such as climate change mitigation by avoiding SOC losses, reducing GHG emissions and sequestering SOC. Such goals can be achieved only when implemented at many farms simultaneously because a single farm has a negligible effect on the global level where ‘climate’ operates.

Interestingly, the current best practices (both biophysical and socioeconomic) that are applied by the different actors occur at the lower scales and are

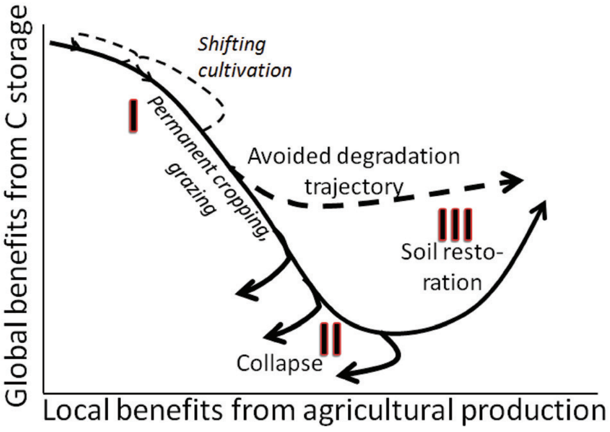

Figure 5. The soil carbon transition curve. (I) Soil organic carbon decline due to land use, (II) collapse of ecosystem services due to soil organic carbon depletion and (III) restoration with application of standard widely known and tested sequestration techniques. Reproduced with permission from [22]

mostly related to biophysical/technological innovations. Fewer best practices are found as we move upwards in the spatial scale. However, innovations are particularly needed to bridge the current incompatibilities between short- and long-term objectives. Such innovations need to be not only of a technological nature but also social. The latter mainly being related to new types of governance structures in the public and private sectors so that policies at higher spatial levels, in governments or companies, filter down effectively towards the lower scales and ultimately reach the consumers and the farmers who can effectively bring about SOC sequestration.

■ Working session 4 – a strategy for taking soil carbon into the policy arena

It is imperative that issues involving SOC must achieve a higher policy profile, and what needs to be achieved by policy is summarized in Table 2.

The multiple benefits derived from SOC interact at scales beyond the individual farm, and therefore should be addressed and remunerated through public incentives at scales ranging from the catchment to the nation. Soil is part of the natural/cultural capital which, together with productive and social capital, forms the wealth of a nation. A more immediate way of considering the benefits of SOC is the value that is attributed to it by people through their willingness to pay for the goods and services that flow from it [18]. A positive experience of trading SOC on the international markets comes from the first agricultural SOC project in Kenya where smallholders use the sustainable agriculture land management (SALM) methodology from the verified carbon standard (VCS) to certify C credits, which are currently purchased through the World Bank Biocarbon Fund.

The World Overview of Conservation Approaches and Technologies (WOCAT) provides a global database

Table 2. Components of a policy process to raise the status of SOC.

		Scale level		
Section		**Local**	**National**	**International**
Policy (what?)	2.1 Policy imperative (build-up and maintenance of SOC)	Agro (urban)-ecological alternative North: Sustainable land management South: Increasing productivity/fertilization	North: SOC into NAP South: SOC into NAMAs	Sustainable development Climate (UNFCCC)
	2.2 Policy profile and discourse (raising awareness)	Adapt to local socio/cultural context Education	Value of SOC Regional patterns	Include SOC in sustainable development (main streaming) Hyperbole
	2.3 Policy rationale (economic/social benefits, soil as a capital)	Develop strategy for livelihoods	Multiple benefits	Maintaining SOC for future generation
	2.4 Policy support (tools and programmes)	Best practices demonstrated at local level (e.g. WOCAT) Field scale SOC models (e.g. Comet VR, cool farm) Smart phones	Soil monitoring networks Modelling tools GEFSOC Google maps	Harmonization SMNs Develop research to valuate soils/SOC
Actors (who?)	3.1 Advocates and institutions	Farmers' organizations, CBOs, NGOs	Cross-compliance ministries, focal points, NARS	Global conventions and partnerships, International NGOs UN, GEF, GM World Bank, FAO, IFAD
	3.2 Governance	Agricultural extension Conservation districts	NAMA's labels and markets Carbon foot print Soil certification	Conference of parties

NAMA: nationally appropriate mitigation action; NAP: national action plans; SOC: soil organic carbon; WOCAT: world overview of conservation approaches and technologies.
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for storage, searching and exchange of land management practices for soil and water conservation and sustainable land management [102]. The FAO's MICCA (Mitigation of Climate Change in Agriculture) programme includes activities and resources relevant to SOC at the local level [19]. Other programmes include the IPCC's emission factors database, which is a repository for site-specific stock change and emission factors needed to make estimates of changes in C stocks in both biomass and soils, and the FAO's Harmonized World Soils database includes local-level information on SOC stocks.

Globally, there are many programmes considering SOC, for example, the European Soil Portal of the EC Joint Research Centre [103], which provides maps of organic carbon content in the surface horizon of soils in Europe [20], and the Global Soil Partnership [104], which is a major international initiative that has recently produced an analysis of state of the art of soil information, including information on SOC. Another example is a new network for francophone Africa, which aims to exchange information on SOC storage and methods to achieve this [105]. A global consortium has been formed to produce a digital soil map of the world at fine resolution [106]. Finally, the Global Soil Biodiversity Initiative aims at developing a coherent platform for promoting the translation of expert knowledge on soil biodiversity into environmental policy and sustainable land management [107].

Local entry points to identify innovative practices, advocate their dissemination or simply raise awareness range from individual to unions of farmers at different scales. Organizations, cooperatives and value chain federations constitute key institutions at the local level. At the national level, the best entry point should include ministries involved in agriculture and forestry, but also in environmental management.

SOC is now recognized as a global environmental issue and policies should capitalize on UN institutions that promote SOC sequestration. At present, most UN agencies are promoting convergent strategies, for example, the climate-smart agriculture initiative and the Global Donors Platforms for Rural Development [108].

Environmental governance may be defined as the rules, practices and institutions for the management of the environment and the standards, values and behavioural mechanisms used by citizens, organizations and interest groups for exercising their rights and defending their interests in using natural resources. Good environmental governance takes into account the role of all actors that impact the process. SOC is often privately managed but has impacts on atmospheric C that is unambiguously global. This planetary dimension requires a collective management approach with governance arrangements that are targeted for different stakeholders at different levels. Governance structures must embed SOC in all levels of decision-making and action. The principal actors involved are land users as the immediate guardians of SOC, local professionals, local government and NGOs. Good governance by nation states has a pivotal role both in filtering down to the local level and aggregating up to the global and international levels.

Conclusions

The outcomes of the discussion in the four working sessions showed that although there is an urgent need to improve soil carbon management and stocks, and despite the existing knowledge about good agricultural practices to achieve this goal, these are not put into practice effectively and globally. The apparent contradiction has to do with a mismatch of policies at different societal and geographical scales, and the low policy profile of SOC. All participants agreed in the need to bring SOC into the core of environmental policies at all levels and to improve the governance of policy actions by addressing the stakeholders in a more effective way.

Financial disclosure

The main financial support for the realization of the workshop was received from The University of Sheffield, the USA National Science Foundation and the EC JRC at Ispra, Italy.

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