ICSU Foresight Analysis

Report 1 International science in 2031 – exploratory scenarios

ICSU
International Council for Science

ICSU

Founded in 1931, the International Council for Science (ICSU) is a non-governmental organization representing a global membership that includes both national scientific bodies (120 National Members representing 140 countries) and International Scientific Unions (30 Members). The ICSU 'family' also includes upwards of 20 Interdisciplinary Bodies—international scientific networks established to address specific areas of investigation. Through this international network, ICSU coordinates interdisciplinary research to address major issues of relevance to both science and society. In addition, the Council actively advocates for freedom and responsibility in the conduct of science, promotes equitable access to scientific data and information, and facilitates science education and capacity building.

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Report 1: International science in 2031 – exploratory scenarios

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Introduction

Why did ICSU carry out a foresight process?

The purpose of this project was to explore how international science[1] might develop over the coming two decades in a changing economic, social, political and environmental context.

ICSU has used this foresight process to test its role and mission and to guide long-term strategic choices aimed at strengthening international science for the benefit of society. To this end, the conduct of the foresight exercise has been synchronized with the development of the ICSU Strategic Plan II, 2012-2017.

The foresight process was also carried out to produce a resource that ICSU Members and Partners could use to help develop their own long-term vision and strategic thinking with regard to international science.

In its simplest form, this project focuses on two key questions:

- **What will be the key drivers influencing international science in the next 20 years?**
- **How can international science collaboration be supported to help science progress and benefit society in the next 20 years?**

1 It is recognized that "International Science" has been used to describe a broad range of approaches to science - from bilateral to truly global approaches. Fundamentally, such science requires (large-scale) international collaboration of scientists in research and in research infrastructures. The evolving nature of international science is one of the key areas to be explored in this foresight. The term "science" is understood to include all domains of science (i.e. natural, social, human, medical and engineering sciences).

Background to the foresight process

What is foresight?

Foresight comes in many forms. Since 2000, foresight has shifted its focus toward developing shared visions, assembling coalitions of actors and mapping out multiple plausible futures that highlight the uncertainties and underline the need for strategic flexibility. Previously the emphasis had been on explicit scientific priority setting. This new emphasis is the approach taken in the ICSU foresight process.

What are scenarios and how can they be useful?

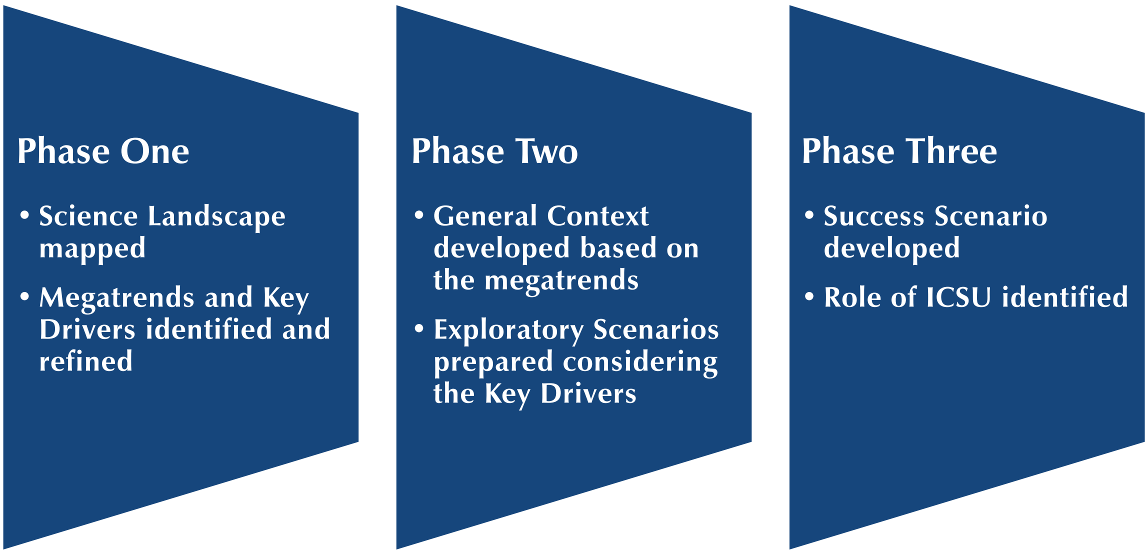
An important part of the process is developing scenarios for describing possible futures. A scenario is a tool for ordering perceptions about alternative future environments in which one's decisions might be played out (P. Schwartz, 1996, in *The Art of the Long View*). Typically, three to five 'exploratory' scenarios are developed, each distinguished by unique combinations of key drivers. The process of building these scenarios provides a structure in which to explore and learn from the interplay of key drivers and their attendant uncertainties. The result is a sense of preferences and what should be avoided. In general, scenarios offer a platform to expose and begin to address differing views among a large community about its shared future. For ICSU, this process will inform on-going strategic choices about its longer term direction.

To connect the exploratory scenarios to ICSU's strategic planning and subsequent actions an additional `Success Scenario` has been developed, reflecting on what was learnt in building and testing the initial exploratory scenarios. This final scenario is the basis for Report Two and explores the ICSU vision for the desirable long-term evolution of international science and of ICSU's role in achieving such a vision.

How did ICSU carry out its foresight process?

The foresight process had three phases.

This first report outlines phases one and two – the development of exploratory scenarios – and the second report presents phase three – the Success Scenario.



The foresight process has been led by ICSU's Committee on Scientific Planning and Review (CSPR), was started in October 2009 and will be completed by February 2012.

On behalf of CSPR, a Task Team of seven advisors has overseen the development and implementation of the process by the ICSU Secretariat. This included expertise in the foresight process and scenario building.

Phase One

In Phase One, the Task Team identified the need for a description of the current international science landscape. Information from the *UNESCO Science Report 2010: The Current Status of Science Around the World* and the Royal Society's publication *Knowledge, Networks and Nations: Global Scientific Collaboration in the 21st Century* was the basis for this.

Phase 1 also involved identifying potential drivers of international science over the next 20 years.

Three primary sources were used: insights from participants at ICSU-related meetings; a web consultation of ICSU Members, bodies, partners and early career scientists (who had participated in a meeting marking ICSU's 75th anniversary in 2006); and a literature scan.

The outcome of the web consultation was 174 separate ideas for drivers from 82 individuals in over 30 countries. The Task Team distilled these and the other submissions into a set of approximately 20 drivers and, after discussions with CSPR in February 2010, further refined this list to those drivers that were highly influential factors.

These were then divided into two categories:

- megatrends - for which trends over the next 20 years are more or less clear, and;
- key drivers - for which trends are more uncertain.

Phase Two

During Phase Two, the Task Team used the megatrends to develop a description, based on an analysis of the scientific literature, of what the world might look like in two decades' time if current trends continue – the General Context. This provided the background in which the influence of the more uncertain key drivers was explored.

The Task Team then used the key drivers to prepare four quite different scenarios considering the ways the key drivers might evolve in the next two decades. These were framed within four distinct 'scenario spaces' defined by two axes:

- whether countries would be more national or internationally oriented, and;
- whether science would act independently or be highly engaged with society.

These scenarios were sent out to ICSU members for comment in January 2011. The comments, and input from CSPR in March 2011, were then used to refine the scenarios.

Phase Three (Report 2)

Phase three, which is the subject of a separate report, was the development of a 'Success Scenario', which is more normative and aspirational but also plausible. This process involved reflecting on the four Exploratory Scenarios and identifying desirable and less desirable aspects and how ICSU might positively influence these.

The current international science landscape

The starting point for the ICSU foresight process was to consider how the international science landscape looks in 2011.

Key Actors

There are broad a range of actors that have important roles to play in organizing the international science landscape. The main areas in which they are operating include agenda setting, resourcing and coordinating the research. There is some overlap in the roles of these various actors across these different areas.

Agenda setting is carried out by intergovernmental organizations (e.g. the United Nations), regional bodies (e.g. European Commission), funding agencies and foundations, industry and professional societies.

Resourcing is done by regional funders (e.g. European Commission), some national funding agencies (e.g. major US agencies), private foundations and big international NGO's and multinational companies.

Coordinating the research is done by international science organizations (e.g. ICSU), international science programmes, national research institutes, universities and multinational companies.

Ultimately it is individual scientists, policy-makers and other societal stakeholders who influence all of these actors and benefit from the outcomes of this international research effort.

Landscape

In 2010 UNESCO published the *UNESCO Science Report 2010: The Current Status of Science around the World*, and in 2011 the UK Royal Society issued *Knowledge, networks and nations: Global scientific collaboration in the 21st Century*. These two analyses give a comprehensive overview of the present international landscape for science and technology. Their main conclusions relevant to this foresight project are:

Science is increasingly global:
This is reflected in the rise of China and rapid developments in India and Brazil. New nations are emerging in the Middle East and South East Asia, and the smaller European nations are strengthening their role. However, the big investors remain the USA, Western Europe and Japan and many less developed countries are struggling not to be marginalized.

A multipolar science world is developing:
The continued strength of the traditional centres and the emergence of new players such as the BRIC countries point toward an increasingly multipolar scientific world.

The scientific world is becoming increasingly connected:
New digital technologies have accelerated the organization of science, making it easier than ever before for researchers to work together. This has been further supported by more extensive and cheaper air travel.

Skilled migration is occurring:
Recent decades have seen significant increase in the global completion for talent. Understanding whether this is brain gain, drain or circulation is difficult as there few data on the factors that influence individuals' choice of location, how long they intend to stay and how they connect back to their home countries. However, brain drain remains a challenge for developing countries, particularly those in Africa.

The primary driver of most collaboration is still the scientists themselves:
However, little is understood about the dynamics of networking and mobility of scientists, how these affect global science and how best to harness these networks to catalyse international collaboration.

Many global assessment and research programmes are managed separately:
This despite the reality that many global challenges are interdependent. This often reflects a lack of co-ordination in the policy sphere.

The role of business in science is growing and transnational:
Spending on research and development by industry in the OECD countries increased from 52% in 1981 to 65% in 2008. From 1993 to 2002 R&D spending by foreign investors in countries grew from an estimated US$30 billion to US$67 billion. At the same time, only 2% of patent applications are from outside of North America, Asia and Europe This pattern is driven by global competition for talent, the result of companies looking outward for new knowledge, and the influence of policies by countries to attract foreign investment. Increasingly multinational companies are decentralizing their research activities, with very significant investment in BRIC countries.

Science is an important part of international diplomacy:
Science increasingly contributes to international diplomacy since the significant issues that societies face are seen as global and science is seen as a key source of information to explain them and suggest solutions. Science is also an important part of national diplomacy for many countries.

How was this information used in the foresight process?

This picture of the current landscape was the starting point for considering what factors might impact on the international science landscape in the coming 20 years. The next chapter identifies the megatrends - those factors for which the main trends are more or less clear over the next two decades.

Megatrends that will influence international science over the coming 20 years

A number of factors will influence the evolution of the international science landscape over the next 20 years. The main directions that some of these will follow are reasonably predictable. They are referred to here as megatrends. (The directions for others are much less certain and they are considered in the next chapter as key drivers).

Megatrends

Demography

The figures for global population growth over the next 20 years can be predicted with some confidence. This overall growth will be combined with a changing spatial and age distribution that will differ across regions. The impacts of migration are less clear than population growth but the overall move from rural to urban areas, especially in developing countries, is a well established trend.

Natural resource availability

Population growth will impact on those resources that are finite. In particular, there will be increasing pressure on water availability, both for drinking and for agriculture. The production of food will be a challenge as the availability of fertile land is limited, a situation that is exacerbated by the degradation of natural ecosystems. There will be increasing demand on finite sources of energy, with fossil fuels having to be extracted from previously unexploited locations. Other rare materials are also being used at rates which are unsustainable.

Global environmental change

The impact of human behaviour on the state of the planet is being increasingly understood and mapped. Data on oceans, ecosystems, the cryosphere and the atmosphere are now available to show what this is likely to mean if environmental change continues at its present rate.

Human health and wellbeing

As the population expands and urbanization increases the prevalence of non-communicable diseases related to sedentary lifestyles and obesity is increasing. At the same time, communicable diseases will remain a challenge and the likelihood of global pandemics may increase as international travel and trade facilitate the spread of infectious agents.

Technological change

The impact of technological change on society is more difficult to predict than some of the other megatrends. However, the exponential increase in the rate of technological change is a pattern that is likely to continue for the next 20 years. Forecasting specific technological developments over two decades is very uncertain but the speed of innovation and change is more predictable.

Enabling information and communication technologies

Information and communication technologies (ICTs) will continue to have a significant impact both in developing and developed countries. Like other technologies the rate of change will continue to increase and new ICTs will surely make a major difference to the functioning of societies over the next twenty years. There will be new ways of communicating and social networking – with implications for science and the production and maintenance of the scientific record.

How was this information used in the foresight process?

These megatrends provide the basis for developing the General Context. This is a description of what is likely to happen in the next 20 years if current trends continue. The General Context is the 'steady state' background all four of the Exploratory Scenarios should operate within.

General Context

> Within 20 years, an increasingly urban world of more than 8 billion inhabitants is projected. Population growth will be concentrated in the less developed regions that are struggling to provide for their current populations. The soaring world population will put further pressure on already scarce resources of water, food and energy, potentially leading to increasing levels of poverty and conflict. New technological advances will assist in overcoming limitations in food production, in providing sustainable energy resources, and in meeting the medical needs of the growing and aging population. However, in spite of medical advances and vaccination campaigns, infectious diseases and global pandemics are likely to remain a serious threat while chronic diseases associated with aging and sedentary lifestyles will certainly be more prevalent. Climate change mitigation and adaptation, fighting pollution and preserving natural habitats and biodiversity will require urgent and concerted action. On a positive note, progress in science has helped societies respond to many challenges in the past, and science and technology retains its promise to do the same in over the coming decades. How the aspiration turns into real capabilities in the inherently unpredictable economic and political context of the future remains to be seen.

The trends in ***population growth*** and urbanization can be predicted fairly well over the next 20 years. By 2030, the world population is projected to surpass 8.3 billion people[1]. Most of the total growth will increase the population in less developed regions. Sub-Saharan Africa, which contains most of the poorest countries in the world, is projected to experience more than a 50 percent increase in population. In contrast, the population of more developed regions is expected to change minimally, further widening the gap between poor and rich nations.

The 2030 population will be more urban than ever before. In 2010, half of the global population is living in cities, although there is considerable variation in the levels of ***urbanization*** across the world[2]. While the more developed regions are mainly urban, major parts of the world in the less developed regions, in particular in Africa and Asia, have remained largely rural. Over the next two decades, the urban population is projected to grow steadily to around 60 percent of the world population, with most of the growth in the less developed regions. Generally, the urban areas are expected to absorb all the global population growth, and to draw in some of the rural population. Rapid urbanization, in particular fast growth of large cities and the associated slum areas, poses specific challenges including transportation, unemployment, poverty, access to clean water and sanitation, access to safe and affordable food, environmental degradation and pollution and related health issues.

Globally, the population aged 60 years or over is the fastest growing[1], and the prevalence of age-related health problems is on the rise. In the more developed regions, the population aged 60 years or over is expected to increase by 40 percent over the next two decades, rising from about 21 percent of the total population in 2009 to almost 29 percent in 2030. The older population of the less developed regions is projected to more than double, with a rise from about 8 percent of the population in 2009 to more than 14 percent in 2030. Although the population of all countries is ***aging***, the population will remain relatively young in countries where fertility is still high. The youngest populations will be found among the least developed countries, mostly in Sub-Saharan Africa. Rapid population growth coupled with a youthful age structure pose challenges for the provision of education, employment, and health and social security services. However, a young population also represents a motor for economic growth, with a larger share of the population making up an active workforce.

On average, the global population will be ***healthier*** and people will ***live longer*** than ever before[3]. Over the coming decades, the general trend of improving health will continue. However, the substantial progress in health has been, and will continue to be, unevenly distributed. While health conditions and life expectancy have improved in most countries, gaps between different social groups have widened and a considerable number of countries are falling far behind. Overall, the ***nature of health problems will change***.

In low-income countries the fight against a number of widespread and deadly ***communicable diseases***[3], including acute respiratory infections, diarrhoeal diseases, tuberculosis, malaria, measles and AIDS, continues. Over the coming two decades, large declines in maternal and perinatal mortality are projected, and reduction in deaths are also expected for nutritional conditions, and for all of the principal communicable diseases, provided that there is continued improvement in the access to treatment. For example, in 2008 there were an estimated 33.4 million HIV infections worldwide, causing an estimated 2 million of AIDS-related deaths[4], mostly concentrated in the least developed regions. With increasing availability of antiretroviral therapy, AIDS-related deaths are projected to decline to 1.2 million in 2030[5]. However, widely spread epidemic diseases and global pandemics remain a threat.

Aging and the effects of poorly-managed urbanization will increase the burden of chronic conditions. Population aging will result in significant increases in most ***non-communicable diseases***, in particular cancers. The four leading causes of death globally (including low-income countries) in 2030 are projected to be ischaemic heart disease, cerebrovascular disease (stroke), chronic obstructive pulmonary disease and lower respiratory infections[5].

Population growth and land-use change will heavily increase pressure on ***ecosystems***. Numerous ***ecosystem services***, that we depend on, are already being degraded or used unsustainably, including fish stocks and water supply[6]. As of today, species are becoming extinct at the highest rate since the last global mass-extinction event[6,7]. The ***conversion of land to agricultural uses*** continues to be the main factor threatening ***biodiversity***, but other factors, such are ***the buildup of nitrogen*** in rivers and coastal waters, ***ocean acidification*** and potential effects of ***climate change***, are becoming increasingly important. Most published environmental change scenarios project continuing high levels of ***extinctions*** and ***loss of habitats***, with associated decline of ecosystem services important to human well-being[6, 7]. If ecosystems are pushed beyond certain ***thresholds or tipping points***, there is a high risk of dramatic biodiversity loss and accompanying degradation of a broad range of ecosystem services[7, 8]. Changes in policy can decrease many of the negative consequences but more drastic interventions will be required to reverse degradation.

On the credit side, total ***food production*** has increased by a factor of about two-and-a-half since 1960. However, this has partly been at the cost of other ecosystem services. Despite increased food production, we are struggling to feed the global population. In 2009, a little over one billion people were undernourished worldwide[9]. To feed the ever growing population, production of safe and nutritious food needs to increase by 40 percent by 2030[10] and pre- and post-harvest loss needs to be minimized by improved food processing, storage and delivery systems. This creates a major challenge over the coming decades. In an increasingly urban world, new technologies will be needed to grow more from less land, with fewer hands[11] and with fewer resource inputs and adverse outputs. At the same time, climate change[12] and increased biofuel production from food cropping land represent major threats for long-term food security.

Inadequate and polluted ***water supplies*** will remain pressing concerns, in particular in less developed regions. Today, 13 percent of the world's population live without access to safe drinking water and 39 percent without access to adequate sanitation[13]. In the absence of new environmental policy actions, almost half of the global population is projected to live in areas of high water stress in 2030[14]. Agriculture is the largest consumer of freshwater; 70 percent of all freshwater withdrawals go to irrigated agriculture. As over the coming decades the food demand further increases, improved water use efficiency will be needed to ensure adequate food production and supply.

Global population growth and urbanization, combined with the needs of emerging economies and the large-scale adoption of certain new technologies, will see increased demand for commodities from the ***mining and metals*** industries. For example, demand for gallium for use in emerging technologies such as thin layer photovoltaics is projected to rise 20-fold from current use of almost 30 tonnes to about 600 tonnes by 2030[15]. Demand for neodymium, a rare earth element used in the strongest known permanent magnets, is projected to rise seven-fold, from the current use of 4000 tonnes to some 28000 tonnes by 2030. Over the coming two decades, geological scarcity is not considered the critical issue; technological developments in exploring, mining and processing mineral raw materials will be the key in keeping up the supply with demand[15]. This is further complicated by the geographical distribution of resources. For example, the worldwide production of a number of critical raw materials needed for mobile phones and emerging technologies such as solar panels and synthetic fuels, is currently concentrated in just four countries: Brazil, China, D.R. Congo and Russia. Other major reserves of raw materials are located in developing regions with unstable political climates and where a lack of infrastructure poses challenges for extraction, processing and transportation[16]. The supply of such materials is particularly vulnerable to changes in geopolitical-economic frameworks. Not surprisingly, the exploitation of natural resources in the Polar Regions is a topic of increasing economic, political and scientific interest and considerable concern.

Currently, approximately 2.4 billion people worldwide lack access to natural gas, propane or other modern fuels, and rely on traditional biomass for meeting their basic ***energy*** needs for cooking , heating[17] and refrigeration. Over the coming two decades, ensuring global energy security, meeting the growing energy needs of the rising economic powers of the developing world, as well as facing climate change and other environmental issues will be the main concerns in the energy sector. In the absence of policy changes and energy supply limitations, the world energy demand is projected to rise by 40 percent by 2030, with non-OECD countries accounting for over 90 percent. China and India alone represent about a half of the incremental demand[18]. The current energy systems of most industrialized and transition-economy countries are heavily (more than 80 percent) dependent on fossil fuels, with nuclear and renewable sources (such as wind and hydro power, biomass and solar photovoltaics) contributing only small amounts to the total energy consumption. There are some exceptions locally, but for next two decades fossil fuels are projected to remain the dominant source of energy worldwide. However, with current technologies, continued reliance on fossil fuels is likely to have serious consequences for climate change, acidification of land and water and human health. It is widely accepted that a sustainable long-term energy future will require increased energy efficiency and reliance on clean renewable energy resources, as well as new low-carbon fossil-fuel technologies. However, the rate at which such an energy transition is likely to occur is very uncertain.

Population growth over the next twenty years will create massive new demands for ***transportation***. At the moment, aviation is the fastest growing means of transportation[19]. Over the coming two decades, personal and goods transport will grow rapidly, driven primarily by rapid economic growth in the emerging economies of the developing World. The development of the necessary transport infrastructure is often lagging behind economic development, generating traffic congestion, pollution and high accident rates. Road traffic accidents are expected to rise from the ninth leading cause of death globally in 2004 to the fifth in 2030[5]. In the absence of policy changes, the total number of light-duty vehicles is projected to increase from an estimated 650 million in 2005 to about 1.4 billion by 2030[19]. Most of this increase will come from non-OECD countries, with China alone accounting for almost one-third of the global increase in cars. Currently, transport accounts for nearly one-quarter of global energy-related CO_2 emissions. Given the current trends, transport energy use and CO_2 emissions are projected to increase by almost 50 percent by 2030. To avoid undesirable consequences, cleaner fuels and more efficient vehicles will be critical in the shift towards sustainable transportation.

The future is ***warmer***. For the next two decades, a warming of about 0.2°C (global average) per decade is projected for a range of emissions scenarios[20]. Beyond 2030, temperature projections are increasingly dependent on specific emissions scenarios[20, 21]. Warming is expected to be greatest over land at high northern latitudes, and least over the Southern Ocean and northern North Atlantic, continuing recent trends. Warming will shrink glaciers further on every continent, which will result in sea level rise, aggravate stress on water and food resources, reduce the resilience of many ecosystems, increase the risk of species extinctions — and possibly increase the number and intensity of extreme weather patterns. The less developed regions are particularly vulnerable, and Africa is likely to be the most vulnerable continent, partly because the adaptive capacity in Africa is relatively low due to limited resources and fragile governance, with conflicts exacerbating the situation. While at mid- to high latitudes food production might even increase at lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease. Over the coming two decades, in some African countries, yields from rain-fed agriculture could be reduced by up to 50 percent[20]. This, combined with rapid population growth in the already energy and food-insecure areas, could have disastrous consequences with a number of climate change related conflicts and refugees. Policies for mitigation and adaptation are urgently needed to reduce long-term climate change risks, impacts and damages.

Natural hazards present a persistent and continuous threat to human health and wellbeing and economic development in many parts of the World. When this threat is amplified by the effects of environmental change it is likely that such hazards will present an even greater threat over the next two decades. Hydro-meteorological hazards may be more extreme, and deforestation and sea-level rise will increase the vulnerability of certain populations. The extent to which such hazards become disasters cannot be predicted, but depends to a large extent on the effectiveness of strategies for prediction, mitigation and response.

Technological advances have been perhaps the most important driver of change in the modern era. Such change is mostly gradual and incremental, but occasionally major transitional breakthroughs happen. While we cannot know the nature and implications of the breakthroughs in advance, there is a high degree of certainty that these will occur in several fields over the next two decades. Areas of potential technological breakthroughs include environmental and energy technologies, materials science, medicine, genetic engineering, geo-engineering, robotics, artificial intelligence, nanocomputing, space exploration, complex system science and military applications[22,23]. The convergence of nanotechnology, biotechnology, information technology and cognitive sciences is expected to rapidly accelerate in the coming decades[24, 25]. These ***Converging technologies*** will make substantial improvement of human performance possible. Nanoscience has the potential to revolutionize medicine, materials and manufacturing, electronics and information technology, environmental remediation applications, water purification, energy production, and other fundamentals of everyday life in the 21st Century[26]. By 2030, the pervasive influence of life sciences on engineering, e.g. synthetic biology and molecular motors, will be a major feature. And over the coming decades, *Global Sustainability Research* will be an area of increasingly integrated research focus, with natural and social sciences pulling together to develop new technological (and social) innovations in response to pressing sustainability issues.

Over the next twenty years, tools to acquire, generate, store, exchange and protect information will be further improved and increasingly distributed data banks and processing techniques will enhance the ability to tackle large and complex tasks. In particular, ***high speed and parallel computing*** will profoundly affect all aspects of society, including the conduct of science. With the development of media to store data and high-speed networks to exchange information, ***data mining*** is already opening up new approaches, in which hypotheses emerge from data themselves. Some areas of science will see a significant shift from hypothesis-driven to data-driven research.

The effects of new ***information and communication technologies (ICT)*** will be many-fold and pervasive. For example, mobile cellular connections in the developing countries have more than doubled since 2005, reaching an estimated 57 percent of the population at the end of 2009[27]. Rapid further increase in connections is expected. As a result of the development of ICT and ***fast growth of the Internet***, social networking has been taken to another level. These changes are fundamentally affecting scientific practices. For example, the Internet has revolutionized the production of, and access to, academic journals. Within 20 years, paper publications might well be eliminated. Remote operation of infrastructures through the Internet, as is already done in fields such as astronomy, is making it possible to be present in localities otherwise not easily accessible. Within 20 years, international conferences, education and collaboration in general will be fundamentally changed by the use of affordable virtual-presence capabilities. Opportunities for ***distance learning*** and ***e-collaboration*** will increase, with potentially significant benefits for developing countries in particular. At the same time, parts of the less developed world that do not have the necessary ICT infrastructure are in danger of becoming increasingly isolated, and practising cutting-edge science in these countries will become very difficult. Elsewhere, the increasing dependence on ICTs may have its own unwanted consequences ... ensuring ***cyber security*** presents a major challenge.

Economic, political and social developments over the next twenty years represent a major area of uncertainty yet they set the arena for international science. As the world struggles to overcome the global economic crisis, a multi-polar system is emerging. The balance of power is shifting towards the East but we do not know exactly how, or on what time scale, this will affect the established world order. The evolution in the roles of different international players, including non-state actors, remains to be seen. Future directions will be, to a large extent, determined by economic developments, which are highly uncertain. Rapid globalization and increasing interdependence of all aspects of society further complicate the picture. But it is reasonable to assume that progress in science and technology will continue to be a major force shaping social and economic development.

How does this General Context link to the Exploratory Scenarios?

The General Context sketched above represents a 'business as usual' world, assuming a continuation of current trends. However, in the long-term this world is not sustainable and it can be expected that measures will be implemented to avoid and/or respond to undesirable consequences.

This is the context in which the exploratory scenarios are developed, taking into account how these megatrends will interact with a number of key drivers whose future directions are uncertain.

Bibliography

1 United Nations Department of Economic and Social Affairs/Population Division *World Population Prospects: The 2008 Revision*

Note: If fertility were to remain constant at the present-day levels, the total world population would increase to approximately 8.8 billion by 2030. The future population growth is highly dependent on the path that future fertility takes; the projected population ageing mainly results from the decline in fertility.

2 United Nations Department of Economic and Social Affairs/Population Division *World Urbanization Prospects: The 2009 Revision*

Note: There are major disparities in the levels of urbanization between regions. Currently, in more developed regions the urbanization level is 75 percent, as compared to 45 percent in the less developed regions. Major differences occur also between countries. For example, in 2009, Burundi, the least urban country in Sub-Saharan Africa, was only about 11 percent urban.

3 World Health Organization *World Health Statistics 2010*

4 World Health Organization *AIDS epidemic update 2009*

Note: Sub-Saharan Africa has remained the region most heavily affected by the HIV virus, accounting for two-thirds of an estimated 33.4 million of worldwide HIV infections.

5 World Health Organization *The global burden of disease: 2004 update*

6 Millenium Ecosystem Assessment

Note: According to the Millennium Ecosystem Assessment, 15 out of 24 ecosystem services examined are already being degraded or used unsustainably.

7 Convention on Biological Diversity *Global Biodiversity Outlook 3 (2010)*
Convention on Biological Diversity Technical Series No. 50 *Biodiversity Scenarios: Projections of 21st Century Change in Biodiversity and Associated Ecosystem Services; A Technical Report for the Global Biodiversity Outlook 3*

Note: This work focuses on synthesizing information from a broad range of models and scenarios.

8 J. Rockström *et al*. (2009), *A safe operating space for humanity*, Nature 461, 472-475.

9 Food and Agriculture Organization of the United Nations *The State of Food Insecurity in the World 2009: Economic crises – impacts and lessons learned*

Note: This is the highest number estimated since 1970, the earliest year for which comparable statistics are available. The recent increase in food insecurity is not a result of decreased food production but because high food prices and lower incomes have reduced access to food.

10 Food and Agriculture Organization of the United Nations *World agriculture: towards 2030/2050– Interim report*

Note: Growth rates are based on 2005/07 average historical data.

11 Food and Agriculture Organization of the United Nations *How to Feed the World in 2050, Discussion paper 2009*

[12] D. B. Lobell *et al.* (2008), *Prioritizing Climate Change Adaptation Needs for Food Security in 2030*, Science 319, 607-610.

[13] World Health Organization *Progress on sanitation and drinking-water 2010 update*

Note: Improved drinking water sources and sanitation facilities are defined in terms of the types of technology and levels of services that are more likely to provide safe water and to be sanitary than unimproved technologies.

[14] Organisation for Economic Co-operation and Development *Environmental Outlook to 2030 (2008)*

[15] European Commission *Report of the Ad-hoc Working Group on defining critical raw materials (2010)*

[16] World Economic Forum *Mining & Metals Scenarios to 2030 (2010)*

[17] International Institute for Applied Systems Analysis *Global Energy Assessment* Report in preparation

Note: Some other sources (UNDP and WHO) estimate that more than 3 billion people lack access to modern fuels.

[18] International Energy Agency *World Energy Outlook 2009*

Note: Reference year 2007. The World Energy Outlook presents two projections. One is their "Reference Scenario" (used here) which simply continues current trends in the absence of policy changes. The other one is their recommendations for policy and technology use changes that target a 450 parts per million of CO_2 equivalent in the atmosphere.

[19] International Energy Association *Transport, Energy and CO2: Moving towards Sustainability 2009*

Note: The Baseline scenario (used here) follows the IEA World Energy Outlook 2008 Reference Case to 2030, and then extends it to 2050.

[20] International Panel on Climate Change *Fourth Assessment Report: Climate Change 2007*

Note: The report links increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level to anthropogenic greenhouse gas emissions (CO2 is the most important anthropogenic greenhouse gas). Here the emissions scenarios refer to the SRES scenarios described in the IPCC Special Report on Emissions Scenarios (SRES, 2000). The SRES scenarios explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting greenhouse gas emissions. These scenarios do not include additional climate policies above current ones. The emissions projections are widely used in the assessments of future climate change, and their underlying assumptions with respect to socio-economic, demographic and technological change serve as inputs to many recent climate change vulnerability and impact assessments. Baseline emissions scenarios published since the IPCC Special Report on Emissions Scenarios (SRES, 2000) are comparable in range to those presented in SRES.

[21] R. H. Moss *et al.* (2010), *The next generation of scenarios for climate change research and assessment*, Nature 463, 747-756.

[22] George Washington University *TechCast*

[23] UK´s Horizon Scanning Centre *Sigma Scan*

[24] US National Science Foundation (NSF) and Department of Commerce *Converging Technologies for Improving Human Performance NANOTECHNOLOGY, BIOTECHNOLOGY, INFORMATION TECHNOLOGY AND COGNITIVE SCIENCE*

[25] European Commission *Converging Technologies – Shaping the Future of European Societies*

[26] The Royal Society and the Royal Academy of Engineering *Nanoscience and nanotechnologies: opportunities and uncertainties (2004)*

[27] International Telecommunication Union *Measuring the Information Society 2010*

Note: While in the developing countries mobile cellular connections reach an estimated 57 percent of the population, in the more developed regions mobile cellular penetration exceeds 100 percent. Internet use has also continued to rise, but at a slower pace. In 2009, four out of five people in the developing world still did not have access to the Internet, and China alone accounted for one-third of the Internet users in the developing world. By comparison, 64 percent of the population in the more developed regions were using the Internet.

Key drivers that will influence international science over the coming 20 years

In addition to the megatrends, whose direction is reasonably predictable over the next 20 years, there are a number of factors that will have a major influence on international science, but whose directions are much less certain. These uncertain factors have been identified as Key Drivers.

The Key Drivers

States and markets

The future preferences of States with regard to socio-economic development will impact on international science. The present range of options extends from free market based approaches to strong state intervention, but new socio-economic models with a stronger focus on sustainability and wellbeing as opposed to economic growth could also be envisaged.

Global agendas and arenas

International relations are set to expand and become increasingly complex as non-state actors influence the international political and policy agenda. This will influence the development of existing and new international policy fora, with important implications for how international science effectively engages and informs decision-makers.

State sovereignty, regionalism and globalism

The scale(s) at which policy (such as that on the environment) will be determined and ultimately implemented is not clear. The future of global policy organizations such as the United Nations is uncertain. Models of state sovereignty may be challenged by regional groupings, or strong individual nations may shape a multipolar world.

Science and society

The relationship between science and society is likely to have a significant impact on the future of international science. This includes how science gets its mandate from society and how science feeds back its knowledge to society. Science education and literacy will be important in determining how appreciation and trust in science will evolve.

Private sector/military science

International science will be shaped on by what proportion of science is conducted in non-academic settings where the market economy or national military or strategic advantage are the dominant driving forces. Access to scientific data and information, which is linked to who conducts the research, will be an important determinant of scientific progress, particularly at the international level.

Scientific integrity and self regulation

Ensuring scientific integrity will be important for generating confidence and trust in science. There are many pressures on scientists and recent cases of misconduct in many countries have attracted considerable attention. How the scientific system adapts to the need for public accountability and whether self-regulation is adequate to deal with misconduct are open-ended questions.

Spatial organization/conduct of science

The spatial organization of science is changing. The impact of emerging science nations and possible new collaborative partners will alter the international science landscape. Such changes could have impacts on approaches to science and the balance between national versus international science. A shift in the 'centre of gravity' of science is also likely to have significant impacts on those nations that have limited scientific capacity.

Collaborative research infrastructures

The nature and location of international collaborative research infrastructures will have a significant impact on international science — presuming that there is an ongoing commitment to such structures at all. How they will be supported and who will have access are key factors in determining the future landscape for science.

Epistemic organization/conduct of science

The places where scientific research will take place may change. Universities and public research institutions are presently key players but consortiums of researchers, companies or new hybrid institutions are emerging. Within these various structures the way science is organized could be different. For example, the traditional university departmental structure based on disciplinary lines may evolve to encourage more interdisciplinary approaches.

Nature of the scientific record

The last decade has seen significant changes in the nature of the scientific record. The move to open-access publishing has considerable momentum, but it remains uncertain how journals and the peer-review process will evolve in the future. With the development of new information and communication technologies the communication of science will surely change, but how? Ensuring long-term access to the increasing volume of data that is critical for international science will be a major challenge.

Values, beliefs, ethics

The relationship between knowledge-based and faith-based societies has major implications for international science. How science will go about handling ethical issues and addressing controversial developments in areas of high public interest will help determine the relationship between science and societies.

Science education and skills

The traditional path of science education could be challenged by the role of new organizations, business and communication technologies. The nature of what students learn, the balance of disciplinary and interdisciplinary courses and the importance of theoretical and applied experience are all likely to evolve.

Scientific careers

The nature of the 'scientific career' could change. This could be impacted on by changes in the epistemic organization of science, the science education process and the conduct and focus of science. The traditional models for academic careers are likely to evolve, with new ways of evaluating scientists and assessing research.

Exploratory Scenarios for 2031

Structure of the Exploratory Scenarios

The four Exploratory Scenarios that follow are set in the context of the megatrends but take into account some of the potential directions that the Key Drivers could take.

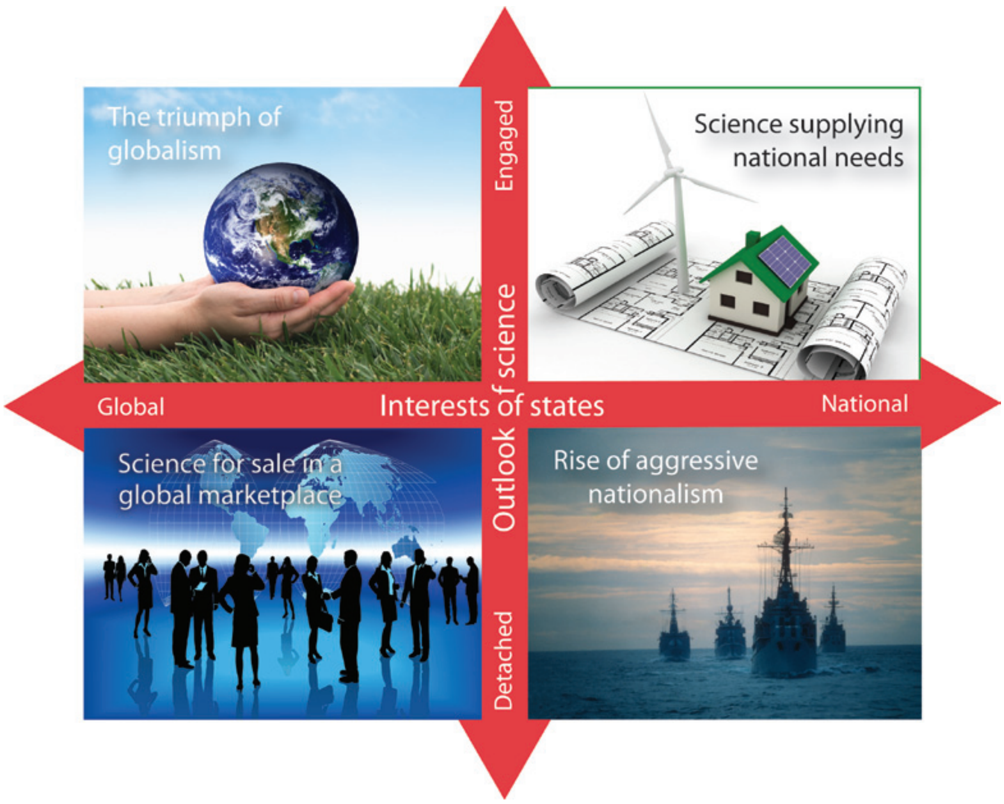
In order to develop plausible and useful exploratory scenarios, these have been framed within four distinct 'scenario spaces' defined by two axes. These two axes were selected from the list of Key Drivers.

In choosing the axis drivers, consideration was given to:

- how influential they are;
- whether they have a plausibly large range of uncertainty;
- ensuring they are as independent of each other as possible;
- how they would generate distinct scenario spaces that are interesting, useful, and relevant with regard to the future of international science; and
- whether the resultant scenario spaces would be able to include positive and negative traits and therefore could be presented in a balanced manner.

Using these criteria, the first selected scenario axis is based on the Key Driver: State Sovereignty, Regionalism and Globalism. At one end of this axis, countries have a nationally oriented outlook and they tend to look inward and address issues unilaterally. At the other end, countries have a global outlook and favour international cooperation and problem-solving. The axis has a continuum from 'global' to 'national' outlooks.

The second selected axis is based on the Key Driver 'Science and Society'. At one end of this axis, science acts fairly independently from society. At the other end, science is highly engaged with society. The axis represents a continuum from 'engaged' to 'detached'.



Exploratory Scenario 1 – The triumph of globalism (global-engaged)

There is recognition that the socio-economic challenges do not recognize national boundaries and are best addressed cooperatively. **Global governance** has received new lifeblood with the full support of the traditional world powers and the newly industrialized countries. While states have taken the lead in establishing this new global order, the emergence of an **active global citizenry**, together with a **newly invigorated UN system**, has played an important role in the formation of new **issue-focused networks** that tackle a range of pressing **grand challenges** around energy, food, environment, health and poverty.

Science acts as a global stabilizing agent in this new global order, is an integral part of a functioning global society and helps to drive global political agendas. It is **policy relevant** and provides influential inputs to decision-making at global and national level. **"Activist scientists"** play prominent roles in shaping global views and promoting the essential role of science. Science is conducted in much more fluid epistemic configurations that are fast-changing and less likely to crystallize into long-lived disciplinary structures.

Both global and national funding sources are available, and investments in science are on the rise in sectors of high societal interest and concern. **International networking** has become the dominant model for conducting science. Research is increasingly conducted using **large-scale networks of smaller and decentralized facilities** that have been strategically organized for global unity to address pressing global challenges. National barriers to collaboration have declined, with greater **mobility of researchers** and **ICTs** playing increasingly prominent roles, which also enables a fuller participation in global science by developing countries. **Internationally agreed data standards** are an essential element of the new organization of science, and global data collection and monitoring systems, such as the *Global Earth Observation System of Systems* (GEOSS), form powerful motors for international research. **Integration of natural and social sciences** has been crucial for the proper framing and answering of problems in society. New reward structures and **online interdisciplinary journals** (e.g. *Nature Interdisciplinary*) provide incentives for interdisciplinary science to flourish.

The spirit of cooperation and global solidarity is also reflected at the non-governmental level, with academies and funding agencies pushing for **a single, strong organization to represent the independent voice of global science**. A global strategic science funding body, combining 2% of each nation's allocated public research funding, has been launched to tackle grand challenges on a global scale.

Exploratory Scenario 2 – Science supplying national needs (national-engaged)

After a series of major global economic crises over the preceding two decades, there is **public disenchantment with globalization** and a strong push towards new localized growth models with sustainability at their core. The goal is to be more self-sufficient, to increase **local production** for internal and regional markets, and to improve quality of life and societal satisfaction, rather than growth *per se*. At the same time, efforts to build effective **global governance structures have largely failed** and instead, complex **national and supranational regional alliances** have formed among states, businesses and civic groups to address pressing challenges. **Diverse national and regional solutions** prosper in a widely experimental society.

A variety of national science and innovation systems have developed in response to specific concerns over employment, energy and food security, ageing and health care costs. But a common feature across countries is that **domestic socio-economic needs strongly affect science agendas** and generally science is more **problem-oriented** in nature. **Locally engineered solutions** flourish in response to pressing societal challenges (including mitigation of the effects of climate change, healthy ageing, etc.), with **traditional knowledge** also being valued in these place-specific solutions.

With this increased social engagement, science becomes a much more distributed and **socially-embedded** activity and is increasingly practised outside of the traditional institutes of state research systems. This partly **undermines some of the institutions of science**, including peer review and publication routines. The concept of scientific **integrity** has expanded to encapsulate the wider societal role that scientists are expected to play.
In many countries research and innovation at the frontiers of life sciences are being slowed by the adoption of **precautionary approaches and regulations.** The balance between the 'social' role of universities and 'unfettered knowledge generation' has shifted significantly away from the latter. **'Blue skies' research is being squeezed**, both financially and due to organized societal pressure. Overall, there are fewer opportunities for curiosity-driven research without clear short-term benefits for society.

In the absence of large-scale global collaboration, **bilateral and regional alliances** are strong players in the international science arena. The global governance of science at the intergovernmental level is fractured, although a variety of non-governmental organizations strive to link the various national and regional efforts.

Exploratory Scenario 3 – Science for sale in a global market place (global-detached)

The global free-market economy reigns and intense levels of interaction occur between economic agents across national borders. **Thousands of multinational companies** constitute powerful international players and drive the **ever-faster pace of globalization.** New scientific discoveries and technological developments have created whole **new industries** that power economic development in advanced and a few rapidly emerging economies. Countries have increasingly specialized in supplying only certain products to global markets, but still compete intensely for the investments of **foot-loose capitalism**. These investments include R&D facilities and funding, which are much more widely dispersed across advanced and emerging economies than in previous times.

As with product markets, **countries specialize in particular fields of research**. For example, the newly industrialized countries with less strict regulating regimes have taken the lead in converging technologies, while EU countries have taken a leading position in certain areas of medical science, such as those relating to ageing. **Countries also specialize in the types of research that are performed**. In the leading scientific powerhouses, states focus much of their funding on **curiosity-driven (and often disciplinary) research** that is ultimately beneficial to leading technology-based firms. It is the sort of research that firms rarely conduct themselves but that leads to the creation of new fundamental knowledge. By contrast, in more scientifically peripheral countries, multinational companies pressure governments to provide facilities and manpower to suit their more immediate experimental development needs.

The ability of states to support public research systems is increasingly compromised, however, by considerable tax-base erosion – a consequence of ageing societies but also of tax avoidance by multinational firms. Ostensible public sector research systems are, in fact, heavily dependent on private firms and foundations for their funding. This has consequences for international science cooperation, with business groups and private foundations increasingly using their own mechanisms of international coordination to set the global agenda for science. Indeed, global research linkages are more often than not mediated through corporate channels meaning little coordination or governance.

Societies in the developed economies are **hyper-consumerist**, with much of their consumption focused on improving health and lifestyles, to which science makes essential contributions. In this way, society's relationship with science is mediated through its consumer behaviour. But access is limited to those who can afford to pay, and with a **widening gap between rich and poo**r, many are excluded. Partly in reaction, a variety of well organized and active anti-globalization movements have emerged, some of them rooted in religious fundamentalism and extreme forms of nationalism. These are hostile to science, which is portrayed as part of an uncaring global capitalism package.

Globalization has also extended to universities and e-training has become an important, and less expensive, means of education in the less developed world. While hailed as progress by many, the global availability of such services acts to obstruct the development of indigenous tertiary education and associated research capabilities, and contributes to further '**brain drain'** towards the more economically advanced countries.

Global governance structures for science are dominated by business and economic interests. This is apparent across both inter-governmental and non-governmental structures. It is difficult for these bodies to maintain independent missions in the light of the shortage of public funding and abundance of private funding.

Exploratory Scenario 4 – Rise of aggressive nationalism (national-detached)

With the rise of the new and emerging economies, an ongoing power struggle for global leadership and resources has created a great deal of **uncertainty and instability in the international state system**. Largely unresolved sustainable development issues and the competition for finite resources present a potential trigger for war. In the uncertain geopolitical environment, **nation states are the key actors**. Economic powerhouses, including the USA, Germany and a number of the newly industrialized countries, act as leadership poles and dominate international decision-making structures. With an increase in international tensions, the economies of the leading powers are largely driven by national military-industrial complexes.

National investments in science and technology are increasing in the economic powerhouses, but other countries have fallen far behind. The **less developed countries are isolated** from the scientific endeavour and maintaining the Universality of Science is a major challenge, with threats both to the freedom and mobility of scientists. International coordination and **global funding sources are scarce**, and the willingness to join forces in addressing global climate change and sustainable development challenges has all but disappeared.

There is a **culture of secrecy and lack of transparency and openness** affecting all walks of life, and science is not immune to this. Countries have placed heavy barriers to the international exchange of knowledge, so that **parallel research efforts flourish** within **nodes of strong national science**. Society's relationship with science is largely mediated through the state, so that **science remains remote from citizens**. While this creates a less complicated landscape for scientific agendas, they are dominated by national political needs. Driven by the geopolitical situation, the **military sector** is a particularly strong research hub. Worryingly, the same technologies that rival countries are developing for inter-planetary exploration and the bio-economy are also being used in new and more deadly weapons.

In the atmosphere of tension and intense competition, large countries like China, the Francophone world and the Spanish-speaking countries have begun to promote **the use of national languages for scientific communication**, with the ability to speak English becoming less of an advantage and bond within the global science community. The **mobility of researchers and students has declined**, and countries mainly rely on their own educational resources to train the next generations.

International governance structures for science are dominated by the most economically powerful nations. A plethora of different global non-governmental organizations for science has evolved, but the majority of these are not truly independent but rather serve as instruments for the global ambitions of individual countries.

Using the Scenarios

These exploratory scenarios offer four distinct, yet plausible images of the future `World order` and of international science cooperation twenty years from now. They are not intended as predictions of the future. Instead, the four scenarios offer storylines that are intended to stimulate creative thinking on future courses of action.

The process of generating the scenarios has already provided useful inputs to the ICSU strategic planning process. But the scenarios are likely to have their largest immediate impact in the development of a longer term vision for international cooperation in science and the role ICSU will need to play. This will be achieved through the development of a ‘Success Scenario’ with a 20-year time horizon outlining a desirable state of international cooperation in science in 2031 and ICSU’s role in its achievement.

The four exploratory scenarios set out in this report provide useful stimulus for more creative thinking on a desirable ‘Success Scenario’ and should encourage a more rigorous treatment of the key drivers that are likely to impact on the future state and directions of international cooperation in science.

It has always been intended for the scenarios to have a wider appeal beyond the immediate planning needs of ICSU, and the expectation is that Members will find them useful in their own planning and visioning activities. In this regard, the scenarios are intended to attract attention to the issues highlighted and provide a starting point to stimulate creative thinking around possible future courses of action. ICSU Members and other users will need to elaborate and evaluate the scenarios in ways that are tuned to their particular needs.

It should be noted that major shocks or extreme events (commonly known as ‘wild cards’) have, for the most part, been excluded from the scenario storylines. They can, however, be introduced during strategic planning processes, as is often done in business environments. Shortlists of relevant wild cards can be readily assembled through a mix of group brainstorming and desk research – a lot of existing information is already readily available from various horizon scanning activities going on around the world. The impacts of each wild card can then be analysed by running them through each of the four scenarios.

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Individuals, committees and ICSU Members who provided input

A large number of individuals provided input throughout this exercise. It includes ~80 individuals who provided suggestions for drivers in response to an open call for on-line input. It also includes more than 100 scientists serving on various ICSU scientific and regional committees who participated in dedicated foresight sessions during 2010-2011.

In early 2011, a number of ICSU Members provided written input on the draft scenarios:

Australian Academy of Sciences

China: CAST, China Association for Science and Technology

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ICSU

International Council for Science

Strengthening international science for the benefit of society

5, rue Auguste Vacquerie
75116 Paris, France

Tel: +33 1 45 25 03 29
Fax: +33 1 42 88 94 31
secretariat@icsu.org

www.icsu.org