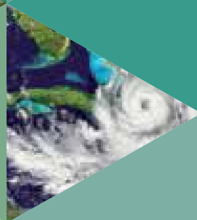
INTEGRATED RESEARCH TOOLS AND STRATEGIES

FOR SUSTAINABLE MANAGEMENT OF HEALTH, FOOD SECURITY, NATURAL RESOURCES, ECOSYSTEMS, BIODIVERSITY AND CLIMATE CHANGE



SCIENCE EUROPE
Life, Environmental and Geo Sciences Committee

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Science Europe is an association of major European Research Funding and Research Performing Organisations, founded in October 2011 and with an office based in Brussels. It supports its Member Organisations in their efforts to foster European research and to strengthen the European Research Area.

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Further information:
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INTRODUCTION

Our planet provides countless natural resources, including water, fuel, air, soil, minerals, food, and sources of medicines. Wasting them poses a great challenge to preserving our natural environment in the face of a growing consumptive population. Combining sustainable living with economic growth might prove to be one of the most difficult tasks for many years to come. The future needs of mankind must be met whilst conserving the planet's natural resources and adapting to various effects of climate change. In response to these challenges, the Science Europe Scientific Committee for the Life, Environmental and Geo Sciences outlines its opinions on the way forward, leading to innovation in science and technology that can contribute useful tools and solutions for research and sustainable management of natural resources.

This brochure contains four chapters dedicated to several topics also included in the current European Union research and innovation framework programme, 'Horizon 2020', and which encompass food security and health, management of natural resources, ecosystems and biodiversity, emerging geohazards, and climate change. These domains of science are often treated as separate disciplines at the level of scientific endeavour and policy. The Committee stresses the fact that fostering multidisciplinary approaches to research, and creating synergies between different disciplines and across basic and applied research, will become essential to achieving success when dealing with future global challenges.

The Committee hopes that the content of this brochure will inspire researchers, and research policy organisations when shaping future research agendas and science policy priorities. Together, the chapters contain opinions on research priorities and innovation strategies in science and technology, aimed at improving the world's resilience to future impacts of global environmental changes. Establishing robust research infrastructures will play a crucial role in 'Big Data Science' developments dedicated to in-depth understanding of complex living systems. The Committee recognises that the challenge of achieving sustainable development will require fostering of international research collaborations on global issues.

Professor Dirk Inzé

Chair, Scientific Committee for Life, Environmental and Geo Sciences, Science Europe

HOW CAN FUTURE FOOD AND HEALTH DEMANDS BE MET IN A SUSTAINABLE MANNER?

© Department of Plant Systems Biology, VIB/UGent, Belgium

WHAT ARE THE CHALLENGES?

Traditionally, food and health have been treated as distinct scientific disciplines both at the level of science policy and in terms of scientific endeavour. This hampers the development of synergies between these two disciplines, and impairs innovative approaches to joint issues emerging in these fields.

While it is estimated that by 2050 global agriculture production will need to increase by at least 70% in order to feed the world's population, the World Health Organisation warns that the main future mortality risks will include excess weight and obesity, high blood pressure and glucose levels, and insufficient physical activity. Hence, the future challenge is how to provide sufficient, safe and nutritious food for the global population. Moreover, the current agriculture and forestry practices have already resulted in major degradation of the environment and soil resources. Future agricultural production calls for sustainable management of resources for the benefit of both the environment and public health.

The future challenge is how to provide sufficient, safe and nutritious food for the global population

Another challenge is represented by the need to provide global food security and to reduce other health-related risks. As food is produced and distributed all over the world, labelling, tracking and tight pathogen control become of paramount importance in health management of food production and in handling possible contaminations occurring in the food chain. The future food supply chain will need to mitigate losses due to various consequences of climate change, as extreme weather conditions such as heat and drought will exert a negative impact on the overall global crop production. In this context, there is insufficient understanding of how plants adapt to environments that are changing as a result of climate change. This, in turn, hampers the development of new generation crops, which are able to tolerate more extreme climatic conditions and which are expected to provide higher yields in order to feed a growing global population.

It is important to keep in mind that there is a gap between experimental research done using model plants and the actual translation of these results into real commercial crops. Future crops should be grown in field conditions and under simulated changing climates. The generation of improved crops with higher yields, stress tolerance, disease resistance and more efficient uptake of nutrients needs to make use of the entire panoply of tools, ranging from marker-assisted breeding to genetic engineering.

Food and Health as a Single Complex 'Life Science System'

The above-mentioned interdependencies of food and health can be efficiently addressed if changes in science policy, science programmes and science education are implemented, bringing together research on food and health as a single complex 'life science system'. Currently, insufficient integration of data and restricted convergence of disciplines are among the main obstacles. Despite the enormous amounts of data being generated, the basic understanding of how molecules, cells and organisms relevant for food and health are connected and operate as an integrated system is still largely lacking. The traditional ways of performing research in silos, restricted to separate disciplines, hamper the provision of integrated data and models that are able to describe systems, rather than single events. In the life sciences, few have been trained to work in large teams because the existing structures of education, funding, publication and promotion impede collaborative research. The complexities of an integrated 'food and health system', where various issues from health, to environment, to climate change and agriculture come together, exceed the expertise of a single scientist.

The current generation of 'Big Data' holds the promise of accelerating the understanding of various processes and systems in life sciences. However, researchers underline that collection of data by itself is only a partial contribution to generating actual knowledge. The real progress is expected to come only through creating and funding new 'Big Data Science' that will carry out meaningful interpretations of produced data.

Several Obstacles to Overcome

Solving complex scientific questions requires multidisciplinary effort and the convergence of various disciplines. Another challenge in knowledge generation and innovation is that the existing funding schemes often have unrealistic timelines for expected deliverables generated from scientific discoveries, and therefore limit the time required for validation of the results and exploration of new directions.

Finally, the societal impact of expected scientific advances is greatly diminished if their implementation is not accepted by the public. Growing public mistrust,

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combined with hesitation shown by policy makers when confronted with new technological advances in scientific research, have led EU countries to lose ground in biotechnology related to food production and health. There should be further investment in efforts enhancing the communication between the research performers and the general public, as well as the policy makers. Evidence-based and transparent science communication can help researchers in building public awareness about the benefits, safety aspects and impacts of new technologies on environment, health and daily life.

THE WAY FORWARD

The Committee identifies the following actions as those which need to be addressed by the scientific community:

- Advancing the management of food security so that it includes increasing agricultural productivity in combination with optimising the entire food chain. This includes: improving access to safe, healthy and nutritious food, optimising diets, and reducing waste in food production, thus diminishing its detrimental effects on the environment. These activities should encourage synergies between research in agriculture and other disciplines, including life, health, and environmental sciences.

- Planning future agriculture strategies that take into account the effects of climate change, and estimate the adaptability potential of crops to changing conditions and demands, by:

- Developing improved crops with higher yields and generating novel crops for future climates, such as crops with improved stress tolerance, disease resistance and more efficient nutrient and water use;
- Fostering the development of various technologies, such as marker-assisted breeding, genome editing and genetic engineering;
- Exploring the world's existing genetic resources and agrodiversity;
- Combining best practices in organic and conventional farming, as well as the deployment of precision agriculture;
- Facilitating modern plant research that is performed directly on commercial crops, preferably grown in field

conditions and in simulated future climates; and

- Implementing across Europe 'safe harbours' for research in biotechnology and field trials, where next generation crops developed in greenhouses could be validated in real field conditions representing different climates.

▶ Facilitating the transition of research towards 'systems science', by:

- Considering that individual biomolecules, cells and species need to be studied in their functional context – that is, the cell, the organism or the ecosystem – and that this is essential for food and health programmes. This new perspective is aimed at understanding the fundamentals of life at the cellular and molecular level; and
- Advancing the development of mathematical algorithms and computational methods for integration of data towards the 'systems approach' between life sciences and other disciplines, including health, agriculture, environmental, and geosciences.

▶ Closing the gap between data generation and actual new knowledge by:

- Creating electronic infrastructures (e-infrastructures) enabling the management of large volumes of complex and heterogeneous data;
- Developing new algorithms to generate knowledge from Big Data;
- Supporting the funding of multidisciplinarity and 'Big Data Science' projects dealing with data interpretation; and
- Introducing innovative transfer media and information technologies for improving implementation of integrated knowledge.

▶ Training scientists for the new tasks by fostering the implementation of multidisciplinarity in education and experimental work, as currently this approach is far from being successfully implemented.

▶ Preparing the general public and policy makers for innovation in food and health research, by developing evidence-based communication strategies that build trust and demonstrate the potential benefits arising from food and health research for society at large.

▶ Maintaining and strengthening basic research as the foundation of knowledge and innovation, by:

- Supporting basic and applied research in a balanced way, keeping in mind that deep innovations come from basic research in unanticipated ways, leading to practical applications; and
- Developing funding schemes that incorporate both short- and long-term goals in order to support a sustainable approach to research that includes risk and impact assessment studies.

HOW DO WE USE NATURAL RESOURCES AND MITIGATE IMPACTS ON ECOSYSTEMS AND BIODIVERSITY?

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WHAT ARE THE CHALLENGES?

As stated previously, the sustainable management of the Earth's geo-resources is one of the major challenges for the future. There is also a rapidly-increasing demand for critical metals such as indium, germanium, tantalum, platinum-group elements, tellurium, cobalt, lithium, and gallium, as these minerals are key components used for technologies in areas of renewable energy and energy efficiency.

Responsible planning and management of these resources require that the supply of geo-resources must be secured on a long-term basis, in order to satisfy the ability of future generations to meet their needs. This implies a balanced use of conventional and alternative resources, whilst taking into account aspects of availability, affordability, and different impacts on the environment.

Other essential geo-resources that are becoming increasingly under pressure are diverse soils and water. These are indispensable for agriculture,

food processing, energy production, extraction of minerals, functioning of ecosystems and human well-being.
In the long-term they must be managed in a sustainable way, since they are crucial for a variety of human activities. Due to current resource-intensive economic activities, soils and water have already been severely depleted, degraded and contaminated. Hence, the main challenge is how to manage them more efficiently in the future, in the context of a global population that is expected to reach around eight billion by 2025.

Degradation of Ecosystems

A similar question emerges for ecosystems, their services and biodiversity. The main contributors to their degradation include extensive exploitation of land, the use of pesticides and fertilisers, waste from livestock production, and resource-intensive extraction of geo-resources. Biodiversity encompasses the variety of ecosystems, genes and species that surround us, and provides populations with a wide range of services upon which we depend. Besides water and soil, ecosystem services include food, pollination, carbon sequestration, recreation and protection against natural disasters such as floods, landslides, and soil erosion. Currently, the ecosystems are degraded to the point where they are no longer able to deliver their valuable services; indeed, it is estimated that a quarter of animal species are already threatened with extinction. Conservation efforts and sustainable management of these natural resources need to be further strengthened. Biodiversity loss is mainly caused by the invasion of alien plant species and by the consequences of human activity, such as the release of greenhouse gases. Ecosystems such as forests and other wooded land are subjected to multiple pressures and suffer a series of damages from living and non-living chemical or physical factors in the environment. In addition, the impact of climate change on animal and plant species is expected to exert pressure on their phenotypical or genetical adaptability to changing conditions, of which we currently have limited understanding.

The Potential of Biofuels

The bioenergy sector can provide examples of new technologies which offer the possibility of reducing the negative effects of greenhouse gases on the environment, and help cope

The use of advanced biofuels as energy sources has great potential to reduce greenhouse gases

with the impacts of climate change. This is especially important given that, according to the International Energy Agency, world primary energy demand will increase by an average of 1.2% per year until 2035. Therefore, the key challenge is how we meet such demand.

The use of advanced biofuels as energy sources has great potential to reduce greenhouse gases. The advantages come from the fact that the carbon dioxide released by biomass burning is approximately equivalent to the carbon dioxide absorbed by plants during their growth. However, recently the explosive expansion of first generation biofuels derived from vegetable oils and carbohydrates such as sucrose and starch has exposed a major conflict between agriculture for food production and agriculture as a source of energy. High prices of fossil fuels and subsidies for biofuels have started to jeopardise the availability of fertile land for crop production. Growing biomass for biofuels has become more profitable than producing food. This tendency has major negative implications for food security and the environment, and therefore should be reversed in the future. Nowadays, research efforts are dedicated to the development of second generation biofuels with the aim of avoiding competition with crops and the destruction of natural habitats. These new biofuels could be an important breakthrough as they are derived from a non-food biomass.

THE WAY FORWARD

All things considered, there is a need to develop a sustainable economy that facilitates ecosystems and biodiversity recovery processes. There should be alternative routes for food and energy production as well as the extraction of natural resources, whilst mitigating the effects of climate change. The sustainable future approach to those challenges should include the following:

- Advancing the understanding and the deployment of best practices for the efficient and sustainable extraction of natural resources, such as natural gas and unconventional gas.

- Improving monitoring and modelling capacity for:

- An integrated spatial assessment of soil and water; and

- A meaningful on-site and remote sensing detection of the status of soil and water resources globally and regionally.

- Building adequate infrastructures for sustainable exploitation of natural resources.

- Deploying best practices and effective methods for the use of soil and water, whilst taking into account the degree to which their exploitation affects the environment, by:

  - Advancing technologies for cleaning and recycling urban residues, water and waste from nanomaterial, micro plastics, hormones and pharmaceuticals, as well as for the recycling of critical metals;

  - Investigating carbon fluxes, and the phytoremediation capacity of plants in relation to air, water and soil contamination; and

  - Developing robust quantification methods for soil fertility.

- Advancing the development of second generation biofuels as sources of energy, avoiding completion with food production and safeguarding natural habitats, by:

  - Using non-food ligno-cellulosic biomass (for example poplar trees and fast growing grasses), algae, and biowaste from marginal infertile lands as fuels; and

  - Recycling and using charcoal (biochar) from thermochemical extraction processes of biomass as a source of fertiliser.

- Increasing efforts in understanding the role of terrestrial ecosystems on biodiversity, whilst taking into account different scales and impacts of living and non-living stress factors in the environment and the role of forests in biogeochemical cycles.

- Strengthening the concept of ‘Green Infrastructure’, which focuses on ecosystem services provision and on the idea that its infrastructure serves the interests of both people and nature.

- Investigating the evolutionary potential and adaptability of the species gene pools to respond to changing environment and climate.

- Increasing the importance of the urban-rural interface as an area of great interest for future research, conservation and valorisation.

- Linking up research efforts in the natural and environmental sciences with social sciences and humanities.

HOW DO WE MITIGATE THE OCCURRENCE OF GEOHAZARDS?

WHAT ARE THE CHALLENGES?

Well-known natural (geo) hazards such as earthquakes, volcanic eruptions, landslides, tsunamis and flooding exert detrimental impacts on the environment, agriculture and other human activities. Tsunamis may arise from strong earthquakes of a specific type, involving vertical motion of the seafloor, but also from major-size landslides in marine surroundings, generated from the collapse of volcanic islands or continental margins.

The European continent encompasses several countries distinctly prone to geohazards, notably Greece, Turkey, Italy, Spain and others in the Mediterranean area. While outside the Mediterranean region, and within the interior of the European continent, strong earthquakes are less frequent, historical records indicate the existence of several high-magnitude events in the past. The occurrence of large landslides can be observed at the Atlantic margin of Norway.

The recent activity of one of Iceland's volcanoes is vividly remembered for its near-global impact.

One of the main challenges in geohazards detection and surveillance in Europe is represented by very long recurrence time intervals between the major earthquakes or volcanic eruptions in comparison with some regions bordering the Pacific Ocean. These time intervals can often be in the range of a few decades, hundreds of years, or even thousands of years according to recent studies. Hence, studying the occurrence of geohazards involves a wide spectrum of spatial and temporal scales that have to be taken into account. Geo-processes taking place very deep in the Earth can also contribute to near-surface processes, including those associated with natural hazards or geohazards.

Synergies between Disciplines

Recent advances in geosciences gave rise to a new approach known as 'Earth System Science', where traditional boundaries between disciplines are crossed. Hence, nowadays geology, geophysics, geochemistry, geodesy and others are increasingly integrated. Typically, while the geosphere/lithosphere (the 'Solid

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Earth') plays a key role in the deep processes underlying earthquakes and volcanic eruptions, atmosphere and hydrosphere are involved in the formation of flooding. This integrated strategy facilitates synergies between disciplines and helps to mitigate various impacts of geohazards, increasing understanding of underlying processes by applying a multi-disciplinary and multi-scale approach. In addition, building and maintaining robust observational, analytical, experimental andcomputational resources will contribute to the reinforcement of a strong position for European geosciences. This, in turn will place European efforts in the forefront of international developments in research dedicated to geohazards, energy and natural resources. Therefore, a joint approach to pan-European and international collaboration is needed in order to cope with the societal challenges related to the global aspects of geohazards. The geosciences community in Europe needs to develop collaborative actions for joint programming initiatives and to establish internationally-co-ordinated research infrastructures with access across borders.

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Pan-European and international collaborations are needed in order to cope with the societal challenges related to the global aspects of geohazards

THE WAY FORWARD

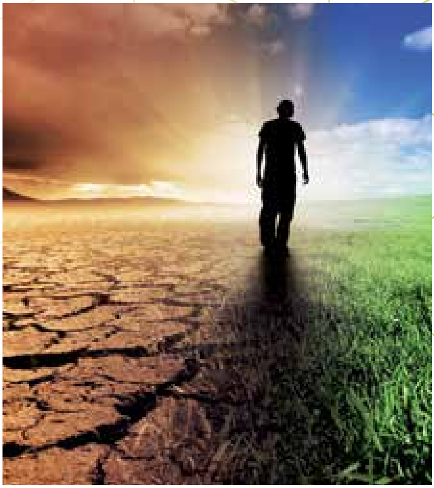
The Committee identifies the following actions as those which need to be addressed by the geosciences community and the funding institutions:

- Investing in efforts towards increased understanding of the processes underlying geohazards.
- Advancing computational methods that allow a quantitative modelling of the Earth System.
- Building robust research infrastructures to monitor the Earth's structure, enabling research in earthquake dynamics, volcanism and tsunami generation.
- Deploying robust systems for monitoring the deformation and velocity field of the Earth's crust of seismically active regions, individual volcanic edifices, and other hazard-prone areas. These efforts should include high-precision Global Positioning System (GPS) and other satellite-geodesy measurements, which in turn will provide first-order information on the building-up stage of future events and their potential magnitudes.
- Developing long-term monitoring programmes, allowing for the advancement of warning systems as a contribution to a safe and sustainable Earth.
- Fostering European and international collaborations needed to maintain and strengthen the role of geosciences in the international research arena. There is a need for European geosciences to embark on internationally co-ordinated and targeted research programmes with top-level infrastructure.

WHAT CAN RESEARCH DO TO HELP US DEAL WITH CLIMATE CHANGE?

WHAT ARE THE CHALLENGES?

The surface of the Earth has already experienced a temperature rise approaching 1°C from anthropogenic greenhouse gas emissions. Although warming has slackened in the last decade, this is almost certainly temporary. It is argued that the 'missing' temperature rise in the atmosphere is due to extra uptake of heat by the oceans.



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The challenge is that the future temperature increase will be characterised by very considerable spatial variability, with some places experiencing significantly larger temperature increases than indicated by the average. Similarly, rainfall, sea-level rise, storms and other extreme weather events that are expected to intensify will not be evenly distributed in space and time. Moreover, the rate of melting of the grounded polar ice caps of Greenland and Antarctica remains uncertain due to insufficient knowledge of the melting rates forecast under various global warming scenarios.

The oceans act as sinks, absorbing the most important greenhouse gas: carbon dioxide. There is some evidence that this capacity has decreased in recent years, taking as examples the North Atlantic and the Southern Ocean. Here, the difficulty is to understand what factors control this uptake and how the size of the sink may vary in the future. In addition, the increasing levels of carbon dioxide absorbed by oceans are known to have negative impacts on marine organisms, from plankton up to corals reefs. Furthermore, the circulation of North Atlantic that is involved in climate control has shown to have considerable year-to-year variability. This poses obstacles in modelling how the circulation may change in the future, as atmospheric carbon dioxide levels continue to rise, with concomitant uncertainty about climatic impacts in the long run.

Both Mitigation and Adaptation will be Necessary

Besides the oceans, terrestrial ecosystems also play an important role in absorbing carbon dioxide. Here the hurdle is to understand their role in relation to changes in climate and atmospheric pollution, as well as to identify the adaptation mechanisms of ecosystems to possible threats, especially in the most vulnerable areas. Air pollution is arguably the most crucial threat in urban and rural environments. However, reduction of greenhouse gas releases is the key factor for addressing climate change globally. Moreover, the current rate at which mankind appears to be able to moderate emissions of carbon dioxide, methane, nitrogen oxides and ozone is not great enough to mitigate their impacts on climate change. For these reasons, adaptation to ameliorate the worst effects of climate change has to be considered. It should also be noted that adaptation alone will not deal with issues such as ocean acidification, which are directly caused by carbon dioxide increases.

Given the scale of the problem, both mitigation and adaptation will be needed. What is unclear is the most cost-effective ratio of the two in particular circumstances and the optimum pathways to their implementation. If insufficient progress is made, then at some point in the future, and *in extremis,* we may need to use geo-engineering approaches (mega-mitigation) such as, for example deflection of sunlight from the Earth's atmosphere and underground storage of carbon dioxide.

Ozone, another greenhouse gas present in the lower atmosphere above a certain concentration, is harmful to people and other mammals; it also has deleterious effects on plant growth, and hence on agricultural production. Thus, how levels of ozone will change in the troposphere over the rest of the century is an important topic with wide implications for society. This is especially so since key precursors of ozone formation, such as nitrogen oxides, are released by fossil fuel combustion processes.

Moreover, particles in the atmosphere, whether naturally produced or from anthropogenic activities, affect the climate issues of radiation balance as well as cloudiness (and rain), and have significant impact on human health. The formation and role of particles of the appropriate size to form cloud condensation nuclei (and hence clouds) is therefore important in understanding the role of man in influencing future climate.

THE WAY FORWARD

It is clear that research is vital in untangling the complex issues involved in global problems such as climate change. Therefore, the Committee provides the following suggestions on the way forward:

- Advancing research on the physical properties of the oceans, and particularly their ability to store and release carbon dioxide.
- Increasing the modelling capacity of climate forecasts, which need to be more detailed spatially and temporally than is possible at present.
- Continuing the current observational efforts of ocean currents so that a long enough record can be obtained for seasonal and annual trends to be identified. These efforts need to be combined with the development of enhanced numerical modelling.
- Investing in efforts towards a thorough understanding of the ecosystems' mitigation potential for climate change, in order to allow optimisation of management strategies. The desirable approach in such studies requires high-quality data and innovative theories that combine experimental data with the modelling of local and global processes, and the different biological and non-biological components of ecosystems.

- Advancing research dedicated to understanding the interactions between climate change and terrestrial ecosystems, and the role of these systems on the following:

  - Biogeochemical cycles, with a particular focus on carbon;
  - The phytoremediation capacity of plants in relation to air, water and soil contamination;
  - Biodiversity at different scales; and
  - Responses to biotic and abiotic stress and the ecosystem services provided by terrestrial ecosystems.

- Increasing efforts to understand the relationship between natural and anthropogenic precursors of air pollution that, in turn, will allow prevention of high-pollution events and related risks to human health and ecosystems.

- Advancing knowledge related to adaptation mechanisms of various organisms to climate change.

- Involving a whole range of natural and social scientists in the research, working together on global issues and sustainable management of natural resources.

CONCLUSIONS

The current level of human activities and natural variations have a profound impact on many of the Earth's processes, leading to severe global environmental changes such as degradation of the environment, loss of biodiversity, depletion of natural resources, and climate change. Failure to secure natural resources and mitigate the effects of climate change will have serious consequences for future generations. The creation of a sustainable future will require incentives and solutions to complex trade-offs and conflicting demands. A growing global population needs to combine economic development with efficient resource management. Science and technology can provide research tools that reduce vulnerabilities and risks, by enhancing the Earth's resilience to the various environmental and human pressures.

The Science Europe Committee for the Life, Environmental and Geo Sciences hopes that the suggestions in this brochure will be a source of inspiration for researchers, as well as research policy organisations.

Colophon

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