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Systemic risks and environmental governance

Final report

Commissioned by the Swiss Federal Office for the Environment (FOEN)

Bern, October 2015

Publishing details

Report commissioned by: Federal Office for the Environment (FOEN), Environmental Monitoring Section, CH-3003 Bern. The FOEN is a unit of the Federal Department of the Environment, Transport, Energy and Communications (DETEC).

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Note: This report was prepared on behalf of the Federal Office for the Environment (FOEN). The authors of the report are solely responsible for its content.

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1 Introduction

Public awareness of the global risks that could arise from the unchecked development of the world's population and consumption of natural resources was definitively heightened following the publication of the 1972 Club of Rome report, "The Limits to Growth". In the meantime, the environment, the economy and society have become increasingly perceived as complex, networked systems in which the effects of disruptions taking place at a given location can be felt at other locations in the world and far into the future.

The creation of the United Nations Environment Programme (UNEP) in the same year, and the adoption of a variety of UN Conventions relating to the environment in the course of the subsequent decades, underscore the fact that overcoming ecological risks is increasingly being understood as a challenge for environmental governance at the global level. The opportunities that were created through technological innovation and the commercial use of natural resources were accompanied by growing risks that called for the introduction of internationally coordinated regulations in order to prevent the fundamental functioning and efficiency of natural systems from potentially becoming irreversibly harmed. Examples here include ozone depletion, the destruction of tropical rainforests and the complex ecological, economic and social impacts of unchecked climate change.

Recent events have given rise to a greater awareness, especially within business circles, that the destabilisation of the global financial system and the susceptibility of complex international information and supply infrastructure to natural disasters (e.g. volcanic eruptions, tsunamis) and man-made disruptions (e.g. cyber crime, terrorism, technical malfunctions) are by no means just pessimistic fantasies. The outbreaks of a number of highly contagious diseases among both humans and animals also show that pandemics have become a genuine threat to today's highly mobile global society.

As a consequence, interest in the behaviour of complex natural and socioeconomic systems and in the risks associated with potential disasters and disruptions, has intensified sharply in scientific circles and in the worlds of business and politics. Given the far-reaching repercussions of local and regional incidents in an increasingly networked world, research organisations and institutions such as the OECD and the WEF, as well as the insurance industry, are now systematically addressing both evident and latent major risks.

At the level of national government, awareness about the susceptibility to transnational systemic risks – whether economic or ecological in nature – and the need to acquire knowledge in order to take appropriate action, has also grown, as evidenced by an increase in the quantity of literature on dealing with threats that go beyond the scope of conventional disaster prevention and response. An analysis of the indirect impacts of climate change on the United Kingdom carried out by PriceWaterhouseCoopers (pwc 2013) on behalf of the UK Environment Agency came to the following conclusion:

> "Climate change impacts around the world multiply existing threats to the UK, and some of these could be an order of magnitude greater than threats from domestic climate impacts."

In 2011, in a foreword to a report on the international dimensions of climate change (GO-Science 2011), Sir John Beddington, chief scientific adviser to the UK government, wrote:

> "… interconnected global networks of governance, finance, business, communications and communities will mean that impacts will be felt across international borders. The UK is a member of many leading international institutions, and a nation at the centre of world finance and trade. These linkages, together with vital international interdependencies in energy and resources will mean that the UK cannot isolate itself from the overseas impacts of climate change."

In the passage quoted above, we could easily replace *UK* with *Switzerland*. The question here is how Switzerland intends to deal with such challenges.

A key approach in dealing with systemic risks is to increase or at least preserve the resilience to systems that are potentially at risk, i.e. to strengthen the factors that help societies, companies or ecosystems to maintain their fundamental structures, functions and efficiencies and to adapt themselves to the changing circumstances while doing so.

This is the context in which the present report is meant to be viewed. The FOEN is looking for answers to the following key questions:

- *How do complex natural and socioeconomic systems behave?*
- *What measures are suitable for dealing with systemic (ecological) risks? How can Switzerland's environmental governance contribute towards the resilience of the involved systems?*
- *What information about the behaviour of complex systems does the FOEN need to obtain in order to fulfil its mandate to secure the sustainable use of natural resources?*
- *How can the FOEN document the state of, and changes to, the environment so that it will also be able to identify at an early stage any need for action at the level of systemic risks?*
- *How can the behaviour of systems and suitable measures be explained and communicated to politicians and the general public?*

This report presents findings obtained from an analysis of the literature built on preliminary deliberations within the FOEN regarding the tendencies and perspectives of environmental governance (and the associated consequences for environmental monitoring). It also includes four extensive interviews with specialists who address systemic risks from widely differing viewpoints.

The report is rounded off with a chapter summarising the conclusions and twelve recommendations relating to the key questions of the FOEN formulated above.

2 Function and characteristics of complex systems and systemic risks

This section explains important terminology and concepts for dealing with systemic risks.

2.1 Complex systems

Society, the economy and nature may be regarded and described as complex systems. Hügli and Lübcke (1991) define a system as:

> "a complex of elements that are interconnected and dependent on one another, and thus form a structured whole [...]; an orderly whole, the parts of which interact in accordance with certain rules, laws or principles."

Simple systems (e.g. mechanical appliances, basic organisms) have a clearly discernible number of relationships and dependencies between the individual elements of which they are composed. By contrast, in complex systems numerous components interact with one another and are simultaneously influenced by the state of the overall system. A distinguishing feature of a complex system is that the system as a whole is more than the sum of its parts (subsystems) − the system's behaviour does not follow linear cause-and-effect relationships, and it may give rise to circumstances that cannot be predicted or explained in detail on the basis of the individual components alone (IRGC 2013; Helbing 2013).

Systems that correspond to this description include the weather, a forest ecosystem, a transport network, a city and its inhabitants, a human being. The global information society is also a typical example of a complex, dynamic system with an increasing density of relationships, interactions and dependencies. According to Helbing (2013, p. 52), the **hallmarks of complex systems** include:

− differing forms of behaviour and development paths depending on the initial state;

− limited influencing or control possibilities from "above" or "the outside";

− self-management and pronounced internal interactions (feedback effects);

− unforeseeable, intuitively unexpected characteristics.

It thus becomes apparent that complex systems cannot be planned and steered in the conventional sense and that intervening in their inner dynamics may go hand in hand with unforeseeable and uncontrollable consequences. Nonetheless, the behaviour of such systems is not *a priori* chaotic: within certain limits, negative feedback effects or the ability to overcome crises make it possible to also deal with major disruptions in subsystems and maintain the performance of the overall system. Such systems possess a certain **resilience** to influences that destabilise the normal functions.

One of the consequences of the tendency towards centralisation, extensive networking and the close coupling of technological and economic systems (e.g. logistics infrastructure, value chains) that has been developing globally in the past few decades is that their resilience is declining and their susceptibility to disruptions (**vulnerability**) is increasing.

Because many complex systems perform key services for society, the vulnerability of society itself is also increasing. According to Renn (2015), with the intensive global networking of production processes, the economy in particular has become systemic: "Climate change affects both our economy and our prosperity [in central Europe], even if the most pronounced impacts have to be anticipated in other parts of the world". The extent of the potential consequences of a failure in individual subsystems is increasing and it is taking longer to restore the normal conditions.

Within the scope of the natural variability of environmental factors (temperature, humidity) and competition and dependency relationships between species, natural systems (e.g. soils, ecosystems) also show varying degrees of resilience to disturbances. If the functioning of natural systems is influenced beyond certain thresholds, their tendency to return to their previous state of dynamic equilibrium diminishes. They may gradually or rapidly lose some of the fundamental properties and functions that had previously distinguished them and that account for their value as a resource for human beings.

2.2 Systemic risks

If the consequences of an intervention in a given system are not foreseeable, this means there is a risk of undesirable impacts. Here, risk is defined as the potential damage that is caused by an event (or is the consequence of one or more events). The degree of risk depends on the probability of the occurrence of an event resulting in damage and the severity of the direct and indirect damage caused by the event.

As a rule, risks are entered into because their acceptance gives rise to opportunities. Innovations, whether of a scientific, economic or technological nature, often promise benefits, but are also frequently associated with risks. In addressing risks it is important to recognise that the bearers of the risks and the beneficiaries of the related opportunities do not have to be identical and the risks themselves or the unintended negative consequences may only become apparent over time. From the political point of view, the aim in such situations is to utilise or facilitate the opportunities associated with the risks within a framework of "residual risk" for those who could potentially be affected (cf. Figure 2 → *Residual risk*) that is regarded as tolerable (IRGC 2010a, p. 5; CRO Forum, p. 2).

Globalisation is a typical example of a process that has facilitated comprehensive positive developments, but has also enormously increased the potential for negative occurrences that are difficult to control[1] (Helbing 2013, p. 51):

> "Today we have a worldwide exchange of people, goods, money, information and ideas which has produced many new opportunities, services and benefits for humanity. At the same time, however, the underlying networks have created pathways along which dangerous and damaging events can spread rapidly and globally."

If the probability of occurrence and the degree of potential damage are known, we speak of a calculable risk. If these prerequisites are not met, i.e. there is uncertainty regarding the occurrence of a risk and/or the potential extent of the damage, then the risk is no longer calculable. This is a typical characteristic of systemic risks. For Renn (2014, p. 330), the potential extent of the impacts is what characterises this type of risk: "The term 'systemic risk' describes the possibility that a catastrophic event could affect the vital systems on which our society is based".

Based on Renn (2014, pp. 331 ff.), systemic risks may be **characterised** as follows:

− As a rule, they cannot be described in terms of linear cause-effect chains, but rather take the form of stochastic (identical causes do not give rise to identical outcomes) and chaotic (marginal changes in a given cause can rapidly result in unexpectedly severe – and potentially irreversible – impacts) response relationships.
  Example: "tipping" of the ecology of a lake following eutrophication

[1] Other pointers to drivers (driving forces) behind systemic risks are cited below in the comments on "global megatrends" and in the text box on page 10.

- They have a global (or at least a widespread) effect and cannot be restricted to a given region and overcome autonomously at their place of origin.[2]
  Example: pandemics

- They are closely linked with response chains of other activities and events without it being apparent at first and spread across a variety of social and economic spheres.
  Example: overuse of fresh water reserves → salination of fertile soil → changed forms of land use → negative consequences on biodiversity, food security and energy consumption

- They are often underestimated by political leaders and society.[3] Although the risks are known, (too) little is done to restrict or mitigate them.
  Example: impacts of fossil-based energy supply on the climate

For new types of risk for which it is not possible to determine either the probability of occurrence or the potential extent of damage, the *International Risk Governance Council* (IRGC) uses the term *emerging risks.*[4] It distinguishes between three types of risk (IRGC 2015a, p. 8):

1. Risks that are characterised by a high degree of uncertainty or a lack of knowledge regarding potential impacts of new products, services and forms of behaviour. Examples: innovations in the areas of nanotechnology, synthetic biology and robotics.

2. Risks that result from the complexity and networking of systems and which can give rise to non-linear system behaviour. Here, it is not the system itself that is the problem, but rather the unforeseeable interactions with disturbances in or disruptions of other systems closely connected to it. Examples: interdependent energy, transport, information and communication infrastructure.

3. Risks arising from changing framework conditions. Here, gradual changes or the probability of unexpected disturbances in the conditions surrounding an essentially trusted technical, social or natural system are underestimated and are not amenable to conventional coping strategies. Examples: ageing population, overuse of natural resources, natural disasters.

Emerging risks are of major importance for the insurance industry. As Schneider (2015) points out, emerging risks are not necessarily new, previously unknown risks. *Exposure* is the determining factor here, e.g. a new stakeholder group is confronted with a risk that is known from other contexts or insurable assets are suddenly exposed to a risk that did not previously exist in this form and at this location.

As far as the networked nature of risks is concerned, Helbing (2013, p. 51, p. 53) draws attention to the **cascade effects** that arise (including delayed and indirect effects) when disturbances occur: the stronger and more closely that networks are integrated, both within themselves and externally with other networks, the more extensive the consequences of punctual disturbances can be. Here, Helbing speaks of *hyper-risks* that arise when different, complex and interconnected systems are involved. Cross-system hyper-risks are exemplified by the global procurement, production and distribution systems for energy, food and water, the associated communication and financing networks, and the natural ecosystems and climate system, which together form an enormous network of mutual relationships and dependencies.

[2] The OECD (2011) uses the term *global shocks* in cases in which occurrences have severe consequences in several continents.
[3] For an example of underestimated risks relating to tipping points in the climate system, cf. http://www.mediadesk.uzh.ch/articles/2015/kuenftige-klimaschaeden-zu-tief-bewertet.html
[4] Unlike systemic risks, emerging risks can have consequences that are restricted to a local context.

The extent and complexity of this interdependency was illustrated by the *water-food-energy nexus* (Figure 1) described in the *Global Risks* report published in 2011 by the World Economic Forum (WEF).

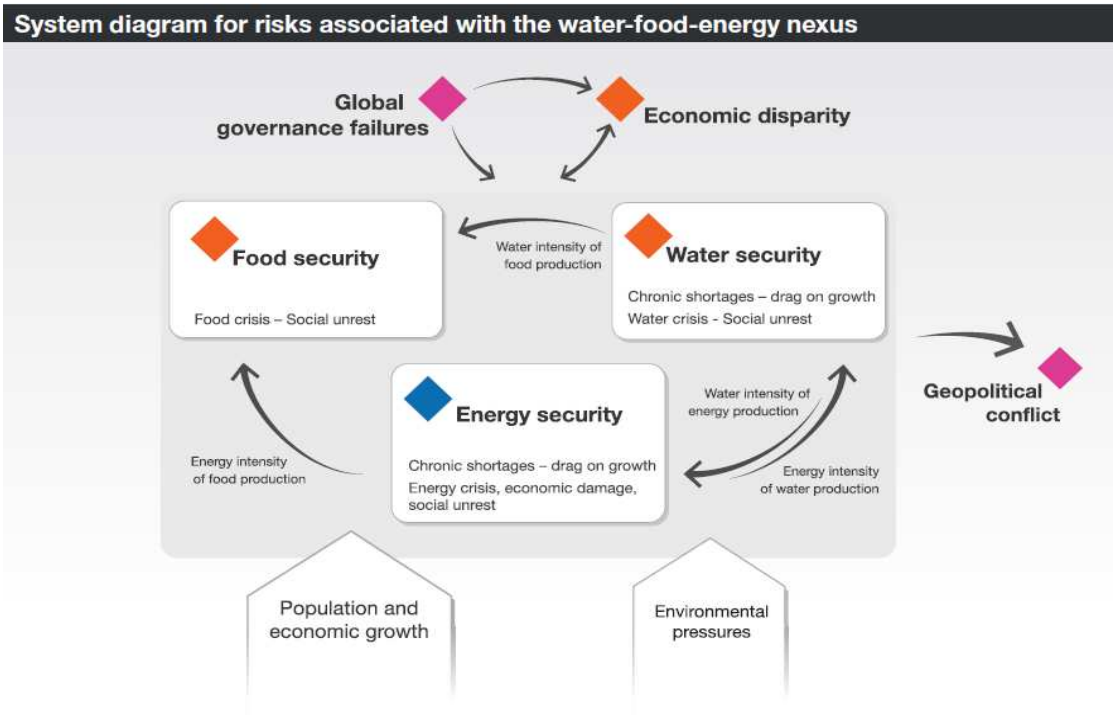


Figure 1: *Water-food-energy nexus* (WEF 2011, p. 29)

Dealing with systemic risks is also a topic in the status reports published periodically by the European Environment Agency (EEA 2010, EEA 2015). The EEA uses the term **global megatrends** to describe the large-scale, extensive and often closely interrelated change processes at the social, technological, economic, ecological and political levels that threaten the resilience of social and ecological systems (EEA 2015, p. 5; EEA 2015, pp. 33 ff.). These processes encompass the areas of demographics, economic growth, production patterns, trade flows, technological progress, deterioration of the condition of ecosystems and climate change and define the production and consumption of resources (food, water, energy, raw materials).

Through the concept of global megatrends, the status reports of the EEA address the message contained in the 7th EU Environment Action Plan, according to which:

> "global systemic trends and challenges, related to population dynamics, urbanisation, disease and pandemics, accelerating technological change and unsustainable economic growth add to the complexity of tackling environmental challenges and achieving long-term sustainable development" (cited in EEA 2015, p. 13).

Drivers of systemic risks[5]

A number of drivers are behind the growing threat potential arising from systemic risks. The increase in the global population and standards of living worldwide and the associated demand for resources and burden on the environment; the ongoing concentration of people, material assets and economic activities in major urban centres and in regions susceptible to (natural) disasters; the globalisation of the economy; the increasingly complex global networks for communication and transport and the rising mobility of people and goods; and technological innovations (e.g. bio- and nanotechnology, artificial intelligence), the long-term impacts of which are exceedingly difficult to estimate.

Alongside these developments in the areas of socioeconomics and technology, political and socio-cultural factors are also contributing to the threat potential arising from systemic risks. These factors include:

- the decreasing ability of some countries and international institutions to come up with suitable solutions to social and ecological challenges in a regional or global context;
- the continued availability of global public goods on a largely free-of-charge basis (e.g. use of the atmosphere, soils and oceans as repositories for emissions and waste, destruction of species-rich, natural ecosystems, overuse of limited natural resources such as fresh water and arable land) and a lack of accountability and liability for the resulting damage;
- the discounting of potential disadvantages arising in the future in favour of the short-term benefits associated with the acceptance of risks.

Dealing with systemic risks always entails balancing present-day and future interests. Thus, in many cases the call for more resilience (cf. chapter 2.4) is coupled with a debate about values. This requires a higher degree of acceptance of interests extending beyond a short-term time frame, i.e. a higher weighting of systemic risks versus opportunities that can be exploited in the short term.

2.3 Systemic ecological risks

With their concept of *planetary boundaries*, Rockström et al (2009) drew attention to the fact that mankind is on the verge of exceeding the breaking points of global natural systems and processes in a variety of ways. Leaving the *safe operating space* proposed by Rockström et al is equivalent to accepting systemic ecological risks of global magnitude that could threaten the existence of mankind.

Three of the ten[6] *planetary boundaries* cited by Rockström et al concern **central ecological challenges**, the significance of which is frequently pointed out in the literature. These are:

- the fragmentation and transformation of natural habitats and the associated loss of **biodiversity**;
- the accumulation of greenhouse gases in the atmosphere and the resulting **change in the global climate**;
- the overuse and increasing scarcity of **freshwater resources**;

and the associated social, economic and ecological impacts.

[5] cf. e.g. Helbing (2013); Renn (2014); OECD (2011)

[6] Climate change − rate of biodiversity loss − nitrogen cycle − phosphorus cycle − stratospheric ozone depletion − ocean acidification − global freshwater use − change in land use − atmospheric aerosol loading − chemical pollution

These three risk complexes stand out in the context of numerous other (geopolitical, social, economic, technological) developments that are regarded as threats or potential risks. They are of tremendous importance for the fundamental functioning of natural systems on which mankind has to depend, and they are characterised by a pronounced need for action, as well as by a low success rate of measures implemented to date with the aim of mitigating risk (cf. WEF 2015, pp. 44 ff.).

For the first two areas cited above, the defined *planetary boundaries* have already been exceeded. The third area, in which the natural limits of resilience are quantifiable and in the view of Rockström et al have already been exceeded (interventions in the natural nitrogen cycle), displays clear interactions with the three areas noted above (cf. Rockström et al, p. 474).

The annual *Global Risks* reports published by the WEF, which are based on the assessments by various stakeholder groups of the greatest risks with which the world is confronted, also emphasise the critical importance of loss of biodiversity, climate change and overuse of freshwater resources. While representatives of the economy account for the main group in the survey, and the reports consequently focus on economic and regulatory risks, in recent years ecological or closely associated social risks have regularly been included among the top five categories. Since 2007, the importance of ecological risks (including the decline in the availability of fresh water), as rated by the participants in the surveys, has increased sharply in comparison with economic risks.

2.4 Resilience

As already noted in the comments regarding complex systems, resilience and the vulnerability of systems are important characteristics that determine how susceptible a given system is to damage as the result of unforeseen and improbable risks.

Like Walker et al (2004), the OECD (2014, p. 23) defines resilience as:

> "...the capacity of a system to absorb disturbance and reorganise itself while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks. "

Vulnerability and resilience are two sides of the same coin: while vulnerability is a factor for measuring the susceptibility of a system to the direct and indirect impacts of systemic risks, the term "resilience" refers to the magnitude of unexpected and unforeseeable problems or the degree of stress that a system is able to withstand (i.e. its ability to maintain functioning or restore functioning within a reasonable amount of time). Resilience does not exclude adaptation to changed circumstances, but it makes it possible to counteract the impairment of a system's essential elements and functions in a self-organised process. Viewed in this light, resilience of socioeconomic systems is also an expression of the ability to autonomously overcome difficult situations.

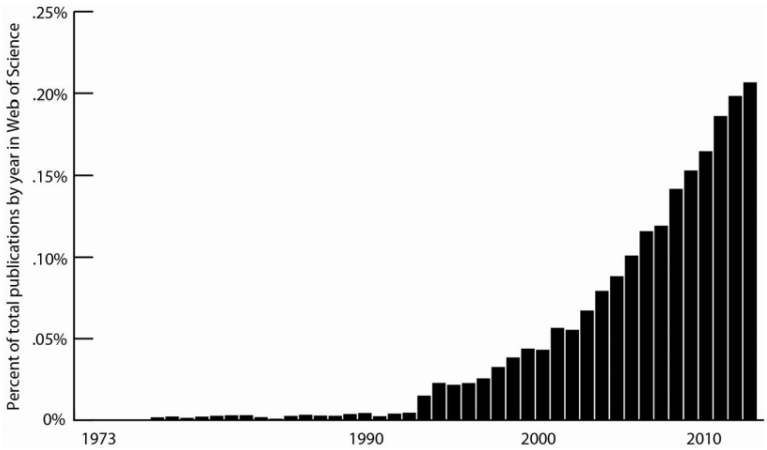
Resilience as described above has a distinctly positive connotation. Here it is important to note that resilience is a **context-based** term (cf. text box on next page). States that are socially or ecologically undesirable can also be resilient to external influences. To cite Holling and Walker (2003):

> "Resilience, per se, is not necessarily a good thing. Undesirable system configurations (e.g. Stalin's regime, collapsed fish stocks) can be very resilient, and they can have high adaptive capacity[7] in the sense of re-configuring to retain the same controls on function. Building resilience of a desired system configuration requires increasing the adaptive capacity of structures and processes (social, ecological, economic) that help maintain this configuration. It also requires reducing the adaptive capacity of those that tend to undermine it."

[7] In the English-speaking world, the term "adaptive capacity" is often used as a synonym for "resilience". Holling and Walker regard "adaptive capacity" as a partial aspect of resilience that emphasises the learning capacity of a system in dealing with disruptions.

Chronology of the definition of "resilience"

Ecologists as well as psychologists started using the term "resilience" in the 1960s and 1970s. In the field of ecology, Holling (1973) is the most frequently cited publication today. The number of scientific publications containing the keyword "resilience" only began to increase noticeably as of the middle of the 1990s, but then to an exponential degree.



Occurrence of the term "resilience" in literature. Proportion of annual publications containing the terms *resilience*, *resilient* and/or *resiliency* in their title, abstract or list of key words.
Source: S. Meerow and J. P. Newell (2015)

The term has now been adopted by various other disciplines (economics, political science, development cooperation, international relations, spatial planning and urban development, risk management, complexity research, etc.). While Holling (1973) already distinguished between two forms of resilience, the diversity of meanings increased further over the course of time. In an article by Brand and Jax (2007), the authors distinguished between ten definitions which they divided into three main groups: 1) descriptive concepts (including those of Holling, but also social science concepts such as those of Adger, 2000); 2) normative concepts (which are expressed in, for example, the call for "longer-term flexibility" or definitions in the framework of "strong sustainability"; and 3) hybrid concepts (for example, relating to ecosystems or in the study of socio-ecological systems). More recent overviews distinguish a similarly broad variety of definitions (e.g. Martin-Breen and Anderies, 2011; Fra.Paleo, 2015).

The term "resilience" and concepts associated with it have not escaped criticism, however. Focusing on the period after 2010, Brown (2014) provides an overview containing a number of points of criticism, including the following: since utilisation conflicts and power discrepancies are not usually addressed, the question of who benefits from measures to maintain resilience remains unasked; resilience is a fundamentally conservative concept that fails to recognise the necessity for major social change – not least in view of ecological threats – and instead only encourages small steps; the social and political dynamics within the social system itself are not taken sufficiently into account; placing sociology beneath the primacy of ecology gives rise to a static view of society.

This criticism contributed to an intensive discussion of issues relating to social resilience, including the *community resilience* concept, transformation research and social movements such as *transition towns* (Brown 2014).

Before strategies aimed at fostering resilience (cf. chapter 3.3) can be considered, the question "resilience *of* what *to* what and *at the costs* of what?" first needs to be answered. Then, in a second step, the question must be clarified of what structures (and associated incentives) heighten vulnerability or hinder the more resilient organisation of critical elements of systems.

Resilience versus efficiency

Resilience renders a system capable of dealing with improbable and unforeseeable situations. Resilient systems typically possess several safety nets that make them insensitive to temporary failures of individual subsystems or functions. This is achieved by incorporating backups of essential system elements or ensuring that the functions of these elements can be performed by several subsystems (for example, water and energy supply systems that are independent of one another), or by including backup systems that can be called on in the event of the failure of critical services (for example, parallel communication channels and emergency power generators, as well as expertise in dealing with difficult situations).

Precautions of this nature often contradict the requirement of economical and efficient use of resources, since they draw on financial, material or human resources, without a benefit being apparent in trouble-free daily activities. Renn (2014, p. 413) notes that a strategy oriented on resilience is, according to standard models for calculating economic efficiency, "not optimal in terms of cost and thus not optimally efficient".

Renn illustrates the risks of a strategy focusing solely on efficiency by citing the example of cereal production (Renn 2014, pp. 504 ff.). Here, efficiency means reducing the number of utilised grain types, investing in artificial irrigation, fertilisation and use of pesticides, and centralising cereal production in large companies. Under normal circumstances, a concept of this sort will facilitate high yields at low costs, but this high degree of efficiency also makes the system susceptible to various disturbances, and this in turn exposes one of the principal functions of the overall system, namely the supply of a basic foodstuff, to heightened risk.

While it is possible to increase redundancy under these circumstances by having the public sector, the private economy or private individuals keep reserve supplies for crisis situations, the resilience of this system and its ability to respond flexibly in the event of unexpected and lengthy disruptions are significantly inferior to those of a system in which a broad variety of grain types with differing requirements and resistances are cultivated by a large number of producers.

The OECD (2011, pp. 6 ff.) cites another example in its comments on the vulnerability of the global goods transport system. Since goods transport focuses on a handful of major hubs, an occurrence like the volcanic eruption in Iceland in spring 2010 can give rise to large-scale disruptions in the affected value chains and thus result in high costs.

In a study on the changing risk landscape throughout the world and the resulting impacts on the insurance industry, CRO Forum (p. 32) comes to the conclusion that "redundancies should no longer be considered as a cost block, but as an investment in reliability and safety". Similarly, GCF (p. 58) describes ecological and social resilience as "the two major insurance policies we have" in order to avoid a downward spiral in the event of a severe loss event.

Referring to the 7th EU Environment Programme, which declares resource efficiency, resilience and the prosperity of mankind as equal objectives, Martin (2015) draws attention to the dominance of the efficiency paradigm at the expense of the other two objectives. In his view, the question of how the three objectives can be brought into equilibrium is unanswered. Renn (2015) is of the opinion that efficiency and resilience do not rule one another out, but nor do they go hand in hand. The

ultimate aim is to find a sound balance. For Bresch et al (in Kupers, p. 53), from an entrepreneurial point of view, strengthening resilience is not a matter of surrendering efficiency gains, but rather of carefully weighing up the costs and benefits of redundancy in each specific case.

According to Helbing (2015), the reconcilability of resilience and efficiency will result from the improved future possibilities for designing and managing systems:

> "If we use the Internet of Things for the real-time measurement of externalities, provide suitable feedback on a multi-dimensional financial system, support the self-organisation of systems with the aid of digital assistants and foster coordination between different systems through interoperability, then diverse and resilient systems will be efficient."

Efficiency as a component of resilience

The fundamental concept of the economical use of resources will not be nullified by giving greater weight to resilience (in the interest of reduced vulnerability). Renn (2014, p. 507) cites two reasons:

Firstly, increasing the efficient use of scarce resources (ecological efficiency) is essential in order to secure the supply of system-relevant products to the economy and society. It is necessary to use the relevant market forces in order to achieve an optimal benefit with the minimum use of resources. However, this is only possible if not only the monetary, but also the ecological costs (external effects), are taken into account, as well as the undesired or unintended secondary consequences for other systems (for example, less resilience to other systemic risks).

Secondly, efficiency is also an important criterion for the realisation of resilient systems. The resources that are required for effectively reducing risks have to be used as efficiently as possible (for example, in the context of climate protection: meeting the declared objectives with the lowest possible use of resources). Thus the type of an investment, as well as its timing, should also always be determined on the basis of efficiency criteria. This in turn calls for a high degree of familiarity with the system concerned, in order to be able to identify the biggest weak points and the greatest need for action.

3 Dealing with risks in complex systems

The focus of this chapter is on the approaches and challenges associated with risk minimisation and elimination in complex socioeconomic systems. There is a very broad spectrum of approaches to dealing with systemic risks (Figure 2).

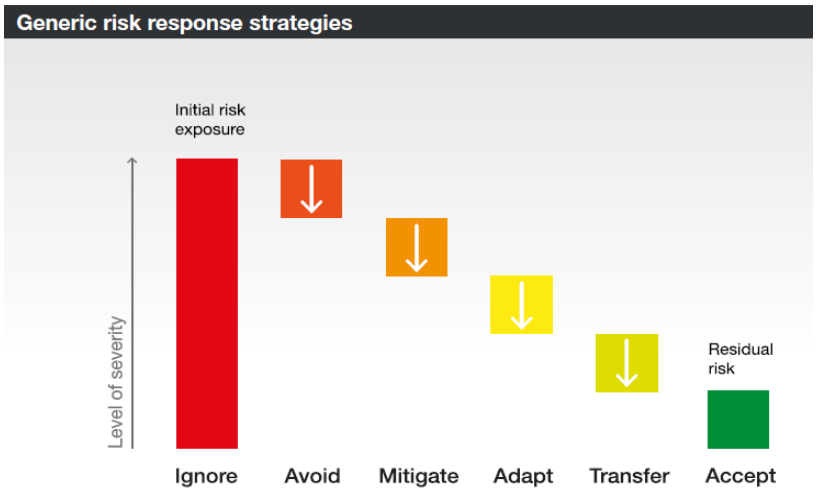


Figure 2: *Generic risk response strategies* (WEF 2011, p. 48)

The current status report of the European Environment Agency (EEA) cites two main strategies for tackling the negative impacts of global megatrends (cf. chapter 2.2): "First, … seek to shape global change in ways that mitigate and manage risks, and create opportunities. … Second, … find ways to adapt to global trends" (EEA 2015, p. 13). With respect to the strategy of shaping global change, the EU notes the progress it has made in reducing environmental pollution and the increase in the efficient use of resources. At the same time, it emphasises the fact that

> "… it is clear that individual governments or regional blocs face significant challenges in influencing global trends. … This observation certainly applies to management of the global environmental commons, for example in efforts to reduce greenhouse gas emissions or preserve public goods such as biodiversity and carbon sinks such as forests. " (EEA 2015, p.15)

The options for influencing global trends and risks are also limited for Switzerland, since at most it can only make a limited contribution towards the collective efforts of the international community to avoid or mitigate developments with inherent risks. The following section therefore focuses on adaptation to systemic ecological risks, i.e. on the perspectives of managing potential impacts of cross-border risks in the national context. The option of risk transfer via insurance solutions/"catastrophe bonds", which concerns action at both the government and the private-sector level, will not be examined in detail here (for further information, see eca 2009, in which the issue of "outlay for investments in safeguards versus the potential costs of a loss event" is dealt with at some length).

As already noted in chapter 2.2, complex systemic risks differ from conventional risks in a number of significant ways (e.g. non-linearity of cause-effect chains, uncertainties regarding probability of occurrence and extent of damage, cascade effects). Thus, in order to deal with systemic risks, other methodological approaches are called for than those required for dealing with less complex risk contexts.

3.1 Governance of systemic (ecological) risks

In the current context, the term "governance" is understood to refer to the collective ability to steer social processes. The traditional political institutions (legislative, executive, judicial authorities) are the main players here. However, Renn (2014, p. 347) points out that, according to a modern understanding, in a plural society a broad variety of players from the spheres of science, the economy and civil society are responsible for these collectively effective decisions and actions. The use of the term *good,* which is often combined with *governance*, indicates that collective decisions should find effective, efficient and fair solutions.

In today's societies, the approach to risks and associated disasters is characterised by the expectation that, although large-scale disruptions are likely to occur, the widely used strategies for dealing with them soon give rise to the restoration of normal everyday life after a certain period of crisis. Due to the degree of confidence in the innovative capacity of human beings and their ability to solve complex tasks, disasters are perceived as occurrences that have to be accepted and can be overcome and which, generally speaking, are caused by external, non-influenceable factors (Renn 2014, pp. 414 ff.).[8]

[8] From the point of view of systemic risks, the illusory confidence in the ability to overcome crises fits in with the current finding of the World Economic Forum that people in general tend to systematically regard the occurrence of future ecological (and thus the associated social) risks as less pronounced and less likely than specialists (cf. http://widgets.weforum.org/global-risks-2015-interactive/risk-explorer.html#landscape//expert/).

The common perception therefore contradicts the nature of systemic risks in a number of key ways. Renn (2015) draws attention to steering problems and underscores three characteristics that are counter to the widespread understanding of management and governance:

- firstly, systemic risks are counter-intuitive as far as the relationship between cause and effect is concerned;
- secondly, systemic risks do not allow for learning from experience – instead they demand political decisions before their effects are known;
- and thirdly, systemic risks are generally associated with the problem of the common property concept, which naturally represents a special challenge for governance.

Realising adequate forms of governance for systemic risks is hampered by a variety of background conditions. These include the short-term orientation of the economy and political players, strong interests in maintaining the status quo (or the unequal distribution of power between risk winners and losers), a low level of interest on the part of decision-makers to address major problems that can only be resolved over the long term, but also the difficulty of allocating responsibilities in the case of diffuse, cross-border threats (Helbing 2013, p. 58; IRGC 2013a, pp. 20 ff.; IRGC 2015a, p. 48).

The sections below focus on the roles of the various players at the international and national levels and the potential strategies national governments can adopt in order to contribute towards the mitigation of systemic (ecological) risks. These sections are followed by a discussion of three elements from the range of instruments for managing systemic risks – early detection and monitoring; promotion of resilience; communication.

International cooperation

As systems grow more complex, the risk of failures of a global magnitude increases, as does the need for international coordination. In its 2010 status report (EEA 2010, p. 93), the European Environment Agency presented an overview of international environmental agreements since 1900. Following a constant increase between the 1950s and 1980s, numerous multilateral agreements were concluded in the 1990s in particular. Around 2003 the number of such agreements started to decline sharply, while other binding forms of environmental governance (regulations and standards, public-private partnerships) and the search for common positions in less formal groupings (G8, G20, BRICS, coalitions of the willing) gained in importance.

According to Martin (2015), the question of whether this is a temporary development remains open. In his assessment, the necessity for international cooperation increases in line with the ongoing economic globalisation. However, experiences gathered during the past two decades have shown that governance at the level of international institutions (UN system, World Bank, etc.) suffers from various deficits that greatly reduce their contribution towards the successful management of systemic risks. A study published by the *Stockholm Resilience Centre* (Galaz et al, 2014a) summarises these deficits as a lack of legitimacy, insufficient effectiveness and the lack of an overall perspective.

While the need for reforms of the UN institutions is still widely acknowledged, their implementation is proving to be extremely difficult due to the existing clashes of interests between groups of countries and the mistrust that prevails between key players. Under these circumstances, making binding decisions is a major challenge, especially when they have to be reached by consensus.

This means that the options for individual countries to help find solutions by participating in international negotiation processes are also limited. Nonetheless, it is important that Switzerland becomes involved at this level as a member of the international community. As Martin points out, in

the context of the international environmental and development agenda, this is a "global process with national responsibilities", and it is therefore important that global megatrends are also addressed at the national level.

It is a widely shared view that there is no alternative to discussing global systemic risks in the existing (international) institutions. It is only in this way that a mutual understanding of the need for action and management strategies can be enhanced and efforts can be made to find ways of overcoming existing barriers. As expressed by the World Economic Forum (WEF 2015, p. 30): "... no collaboration is the worst possible outcome".

Risk governance at the national level

At the national level, the question arises for Switzerland as to who is best able to help ensure that adequate solutions can be implemented for dealing with risks arising from a variety of different sources – whether for mitigating the risk itself or for overcoming the risk-related consequences.

As a core element of governance, the collective ability to steer social processes is no longer questioned in Switzerland. In view of the wide-ranging participation and co-determination options, the system of opinion-building and decision-making may be regarded as fair. However, in a rapidly changing environment, the existing structures for dealing with systemic risks, along with the range and roles of the involved players, need to be constantly reviewed.

Given the diversity of uses to which individual commercial goods can now be put, Renn (2015) poses the question of whether we would be able to quickly procure a substitute product if we were to experience temporary interruptions to the supply of palm oil, for example. In his view, such scenarios should be examined from the point of view of securing supply, without the exaggerated aim of attaining full national self-sufficiency. A systematic presentation of the indirect impacts of climate change on the UK can be found in pwc (2013).

For Switzerland, the key parameters for securing national supply in crisis situations may be summarised as follows:

In accordance with Article 102, paragraph 1 of the Federal Constitution, it is the duty of the federal government to secure the country's supply of essential goods and services in the event of threats of a political or military nature, or during periods of severe supply shortages that the economy is not able to overcome on its own. Here the relevant authority is the Federal Office for National Economic Supply (BWL).

Very close cooperation between the economy and the public sector is one of the main characteristics of the existing division of duties in this regard. BWL (2009, p. 3) cites the following central principles:

- subsidiarity (the government should only intervene if the economy is no longer able to fulfil its duty of supply);
- cooperation (the economy and the government have to work together in order to ensure that the corresponding know-how and existing structures of the private sector can be utilised for securing performance of the duties of the public sector in a crisis situation);
- networking (in the organisation of the national economic supply, representatives of all the main sectors of the economy should assume management responsibility so that networked know-how can be made widely available; at the same time, exchanges of information and experience can be made with other countries and international organisations, and efforts to bring about various forms of cooperation can be pursued).

In the area of national economic supply, the initial situation is comparable in many ways to the challenges arising from systemic environmental risks (cf. BWL 2014 and 2013). The detailed mandate specified in the Federal Act of 8 October 1982 on the National Economic Supply clearly differentiates it from the aspect of protection against systemic environmental risks.

An in-depth study to determine whether the approach applied in Switzerland for dealing with supply crises meets the challenges of systemic ecological risks would go beyond the scope of this report. Renn (2015) names four partners that need to cooperate in order to deal with systemic risks: science, the economy, civil society and government. In his view, each of these groups stands for one of the four main criteria (effectiveness, efficiency, fairness and resilience) that form the basis for assessing risk management.

While science is able to provide the models for assessing the effectiveness of measures under conditions of high complexity, the economy is best suited for fulfilling the criterion of (cost) efficiency. Since efficiency is often in conflict with the criterion of fairness, the challenge for civil society is to find an acceptable balance. Resilience in the sense of successfully dealing with unusual occurrences can best be assured via state organisations.

Renn (2015) also emphasises that in the case of stochastic events – where the goal is to prevent potential damage in the future that could occur, but does not necessarily have to – there is an urgent need for state regulation, at least at the level of risk prevention. It is often the case that economic stakeholders are unable to "afford" resilience for reasons of competitiveness, but they are not opposed to the introduction by the government of generally applicable regulations.

From the point of view of the private sector, the *Resilience Action Initiative* (a network of large, globally active companies) has been examining the importance of participation processes, and this has culminated in a call for increased cooperation within public-private partnerships:

> "... we refer to the extreme events of recent years … to strongly advocate more collaboration and joint action of private and public stakeholders. Company owners and managers and state and local government officials need to form a new joint vision and implement coordinated resilience strategies to safeguard welfare and prosperity in the face of the energy-water-food nexus." (Arizzi et al, in Kupers 2014, p. 137)

Schneider (2015) draws attention to the concept of risk appraisal developed by Renn as an integral component of risk analyses (cf. Renn, undated and IRGC 2005), which ensures that risks can be observed not only from a technical and scientific point of view, but also in their social and economic dimensions. The different perceptions and assessments of risks by the various stakeholders are a central element in this process.

In their comments regarding risk management, Helm and Helbing focus on the management of acute crises rather than on prevention. This also affects the perception of the role of government institutions: while Helm (p. 24) does not question the government's controlling function in the management of crisis situations, he nonetheless points out that, following the disastrous earthquakes that occurred in New Zealand in 2010, at the local level the "social capital" (neighbourhood assistance, voluntary organisations) proved to be a decisive factor in overcoming such situations. He therefore attaches high priority to the principle of subsidiarity and the promotion of self-organisation processes and warns against rigid crisis management structures.

The sceptical comments of Helbing (2013, p. 57; 2015) about the principle of a "caring state" go in a similar direction. A caring state is neither able to respond sufficiently quickly to failures in a complex system, nor does it have the authority to define objectives that have to be pursued in the public interest (cf. box below). Relying on the principle of subsidiarity he therefore calls for "decentralised

coordination" between directly involved subsystems (e.g. neighbourhoods) while utilising locally available resources. This approach offers a higher degree of resilience towards failures in comparison with a government-controlled top-down procedure.

Based on the cited sources it may be concluded that when dealing with specific occurrences (crisis management), the government should adopt a subordinate role at the operational level. On the other hand, it has to perform important risk prevention duties in close cooperation with other players. The report entitled *Boosting Resilience through Innovative Risk Governance* (OECD 2014), which deals with this topic in depth, formulates a number of recommendations regarding effective (preventive) risk management. These can be summarised in the form of three objectives:

1. Identifying and observing risks at an early stage
2. Facilitating and implementing measures to strengthen resilience
3. Incorporating a broad range of players, conducting dialogue on risk and building up trust

The third objective has been addressed in this chapter. Comments on the literature consulted and the corresponding recommendations that can be applied to the other objectives and fields of action are given in the following three sections.

IT-based management of complex systems

With respect to complex issues such as those that have to be resolved in connection with systemic risks, Helbing (2015) insists that it is wrong to define a single objective that has to be pursued (at the expense of other objectives) in the public interest. He calls for diversity as the recipe that keeps the risk of taking the wrong action within reasonable bounds:

> "Diversity is of the utmost importance for the innovative capacity of the economy, for the resilience of society to sudden shocks – i.e. for systemic resilience – and for collective intelligence. ... Diversity, resilience and collective intelligence can be attained more easily with systems that have a certain degree of decentralisation."

Helbing's vision of the management of complex systems is based on five functions that need to be made available in the future within the scope of IT applications:

1. Real-time measurements of the environment, including externalities (e.g. emissions of all kinds), positive interaction effects and resources;
2. Drawing attention to the implications of decisions and actions (options, alternatives) with the aid of digital tools;
3. Utilisation of data in order to gain scientific insights into complex systems (including non-visible social resources worthy of protection, e.g. trust, reputation, solidarity);
4. Supporting the ability of complex systems to self-organise through feedback effects;
5. Creation of collective intelligence (flexible combination of the knowledge and ideas of a broad range of players in order to find better solutions).

Taking the sustainable management of resources as an example, Helbing maintains that these functions can help find answers to questions such as: How many resources exist, and where? Who consumes large quantities of these resources? How can differences be explained? What are the conclusions for our own behaviour?

3.2 Early detection and monitoring

The purpose of environmental monitoring is to document the state of the environment and its development as objectively as possible and use the findings as the basis for decision-making. This involves assessing the situation in Switzerland, as well as using international data. The latter are generally based on national reference areas or take the form of aggregated national data. However, the usefulness of country-specific data on risk-related trends in distant regions is limited as long as it is not clear how these trends fit in a global context ("megatrends") and what their impacts could be in the area concerned (e.g. Switzerland).

Furthermore, the value of data that depict historical trends is limited when it comes to assessing the development of risks over limited timeframes or risks that follow linear patterns to a limited extent. Martin (2015) underscores this: "Overall, the balance with regard to our efforts towards measuring as opposed to trying to understand what may be coming towards us is rather skewed".

According to the OECD (2011, p. 14; 2014, p. 17), nationally oriented early detection and monitoring structures should be further developed so as to make it possible to depict the development of risks abroad that represent a threat on the domestic front. For this purpose it is necessary to keep an eye on a broad range of drivers and their interdependencies and potential cascade effects.

IRGC (2013a, p. 11) stresses that monitoring of the environment from the point of view of systemic risks not only has to identify deviations from earlier trends, but also indicate possible impending trend reversals, regardless of the subsystems in which they initially become apparent or where they manifest in a cascade of concatenated occurrences.

The European Environment Agency also shares the view that systemic cross-border risks call for suitable forms of monitoring:

> "Improving Europe's responses to global megatrends also depends on credible information on possible future developments and choices in the face of global risks and uncertainties. Better information is needed to mainstream long-term and global perspectives into policy. **Increased use of foresight methods** … could strengthen long-term decision-making by bringing together different perspectives and disciplines, and developing systemic understanding. ... Including forward-looking assessments and indicators in regular reporting on the state of the environment could likewise improve understanding of future trends and uncertainties." (EEA 2015, p.16f; emphasis added)

In the opinion of Martin (2015), this means that the existing range of instruments for monitoring the environment needs to be more precisely oriented on future challenges and also needs to be expanded. Broadening the scope and spectrum of the applied methods means that the expertise requirements also change: "… you need to think about participation that is rather varied in expertise and background, bringing public and private, social, technological, economic and environmental interests into play".

Early detection methods

IRGC (2015b, p. 14) describes strategic foresight as "forward-looking approaches intended to identify future opportunities and risks [including] scenario development, horizon scanning, expert workshops, benchmarking with peers, and the analysis of scientific and professional literature and reports on future threats and opportunities". EEA (2011, p. 7) cites "horizon-scanning approaches, model-based projections and comprehensive scenario-planning approaches" as the most important tools that can be used for supporting long-term decisions.

IRGC (2015b, pp. 14 ff.) closely examines scenario-based approaches for dealing with emerging risks. It refers to various other instruments, including a special toolkit that was developed within the scope

of the UK government's *Horizon Scanning Programme*[9] (HM Government, undated), which describes nine tried-and-tested *futures techniques*. CSS (2013, pp. 26 ff.) also provides a brief overview of five early detection methods. Deliberations regarding the design of horizon scanning as an instrument for the systematic procurement of information on emerging trends and risks can be found in Habegger (2009).

In its report on governance in dealing with emerging risks in the public sector, IRGC (2013b, p. 11) states:

> "Today it is commonly recognised that the design and implementation of early warning systems, the monitoring of early warning signals and the use of relevant criteria for evaluating the meaning of the signals provided are very useful tools to guide risk managers about when it is time to act."

However, foresight approaches have barely been applied to date in the context of systemic ecological risks.[10] To quote Martin (2015): "The use of foresight approaches is at a very immature stage compared with what we might need, given the systemic nature of the challenges". This is in line with the comment by the EEA (2011, p. 7) that although a great deal of knowledge about the various methods is available, almost no systematic findings exist regarding the practical benefits and effectiveness in ecological contexts.

Here the fact should be borne in mind that the increased use of early detection methods could also be associated with problems relating to acceptance. Models are often perceived as very technical, and qualitative scenario studies as very subjective (EEA 2011, p. 10). Both are unwelcome for political decision-makers, who prefer to base their decisions on facts. This problem is addressed in greater detail below (under "Quantitative versus qualitative data").

Working with large quantities of data

Technical developments in recent years have made it possible to permanently record and document ever larger quantities of data in a variety of ways. We are now living in the era of Big Data. However, the way in which political decisions are taken has to date changed very little. On the contrary: the abundance of available data often creates frustration over the fact that the greater quantity of information does not give rise to better decisions (IRGC 2013b, p. 14).

In view of the current interest in Big Data, the technologies for procuring and analysing data can be expected to develop rapidly and the corresponding instruments to become more efficient. This raises the question of how they can be practically applied in the early detection of symptoms of systemic risks (GCF, p. 178; OECD 2014, p. 118).

Martin (2015) regards Big Data above all as a challenge for existing statistics systems, but also as an opportunity to assess the status of the environment and society in new ways with the aid of entirely different data sources. In his view, the question of whether it will be possible to utilise Big Data for the purpose of early detection and monitoring of risks remains open.

Helbing (2013, p. 58) has great expectations of the potential arising from the increased dissemination of networks for measuring a broad variety of parameters. He envisages the creation of an open information ecosystem in which the data collected on interactive platforms will be placed at the disposal of everyone (cf. box below).[11]

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[9] https://www.gov.uk/government/groups/horizon-scanning-programme-team

[10] The activities of the UK Government Office for Science (cf. GO Science 2011) are an exception.

[11] The brochure entitled *FuturICT: Global Computing for our Complex World* (undated, available for downloading from www.futurict.eu) presents a vision of how this could be realised.

Big Data: basis for early warning systems – opportunity for risk management?

The option of continual global input of status data via the Internet of Things raises questions about the potential benefits of Big Data for the early detection of environmental risks. Will the existing observation and monitoring systems soon become obsolete because it will be possible in the future to collect and evaluate data on the state of the environment with a higher degree of accuracy and in real time? Are Big Data truly a "transformative opportunity" (Martin 2015) for monitoring the environment?

Helbing (2015) is of the opinion that, together with the mobilising potential of social media and the expertise that people contribute ("basically there are hobby experts for everything"), the Internet of Things opens up entirely new opportunities for collecting and integrating knowledge and making it available to third parties (companies, politicians, scientists). In combination with suitable ICT applications, the enthusiasm for certain issues could mobilise previously unutilised resources. In this way it would be possible to quantify how various system elements and entire systems influence one another, in other words to obtain "an image of the world in the digital range … to a certain extent, even in real time". In this context, Helbing speaks of an opportunity to remap the world together: "World survey 2.0 is imminent".

For Helbing, the greatest benefit lies in the analysis of large quantities of data when they are used in the context of suitable models. He compares this with the weather forecast, where a lengthy process of data collection and the development of models is required before reliable and high quality forecasts can be produced.

With regard to the suitability of ICT applications for early warning systems relating to the overuse of global natural resources, Helbing is of the opinion that tipping effects exist in both economic and ecological contexts that often manifest themselves in the form of an accumulation of relatively minor occurrences such as those that can be observed shortly before a lake reaches tipping point.

Renn (2015) acknowledges that for many natural disasters precursors exist that can be detected with the aid of sensors. He is sceptical, however, with regard to those risks for which no reliable sensors exist that could warn us in advance when a disaster is about to occur. In connection with systemic risks, Renn regards the notion that, "if we can measure it, we can also master it", as a widespread illusion:

> "We are aware of many ecological indicators… and there is also a large number of sustainability indicators. But this is not measuring in the sense of an early warning system because as a rule we do not know the non-linear tipping points. We do not know when the Gulf Stream may stop flowing. No figures are available because it has occurred too rarely and we do not have any reliable data at our disposal concerning either distribution or, in particular, a potential cause. With respect to these issues, our models are often based on mere speculations.[12] We also do not know how such an occurrence might manifest itself. ... With respect to tipping points of this kind, models are very uncertain."

For Renn, the potential of Big Data as the basis for early detection applies less to ecological risks than to social phenomena and dynamics (e.g. social unrest). In such contexts, the corresponding analyses can deliver surprisingly good results.

[12] Schneider (2015) shares this scepticism. In his view, systemic risks are often "domino effects … that are almost impossible to model and for which scenarios have to be created in order to be able to confront people with the potential impacts."

For Helbing (2015), examples that illustrate this potential include initiatives in Japan, where citizens measure radioactivity levels, and in California, where citizens carry out earthquake measurements. Citizens are becoming increasingly active in building up "sensor networks" so that data can be collected that would otherwise not be possible to collect because of the high costs. Helbing sees the more accurate assessment of risks by insurance companies as one of the specific benefits of these data.

However, Helbing also understands that large quantities of data go hand in hand with new challenges. Too many data can obscure important trends instead of drawing attention to them more clearly. For such data procurement systems it is therefore necessary to initially tackle demanding problems relating to the selection of relevant parameters and filtering and interpretation of the collected data. On the one hand, Helbing regards intensive interdisciplinary cooperation as a prerequisite for the use of Big Data, while on the other hand he draws attention to new technological opportunities such as cognitive computing.[13]

King et al (2015, p. 139) emphasise that, unlike data acquisition, risk assessment calls for other skills and therefore needs to be assigned to a team of specially trained experts.

Early detection of emerging risks: the example of Swiss Re

The globally active reinsurance group, Swiss Re, has chosen a pragmatic path for the needs of a reinsurer when dealing with emerging risks (Swiss Re 2013; see also IRGC 2015b, pp. 7 ff.). It has created an Intranet platform called SONAR, on which around 500 experts from various risk segments in which the group is active enter their perceptions (which they refer to as "notions") concerning new developments (risks *and* opportunities), together with the reason why they regard these to be of relevance for Swiss Re. These notions may be based on observations and discussions, as well as on articles in the media, etc. The platform also facilitates interactions between the participants so that an initial opinion-forming process relating to the relevance of a given notion can take place at this early stage.

The submitted notions are examined on the basis of other information sources such as research institutions, think tanks and relevant literature by a team comprising four specialists in the field of emerging risks, who then evaluate and prioritise them by calling on a very broad spectrum of expertise within the group. The findings are submitted for discussion by around 30 managers from various business segments at quarterly round table talks. Here they work with "maps" on which certain risks are depicted, together with the degree of priority with which they need to be addressed ("non-priority", "monitoring" or "immediate need for action"). Notions that have been confirmed in this way as relevant for Swiss Re are then processed and published for the attention of selected internal target groups (Swiss Re 2013, 2014, 2015). This enables Swiss Re to present a broad periodical overview of risks that could be significant for the group's future business activities or indicate where opportunities could arise for new business areas.[14]

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[13] "Cognitive computing systems learn and interact naturally with people to extend what either humans or machine could do on their own. They help human experts make better decisions by penetrating the complexity of Big Data." … "Rather than being programmed to anticipate every possible answer or action needed to perform a function or set of tasks, cognitive computing systems are trained using artificial intelligence (AI) and machine learning algorithms to sense, predict, infer and, in some ways, think." (http://www.research.ibm.com/cognitive-computing/, 23 September 2015)

[14] According to Schneider (2015), the success rate of SONAR is around 60 percent, based on the topics entered between 2010 and 2013 and the occurrences documented in 2015 that are directly related to these topics. In around one-third of the cases, no occurrence was reported in the assessment period that corresponded to the formulated risk.

SONAR may thus be described as a systematic, web-based, further development of the conventional process of issue monitoring. Käslin (2008) characterises this form of early detection as a kind of "strategic radar" for monitoring a company's internal and external spheres that uses weak signals as indicators of impending discontinuities. Here, information that is initially vague and often qualitative evolves over the course of time to acquire a status in which cause-effect correlations become identifiable.[15]

This form of early detection, which is widely used in the insurance sector, is usually characterised by network-based structures: a selected group of participants summarises relevant observations that are then evaluated in an exchange with a specialised core team and subsequently placed at the disposal of decision-makers within the group (cf. Figure 3). The problem with respect to the quality of the collected data is mitigated thanks to the available expertise and as a result of the basis of trust that exists between the involved participants. As the main corporate cultural factors for the successful functioning of such systems, Käslin (p. 183) includes communication, further education and promotion measures, as well as incentive structures that "help ensure that as many employees as possible can be actively involved in the detection of emerging risks".

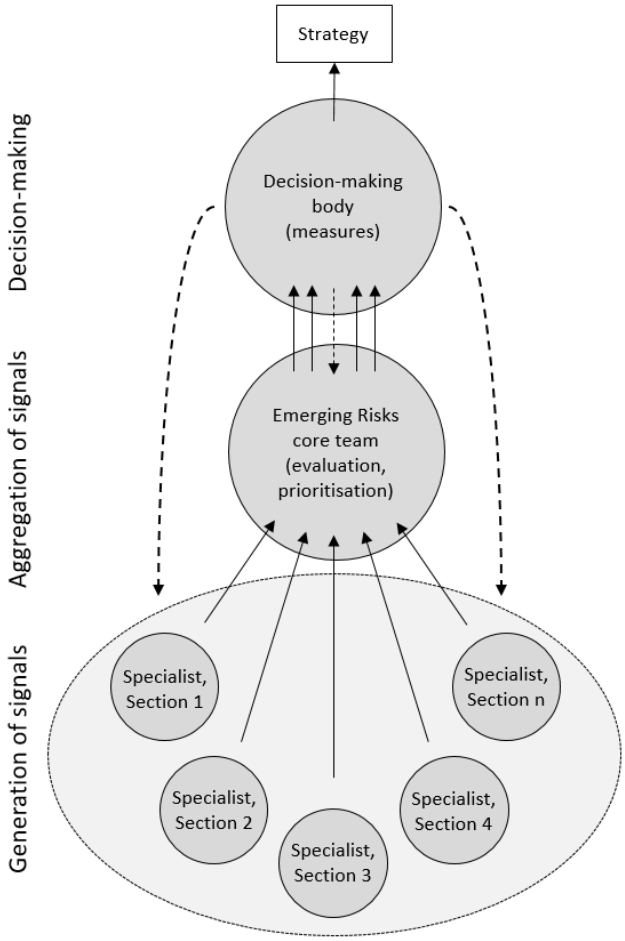

Figure 3: Outline of early detection system (according to Käslin 2008, p. 194 and Schneider 2015)

A procedure based on this approach would also be conceivable among specialists in the field of early detection and monitoring of ecological risks. Particularly in the area of systemic environmental risks, in which a certain latency period exists between cause and potential effects, the initial situation is

[15] An outline of the further development of participatory measurement systems for the early detection of extreme events with the aid of crowd-sourced smart data can be found in Helbing (undated).

similar to that of an insurance manager, an environmental authority or a politician: the player concerned either invests resources in a given area where no signs of success are immediately apparent or may otherwise be accused of having ignored the risk that should have been identified at an early stage.[16]

According to Schneider, the main difference between the point of view of the public sector and that of the insurance industry lies in the applied relevance filter: for Swiss Re, the degree to which a given risk can be insured, or the business opportunity, plays a central role, whereas in the public sector the focus is on protecting intangibles (e.g. biodiversity) before their condition is perceived by the economy or society as a threat.

Figure 4 presents a current example for the synoptic depiction of emerging risks that arise as a result of working with SONAR at Swiss Re.

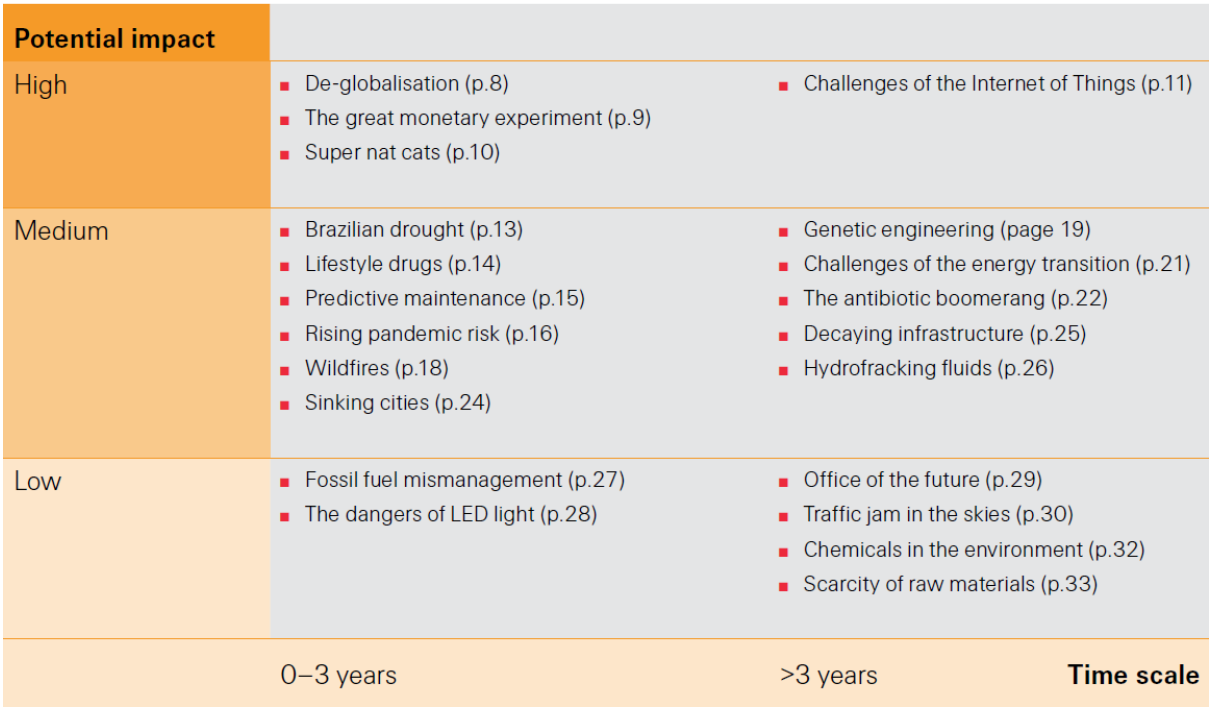

Figure 4: *Overview of emerging risk topics by timeframe and potential impact* (Swiss Re, 2015, p. 7)

Quantitative versus qualitative data

As the example of SONAR and a variety of published studies show, qualitative data are of very great importance in dealing with systemic risks. In this context, processes that are suitable for using "soft" data such as the opinions of experts[17] are often more useful than conventional methods of data collection via monitoring and measurement systems.

[16] In this context the comment by Schneider (2015) to the effect that, on the government side, minimum requirements exist on the management of emerging risks in companies in the insurance sector, is relevant. The Swiss Federal Financial Market Supervisory Authority (FINMA 2008, p. 7) notes that "risk detection and assessment ... should incorporate a prospective form of observation". Requirements of this kind also provide additional assurance that foresight activities do not fall prey to internal resistance or economising programmes. In Schneider's view, pressure from a regulatory authority gives rise in this case to desirable impulses in the interest of the general public.

[17] According to Käslin (2008, p. 175), in practical application in the insurance sector the assessment of emerging risks is based on expertise, knowledge of the market, long-term professional experience and "gut feelings".

Systemic risks often have several origins that interact with one another via non-transparent feedback processes. They have complex impacts that need to be fully understood in order to be able to develop appropriate strategies. Generally speaking they develop over lengthy timeframes, and this makes it necessary to think in terms of scenarios (IRGC 2013b, p. 13). To some extent, dealing with systemic risks therefore evades a policy aimed at basing decisions on hard facts (i.e. an "evidence-based policy").

The hesitance on the part of politicians to deal with systemic risks can to a certain degree be explained by this factor. Here, the option of justifying far-reaching decisions by referring to measurements and calculations that have been carried out using recognised methods no longer applies. However, a lack of scientific evidence and well-founded opinion-forming processes do not rule one another out. In their empirical study on evidence-based policy in the Netherlands, Slob/Staman (2012, p. 6) draw the following conclusion:

> "Politicians need to realise that more scientific knowledge will not necessarily help eliminate uncertainties; quite the contrary, in the case of complex problems, more science often creates greater uncertainty."

Decisions concerning political issues that incorporate a variety of assessment dimensions (e.g. short-term and long-term interests, opportunities and risks in various subsystems) cannot be taken scientifically, because there is always a number of scientifically founded (or substantiable) solutions that are not reconcilable with one another (Slob/Staman, p. 38). Comments published by the European Environment Agency regarding success factors for the use of futures thinking in governments back up this appraisal (EEA 2011, chapter 1.4).

Political opinion-forming and decision-making regarding the treatment of systemic risks must never pursue the objective of eliminating uncertainty (with the aid of scientific analysis). Decisions have to be taken in awareness of the fact that *a priori* no certainty exists regarding the conditions and consequences of a decision. However, soft facts, i.e. expertise that contributes important viewpoints in a transparent, structured form in a qualitative manner, can be of enormous value in dealing with systemic risks.

3.3 Promotion of resilience

As noted in chapter 2.4, with respect to the promotion of resilience the question of "resilience *of* what *to* what and *at the costs* of what?" first needs to be answered. In the current context, two approaches are of relevance:

Criteria for maintaining the resilience of (global) natural systems

As far as the causes for destabilisation are concerned, or measures for maintaining the resilience of natural systems and avoiding the associated risks, the question cited above can be formulated as follows: How can (national/international) environmental governance contribute towards complex natural systems (e.g. the climate system, the natural water cycle or natural ecosystems of major social importance) being utilised so that their usefulness can be permanently sustained? What price is governance prepared to pay (e.g. in the form of restrictions on use or costs for remedial measures) for this?

From this viewpoint, the most important measures for maintaining the resilience of natural systems are as follows:

- the most sustainable possible use of resources (mitigation of risk potential), including efforts to promote sustainable value chains;

- proactive participation in international environmental governance processes (collective management of systemic risks);
- broad-scale sensitisation to the importance of global ecological risks for Switzerland (risk awareness and promotion of acceptance for the two strategies cited above).

Criteria for promoting the resilience of socioeconomic systems in Switzerland

If we consider how failures that can be brought about through destabilised (global, natural) systems are dealt with, the above question has to be reformulated. How can a social community or a business sector protect itself against systemic (e.g. ecological) risks, and what price are they prepared to pay for this (e.g. in the form of prevention costs or efficiency losses)? Here the focus is on successfully mastering the impacts on the economy and society. The comments presented below apply to this second viewpoint.

According to Renn (2015), the promotion of resilience can be interpreted as a precautionary principle applied to systemic risks.[18] He favours the approach of also being prepared to deal with unlikely occurrences, even if we do not know which one will affect us, but only that one of them will inevitably do so.

Renn illustrates his understanding of precaution and resilience to complex risks citing the example of the Deepwater Horizon oil disaster that occurred in the Gulf of Mexico in 2010. Even if a company does not want to take comprehensive and costly precautions, it has to at least be aware of what has to be done in the unlikely event of an oil pipe fracturing on the seabed.

The comments by the EEA regarding the accusation often made in business circles that the principle of precaution gives rise to overregulation are also of interest in this context:

> "In debates surrounding the precautionary principle it is often claimed that widespread application of the principle will lead to a large number of regulatory false positives – over-regulation of minor risks and regulation of non-existent risks, often due to unwarranted public 'fears'. (…) Overall, the analysis shows that fear of false positives is misplaced and should not be a rationale for avoiding precautionary actions where warranted. False positives are few and far between as compared to false negatives and carefully designed precautionary actions can stimulate innovation, even if the risk turns out not to be real or as serious as initially feared." (EEA 2013, p.17)

These comments are congruent with experiences made by Swiss Re. A majority of the emerging risks identified internally in the past few years have proved to be business-relevant. Their observation was therefore in the group's business interest (cf. footnote 13).

Strengthening resilience to the impacts of systemic risks encompasses a broad spectrum of measures, ranging from the creation of suitable framework conditions for "systemic" access to risk assessment and prevention within interdisciplinary, cross-institutional and cross-border structures to the analysis and modification of incentives hampering resilience at the national and international levels, through to the propagation and implementation of specific measures incorporating all relevant interest groups (cf. OECD 2011, OECD 2014).

The criteria cited in Table 1 (cf. next page) for promoting the resilience of socioeconomic systems in a national context create buffers, potentials and resources for intervening in the event of unexpected disruptions, preventing cascade effects and maintaining important system functions and services (e.g. value chains, infrastructure, supply systems) even under changed conditions (Renn 2014, pp. 502 ff.; Helbing 2013, p. 53; Bresch et al, in Kupers 2014, pp. 49 ff.).

[18] cf. the differentiated application of various risk management strategies based on the criteria of complexity, security and ambiguity in Renn (2008) and the strategies for managing emerging risks in IRGC (2014, p. 2).

The examples cited in the table are intended to be illustrative in nature, but have not been selected arbitrarily. On the one hand they are based on measures cited in the literature (especially Renn 2014; Bresch et al, in Kupers 2014; OECD 2011, 2014) aimed at promoting resilience, and on the other hand they have been inspired by publications of the Federal Office for National Economic Supply (BWL 2009, 2013, 2014) and the report on the perspectives for 2030 for the attention of the Federal Council (Federal Chancellery 2014).

Strategic criteria for the promotion of resilience	Examples
• Redundancy Backup systems are used for bridging failures of critical services and reducing the degree of dependency on third parties	− Water and energy supply systems that are independent of one another; warehousing − Protection of valuable agricultural land − Networking of natural habitats
• Decentralisation Essential system functions can be performed by several subsystems; responsibilities are widely dispersed	− Decentralised connectable sources for water and electricity supply − Decentralised structures in the healthcare sector − Cooperative/federalistic structures
• Diversity Diverse skills, resources, technologies and strategies support the provision of a service or the maintenance of a function	− Multiple transport/communication systems − Locally adapted/resistant species, various production/management technologies − Promotion of biodiversity
• Error tolerance Incorporation of safeguards against human or technical errors	− Safeguards in infrastructure systems − Dual control principle for important decisions
• Robustness/loose coupling Detection of weaknesses, anticipation of unlikely disruptions, implementation of measures against cascade effects	− Emergency plans for responding to epidemics/ pandemics; planning for new health risks − Planning of predetermined breaking points or overloads (electricity network overloads, obstacles in the event of flooding)
• Social capital Promotion of self-organisation; creation of trust through transparent, smoothly functioning institutions and networks; appropriate allocation of responsibility for risks/risk management[19] •	− Capacity building as an element of the education system − Social cohesion, e.g. thanks to social balance − Fostering prevention-oriented thinking − Communication of critical trends, promotion of risk awareness (dialogue on risk) − Coherent warning and crisis communication

Table 1: Criteria for the promotion of resilience to the impacts of systemic risks

3.4 Communication of systemic risks

Providing information about systemic risks is a prerequisite for creating awareness of the existing need for action and the necessary acceptance of the available options for taking action. In a broader sense, this could also be understood to include a general consideration of the causes (e.g. the non-sustainable use of limited resources) and the (ir)reconcilability of global population and economic growth and increasing consumption with planetary boundaries.

This broad interpretation of risk communication goes beyond the scope of this report and its central issues and is also not the focus of the principles applied here. Hence, the framework conditions and

[19] Schneider cites an additional dimension specifically relating to the economy: “In a disaster the economy also sees an opportunity for renewal in that it is to a certain extent able to re-emerge from the ruins in a completely new organisational form. This, too, is an aspect of resilience.” In this context he uses the term “transformation capacity”.

potential focuses of risk dialogue (i.e. the communication of complex risks, the threats associated with them, and the potential consequences for the various involved players) will be addressed below.

It is in the nature of systemic risks that they are generally difficult to perceive. As a rule, problematic developments take place gradually over lengthy timeframes. Due to the complex, non-linear interactions, it is difficult for non-specialists to identify causal relationships. Psychological barriers are another significant factor: people tend to dispel potentially serious but unlikely occurrences and are unwilling to take comprehensive action to prevent damage that may never arise (Renn 2013, 2015).

As a consequence, except in situations that arise in the form of disasters, systemic risks are difficult for the media to communicate and little attention is paid to such reports. But complex international negotiation processes also contribute towards the fact that people tend to focus on controversies between the involved players rather than on the causes of problems and their potential solutions.

Another factor that makes it difficult for politicians to communicate systemic risks is that the associated messages are unattractive:

- short-term benefits have to be waived due to long-term disadvantages;
- upon closer examination, the causes can be traced back to shortcomings in human nature and the way in which consumer society functions;
- if the risks were to be taken seriously, the belief in strategies that have proved to be successful in the past would have to be questioned, as would the optimism concerning the (financial, technical) feasibility of as yet unknown solutions (IRGC 2013a, p. 21; Renn 2014, pp. 414 ff.).

The arguments outlined above make it clear that the conditions for the communication of systemic risks and measures to promote resilience are very difficult.Nonetheless, there is no alternative here, just as there is no alternative to the necessity of looking for consensual solutions at the international level.IRGC (2013a, p. 25) formulates this as follows:

> "A necessary condition for risk to be handled effectively is that those who hold the ultimate power must agree about the significance of the risk. In Western democratic societies, this means that public perception holds the key."

The summary below cites approaches and recommendations from the consulted literature for enhancing the prerequisites for the successful communication of risks.

- *Story telling and the importance of trusted contexts*

The nature of systemic risks and the way in which they have an impact can be clearly illustrated by presenting vivid and memorable stories about events that have actually occurred or which could take place. Stories are more easily understood than conditional statements linked to potential occurrences that are typically incorporated into scenarios.

Several examples of causal chains that illustrate the close dependencies in modern-day global value chains are cited in OECD 2014 (pp. 36 ff.).[20] Three of these are described below:

> "The Great East Japanese Earthquake in 2011 caused disastrous impacts not only in Japan; it led to slowdowns in the global automotive and electronics industries which rely on Japan for inputs to their value chains. For example, car manufacturers in Detroit were affected when Renesas, a large supplier of microchip controllers in Japan, halted production due to the destruction of its factory. Single sourcing was equally the root cause of a global disruption in the supply of car paint due to a factory that was destroyed in North East Japan. The supplier provided 100 percent of global car paint demand, leading to major disruptions in car supply chains worldwide."

[20] Other examples can be found in King et al (2015, pp. 109 ff.).

> "The floods that affected the Bangkok metropolitan area in Thailand in 2011 hit a particularly industrialised part of the city, where more than 1,000 factories were affected. 45 percent of the world's manufacturing capacity of computer hard disk drives are produced in the affected area. It is estimated that global hard drive supply saw a decrease of 30 percent that year."
>
> "The severe and prolonged drought in the United States that is estimated to have started in 2012 and that lasted until 2013 has had severe economic impacts. The low water levels in the Mississippi River, for example, where 180 billion US dollars worth of goods are moved every year, forced barges to reduce the amount of cargo they can carry by two-thirds of their usual load."

The latter occurrence recalls to mind the hot and dry summer of 2003 in Europe, which caused major restrictions of shipping operations on the Rhine. The analysis of this occurrence (BUWAL/BWG/MeteoSchweiz, 2004) concluded that it was not only shipping activity that was affected: the rail freight capacities along the Rhine were also insufficient for taking over the transport of oil products, containers and metals from the North Sea ports. This meant that large quantities of grain products had to be stored at these ports until the situation on the Rhine had returned to normal.

This occurrence provides useful points of reference for illustrating the often unexpected facets of systemic risks. It demonstrates in an exemplary manner that event analyses form a valuable analysis for depicting complex correlations.

In this context, the comment by the OECD (2014, p. 43) that, as measured by the global value chain participation index, the majority of Switzerland's export products are realised through inputs from abroad or flow into export products of other countries in the form of inputs, is also of relevance. The direct and indirect dependencies that exist on the basis of cross-border trade flows tend to be generally underestimated by politicians as well as the general public. Specific, well-researched examples can be used as illustrative material to sensitise people to the susceptibility of supply chains, but also of companies, sectors and economic output, to disruptions.

In the insurance sector, too, it is important to depict the consequences of developments associated with risks in a manner that enables those who could be affected to draw a realistic picture of the existing threat. Schneider (2015) describes this challenge as follows:

> "We would have to plunge in here and draw up stories and scenarios that occur within this trend and so as to become concrete enough that we can envisage what the problem is … a very specific story from which someone in our company who issues a policy realises: Aha, that's the new exposure ... Without this context I cannot inspire anyone. I have to be able to trigger this personal involvement. People need a certain heuristic anchor in the form of recognition points. If I only communicate new facts, people will be overtaxed."

Parallels clearly exist with the political approach to systemic risks: politicians as well as the general public have to be convinced of the need to take out "insurance" by investing in suitable precautionary measures.

Martin (2015) draws attention to another aspect of story telling. Based on his experiences, the global megatrends developed by the EEA are being positively received because they present environmental issues from a different perspective: "[they] draw people into a narrative, a story that is not so known and understood and, therefore, by its nature, is more interesting". This is in contrast to the inherited negative terminology that is normally in the forefront of communication on environmental issues. Martin recommends repositioning the environment as a positive narrative and emphasising the benefits to a greater extent instead of the deficits ("We have this fantastic thing called biodiversity and all we do is apply negative connotations to it").

Another example of the "translation" of complex scientific content into more practice-oriented language is the water-food-energy nexus referred to in chapter 2.2, which deals in a concise and politically relevant manner with the planetary boundaries formulated by Rockström et al (2009). While planetary boundaries call for an advanced understanding of natural science contexts, the reinterpretation as a threat to the global supply of water, energy and food is a topic that is immediately understood and attracts attention in political circles as well as in the economy (cf. Kupers 2014, p. 25; WEF 2011).

- *Initiating or supporting social/collective processes*

Helbing (2015) notes that topics such as environmental protection and sustainability are widely associated with restrictions and waivers, and related calls for changes in behaviour are not always insightful. This means that the existing potential for solidarity and a sense of responsibility is not exploited. In the future, ICT applications such as those currently being developed at the Federal Institute of Technology, Zurich, within the scope of its "Nervousnet" project, could help people make better decisions painlessly.

In Helbing's view, climate change is an example in which the conventional approach is to dictate a CO_2 reduction target from above, combined with a quasi ban on additional emissions. This approach leads to a situation in which no one wants to hear any more about it. Helbing favours a bottom-up approach in which, for example, cities join forces in order to do something to protect the climate. In projects of this nature, the aim is

> "… to encourage an attitude of change and an atmosphere of cooperation. [This] would not be based on prohibitions, but instead would mobilise a sporting spirit and social interaction..."

In Helbing's opinion, such options should be used, at least as a complement to present-day approaches (cf. box on page 22).

- *Communication about (deficits in) risk perception*

Renn (2015) emphasises the fact that risk dialogue is primarily important in order to draw attention to perception mechanisms, as well as to a certain extent to the false assessment of complex content. Here the objective is to help increase people's risk awareness.

> "People have forgotten that it makes very little sense to provide information about the level of a given risk. By contrast, communicating risk perception is highly relevant because this enables people to gain a critical understanding of their own power of judgement and its systematic weaknesses."

This calls for "popular scientific education in which the major lines of thought are deliberately taught instead of detailed facts".

One tool that illustrates how difficult it is to classify statements relating to the probability of rare occurrences can be found at http://global-risk-indicator.net/. Here, the likelihood of various manifestations of climate change is compared with occurrences such as aircraft crashes or the risk of being struck by lightning.

- *Visualisation of complex issues*

The implementation of statistical statements in graphic form is a tried-and-tested method of enhancing the comprehensibility and clarity of complex issues. With the aid of specialised software applications (cf. http://www.creativebloq.com/design-tools/data-visualization-712402) it is possible to illustrate complex issues and the associated risks and opportunities in such a manner that they are readily comprehensible for decision-makers as well as the general public (GCF, p. 178).

The visualisation of (mostly conventional) risks is the main focus of a report by the Risk and Resilience Research Group at the Centre for Security Studies, Federal Institute of Technology, Zurich, that was commissioned by the Federal Office for Civil Protection (CSS, 2012).

In combination with a narrative presentation, the use of story maps is another method of simplifying complex correlations and rendering them readily comprehensible. In this regard, the Federal Office for the Environment is able to build on existing experiences (http://storymaps.geo.admin.ch) and increasingly apply them to systemic risks with a high degree of relevance for Switzerland.

Another good example for dealing with a complex ecology-related issue of global importance for a broad public is the film, "More Than Honey" by Markus Imhoof (http://www.morethanhoney.ch/).

- *The right proportions*

In its report on risks of potentially disastrous magnitude, the Global Challenges Foundation (GCF, pp. 179 ff.) draws attention to the fact that addressing probabilities and extremes is a specific challenge of risk communication. Citing various examples, the authors demonstrate that the context in which the figures are placed, and the choice of wording relating to unlikely, but still very risky occurrences, can have differing impacts on the target group. In view of this, in the environment of risk communication a cautious and conscious approach to these aspects is of the utmost importance.

Schneider (2015) notes that in forming opinion about options for action, given the uncertain risk, it would be advantageous to compare the outlay for investments in preventive measures with the potential costs of an event resulting in damage. A corresponding methodology was developed by the Economics of Climate Adaptation Working Group (eca, 2009). In this way it is possible to realistically assess whether an investment in preventive measures is preferable or it would be sufficient to take out insurance cover.

- *Boundary objects (bridging concepts)*

Boundary objects are definitions, concepts or objects that enable various professional groups, scientific disciplines or representatives of diverging values to enter into dialogue with one another. The concept of sustainability, for example, gave rise to exchanges between economists and ecologists (Brand and Jax 2007, p. 23). The definitions of boundary objects are often vague and the objects themselves are ambivalent. But, in the view of Star and Griesmer (1989), this is precisely where their strength lies. For Brand and Jax (2007), given the large variety of definitions and areas of application, the term "resilience" can be regarded as a boundary object.

4 Conclusions and recommendations

This chapter draws conclusions regarding the questions posed in chapter 1 and formulates recommendations for the attention of the Federal Office for the Environment (FOEN) concerning the aspects of governance, environmental monitoring and reporting, and communication.

Question 1 How do complex natural and socioeconomic systems behave?

Complex systems follow non-linear cause-effect relationships and display differing forms of behaviour and development paths depending on the initial status. They are characterised by pronounced internal interactions (feedback effects). Within certain limits, they can also maintain the functions of the overall system or adapt themselves to changed circumstances, even in the event of major failures or disruptions. (→ *cf. question 2*)

The options for managing complex systems in a targeted manner from "outside" are limited. Interventions in their internal dynamics can have unexpected and uncontrollable consequences.

Question 2 Which measures are suitable for dealing with systemic (ecological) risks? How can Switzerland's environmental governance contribute towards the resilience of the involved systems?

Here the focus is on two main strategies: the first is to combat developments that destabilise a system, and the second concerns the mitigation of the susceptibility of a system to disruptions.

In the first strategy, Switzerland can, for example, take measures to reduce its contribution towards critical forms of environmental pollution abroad, promote sustainable value chains or campaign for more efficient international environmental governance.

With the second strategy, it can support efforts to render society and the economy more resilient to negative "external" influences.[21] The characteristics of resilient socioeconomic systems are redundancy, decentralisation, diversity, error tolerance, robustness, loose coupling and social capital as a resource for overcoming crises. *(→ Examples, see Table 1 on page 28*)

Measures to maintain or strengthen resilience can also be linked with economic opportunities, for example in areas such as know-how and technology transfer.

Question 3 Which information about the behaviour of complex systems does the FOEN need to obtain in order to fulfil its mandate to secure the sustainable use of natural resources?

There is no general recipe for monitoring complex ecological systems and identifying system-related risks at an early stage. In view of the global dimension of many systemic risks, international cooperation is of the utmost importance. Projects that give rise to a better understanding of the interactions between developments at the global and national levels (e.g. within the framework of the EEA) facilitate the alignment of environmental governance with the declared objectives.

Question 4 How can the FOEN document the status of, and changes to, the environment so that it will also be possible to identify at an early stage any need for action that may be required at the level of systemic risks?

Various early detection methods exist (→ *Examples, cf. chapter 3.2*) that can be applied in order to assess developments in the environment and the associated risks for socioeconomic systems, and to prepare them for use by decision-makers. The use of such methods is still very limited and is tied to suitable institutional, organisational and technical framework conditions.

[21] For example, market destabilisation, interruptions to essential supplies, the failure of ecosystem services, political conflicts, migration.

It is conceivable that, with the realisation of the Internet of Things, additional options for the early detection of systemic ecological risks will be opened up in the future.

Question 5 How can the behaviour of systems and suitable measures be explained and communicated to politicians and the general public?

Political and economic resistance and blocking mechanisms at the individual level hamper communication about systemic risks and potential counter-strategies. Experience has shown that, to ensure successful risk communication:

- the "translation" of complex natural-science contexts into trusted policy-relevant and practice-related definitions and contexts is of central importance;
- stories that touch on the spheres of experience of the targeted public greatly facilitate dialogue on systemic risks and measures to overcome them;
- the incorporation of all potentially involved interest groups into the assessment of risks and options for action is essential for creating acceptance for proposed measures.

Recommendations

... concerning the governance of systemic ecological risks

Recommendation 1 The governance of systemic ecological risks should be structured as a participatory process with the appropriate involvement of the economy, scientific circles and civil society. It calls for specialised know-how, but should not be delegated to an internal team of specialists within a unit of the federal administration. The FOEN should promote professional, institutional cross-border cooperation in order to develop workable strategies and measures.

Recommendation 2 The principle of precaution is also of relevance to the management of systemic risks. By consciously focusing at an early stage on the potential consequences of even improbable occurrences causing damage, and on the documentation and communication of event-specific options for action, the FOEN will be able to greatly contribute towards the strengthening of Switzerland's resilience.

Recommendation 3 At present there is no systematic overview of the significance of systemic ecological risks for Switzerland. An analysis of the indirect impacts of climate change, loss of biodiversity and the unsustainable use of water on society and the economy in Switzerland would enable the FOEN to support its strategy for dealing with systemic ecological risks (including monitoring and communication) on a well-founded basis.

... concerning the further development of environmental monitoring and reporting

Recommendation 4 Given the broad spectrum of systemic ecological risks (for example, with respect to planetary boundaries) it is necessary to focus environmental reporting on aspects that are of particular importance for Switzerland. Based on the country's international ties and dependencies, the FOEN should determine which ecological and socioeconomic risks are of particular relevance and monitor them closely. (→ *cf. Recommendation 3*)

Recommendation 5 The FOEN should actively participate in the existing processes for monitoring and better understanding systemic ecological risks (including their causes and potential impacts on Switzerland) and manage the exchange of information and experiences with national and international bodies specialising in risk governance – including on innovative options for risk monitoring (keyword: Big Data).[22]

[22] Relevant bodies include, for example, the IRGC and informal groupings of private and public-sector institutions (Schneider 2015).

Recommendation 6 Systemic risks can only be identified to a limited extent with the aid of conventional, quantifying risk analysis criteria. Together with other institutions that work with future-oriented methods, the FOEN should set out to ensure that processes are utilised that enable the use of qualitative expertise for formulating precautionary strategies in the area of systemic risks.

Recommendation 7 The FOEN should examine whether the existing environmental monitoring and issue monitoring instruments could be supplemented by a future-oriented component that permits the targeted early detection of systemic ecological risks. Here it would be possible to incorporate the insurance sector's many years of experience in managing "emerging" risks.

Recommendation 8 In the context of systemic ecological risks, environmental reporting should also contain information about how the use of natural resources by Switzerland is changing elsewhere. The FOEN should examine whether the existing indicators need to be supplemented by incorporating selected and particularly relevant aspects of the use of resources in other countries. Within Switzerland, the development of social capital as a resource for the successful management of crises is of special interest.

... concerning risk communication

Recommendation 9 The effective management of systemic risks requires a common fundamental understanding on the part of the main interest groups regarding the existing need for action. In its risk communication, the FOEN should therefore be able to convincingly explain why Switzerland is (potentially) affected and thus needs to take measures aimed at managing global systemic risks.

Recommendation 10 For the general public, systemic risks are very difficult to assess due to complex correlations, timeframes and uncertain developments. Specific occurrences and analyses thereof provide a great deal of illustrative material that should be used to an increased extent in order to improve the degree of risk perception and awareness among the general public.

Recommendation 11 Communication about systemic ecological risks should be tied as closely as possible to the spheres of experience (interests, needs, identification) of the various target groups. The FOEN should examine how it would be possible to work to an increased extent with stories, narratives and images within the framework of environmental reporting in order to trigger a sense of individual concern and mobilise existing potential in the form of people's sense of responsibility and solidarity.

Recommendation 12 The origin of many systemic risks lies in the exploitation of short-term opportunities at the cost of long-term risks. As the federal authority that advocates the sustainable use of natural resources in the interest of future generations, the FOEN should consistently draw attention to the trade-offs between short-term benefits and long-term costs, as well as to the opportunities that arise from the increased weighting of longer-term interests.

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Jock Martin, Head of Integrated Environmental Assessments, European Environment Agency (EEA), Copenhagen (interview, 1 September 2015)

Professor Ortwin Renn, Department of Technology and Environmental Sociology, Institute for Social Sciences, University of Stuttgart (interview, 4 August 2015)

Reto Schneider, Head of Emerging Risk Management, Swiss Re, Zurich (interview, 3 August 2015)

Appendix

Reto Schneider (interview, 3 August 2015)

Head of Emerging Risk Management, Swiss Re, Zurich

MN: Reto Schneider, in specialised literature we often read about systemic risks, though for you the focus is on emerging risks. What in your view are the special characteristics of emerging risks?

RS: We define emerging risks either as new risks that do not yet exist because, for example, a new technology is about to be made available, or as a situation in which something that has become well established is applied to a new stakeholder group or – for example in the case of asbestos – something that already exists but which gives rise to a new kind of problem in a new context. In connection with the insurance of assets or insurance policies that face a threat, we speak of "exposures". In the area of emerging risks, the degree of exposure changes, while the risks themselves are often the same or well known. Major fluctuations may occur in that which can be negatively impacted, i.e. the assets.

And what is the situation with respect to systemic risks?

With regard to systemic risks it is the dependencies that are difficult to grasp. In the past, in the world of finance (banks and insurance providers) it was often assumed that risks are independent but now it is clear that the financial markets are also interdependent. The OECD has conducted a number of studies in which it has understood systemic risks to include occurrences such as financial market crashes, the collapse of the Internet, widespread and long-lasting power cuts, cyber attacks, pandemics, etc. In these cases, systemic risks are often regarded as domino effects that are almost impossible to model and for which scenarios have to be created in order to be able to confront people with the potential impacts on society, the economy, politics and infrastructure.

In your view, when does an emerging risk become a real risk?

An emerging risk becomes real if it can have major impacts in a relevant area. For me as an individual, a relevant area is anything in which I am personally involved. So as a manager in a company, this means my business areas, my clients, my products, my raw materials. If I am a politician, an authority or a unit of the administration, then the focus is on human beings, citizens, maintaining law and order, protection of the landscape, protection of the environment, etc.

In your opinion, is there a special category of ecological risks?

Ecological risks become highly relevant for us if a company's reputation is threatened. Take the example of palm oil. At Swiss re we have a framework that stipulates how we have to deal with companies that are active in the palm oil segment. These are special reputation-risk frameworks such as those that exist for nuclear technology, weapons and experiments on animals. The umbrella term is "sustainability risk framework", with human rights and the environment among the main protection goals. But the focus of an insurer remains on losses and damages. At the end of the day, the question is always "how much does it cost?" For us it is always the monetarisation of losses or damages that counts.

At Swiss Re you work with an instrument called SONAR. Could you explain how this functions by citing a specific example?

We tap into a variety of sources. These include our 11,000 internal employees throughout the world, 500 or so of whom actively feed us with what we refer to as "notions". These take the form of observations, magazine articles, TV reports, discussions with business contacts, etc., which the employees concerned believe could be of relevance to the company. We ask them to tell us why they feel a given notion is relevant and could have an impact. There are always risks *and* opportunities. We augment these notions submitted by employees through our contacts with universities and think tanks that focus on the future and monitor the development of technologies, as well as by consulting existing literature and thus generate our own notions.

When you say "we", to whom are you referring?

I am referring to a core team of four people. We also organise roundtable discussions at which we take a close look at these notions. Our task, now and in the future, is to determine their relevance. We have to inform our specialists about the potential impacts of these new scenarios.

So the specialists you refer to are internal personnel?

Yes, that's correct. If we take the example of raw materials, we will have discussed the various notions with our Engineering Unit, which insures mining operations, and with construction specialists who are able to judge how the quality of the utilised concrete or sand will influence the quality of the structure concerned. In the case of health risks, we consult doctors or biologists. We are fortunate in being able to cover practically all the relevant professions internally. As a biologist myself, I am also able to think in systemic terms, which is of course a benefit.

In this way, given risks can be judged to be of greater or lesser relevance?

That is correct. It is of course also important to know how whether a given development is likely to take place soon or in the distant future. Here, the insurance perspective becomes a factor, along with the question of whether the development concerned is likely to be of relevance to us at all.

In the case of biodiversity or invasive species, while the problem is well known, from the point of view of an insurer there is no insurable risk, and this means it no longer appears on our screens. Alternatively we might say, although these risks are not insured at present, we can imagine developing a product in the future, in which case the topic would be regarded as an opportunity. If in the Great Lakes in the USA a particular species of mussel should block the cold water intakes of nuclear power plants, thus causing them to be shut down and subjected to lengthy repair work, this could be a cost driver about which it would be necessary to decide whether it would be worthwhile to introduce a corresponding insurance product. The degree of relevance is based on deliberations of this nature. We are less interested in how the ecosystem looks or how biodiversity is changing.

Is the process already concluded after you have held discussions with your experts to determine the degree of relevance, or do other steps have to be taken?

We have to put the findings into practice. We also have to talk to senior managers, who bear responsibility for a given business area, to find out whether they envisage an opportunity or a pure risk. We have to "map" this in a suitable manner. In other words, we compile a map on which certain risks are depicted with a certain degree of urgency. In this way we can assess the priority with which the matter should be addressed, if at all, or whether monitoring is sufficient for the time being.

On the product development side we have various teams of specialists. On the risk side, the findings flow into the risk management process, where a list is compiled of risks that can be assessed, other risks concerning which a decision can be taken regarding the next steps, and still others that can be eliminated or which in terms of frequency and impact can be lessened so that they become tolerable.

Today, in discussions on risk governance we speak of our "risk appetite", how we can describe it and how we can specify limits. In the insurance industry, the terms "loss limit" or "damage limit" are equivalent to the "limit levels" specified by public authorities, for example for air pollutants. When it comes to reputation risks, these descriptions are qualitative in nature instead of quantitative, and take the form of "stories" that describe the potential impacts.

You have referred to cases in which the conclusion is drawn that something has to be done, and to others in which it is decided that monitoring the development is sufficient. What form would such a monitoring process take?

This depends on the evidence required and on the quality it has to be to convince a manager or other decision-maker to take action. Is it possible, for example, to feed data into a suitable model and calculate the level of an anticipated damage or loss, or do we have to live with uncertainty regarding the loss level?

In the area of emerging risks we often have to deal with major uncertainties and are seldom able to indicate degrees of probability. However, we can estimate the degree of a potential loss. In order to motivate someone to take action, we say that a particular event is likely to occur within the next five years. This means a 100 percent probability over a period of five years. But if we say the probability is only two percent in the next ten years, no one will take any action at all.

If there are no immediate consequences but you nonetheless decide that monitoring is called for, is there a specific follow-up procedure?

Let us take the example of antibiotic resistance, a phenomenon we have been observing for more than a decade. It began with a thesis presented at the Federal Institute of Technology on the topic of anti-microbial

resistance in cured sausages, and subsequently in hospital sewage (as documented in a report by the aquatic research institute, EAWAG), which resulted in studies being conducted in sewage treatment plants. In the meantime, maps depicting the dissemination of resistant bacteria have been produced at all points where purified water from sewage treatment plants is fed into bodies of water. This is an example of a development we are keeping a close eye on because we have the impression that something is brewing.

Does this mean you primarily study the available literature?

We keep a close eye on the literature, of course, but also on publications on the Internet and on reports of conferences and congresses. And of course we also have our contacts at EAWAG and in selected hospitals.

How many of the notions you receive actually give rise to a need for specific action?

In our most recent report we evaluated approximately 150 notions, from which we formed into different clusters. We then went on to present 20 to 25 relevant issues. The question that has to be asked, of course, is whether we should leave them to their own devices or attempt to get to grips with them in one way or another. I have drawn up a small set of success statistics: where did we make a mistake, where did our decision prove to be correct, and where is a decision still pending[23] – for example with regard to new nanomaterials or carbon nanotubes, about which it is still unclear whether they behave in a similar manner to asbestos. This is a matter of considerable concern for us, but there are still no studies or incidents that make it possible to draw definitive conclusions.Hormone-like substances – endocrine disruptors – are another example. The focus has been solely on estrogenic substances in the past.Here, too, it is clear to us that scientists are continuing to build up evidence indicating that this could prove to be a major problem, but we are not yet reacting because, from an insurance point of view, it is not yet relevant on the loss side.

In your 2014 report you also address the threatening collapse of oceanic ecosystems. Based on this example, could you describe how you are monitoring the development of this risk?

Here we read reports about microplastics that pass through sewage treatment plants, are absorbed by plankton and enter the food chain, where their presence can be detected. We are particularly interested in the chemicals that are found in microplastic pellets, and from time to time we employ a student to study the existing literature and summarise the current status of knowledge so that we can obtain periodical updates.

I thought that this problem was attributable to over-fishing rather than pollution.

It is actually a highly complex issue. We also maintain contacts with the major food manufacturers, of course. If one of them begins to express concerns about the presence of chemicals in fish fingers that originate from PET bottles, the circle closes in that it is no longer possible to sell fish fingers because PET bottles are used for beverages. We monitor developments of this kind and ask the involved parties to inform us about their concerns.

[23] Information submitted later by Reto Schneider:
Overview 2010-2013
- 72 risk themes total
- 45 risk themes came true
- 23 risk themes did not come true (yet)
- 4 risk themes were not further analysed

Positive examples (came true)
- Cyber attacks (first published in 2010): massive cyber attacks against Sony Entertainment in November 2014.
- Product recalls (first published in 2010): in 2015 Toyota/Nissan had to recall more than 6.5 million cars due to defective airbags.
- Unmanageable deflation trap (first published in 2014): in January 2015, the Swiss National Bank (SNB) discontinued the minimum exchange rate of 1.20 Swiss francs per euro.

Negative examples (did not come true)
- Oil price surge (first published in 2012): after its peak in 2008 the oil price fell more than 70%.
- Unforeseen consequences of electromagnetic fields (first published in 2012): no damage/claims related to electromagnetic fields are known yet. Scientific debate is highly controversial.
- The future of medicine/personalised medicine (first published in 2013): pharmaceutical industry is heavily investigating in personalised medicine but so far the vision has not been realised.

Are clarifications of this sort limited to your core team or do you also get back to the personnel who submitted notions to you? Do they remain involved over the long term?

They receive feedback from us. We have noticed that this is important, because otherwise they will not submit a notion again if they have the feeling their submission was a waste of effort. If they see that they have triggered some sort of action, this will give them a certain amount of satisfaction. This is also one of the purposes behind our report.

So you have to keep the interest of the personnel in this pool alive?

Yes, certainly. This functions rather like a social network in which younger employees in particular have an opportunity to submit a notion. In a way, it's similar to a blog. Sometimes discussions take place with others who share an employee's view or are of a different opinion. The issue of ocean pollution in particular has triggered countless reactions among people who feel that there is an urgent need for action. For an insurer the situation is difficult insofar as the ocean doesn't belong to anyone, and there is therefore no call for insurance. Instead it is ships or fishing yields, for example, that would have to be insured.

Viewed from a greater distance, what are the biggest challenges associated with the operation of a platform like SONAR?

One of the problems is the fact that people who bear responsibility – and this presumably applies to politicians as well as managers – want to make a positive impression. They want to be re-elected, receive a bonus, display their management skills in a positive light. We provide these people with challenges in the form of emerging risks for which there are no obvious solutions. At first glance it often appears there are only losers. The chances that they can adjust a systemic risk with simple, clear and immediately effective measures, are very small. Managers will try to avoid such a situation like the plague, because they can only lose out: either they spend a lot of money without being able to quickly determine the degree of success of the chosen measure, which inevitably brings them criticism, or they miss something and everyone wants to know why they failed to see it coming.

For me, the main challenge lies in the chronological proximity, or relevance, of the scenario. When we prepare national risk maps for our company, issues are clearly depicted that need to be addressed without delay and about which the people with the necessary experience know what has to be done. Solving such issues is rewarding and those involved can pat themselves on the shoulder. But this is much more difficult in situations in which the impacts are not immediately apparent, and this also applies to the FOEN.

Is this not a kind of plea to do away with your team? You can only make yourself unpopular and no one wants to hear what you have to say. So why are they still convinced about the value of your work?

Because there is a regulator – in this case, the Swiss Federal Financial Market Supervisory Authority (FINMA), which explicitly requires us to report the foresight activities we carry out. We are part of the framework that has been constructed in order to get a grip on future developments and trends, and to demonstrate that we anticipate them and do not merely react to them.

Is FINMA really the only reason?

We have been doing this for a long time already, and when FINMA took a close look at our actions it viewed them in a positive light, in the same way as regulators in other countries. We were the first company to operate this system, well before it was called for by the regulator. But the fact that, in its circular number 32 dated 2008, FINMA writes that risk detection and assessment should incorporate a prospective analysis, and in February 2010 goes on to state that the detection of emerging risks is a weak point, represents an additional assurance that an early warning system will not be done away with or fall prey to a cost-cutting programme.

An unexpected role for a regulator, is it not?

We can go even further: for a workshop with the aviation industry, hospitals, nuclear power plants and railway operators we prepared a white paper containing a variety of hypotheses, including one stating that regulators could become drivers of innovation if they were able to provide industry with impulses by exerting the right kind of legal pressure. The difference between being a regulator that strangles the economy by imposing too many rules and regulations and one that drives companies is not easy to manage.

Can you tell us roughly how much effort is required to operate SONAR?

We have a core team with an equivalent of 3.5 full-time jobs, plus a SONAR officer network comprising approximately 30 personnel – these are managing directors with whom we hold structured meetings four times a year at which we present the notions we have received. Then there are around 50 experts whom we can contact and who provide us with specialised know-how, and finally there are 500 active providers of notions who observe the scene and send in reports once or twice a year.

Are there other inputs that you take into account besides those from the sources you have cited?

For the past ten years we have been involved in the compilation of the "Global Risks Report" of the World Economic Forum, and this is a source of information that we include in our own report. The content of most reports (Ernst & Young, KPMG, PWC, Oliver Wyman, Banana Skins) tends to be fairly similar but our approach is different and we try to draw attention to our own priorities. I regard think tanks as an important source, for example W.I.R.E. (*Web for Interdisciplinary Research and Expertise*), an institution created jointly by the Collegium Helveticum (Federal Institute of Technology, Zurich) and the University of Zurich.

What is the importance of Big Data, the fact that an ever increasing volume of data is becoming available via an ever greater number of channels?

We distinguish between the cyber risk complex and Big Data in the context of "Industry 4.0" or the Internet of Things. Here, together with other large companies and providers we are examining how we can use Big Data for our own purposes. For an insurance provider this is a considerable threat because today, data that are of relevance to insurance and which were only possessed by insurers because they managed the losses, can be found on the Internet. It is more important today to efficiently analyse data and to know how to obtain them. It is no longer so much a question of to whom the data belong, but rather who has a good idea how to find relevant data and how they can be put to use analytically.

Do you also envisage an opportunity?

Almost every major insurer now possesses a strategy team that has identified Big Data as a key area and has introduced corresponding initiatives and built up a project portfolio. We are focusing on developing Big Data analysis and are recruiting the necessary personnel for this purpose. We possess various tools for the semantic analysis of unstructured data available on the Internet. This is an area in which a great deal is happening. The problem consists in the fact that we work very efficiently as an industry, and now there is the additional aspect of Big Data, which opens up even more possibilities. This requires new specialists and a new way of thinking.

In your most recent report you also touch on the issue of "macro-trends". What was the reason for this?

Essentially, a trend is nothing new, because it is already recognisable as such and everyone is talking about it. But in the business world we now speak of "new trends", and the question arises as to how we can adapt our strategy so that we can make use of them. For this purpose we have formed a partnership with our strategy team and now incorporate those trends that are of relevance into our report.

So this is another team that has a somewhat different perspective?

Precisely. If you plunge yourself into technology and the natural environment, for example, you will find the main drivers there. The Internet of Things, for example, is the "Industry 4.0" that generates and utilises Big Data. We would have to plunge in here in and draw up stories or scenarios that occur within this trend so as to become concrete enough that we can envisage what the problem is if, for example, a provider offers a process control via the Internet and can tell us what condition a given component is currently in so that we can determine a maintenance interval and change the component in question as the provider specifies. This all takes place via the Internet, i.e. via a link that can be hacked. In such a case we find ourselves in a very specific story in which someone in our company who issues a policy realises: Aha, that's the new *exposure*.

For certain emerging risks you attribute an additional context?

Precisely. Without this context I cannot inspire anyone. I have to be able to trigger this personal involvement. People need a certain heuristic anchor in the form of recognition points. If I only communicate new facts, people will be overtaxed.

Does this also mean you have to track the drivers behind the trends and risks?

No, that is not the case. But if we want to see how far a given trend has progressed, we could search for indicators. Let us take the example of autonomous vehicles. I want to find out what the current status is. In

order to do this, it is necessary to know what vehicle manufacturers are doing. Volvo, for example, is involved in this trend. So which projects has Volvo initiated, for example for goods vehicles, in, say, Gothenburg where there are already autonomous vehicles on the road?

Indicators provide us with the following facts: autonomous vehicles are already on the road, but apparently the EU has blocked the adaptation of the relevant legislation, and this means the activities of the manufacturers are also blocked. Only after users of autonomous vehicles can be released from liability will these vehicles have a chance on the market. If we are able to tell stories in this way, people can get a better idea of the situation.

Can you imagine that the public sector, in this case the FOEN, could benefit from the experiences of the insurance industry in the context of early detection of ecological risks?

Yes, certainly. The International Risk Governance Council recently published a brochure entitled “IRGC Guidelines for Emerging Risk Governance”, to which we contributed, as well as Ortwin Renn, who adapted the risk management process and turned it into risk appraisal. Risk perception on the part of stakeholders is just as crucial as technical and scientific risk analysis.

If, for example, I want to implement a geothermal project, but the population harbours irrational fears about it, this would be just as great an obstacle for a politician as the use of toxic substances for fracking would be. Within the scope of stakeholder management it is important to take such fears seriously and try to reflect them when we make our decisions. This risk appraisal process would be of interest for a public authority because it would allow it to have a finger on the pulse of the population and thus to become aware of a developing situation at an early stage.

I would now like to turn to the keyword, resilience: how would you define the promotion of resilience that is being called for everywhere now?

Resilience means being able to stand on your own two feet again after the occurrence of a major disaster, an accident, a fire, etc. How quickly can I function again as an individual, a family, a company, a municipality, a country? This has a great deal to do with the capacity to absorb shocks and bring things back into balance. In a disaster the economy also sees an opportunity for renewal in that to a certain extent it is able to re-emerge from the ruins in a completely new organisational form. This, too, is an aspect of resilience.

As an insurance provider, this is somewhat more complicated in that we distinguish between various “lenses”. For example, we observe the structure, integration from a variable number of units, as well as the transformation capacity: can we change as a consequence of a given occurrence and ultimately even find ourselves in a better position than before thanks to appropriate management?

You have primarily been referring to reactions to an occurrence: but is it also possible to actively improve or strengthen resilience?

When we speak of municipal or corporate structures, we are often referring to redundant systems – for example, when we mirror accounting at another location. This is a question of modularity. Just as in nature, we can create diversity if we do not put all our eggs in one basket. Diversity is thus a component of resilience. By contrast, developments such as lean production represent a threat to resilience. This means we have to introduce a certain degree of warehousing, install buffers.

For companies this means additional costs, of course, and they can only benefit from this in the event of a disaster or an event resulting in damage. How efficiently is Switzerland’s disaster prevention structured? Are there sufficient financial resources, tools and equipment in the regional centres? If we want to change Switzerland’s resilience status in the context of disaster prevention, we have to talk about the costs that arise if we want to purchase cranes, bulldozers and similar equipment, and recruit the personnel to operate these machines. So the question to be asked here is: how can we justify investments in loss prevention or measures to mitigate damage if no such events have already occurred?

At a conference on disaster risk prevention that was recently held in Brussels, the point was made that it is very easy to purchase fire engines following the occurrence of a fire. But if we want to increase the height of a wall to protect against flooding, we are unlikely to receive the necessary money until a flood occurs. If I am able to explain to the relevant authority why I need a few million Swiss francs to invest in a flood barrier, I might possibly receive the money – otherwise this would be very difficult.

This leads me to my next question: what do you do in order to make measures to strengthen resilience more attractive to stakeholders?

Together with McKinsey we have developed a tool named "Economics of Climate Adaptation", that can be used to compare the costs of investments in loss prevention with the costs that could be incurred following an event resulting in loss or damage. So with the aid of this tool we can say, if we invest this or that amount in a specific measure, the damage will be reduced by this or that amount. In some cases, even higher savings can be obtained from protection measures, which makes the whole exercise even more worthwhile.

We did this in order to show that investing in structural measures would be good in one particular situation, while in another situation it would be better to invest in an insurance policy because the event in question seldom occurs, and if it should in fact occur, at least a certain amount of emergency capital would be available. But in practice there is the problem that people in a municipality, city or canton expect to be protected and not that they only receive money in the event of an occurrence resulting in damage. And if a family member should be killed, the money can never compensate for the loss.

Does this mean your recommendations are not accepted because of the expectations people place in politicians?

Politicians simply have a different agenda. They want to be re-elected. They want to be perceived as people who do good things. If a politician tolerates flooding and perhaps promises the victims a new home somewhere else, people find this less acceptable – as we have recently witnessed in Germany. This is why investments are made in, for example, the construction of tunnels designed to divert water, even though this may cost hundreds of millions. The people can stay where they are, and politicians have a better chance of being re-elected.

What does stakeholder dialogue mean for you as an insurer?

For us, what counts is that we are able to illustrate a loss scenario that appears to be plausible and relevant for the client – a company or a private individual. But if the other party comes to the conclusion that the likelihood of damage is very low, or the damage is not going to occur (or at least not during his or her lifetime), then we will lose out on the deal. But we also need to be careful not to give the impression that we want to make people afraid so that we can ask for a higher premium. This is our handicap, which is why we are sometimes happy for the message to be communicated by someone else.

Ortwin Renn (interview, 4 August 2015)

Professor at the Department of Technology and Environmental Sociology, Institute for Social Sciences, University of Stuttgart

MN: Professor Renn, in specialised literature we often read about systemic and complex, as well as emerging, risks. What in your view are the special characteristics of systemic risks?

OR: Systemic risks have four characteristics: firstly, they are global in nature; secondly, they are interlinked and therefore complex; thirdly, they are stochastic; and fourthly, they are non-linear, which means that levels of effects exist, as a result of which nothing happens at all for a long time, and then the desired (or in this case, undesired) effect is triggered all of a sudden. These are the four main characteristics of systemic risks.

In the literature it is not always easy to differentiate emerging risks. Am I correct in assuming that systemic risks can, but do not necessarily have to, be emerging risks?

Yes, that is correct. Because of the way in which emerging risks develop, we cannot initially know whether they are systemic, but it is certainly advisable to regard them in this light right from the start in order to avoid nasty surprises.

One of the four characteristics you mentioned is that systemic risks are global in nature. How should this be understood? Does it simply mean they can no longer be clearly allocated to a specific area?

I use the term "global", though Ulrich Beck speaks of risks that are "not confined within borders". Global risks quite clearly exist, for example climate change and movement of capital. But there are also other risks that simply emanate chronologically and spatially, though perhaps not always as far as, for example, Papua New Guinea. So Ulrich Beck's term might in fact be more appropriate.

In your book on the risk paradox you describe systemic risks as a special challenge for governance. What are the most important points in this regard?

Three of the characteristics that we have just cited which run counter to our understanding of management and governance: the first is that systemic risks are highly networked and complex and consequently no longer correspond to our intuition of cause and effect. Their causality is counter-intuitive, and this makes it very difficult to communicate and manage them, because it is necessary to start from a point at which it is either not yet possible or very difficult to identify the consequences associated with the risk concerned. For example, climate change: because you drive a car, the risk of flooding in Bangladesh increases. This is, of course, quite an absurd idea. So a great deal of modelling know-how is required in order affirm this counter-intuitive association. That is the first point: it is counter-intuitive and difficult to manage.

The second point concerns the combination of globalisation (or non-confinement to borders) and non-linearity. As a rule, we learn through trial and error. This is the method by which we learn and on which our economic system is based. A bankruptcy is nothing more than an error that can be remedied. But this normally does not apply to systemic risks. For example, I receive a report that something negative has occurred, and when the damage arises it is so severe that I can no longer learn a lesson from it, or only at an extremely high cost. I therefore have to anticipate the potential damage and let it occur in the virtual world so that I can take the appropriate action before it occurs in the real world. This is the major challenge, which contradicts our entire learning experience. That is the second main point that is a special challenge for governance.

The third point concerns a principle related to the idea of public property, whereby no one actually takes any action if everyone or a large number of people are involved. Each person believes he or she is only marginally involved. It is up to the others to do something. While those who are more directly involved say when we have to do something, the others are freeloaders, which is why they don't do anything. In the end, nothing happens at all. In my view it is these three points that represent the major challenges that we need to master.

Opinions differ regarding the role to be allocated to the government in managing systemic risks. Perhaps this role is not a central one at all and should instead be assumed by the economy and private individuals. What is your opinion here?

For me, four main criteria apply to the management of risks. They are effectiveness, efficiency, fairness and resilience. In my view, different players in society can possess competence in one of these four areas, but none can possess competence in all of them.

With regard to effectiveness it is science that has to play the greatest role. When things are complex we need good models that tell us what really works. With respect to efficiency, the main focus has to be on the economy. Saving costs is clearly something that is the interest of businesses. We also have to be efficient in our use of scarce natural resources. Efficiency does not always guarantee fairness. This concerns the question of distribution, including, above all, opportunities in life. And here the main role has to be played by civil society. With regard to resilience, i.e. the capacity to withstand unusual occurrences, in my view this is the responsibility of governmental organisations.

So as I see it there is a governance regime in which science, the economy and civil society each have to adopt certain important management functions and thereby ensure that these four criteria can be met – even though they to some extent conflict with one another. Cooperation forces the involved players to tolerate conflicts of interest and come up with purposeful trade-offs. Maximising one of the criteria to the detriment of the others is, however, unacceptable.

If we now turn our attention to ecological systemic risks in particular, are these on the same level or do you consider them to have a special status?

Many ecological systemic functions are fundamental prerequisites for ensuring that opportunities in other areas can be seized in the first place. If we no longer have any air, water or soil, even the greatest wealth is of no use to us. Viewed from this perspective, ecosystem functioning is absolutely essential.

If the entire global economy should collapse, the impacts would be equally problematic, but economic efficiency is not a prerequisite for securing the existence of mankind, even though it would mean widespread poverty. With respect to ecological risks there are scenarios in which our existence would no longer be possible. They therefore have a certain primary function. In terms of structure, however, I would not place them on a different footing than other systemic risks.

The management of ecological risks is often based on the principle of precaution. However, precisely in the case of ecological systemic risks it would appear to be difficult to legitimise preventive action by the government, since it is not possible for the latter to obtain reliable information concerning where and when the risks might manifest, nor the course they could take.

This is precisely why resilience is of such importance, i.e. why it is essential to reduce the degree of vulnerability of the absorbing systems or targets to the risk concerned. This means that, regardless of what happens, we can be better prepared. The principle of precaution comes into play in connection with resilience. Here, precaution would not mean regulating before we have absolute certainty regarding the dose/effect relationship. Instead it means enhancing the ability to also withstand extraordinary risks, even if we do not yet know the exact nature of those risks.

This is, of course, associated with costs – a topic we will undoubtedly come back to. So the principle of precaution is also the justification here?

It is somewhat of a reinterpretation of the principle of precaution, but not totally. We simply have an even greater uncertainty in that we do not know when and where the risk may arise, nor to what extent. I always tell my students the following: assume that a given event will occur with a probability of 10 to the power of minus 6 and that there are a million such events. The likelihood of an individual event occurring is extremely small. However, the probability that some unlikely event will occur is extremely high. I therefore have to be prepared for unlikely events; I do not know which one will affect me, but one of them inevitably will.

In the past few years, the International Risk Governance Council has repeatedly focused on topics of major ecological relevance, in particular the risks associated with the use of technological solutions in the energy sector. By contrast, however, its reports have not touched on the unsustainable use of resources and its accompanying impacts such as climate change, loss of biodiversity and the scarcity of fresh water. What is the reason for this?

The IRGC has written some reports on climate change. But you are right: some of the obvious candidates for systemic risks are not included in its reports. There are however reasons for this. The IRGC chooses topics about which it possesses expertise under the auspices of the Scientific and Technical Council and where it does not feel exposed to competition from countless other bodies that are able to deal with a given subject as least as well as, or even better than, the IRGC itself. The programme is therefore somewhat eclectic. In addition it should be noted that we receive requests, for example from Swiss Re or Munich Re, to examine certain issues for which payment is available.

I would now like to come back to the terms “vulnerability” and “resilience”. You make a clear recommendation that critical systems should be made more resilient. Could you please explain what you understand by promoting resilience?

This concerns two separate tasks. The first one is to reduce vulnerability, i.e. the susceptibility of systems to stress effects. This can be accomplished, for example, by constructing buildings more robustly or avoiding regions that are susceptible to flooding. There are countless measures that can be taken to increase the degree of resilience or, vice versa, reduce the degree of vulnerability.

The second task consists in structuring organisations so that they are able to perform their functions just as well in emergency situations as in normal circumstances. This starts with disaster prevention personnel continues right through to the hospital.

So this refers to an event resulting in damage from which lessons can be learned...

Deepwater Horizon is a good example: The disaster that occurred was classified as so unlikely that no instructions at all concerning such an occurrence were included in the operating manual. Discussions were held over a period of two weeks to determine what action could be taken in response to the problem, but a disaster of this nature has to be anticipated at an early stage. Although it is highly improbable that a pipeline on the seabed will rupture, a resilient system would at least ensure that the operators would know what action has to be taken in response, even if they do not want to take any comprehensive and costly precautions.

It is often postulated that efficiency and resilience rule one another out because redundancy is an essential prerequisite for resilience and it costs a lot of money. What is your opinion?

While they are not actually opposites, efficiency and resilience do not exactly go hand in hand. Here it is necessary to find an appropriate balance between them. As we are witnessing in connection with logistics systems, the tendency is to move away again from extreme efficiency, i.e. from just-in-time production and

just-in-time distribution. The same tendency was observed with regard to the supply of urgently required medicaments, where it was found that it was no longer possible to provide people with their medicaments because of flooded access roads.

For reasons of resilience, a certain degree of storage is advisable, though no longer to the same extent as in the past, and no longer in a manner as susceptible as just-in-time supply. In my view it is necessary to make trade-offs between efficiency and resilience. A system that focuses solely on efficiency cannot attain resilience and vice versa, a system that focuses entirely on resilience is likely to go bankrupt.

Is this view widely shared, and if so, can people readily comprehend it? Or does more need to be done in order to make resilience attractive to stakeholders?

This is by no means an easy task. There are two antagonistic psychological mechanisms at work here. The first concerns the fact that we are unwilling to think about terrible or unlikely occurrences, while the second concerns the thought of having to spend money in order to prevent damage that might never occur. This is an aspect of the stochastic we touched on earlier: the notion of having to spend money today in order to prevent potential damage that could possibly, but in all likelihood will not, occur in the future, contradicts intuition.

Cases do of course occur from time to time in which it becomes apparent that investing in a given precautionary measure turned out to be a wise decision. But precisely in cases where damage is difficult to predict, there is an urgent necessity for state regulation. In my view it is often so that economic stakeholders are unable to “afford” resilience for reasons of competitiveness, but they are not opposed to the introduction by the government of generally applicable regulations because they can then remain competitively neutral.

Could you cite a specific example here?

Well, the government can specify structural requirements for preventing natural disasters, for example, or introduce safety standards for power plants or define zones in which no buildings may be constructed. There are plenty of available options in this regard.

But are we still talking about systemic risks? Can resilience also be promoted in the context of climate change or loss of biodiversity?

If we take the case of the Netherlands, where the consequences of climate change are being studied very intensively, we can certainly speak of measures aimed at enhancing resilience. If, for example, houses are being constructed on stilts which are not yet required, or dykes are being dismantled and replaced by polders, these actions are being taken because extreme events are anticipated that are associated with ongoing climate change. Or take the case of malaria, which now appears to be spreading to Europe (e.g. Italy and Spain), where the introduction of tropical disease clinics is already being planned, although there are currently no patients other than a few tourists. After all, if it turns out that malaria really becomes a problem in Europe, clinics cannot be built in a day.

You may have already anticipated the answer to my next question, namely whether in highly developed economic areas such as central Europe we need to be concerned at all about systemic ecological risks.

In Germany and Switzerland, too, we are now being confronted with visible effects of climate change, for example the melting of our glaciers. Plus or minus two degrees Celsius will have little effect on the overall climate in Germany, but when it comes to extreme weather events, things look rather different. At the same time we are becoming increasingly dependent on other regions.

In a highly networked economy we would experience major problems if, for example, all palm oil plantations were to be suddenly flooded. In 2011 we witnessed how the tsunami disaster in Japan gave rise to the biggest ever payment by insurers to Toyota as compensation for the collapse of its logistics system. Toyota was no longer able to assemble vehicles on time because it was unable to receive the necessary components. This, too, is an example of just-in-time production. Or take the case of Mercedes, which assembles its vehicles in Stuttgart using components that are supplied from 38 countries. Our economy in particular has become distinctly systemic. In other words, climate change affects both our economy and our prosperity, even if the most pronounced impacts have to be anticipated in other parts of the world.

Does this mean that the remedy consists in investing to a greater extent in warehousing and integrating other redundancies into the system?

Yes, we have already touched briefly on this topic. The term “just-in-time” implies that supply security is assured. But this is something we can no longer guarantee today. Hence, storage certainly makes sound sense.

And the question whether the provision of basic supplies is still possible without large-scale imports also fits in this context. No one seriously wants complete national self-sufficiency – that would simply not make sense. But it certainly makes sense to ask ourselves whether we would be able to quickly procure a substitute product if we were to experience temporary interruptions to the supply of, for example, palm oil. Scenarios of this nature certainly need to be examined so that we can see the extent to which we would be able to secure our basic national supply.

If we look at how environment policy addresses international ecological challenges, the main focus is on increasing the level of ecological efficiency, closing material cycles and developing renewable resources. In your view, are these strategies sufficient for overcoming systemic ecological risks?

It is important not to focus on too many issues. Things such as the new UN sustainable development goals make me sceptical. I am in favour of a certain degree of focus. Three goals that are at the forefront of the ecology issue in my view are decarbonisation, dematerialisation and renaturalisation. These three goals cover an enormous range – they encompass almost all ecological problems of global significance, and focusing on these would also be a resilient strategy.

I would now like to address the aspect of early detection of risks. In 2013, the IRGC published a report called "Public Sector Governance and Emerging Risks", which said that early warning systems for such risks are broadly recognised today. But what is the situation with respect to the practical use of such instruments, beyond the conventional areas of application such as security policy and dealing with natural hazards? Are you aware of such early warning systems?

Not in this form. It is, of course, often the case with systemic risks that it is only possible to resort to proxies. This usually works in the event of natural disasters because precursors exist that can be detected with the aid of sensors. But in the case of events like the collapse of the capital market we do not have reliable sensors at our disposal to warn us in advance that a disaster could occur in one, two or five years.

We are aware of many ecological indicators, for example CO_2 emissions or figures relating to the extinction of species, and there is also a large number of sustainability indicators. But this is not measuring in the sense of an early warning system because as a rule we do not know the non-linear tipping points. We do not know when the Gulf Stream may stop flowing. No figures are available because it has occurred too rarely and we do not have any reliable data at our disposal concerning either distribution or, in particular, a potential cause. With respect to these issues, our models are often based on mere speculations. We also do not know how such an occurrence might manifest itself and this makes things very difficult for us. As already noted, we can only learn from simulations, not from experience. But with respect to tipping points of this kind, models are very uncertain.

Today we have satellite-based monitoring systems that record the statuses of bodies of water, etc. Is this something that could be used to help alleviate systemic risks?

While it is good to know the condition the world is in, this still doesn't tell us when a system might tip. The notion is often expressed that "if we can measure it, we can also master it". This is, of course, a misconception, a widespread illusion, as is the saying, "forewarned is forearmed". In the worst case, it can even act as a dangerous diversion as we occupy ourselves with measuring right up until the disaster actually occurs.

How do you assess the potential of Big Data? Are there any possibilities for early detection here?

I would apply Big Data to occurrences such as social unrest or social movements, to the development of preferences or trends, but not to ecological risks. It is amazing how effectively these analyses can be applied to social phenomena and dynamics, and it is possible that we could use them to counteract systemic risks arising from society and the economy.

How important are scenarios?

Scenarios, simulations, models – these are all connected. They all involve the virtualisation of a real threat so that we can learn how to respond to it before it actually occurs. The aim is to transfer the findings to real systems before the latter collapse or trigger disastrous occurrences.

Scenarios are theoretical situations that we develop in order to learn something for the present. In order to avoid a given scenario we have to do this and that. Ultimately they are all planning instruments, strategies to plan for events that could, but do not necessarily have to, take place, and the extent of which we are often not able to estimate.

In your publications you point out that the limits of human perception and evaluation are notable causes for the underestimation of systemic risks. What is the importance of dialogue on risk in connection with climate change, loss of biodiversity, etc.?

Risk dialogue is primarily important in order to draw attention to perception mechanisms and in part also to misjudgements of complex content. This does not mean adopting a schoolmasterly pose. The objective is to help people become more risk conscious in line with the old wisdom of "know thyself!"

People have forgotten that it makes very little sense to talk about risk levels. On the other hand, *communicating* about risk perception is highly relevant because it enables people to gain a critical understanding of their own power of judgement and its systematic weaknesses. We learn that we can be influenced by many things, and unfortunately in some cases by the wrong ones. If I learn about stochastic risks that are non-linear, then I can understand why I underestimate them – for example, why I write off climate change as a myth when it's cold outside. Dialogue on personal perception has a high educational value.

But these are demanding issues. How can we communicate messages of this sort to the general population?

I think that science is the best source here, because it enjoys a high degree of credibility among the population. And I don't think we can release it from this responsibility. Science journalists also have a role to play here, but unfortunately they are growing increasingly scarce because no one is willing to pay for their services. However, initiatives have been launched by science academies, for example, including one aimed at creating a fund for financing science journalists in order to restore greater legitimacy in society for this important task.

There is also a need for schools to take action. Society needs popular scientific education in which the major lines of thought are deliberately taught instead of detailed facts. I also make this point in my book on risk paradox, which is written in a very popular scientific style. If, for example, you are invited to participate in a talk show, you have an opportunity to draw attention to certain points without over-simplifying.

What in your view is the role of the government?

Government and industry are often regarded as a *single* party. This is perhaps less the case in Switzerland, but it certainly applies to a greater extent in Germany. This is attributable to a widely held suspicion that they want to manipulate us: industry wants to persuade us that everything is safe and sound, and the government wants to assure us it has everything under control. But in fact, both players need to work together in the area of risk management.

When the government and the economy work together, for example within specialised organisations, they can achieve results. It is only possible to limit and address risks if state regulation is combined with responsible action on the part of the private economy. As already noted, this actually involves four partners: government and industry, plus civil society and science.

What is your opinion of the reports by the European Environment Agency?

The entire communication chain is made up of numerous links. Reports such as those published by the EEA are seldom read by the general public, but they provide important background material for science journalists and for other players (for example, the public authorities) who are active in the field of communication. They provide background information as well as useful pictorial material, though the reports themselves are frequently written in a way that only makes them suitable for a specialised readership.

Can you name any good examples of successful communication of systemic ecological risks?

Hans Joachim Schellnhuber, director of the Potsdam Institute for Climate Impact Research (PIK), has for many years been endeavouring to fulfil this educational mandate, and even published a comic on the topic of climate change – though in my view this was not a particularly successful venture. Nonetheless, it was a serious attempt to popularise a complex issue in a suitable manner. The PIK has also produced a number of films aimed at helping people gain a better understanding of climate change. The IASS (International Institute for Advanced Sustainability Studies), Helmholz and the Max Planck Institute are also major institutions that attach a great deal of value to providing education about risk awareness. And we should also not forget insurers: Munich Re, for example, has made major contributions towards the understanding of ecological risks, as well as communication about them.

Dirk Helbing (interview, 26 August 2015)

Professor of Computational Social Science COSS, Department of Humanities, Social and Political Science at the Federal Institute of Technology, Zurich

MN: Professor Helbing, the existing literature often contains references to complex systems and emerging risks. What in your view are the special characteristics of complex systems?

DH: The term "complex systems" is often understood to refer to complex dynamic systems that comprise numerous different components. In the context of ecological issues, this would include various flora and fauna, for example, as well as weather and other things that interact with and influence one another so that many of these system components react to one another.

This reaction results in dynamics that can give rise to emerging phenomena. This concerns system properties or behaviours that are formed through the interaction of various system elements and which cannot be interpreted as the sum of the properties of the system elements.

When does a given risk become a systemic one, and how are complex systems and systemic risks connected?

An ecological system is certainly a complex system if it encompasses a sufficient number of species, so the complexity theory is clearly of relevance here. The behaviour of complex systems can be stable or unstable, and we classify a system as stable if it has the ability to be in a state of equilibrium.

By contrast, we classify a system as unstable if it demonstrates the tendency to depart from an equilibrium or normal status. In the latter case, even minor fluctuations can give rise to major knock-on effects or develop into serious threats due to cascade effects. This means that a given problem can get out of control and have consequences for the entire system. And under these conditions we speak of a systemic risk. Examples of global systemic risks include climate change, the economic and financial crisis, and the threat of a world war.

Does this mean that a systemic risk can, but does not necessarily have to, possess global dimensions?

This always depends on which system we are talking about. As a rule we tend to zoom in to a subsystem, but this approach is not always purposeful because systems are becoming ever more networked and interdependent. Our energy system, mobility, environment, political sphere, economy and countless other systems are networked and influence one another.

If, for example, we endeavour to do something to slow down global warming by cultivating plants for the production of bio-fuels, this creates competition with food production, which in turn can give rise to the overuse of agricultural land or higher food prices, and thus to political instability. There is always a risk that making an improvement in a given system or subsystem could result in the deterioration of another one. It is therefore important to not only think in systemic terms, but to also think beyond the bounds of one particular system.

With respect to the management of risks, you primarily focus on the use of new applications in the world of information and communication technology. Why in your view are these so important when it comes to dealing with systemic risks?

With the data we now have at our disposal we are able to determine the extent to which the various system elements and entire systems influence one another. This enables us to create a digital picture of the world, including to a limited extent, in real time.

For example, tracking the world's commodity flows would be an interesting Big Data project. This would not have the privacy implications associated with the handling of personal data. Switzerland has a number of companies that are active on the commodity markets, as well as many others that are active throughout the world in a broad variety of trade segments. It would therefore be possible to initiate a project aimed at recording these flows of goods and raw materials in real time in order to determine which goods are currently where, and in what quantity, where there are signs of bottlenecks, and so on. In this way we could potentially take action to prevent recessions, for example, or reduce stop-and-go traffic on motorways with the aid of driver assistance systems.

Mapping the environment would also be a conceivable option. Here we could determine which flora and fauna (including birds, for example) exist where, and in what numbers. This could, of course, also include the world's

human population. We are currently in the process of developing the "Nervousnet" platform.[24] Before long it will be possible to upload geo-localised material such as photos, short video clips, audio recordings, reports, etc., which people will be able to use for social interaction, though it is also conceivable that hobby ornithologists, for example, could start recording birdsong and mapping the whereabouts and numbers of bird species. Other people are interested in butterflies, orchids, and so on, and I therefore believe we will be able to jointly remap the world in the not-too-distant future. "World survey 2.0" may be just around the corner.

Today there is a broad variety of risks, ranging from climate change and loss of species diversity through to terrorism and threats to the financial system. In your view, are all these risks equal in the end, or are there certain types of risk for which the options of information and communication technology are better suited or offer particularly sound benefits?

The cost-benefit relationships and degrees of complexity vary for ICT applications. The degree of scalability is a central issue. Can we depict major systems at an acceptable cost and if so, how? Today, many systems are not purely technical in nature, but are also socio-technical. Consider Facebook, for example, or Twitter – in fact the whole range of social media from Airbnb through to what is now taking place in the sharing economy. All these systems involve people, and the use of information technology and refinement of data by people are based on interaction.

In many cases, social media successfully mobilise people. A few moments ago I mentioned hobby ornithologists, but of course there are hobby experts for everything because people now have entirely new opportunities for sharing their knowledge. This knowledge can be collected and integrated on platforms and placed at the disposal of other users, including companies of every kind, as well as politicians, scientists, etc. Enormous benefits can be created via such platforms, especially if they are open to everyone.

It is sometimes the case that ecological systemic risks involve aspects that are not necessarily visible, that develop gradually over large areas and that may only reach a critical point after a considerable amount of time. Do these also fall in this field of application, or is applicability limited?

I do not wish to claim that everything is easy to solve, but placing data at the disposal of science and perhaps further afield opens up the opportunity for people to address these issues professionally and on the basis of quantitative fundamentals. In the past this was seldom possible, and everyone had to rely on theoretical analyses or computer simulations.

Today, the goal is to combine the two, i.e. to refine computer models with data and vice versa. Big Data analytics is of course auspicious, but combining these analyses with models is even more promising. We have to be aware that we have an enormous task ahead of us. But this was also the case with weather forecasting, which has meanwhile evolved into a highly useful instrument. Every franc that is invested yields tenfold benefits, but the cost-benefit ratio of the systems we hope to develop could be even higher. In my view it is in any case worth making an investment, and it is also high time to make a start – not only because it is becoming technologically possible, but also because we now face numerous problems that have to be solved and there is need for action in many areas. Thus everything is now conveniently coming together.

In your article in "Nature" you state that weak system components can be used to produce early warning signals. Have you considered what this could mean in terms of the anticipation of risks associated with the worldwide overuse of natural resources that have limited availability or are coming under pressure?

Major fluctuations are often a warning signal. And if minor variations occur, it is always important to pay appropriate attention to them. This applies, for example, to a situation in which a body of water appears to be on the brink of "tipping". Often there are also warning signals like this on the financial markets. I believe that what we are currently witnessing is a matter of concern. There are warning signals in many systems throughout the world and in view of this we can expect to face a number of major challenges in the near future.

Would you say that there is a sufficiently detailed understanding of the modelling of the involved systems (e.g. environmental systems) for the specialists to know what to look for and which signals are relevant?

Here, interdisciplinary cooperation is important. What doesn't function well is the practice of hiring analysts who work with Big Data and study various correlations while knowing next to nothing about ecology or biology. If we rely solely on biologists, although they of course know a great deal about system dynamics and ecological systems, they are unlikely to be proficient in handling large quantities of data. But if biologists and Big Data

[24] http://www.nervous.ethz.ch/

specialists, along with physicists and other experts, work together in a team, it would be possible to achieve significant progress. It is essential that these experts communicate with one another and share knowledge in a broad variety of areas. At the same, it is also important to make use of new technological developments such as cognitive computing.

In your view, do ICT-based methods also have any disadvantages or weaknesses? Are there situations in which conventional approaches relying primarily on expertise offer advantages?

There is no "either-or" answer here. The strengths of various methods should be combined. There is no universal method that functions perfectly for everything. The best results can be achieved by integrating the various methods – that is the approach that needs to be adopted in the future.

We are currently witnessing a great deal of activity relating to the use of Big Data whereas three years ago very little attention was paid to it. In the meantime, an enormous number of initiatives have been launched in North America, Europe, Japan, South Korea, China and Russia focusing on data-driven projects. A lot has happened here, but the same can be said for modelling and crowd sourcing.

In Japan, for example, initiatives have been launched in which citizens measure levels of radioactivity. And in California, people now measure seismic activity. Citizens are now building up "sensor networks" so that data can be collected that it would otherwise not be possible to collect because of the high costs. The resulting data would clearly be of interest to insurance providers because they would be in a better position to assess risks.

We are also witnessing the rapid spread of citizen science. *Galaxy Zoo*, for example, is a platform on which users can view thousands of images of galaxies and classify them into a broad range of categories. Without the aid of "citizen scientists" it would never be possible to evaluate all the data. Computer programs are still not good enough for this purpose. It is necessary to have people who cast an eye over them, and many hobby researchers are happy to do this.

A commitment of this kind can give rise to benefits for everyone. Enthusiasm for certain issues can mobilise previously unutilised resources.

You have expressed scepticism a number of times concerning the role to be played by the state in dealing with complex systems and systemic risks. Why are these a problem for a government?

Systemic risks are always a challenge, for the economy, or the state or society – or for all three. These risks have to be closely monitored because they can eventually give rise to major problems. It is therefore essential to ensure they are on the radar screen.

The state can play a significant role in the procurement of public infrastructure – in this case, digital infrastructure – and "data commons", i.e. shared databases. The Swiss concept of common property is an admirable institution, In Switzerland we have learned how to encourage citizens to contribute towards the general good so that a "fair give and take" results. This concept now needs to be transferred to digital platforms.

Public infrastructure and investments have always been required in order to ensure that the various sectors of the economy function smoothly. For example, we pay billions of Swiss francs each year for agriculture, we construct public roads so that the industrial sector can function and we construct schools and universities in order to ensure that the services sector runs smoothly. So the question now is, which types of public digital infrastructure do we need in order to benefit the digital economy and society?

In connection with the distribution of roles between government and the private sector you have used the term, "assisted self-organisation".

Here you are presumably referring to my comments on topics such as "top-down versus bottom-up".

It is generally the case that certain things can be optimised "top-down", but this tends to apply to systems that are not highly complex, which can be numerically mastered and strictly optimised. In the case of many complex, dynamic systems, the complexity is often so great that even the largest computer is no longer able to optimise it in real time. This means that heuristics, i.e. approximation methods, have to be applied in order to come close to finding acceptable solutions.

Many of these heuristics are ultimately decentral in nature. Good solutions often require local knowledge. But if decisions are taken centrally, a certain amount of this local knowledge is lost, because the transmission rates and data processing capacity are limited. In order to find the best solutions, a certain degree of decentralisation may be necessary.

Which target function should in fact be optimised is often the most difficult question. In a global context, we could optimise the per capita gross national product, for example, or sustainability. We could optimise power, or peace, average life expectancy or satisfaction with life.

There are so many possibilities, but unfortunately there is no scientific method we can apply to determine which is the right target function. We often only discover in retrospect that we have made the wrong choice – that we have made a mistake. And if we have applied what we believed was the ideal solution to the whole country or the entire world, under certain circumstances such a mistake could have disastrous consequences.

Let us assume that the target function is a stable climate. What would that mean in this context?

If we are looking for solutions to a complex problem, it is often necessary to retain a certain degree of diversity, i.e. the option of implementing not just one solution globally, but two, three, four or five. Diversity is a kind of recipe that keeps the risk of taking the wrong action within reasonable bounds. This is how we proceed when we invest on the stock market. If we approach this reasonably professionally, we do not buy one category of shares, we invest in a portfolio. In this way we reduce the level of risk and increase the likelihood that we will make a profit in the end.

This approach should also be applied in politics and the economy. We have to be careful to ensure that diversity and plurality are not jeopardised. In theory we can also implement this top-down with information systems, but this calls for sufficient transparency and input from all relevant groups. Otherwise diversity would sooner or later suffer. Diversity is of the utmost importance for the innovative capacity of the economy, for the resilience of society to sudden shocks – i.e. for systemic resilience – and for collective intelligence. If we use artificial intelligence systems in order to govern society like a benign dictator or wise monarch, there is a considerable risk that these virtues could fall by the wayside. Diversity, resilience and collective intelligence can be attained more easily with systems that have a certain degree of decentralisation.

I can imagine that systems could be organised in line with the principle of subsidiarity. I believe that subsidiarity will also play a significant role in the future. With the aid of incentive systems and feedback mechanisms, coordination can be achieved between the various systems and system hierarchies. This approach would be minimally invasive, while taking account of diversity and plurality. Here it would be important to ensure that the system is not disturbed more than it is supported.

Can you illustrate this for us? We know, for example, that phosphorous is an essential resource for agriculture, but its availability is limited. In your view, how can this be most effectively regulated so that this resource is not depleted? What would your approach be?

In the context of our “Nervousnet” system, over the course of time our aim is to provide five main functions. Firstly, we want to make it possible to measure the environment in real time, including various externalities, so that we can, for example, depict emissions of all kinds, as well as positive interaction effects and resources.

Secondly, we want to draw attention to the implications of decisions and actions. What happens if I do this or that? What are my options, my alternatives? What can I do better? It is often not clear to us which options we have and which alternatives would be better. For this reason we need support in the form of digital assistants.

Thirdly, we want data to be used in order to obtain scientific insights into complex systems, and in particular to make things visible that we cannot see in the normal way. In physics, for example, it has frequently been possible to make enormous progress when new measurement processes have rendered things visible that we were previously unable to perceive. I believe we will soon be in a position where we will also be able to render social capital visible, for example trust, reputation, solidarity and other things that are decisive for our economy and society. Because these are not visible to us today, we often do not notice when they become damaged. It is just as important to protect social capital as it is to protect the environment.

The fourth function is to support the ability of systems to self-organise through feedback effects, while the fifth concerns the creation of collective intelligence, i.e. the flexible combination of collective knowledge and ideas in order to find better solutions.

And what does this mean in practical terms?

If we were to apply this approach now, we could say we need real-time measurements of phosphorous. How much exists, and where, and how much am I using? Are other farmers using less than I am, and if so, how?

I recently learned of an interesting example in Japan. As we know, the Japanese shut down all their nuclear power plants following the incident in Fukushima. The question that then arises is how they can cope with the

drastic reduction in electricity production? If I am not mistaken, the answer was to display a kind of power meter on TV screens, which indicated how much of the available capacity was being utilised. When the indicated level was close to 100 percent, everyone knew they somehow had to save energy, for example by switching off their air-conditioning or turning down their heating. And this approach proved to be surprisingly effective.

It was also interesting insofar as people did not have to do this every day. During periods when there was sufficient capacity, they were at liberty to use electricity as they wished. And this is an important point: people should not have to be subjected to restrictions permanently and everywhere. They should only have to expect them when they become really necessary. And that is the recipe for success: many people have a sense of solidarity and responsibility, but we do not yet have the necessary instruments at our disposal to help us make better decisions without painful consequences.

As far as climate change is concerned, the standard approach is to say we all have to save this or that much CO_2. This would be specified by the authorities, which means that consuming more would be effectively prohibited. Everyone would have to impose restrictions on themselves, and no one wants to be forced to do this. For a long time, attempts were made to reach agreements on a global scale, but this resulted in very little progress. So the question to be asked here is whether top-down and bottom-up principles should be applied as complementary approaches.

For example, major cities such as New York, Sydney, Hamburg or London that border on bodies of water should join forces in order to set a good example instead of waiting until a global agreement can finally be reached. This would also give them a first mover advantage.

But there are also other options: we are all aware that the climate is not in good shape. The question is, how can we encourage an attitude of change and an atmosphere of cooperation so that each of us asks ourselves, "What contribution can I make? One of my neighbours has installed solar panels on his roof, and the other has installed a heat pump. What should *I* do now?"

I think we could appeal to people's sporting spirit. I can imagine something along the lines of a "climate Olympics" – a kind of environment competition between cities throughout the world. This would, of course, be followed by the media. And there could be various disciplines, for example constructing the most efficient solar cells, heat pumps or air-conditioners, or which city succeeds in persuading the most people to buy and install energy-efficient systems.

Encouraging an attitude of change and an atmosphere of cooperation would not rely on prohibitions, but instead would mobilise a sporting spirit and a sense of social togetherness in order to tackle the major challenges we face today and in the future. This strikes me as being worth the effort, at least as a complement to the current approach.

Our society faces challenges not only relating to climate change, but also in connection with the digital revolution. I believe that we will only be able overcome these challenges if we can get a large number of people on board. In the next 10 to 20 years, around 50 percent of today's jobs will be lost. This represents a threat to the stability of the economic system, as well as to politics and society. In the worst case we could face the threat of revolutions and wars. Here, too, urgent measures need to be taken in order to prevent the development of a worst case scenario.

To return briefly to the aspect of resilience: the theory is often expressed that, from an economic point of view, resilience and efficiency rule one another out because things such as diversity and plurality have to be "bought". What is your opinion here?

I would not say that resilient systems necessarily have to be inefficient, nor that diversity has to come at a price. It is a fact that, under the present-day circumstances, we can gain short-term advantages by reducing diversity or resilience, but in the longer term we pay a high price for this. Over the long term, resilient systems increase the degree of success and ability to survive. They are more sustainable. If we use the Internet of Things for the real-time measurement of externalities, provide suitable feedback on a multi-dimensional financial system, support the self-organisation of systems with the aid of digital assistants and foster coordination between different systems through interoperability, then diverse and resilient systems will be efficient. In my view this is an excellent perspective for the future, and we should now join forces in putting it into practice.

Jock Martin (interview, 1 September 2015)

Head of Integrated Environmental Assessments, European Environmental Agency EEA, Copenhagen

MN: Jock Martin, in recent years, systemic risk – be it in the environmental domain or in other areas – has become an issue of considerable attention at the international level. The EEA has used the concept of "global megatrends" to highlight the complex socio-economic context affecting the state of natural resources and ecosystem services. What is your personal understanding of the concept of "global megatrends"?

JM: The term "megatrends" refers to large-scale, high impact and often interdependent social, economic, political, environmental or technological changes. We embarked on an exercise on global megatrends for the environment back in 2009 because it became evident that, in a rather short period of time, perhaps driven by the current cycle of economic globalisation since, we needed to give more attention to global dynamics in our assessments. That led us to think about how to capture global dynamics in a way which was relevant to the environment and particularly to the European environment.

Our remit is to produce an SOER every five years. Global dynamics are not necessarily just environmental. We use this framework called STEEP which means we look at social, technical, economic, environmental and political dynamics. You have to, in staying within your remit, consider how these dynamics are environmentally relevant. That led us to look at eleven global megatrends. In some of those megatrends, the relevance for Europe's environment is rather evident, in others it is more difficult.

When we came to look at global megatrends in the 2010 SOER, we were making this link to systemic risks and systemic challenges. Systemic challenges are characterised by a lot of things coming together in complex, uncertain and interdependent ways. In the framework for global megatrends we are trying to understand how the social, technical, economic, environmental and political dynamics individually and together contribute to and impact on Europe's environment.

This is a classic systemic approach. You can look at how a series of dynamics, that are powerful in their own right, can also be understood in combination. In arguing for looking at the environment and how we understand changes in the environment and possible future responses, we should have more of a systemic perspective in our minds. Most of our policies have been built over 40 years in the EU with a rather non-systemic perspective in mind, for very good reasons: we wanted to stop pollution of bodies of water and the air, and therefore we had to take very specific measures. Eventually, we tried to be more integrated in terms of how the environment and sectors such as agriculture and energy interact. Now we are moving into an understanding that we need to be more systemic, and global dynamics are a big part of that approach and reasoning.

When we started to prepare the 2015 SOER, we discussed whether to update the global megatrends, and if so, with what scope. We came to two answers: one was that megatrends should be updated in a multi-annual (3 to 5 year) frequency. Thus, in the design of the 2015 SOER, we had a megatrend update as part of the project. The second consideration was, should we stay with the 11 megatrends we had in 2010 or should we extend these? The answer was that a key characteristic of megatrends is that they are big and somewhat lasting and relevant over time. Therefore we decided – for a combination of that reason and resource reasons – that we would stay with the 11 and try to improve our understanding and our ability to connect these together as well as back to Europe's environment.

How are global megatrends related to the DPSIR scheme?

Essentially the STE of STEEP are the drivers. The megatrends have a very strong driving dimension to them. When you come into the environmental and the political dimensions of STEEP and megatrends then you are looking more at the PSI and R, respectively, of DPSIR. At the same time, when you have a more systemic look at things, it gets more difficult to strictly apply a DPSIR logic.

In your perception, has using the concept of global megatrends affected the way environmental challenges are addressed by policy makers?

Megatrends have been most effective in raising awareness at the EU policy level about the extent of EU regional to global dynamics. Particularly the STEEP framework has encouraged people to think about social and

technological issues alongside economic issues in a way that is not so prevalent in the environment discourse. In the feedback that we receive, I often find that the megatrends report is perceived as the more interesting one, perhaps because it is "top down and global" in its character and because it brings knowledge to the table which is different from the mainstream information that comes with the SOER synthesis report, which is largely drawn from implementation of the last 40 years of EU environmental policies.

Do you believe that individual EEA member states, at their national level, can profit from the EEA's work on global megatrends or is this beyond the scope of working with megatrends?

What we've been doing since the publication of the SOER 2015 is looking at downscaling the global megatrends to national reality. Switzerland is one of the "experimental countries" that we're working with. The reason why megatrends can be relevant for a country is that national governance still largely supersedes regional and superregional global governance. One could also argue that the trend has been rather reinforced back to national governance perspectives in recent years.

In an increasingly globalised world, megatrends – understood at the national level – are quite pertinent and may become more pertinent with regard to the upcoming decision on Sustainable Development Goals and the indicators and targets that are expected to accompany this. Here we are going to see rather explicitly that this is a global process with national responsibilities. Downscaling megatrends to the national level could be helpful in that way.

Individual governments or regional blocs are met with significant challenges in influencing global trends. Given this situation, how can an individual country such as Switzerland best contribute to the sustainable management of natural resources and ecosystem services at the global level?

You could argue that the big picture is going in the wrong direction with regard to that question. In the 2010 global megatrend assessment report you see this graph showing from the 1970s to the 2000s the emphasis towards global agreements on the environment. The 1990s are the heyday of environmental agreements at the global level. Whether this is a cycle and we return to that sort of perspective remains to be seen. But in my opinion the globalisation cycle has indicated that there is a need for more global cooperation while in the trends there appears less evidence of it.

In your view, what are the implications of an increasingly complex world for the monitoring of environment-related parameters at the European and at the national level?

We have been arguing for more than 5 years for the systemic perspective to be embraced, whether in the area of policy or science. If we accept that the challenges are more systemic, and that we should be paying more attention to them through science and policy and other means, then this brings us to some interesting discussions, e.g. on the issue of managing risks.

In the past we have largely talked about managing risks to do with substances, processes and products. If we have a discussion with partners such as EFSA, the food safety agency, then they are rightly very much focused on substances and products. Processes in industry tend to be things that the Environmental *Acquis* looks at with regard to emissions from different sources. But the idea is that systemic risk is something that we would have to bring more to the table. It brings with it several dimensions which are understood in the policy debate but one might say that they are not so practiced.

One dimension is the application of the precautionary principle and, looking at systemic risk, that the unknowns are rather greater than the knowns. How could the precautionary principle help you in that regard? The second dimension is the issue of monitoring and observation, the idea of the systemic in itself. When you come to the future and looking at risks, the role of foresight, the use of the tools in the foresight toolbox, become much more prominent and relevant.

Where do we stand when it comes to dealing with systemic risks?

Traditionally we have mainly measured certain phenomena. Now, looking at the challenges that we have, we are recognising that we are in a world of a more systemic character. The picture has shifted. This raises the question, what tools do we bring into the domain of systemic challenges.

One of the answers, I think, is to be aware that we live in a world that is changing at an unprecedented rate. This brings the systemic to the fore, not just because of the changing nature but because of the interactions that are involved. We are very, very immature in how we use these tools and the results obtained with these tools and how they are translated into actions.

Are you aware of any institutions or countries that have taken steps in that direction, using foresight approaches to look at how things might evolve in the environmental domain and how they might be affected?

The use of foresight approaches is at a very immature stage compared with what we might need given the systemic nature of the challenges. The Blossom reports certainly are a source for understanding the institutional responses across many countries. We've updated that and that would give directions where to explore with countries.

Overall, the balance with regard to our efforts towards measuring, as opposed to trying to understand what may be coming towards us, is rather skewed.

In what way would you broaden the approaches that are used right now, beyond conventional data collection and trend assessment? Would using foresight tools be on top of that?

To a large extent it will be on top because a lot of our monitoring is associated with our legislation and, having built that over 40 years, we don't want to throw it away. We may want to recalibrate our understanding of what it is useful for. But if we want to change things, this can take a long time because they are linked to legislation. This is why we are probably talking about building on top of the existing while we streamline it and maybe recalibrate it to making it more useful to how we understand and manage Europe's environment from today into the future.

It's going to require additional things to come on top because this involves engaging with systems science. A number of people have written about this since the turn of the century. But it does not have a prominent place when we come to research programmes and so on. It's growing but so far this is rather a niche in its character. In Volume 2 of "Late lessons from early warnings" we provide a chapter and some references on the relevance of systems science and managing systemic challenges and risks.

Risk is something we are looking at now because it is in the 7th Environment Action Programme: developing a systematic – not a systemic – approach to risk with special attention to emerging risks. That also brings the foresight dimension into play.

With regard to the issue of linking risks to foresight and using foresight techniques to manage risk, so far we don't tend to be so explicit in doing that. We use the tools to help us deal with understanding, managing the future and risk is a key element in that. But, in my experience, the link is not so explicit. One would need to look at the Blossom reports to see what countries are doing over the long term.

In EEA materials I find a number of quality criteria attached to foresight. Amongst these is that foresight should be open and participatory. Are these criteria highlighted because there exists a deficit in this regard?

In the context of systemic challenges, where you have many different dynamics interplaying, you need to think about a participation that is rather varied in expertise and background. You're looking at bringing public and private, social, technological, economic and environmental interests into play, recognising that many players are involved.

The openness is important for doing these exercises of exploring plausible futures. You don't know where things are going to. Thus you have to give the opportunity to these different players from many different backgrounds to come with their perspectives and have an open mind towards what is coming at you. Our minds are largely conditioned by what we have experienced and we are rather closed. The terms "open" and "participatory" are related to a future that we don't know so the motto is "let's see what we can work out together, what a plausible scenario could be".

What do you expect from Big Data or related ICT applications? What could their contribution be to the monitoring of the state of the environment or a tool for early warning?

This is not an area that I have been able to give attention to and I'm therefore not very knowledgeable on the issue. I am, however, a statistician by qualification.

What we do in Europe when we collect information called “statistics” on various issues is not what the rest of the world does. We are in this very privileged position that still, largely, the political governance system pays due regard to the statistical system.

But our statistical system has been born of the necessity, very legitimately, of trying to understand the socio-economic dynamics of what is going on in a country. Therefore, when you went up to the end of the 1980s it was a rather straightforward exercise. It maintained a consistent approach for a good 40 years from the end of World War II, not only to build an economy but also to measure an economy as well as other elements of society such as welfare.

After the globalisation cycle you start to see that things change. Europe itself decided that it would no longer collect data on trade between European countries in keeping with internal market dynamics. Rather it will collect data on trade with the rest of the world, since the European Union is a single market entity in itself. We have lost a lot of information there. But the point is that the demands on the statistical system have evolved rather rapidly during the globalisation cycle while the statistical system itself has moved rather slowly in response.

When you look at Big Data, then the question for the statistical system is: is it a transformative opportunity? It opens up the ability for statistics to be regarded in a very different way, how we measure the overall well-being of society in Europe and across the globe, using very different data sources. Big Data could actually open up some rather fundamental opportunities for the statistical system which was born in a very different world from what we experience today and what we are likely to experience in the future.

Big Data in the context of foresight: I really haven't thought about it, to be honest. On the environmental monitoring side, of course, we have satellites, in-situ monitoring and statistics and have been able to use one in support of the other. I remain of the opinion that satellite monitoring is delivering for the environment and that it can be very effective for real-time visible or emergency situations – such as monitoring plastics in the ocean, migrant issues or forest fires – but for the idea of monitoring changes which can often be quite slow or invisible in relative terms, e.g. in ecosystems or in the climate, its usefulness is still to be proven.

What are your experiences with communicating global megatrends and related risks?

The opportunity with risk is that we deal with it all the time in our daily lives. However, when you come to communicate risk which is somewhat removed from our daily experience then we are often met by either scepticism towards what we are saying or disinterest. In general terms, the environment suffers from a not very positive overall position in the societal debate these days. When it’s not directly related to people’s lives it can be met with scepticism as well as indifference.

When giving a global megatrends presentation before an audience in Barcelona in December 2014, I was asked a lot of questions by a generally informed public audience. Some of these were recognising and welcoming the dynamics between the local or regional context and the global dynamics. But I was also met by dismissiveness: “This is global. This is not relevant.” There was very little middle ground. That may just be the nature of public discourse, that people talk either for or against, and that talking about things in a balanced way in the middle is not so attractive. But I was struck that by bringing the global megatrends to that particular setting I was met by this spectrum of responses.

Has giving some prominence to global megatrends in the SOER reports led to sceptical reactions as well?

No, quite the opposite. Global megatrends draw people into a narrative, a story which is not so known and understood and therefore, by its nature, is more interesting. We generally have a communication problem, because all these terms including “climate change”, “loss of biodiversity”, “unsustainable use of resources”, etc., either carry almost no cachet when it comes to capturing attention or they have this often negative connotation.

For example, why have we said that the EU target is "halting the loss of biodiversity"? We have this fantastic thing called biodiversity and all we do is apply negative connotations to it. In the environment area, I think when it comes to communication, we have rather a lot of hurdles to overcome before we are even remotely listened to by large sections of the public.

To a large extent it's our own failing. We haven't really thought sufficiently through the years and decades about how to make the environment a positive narrative in a broader socio-economic discourse. Actually, we have never had to because people are happy to see the pollution cleaned up, that their waste is taken away and ends up somewhere where it can't be seen. We are happy with all that but today, with the systemic issues that are in play, it's not enough.

In what direction do you expect the SOER reports to evolve?

We have made it very clear in the conclusions of our 2015 report that we need to think about the knowledge implications of systemic challenges. We come with a long-term transition perspective around systems like mobility, energy, food and housing – which are the biggest sources of environmental pressures – and ideas about where and how we can "marry" the efficiency, resilience and well-being dimensions of the 7th Environment Action Programme.

In all likelihood, when we get to the SOER 2020, the knowledge base for the environment will still largely be characterised by the implementation of the Environmental *Acquis*. What breakthroughs, what innovations are we going to make in terms of new knowledge around the called-for long-term transitions? The *Acquis* knowledge base by itself will not provide the basis for being able to understand how to achieve long-term transitions. We need to ask different questions and obtain different knowledge around transition. How do we do it? Where are we in the process? It requires us to think about at least three things:

The first is how we much more bring the systemic perspective into the knowledge base itself, be it around systemic risk, around precaution, around foresight, various things. Chapter 7 of the Synthesis Report for example looks at the relationship between the four environment principles of the EU Treaty – polluter pays, prevention, precaution and rectification of damage at source. I see such a framework as a potential for bringing, in line with the Treaty, a more systemic perspective into the knowledge base and into policy.

The second is that we have to get much more to knowledge on what's happening solution-wise in countries. What are the actions that are being taken to transform the energy, mobility, food systems? Already now we are seeing things happen to transform systems, e.g. because of obesity and food allergies, and we have to capture that in our knowledge base in a way that we have never had to do before.

The third aspect is, how can we, on top of all that, marry the efficiency, resilience and well-being perspectives? How are we doing this in ways whereby, in the economic discourse, we move away from the efficiency paradigm, which really dominates, to something that recognises that you can actually be highly efficient and *not* deliver well-being and undermine the resilience of ecosystems? How can you bring these perspectives forward in balance with each other?

These are just three dimensions of our knowledge base that need attention, there will doubtless be others. The challenge is huge because 95 percent of our knowledge investments are in what we know already. So how do we close gaps with limited human and financial resources? Three possible avenues are: to work more closely with EU partners on knowledge co-creation by pooling resources and expertise, to develop new partnerships and interfaces with communities of expertise and knowledge streams in the areas of systemic transitions, and to develop assessment capacities in cooperation with academic partners through experiments in knowledge innovation.