Resilience Thinking: Push-Start of a New Enlightenment in the Light of the Sustainability Paradigm

Peter A. Wilderer and Michael von Hauff

Abstract Resilience Thinking stands for a method capable of securing the continuation of entrepreneurial success, as well as of continuing well-being of societies including individual families. In essence, Resilience Thinking favours sustainable development of societal and economic systems in an ecological context. It is rated as the cognitive counterpart to the self-regulation properties inherited in ecological systems. The process which is key to Resilience Thinking is the adaptive cycle. This cycle needs to be continuously kept revolving in response to changes within and outside of the system under consideration. Initiation and control of the adaptive cycle require permanent monitoring and readiness to give up on obviously outdated practices. Stubbornness of private and public management and even worse: provision of subsidies bear the risk to end up in a catastrophic situation. Adoption of the principles of Resilience Thinking could even be seen as the first signs of a new Enlightenment.

Keywords Resilience · Anthropocene · Ecosystem adaption · New enlightenment · Sustainable development

1 Introduction

The authors of the recent report to the Club of Rome, Ernst Ulrich von Weizsäcker and Wijkman [14], investigated the current situation of the human-dominated world—also known as the "Anthropocene". According to their diagnosis misbehaviour of humankind at large is a considerable reason for a very dangerous breakdown of

P. A. Wilderer (✉) · M. von Hauff
International Expert Group on Earth System Preservation, TUM Institute for Advanced Study, Garching, Germany
e-mail: peter.wilderer@mytum.de

P. A. Wilderer
TUM Senior Excellence Faculty, Technical University Munich, Munich, Germany

M. von Hauff
Technical University of Kaiserslautern, Kaiserslautern, Germany

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societal, economic and environmental stability on Earth. Eventually, the authors come to the conclusion that the world needs a "New Enlightenment" as a means to contribute to the strengthening of the balance between society, economy and nature, the balance between production and consumption, as well as the balance between gains of scientifically based advanced knowledge, and efficient transfer of that knowledge to the general public.

Today, the willingness to use concrete measures to implement sustainable development is still rather low, although there are many concepts and measures that are outlined in the second part of our paper. Balancing the demands of nature and society, of local communities and central governance, of the dealing with technical and societal risks, of protection and conservation of the Earth system—just to name a view—has been the main topics of the workshops organized since 2008 by the International Expert group on Earth System Preservation (IESP: https://www.ias.tum.de/iesp/whoisiesp/). In general, fostering the resilience of the Earth System which humankind is a part of (see appendix of this chapter) is in need. Engagement in the exploration of the consequences of human misbehaviour and resilience of societal, ecological and economical subsystems—human health included—was a logical further step of the IESP´s program.

In the following, we invite the readers to join us on a journey through the world of resilience thinking. Our intention is to stimulate sustainable development hand in hand with the evolution of a new enlightenment by bringing together scientifically sound analysis and recommendations for practical action in responsibility for the whole.

2 The Essence of Resilience

The term "resilience" is derived from the Latin "*resilire*" (jumping back). It refers to the ability of a system—for instance, an ecosystem, a societal system, a political system or just a family or a company—to continuously adapt to changing ambient conditions and still retain its basic function an structure, identity and integrity [13]. Thus, resilience is to be understood as the property of a system in permanent evolution where the governing processes are dictated by a great number of influences from outside and from inside of the system. The system itself consists of a multitude of components interacting dynamically with or independently from each other, particularly when exposed to disturbances.

To introduce some of the basic principles of resilient thinking we use in the following a very simplified model of the complex interactions of a system with its environment. For this particular reason, we have chosen the so-called "Ball in the Bowl" model described by [13]. Figure 1 shows the cross-section of the bowl representing the particular environment under consideration. The ball resting at the bottom of the bow, called the point of attraction, represents the system under consideration. Triggered by modest changes of the ambient conditions (called: perturbation or disturbance such as a power failure) the systems gets temporarily driven away

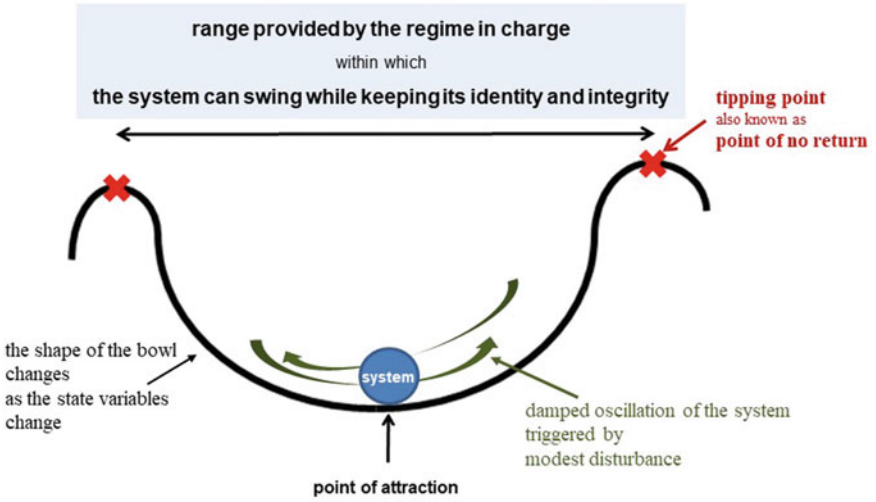

Fig. 1 One-dimensional model of resilience: The bowl is shaped in width, depth and curvature by state variables such as climate, biodiversity, resources availability, economy, governance, political leadership, society. (Graphical presentation adopted from Wilderer and von Hauff [15])

from the attraction point. Once the disturbance has vanished the ball returns in an oscillating manner to the attraction point. The sequence of displacement caused by perturbation and return to the rest symbolizes the dynamic properties of resilience.

Resilience is a balanced state. Resilience thinking is a concept dedicated to the achievement and maintenance of the status of resilience. It is a means to deliberately develop an understanding of the relationship between causes and effects. It enables responses as a matter of good practice. Resilience thinking is, thus, a measure to investigate how interacting systems of people and nature can be best managed in the face of disturbances, surprises and uncertainty. It ensures a sustainable supply of the essential ecosystem services which humanity depends on [1].

Historical evidence suggests that—even in times before humans appeared on Earth—the Earth system was exposed to often dramatic changes of ambient conditions. For instance, the outbreak of volcanoes and changes in solar radiation caused the Earth to cool down for centuries. Glaciation was followed by extreme global warming. Some of the organisms living on Earth could not stand either extreme cold or extreme warm climatic conditions and disappeared. But life as such continued to exist. Life demonstrated the ability to adjust and persist. It demonstrated resilience.

Eventually, *Homo sapiens* appeared on Earth and became part of the ecosystem. Humankind, from early on, modified actively environmental conditions—for instance, by slash-and-burn [6], and continues to do so until today be it for the better or for the worse. From the beginning on human kind demonstrated also the ability to adapt to very different environmental conditions, be in the tropic, the deserts and in the arctic. The sentence "*Tempora mutantur et nos mutamur in illis*" (times change, and we change with them) supports this assumption. It refers to the changes, time

brings about. The phrase was borrowed from Ovid´s poetry by Caspar Huberinus in 1554. Based on modern developments the sentence should re-formulated, however. There is no automatism that drives us, human beings, to change in times. Many of us are known to stick to what we are used to or what was successful so far. As we explain in the following, this retrospective approach called "business as usual", is dangerous. We better should phrase that sentence to: "Times change, and we must change accordingly".

Based on the rapid increase of knowledge and advances in technology "times" change nowadays unprecedentedly fast and substantial. Under those conditions, some of our fellow humans obviously struggle with appropriate adaptability. Conservation of the past is often considered more important than risking the unthinkable. The Earth system is highly dynamic in nature and so is economy, technology and society. It must not be considered a museum, though. Conservation areas are an example of this backward-oriented approach.

Even in former times people, particularly the elders, were reluctant in departing from the assumption that their so far successful doing is the benchmark for the young generation. "The old is gone, the new has come" (Corintians 5:17) is not a rejoicing wisdom shared by those who were successful in the past. It rather is a never-ending matter of frictions and disputes between the young and the elder generations. Or as Machiavelli wrote in his book "The Prince": "Nothing is more difficult to achieve, more risky in realization, and more uncertain concerning success than to introduce a new order, since the innovator has as an enemy those who were successful under the old order, and receives only luck-warm support by those who could profit from the new order".

With respect to resilience of businesses, political systems and coherence of society reluctance against evolution is a significant problem. The overarching concept of resilience thinking might be considered as a means to overcome such problems.

3 Resilient Systems Under Threat

As already elaborated above, the concept of resilience refers to social–ecological systems capable to withstand perturbations, to continually rebuild and renew itself. Moreover, it provides a framework for analysing and actively responding to a changing world facing a multitude of unique uncertainties and challenges [1].

In this respect, it is important to understand the difference between slowly and abruptly developing changes of state variables. State variables may develop slowly over time. So, they are often overlooked and thus become eventually a threat. With reference to the "Ball in Bowl" model, slow-developing threats might lead to the shallowing the bowl's curvature (Fig. 2). Even slight displacements of the ball (system under consideration) away from the point of attraction could drive the system close or even over the tipping point to the right side of the bowl.

The examples described in the subchapter entitled "The subsidy trap" illustrate the threats associated with not realizing, even ignoring the effects of slowly developing

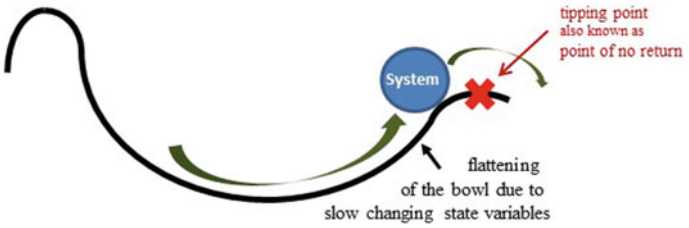

Fig. 2 Slow changes of state variables may conceptually be visualized by flattening of the basin. This bears the danger that the system even under modest perturbation gets driven close to and even over the tipping point

state variables. In a figurative sense, they may cause flattening the shape of the bowl. Slow changes in market demands, consumer´s preferences, as well as innovative communication and information possibilities are some examples of the reasons for causing the "the bowl to flatten". Displacement of the "ball" away from the point of attraction could readily drive the ball (the system under consideration) over the tipping point.

Figure 3 visualizes the response of a social–ecological system to major threats such as an outbreak of pandemic infection of monoculture forestry or agriculture, bankruptcy of a company, breakdown of the financial system, sudden change of the political agenda or a civil war. Such catastrophic events might drive the systems of concern to and over the tipping point into a world governed by a regime, different from what was so far familiar to the agents. It will definitely offer surprises but also challenges. Will the new regime be better or worse? The answer to this question depends very much on the standpoint of the observer. To avoid transforming to any adjacent regime requires the realization of early warning signals and, thus, future-oriented actions including the welcoming of the new world of chances.

As an example, the breakdown of the Soviet Union led to the liberation of the former satellite States and to the reunification of Germany. The change of the regime was welcomed by some but caused loss of the working merits, pensions and pride

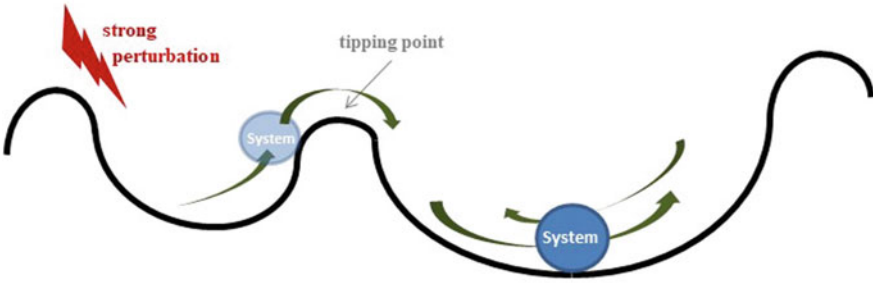

Fig. 3 Caused by a strong perturbation the system is forced to slip over into an adjacent basin of resilience while losing its former but gaining a new identity and integrity

particularly of elderly people in East Germans. The oscillation of the pros and cons in the Eastern part of Germany lasts longer than originally expected. After almost three decades, the state of full eco-social equality and resilience has not been established yet, as the current right-wing populism clearly demonstrates.

4 The Adaptive Cycle

At this point, the question arises which actions should be taken in order to make sure that the system of concern remains close to the point of attractions symbolizing the state of resilience—or at least keep the system away from the tipping point. Buzz [8], the godfather of resilience science, was the first who gave answers to this question. Walker and Salt [13] elaborated the graphical model suggested by Holling.

The basic message is: In order to maintain resilience of socio-economic systems, a company, for instance, it is crucial to govern the system through a continuously revolving cycle of exploration, evaluation and decision making.

In living system, particularly in ecosystem, self-regulation processes on the community level provide the ability to resist collapse and even more importantly to adapt to changes in ambient conditions. Ecological evolution is not cyclic as Walker and Salt clearly demonstrate in their book (2006). In contrast, self-regulation processes play only a limited role in societal systems. They are primarily replaced, controlled and affected by cognitive interventions executed by individuals, the society as a whole and by governance. Instead of trusting on self-regulative processes, it is the responsibility of the human society to respond to perturbations and disruptions on the basis of general ethics and with wisdom and creativity.

Holling's graphical model of intertwined loops considers a continuously repeating sequence of processes required to anchor a small or medium-size enterprise or a group of companies in a sustainable state of resilience. The model distinguishes four major phases:

Start-up
growth and expansion
consolidation and conservation
release (4a) or continue business as accustomed to (4b)
reorientation and reorganization.

A simplified version of the loop model is presented in Fig. 4. In the chosen case study, an entrepreneurial system is addressed.

The cycle begins with the installation of a new leadership committed to drive the company into a considerably profitable direction (Step (n + 1) 1). "n" stands for the number of former cycles of adaptation. As the output of the company shows a positive response the company starts to grow in size and to expand its market share (Step (n + 1) 2). Gradually the company stabilizes its position (Step (n + 1) 3). The leadership team as well as the employees enjoy success and recognition by the local and even international market. Meanwhile, the government considers the company

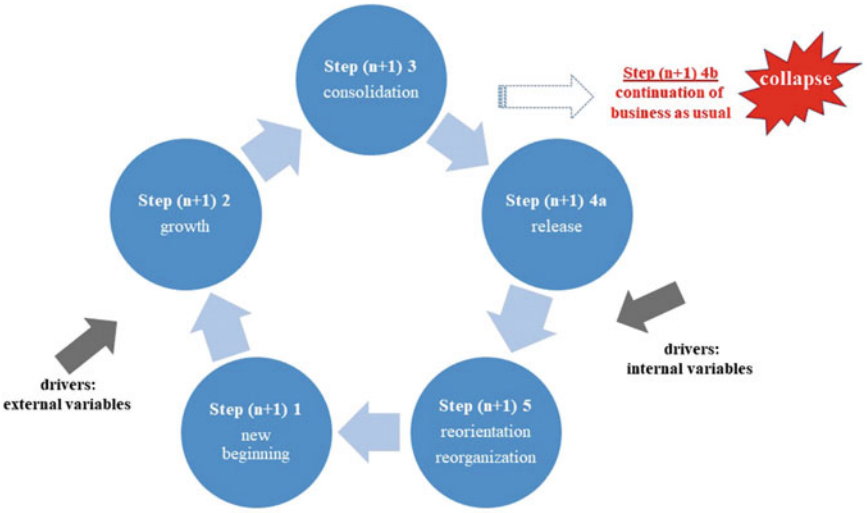

Fig. 4 Graphical representation of the adaptive cycle

as a major factor of economic attraction and as an important employer. The latter is also positively recognized by the respective labour union.

Courage to release business-as-usual practices and to enter into a process of reorientation and reorganization keeps the system in the state of resilience

Drivers of this development are external variables, which are gradually evolving. Some examples may illustrate such external drivers: innovative production schemes, behavioural changes and alternative preferences of buyers and consumers, change of distribution management, of taxation, money exchange rates, governmental regulations and so forth. Moreover, the management of the company is confronted with internal variables such as foresight, courage, responsibility. If clever, the management has realized new possibilities of financing, production methods and sale opportunities. Subsequently, a complete change of the product portfolio is under dispute. Relocation of the company is taken into consideration although the local government, the employees and the labour union protest heavily against such planning. Discussions follow discussions. The German "discussion culture"—presumably to be understood as the aftermath of the liberal education of the 1968s—is in full progress. The generation of that time acts reluctantly when it comes to the point of decision making. Instead, people are eager to discuss endlessly options over and over again. Time is wasted. Obviously, we do not have a lack of ideas of solutions, but a tremendous lack of getting solutions implemented. We lack a rigorous, highly effective "decision making culture" based on general ethics, on the principles of sustainable development and in line with the resilience paradigm. However, the contemporary young generation is fed up with the lack of courage expressed by the generation currently in leading positions. Greta Thunberg with her "Fridays for Future" initiative is just

an example. Likewise, a multitude of young entrepreneurs in various fields of technology, including agriculture, are spearheads of a new generation of actors dedicated to paving the way towards a resilient, sustainable future.

Back to our case study, the owners of the company are forced to make decisions of significant implication: Release or continuation of the so far seemingly beneficial conduct of business (Step (n + 1)4a or Step (n + 1)4b). Choosing Step (n + 1)4b is a striking example of human misbehaviour since it implies against better knowledge the risk of running sooner or later into the collapse trap. There is a great number of examples of cases that ended foreseeable in bankruptcy, financial crises and civil wars. The endless and destructive debate about "Brexit" belongs to this list of misbehaviours on the governmental level.

Choosing the release option (Step (n + 1)a) is certainly not free of risks. What is needed is the courage to enter in a rigorous, carefully and professionally conducted reorientation and reorganization phase (Step (n + 1)5) to start a new phase of the adaptive cycle.

5 The Subsidy Trap

In the following the term "human misbehaviour" is understood as acting against better knowledge—knowledge which is well documented in the scientific literature or pretended in law, experience and common sense. We argue that in the case of an outdated economic enterprise—soft-coal mining for instance—providing subsidies is an expression of human misbehaviour with often detrimental long-term effects (e.g. regime shift as illustrated in Fig. 3, and collapse as shown in Fig. 4).

At the entrance of some of the US national parks visitors are prompted not to feed wild animals. "Don´t feed the chipmunks" is written on information boards. With reference to economic systems this slogan could readily be translated to: Don´t support outdated economic systems with subsidies. The animals in the national parks might get used to get food from visitors (comparable to subsidies), get lazy and lose their natural habit to take precautions for winter times. Learning from nature is a good idea, whatsoever, also for managers of companies and State authorities. Investment in innovation, education and transformation beats conservation of outdated business.

Granting subsidies is a typical but often short-sighted counteraction to regain control over outdated unstable sectors of economic systems. Subsidies are granted by governments driven by arguments brought forward by the clientele of lobbyists. They forecast, for instance, increase in unemployment or bankruptcy unless financial aid is granted by state governance. It is known by experience, however, that access to subsidies very likely hampers the readiness of the recipients to strive toward alternative business opportunities, innovative methodology and generation of alternative jobs. Subsidies easily support laziness of the economic actors. Nota bene: State authorities have the responsibility to create the sustainable infrastructural background for ecologically healthy economics. Granting subsidies helps under certain circumstanced but this instruments need to be applied with care and far-sightedness.

Generally, economics, like any other discipline, should not be further developed only as an end unto itself, but as a response to national and international challenges. Solutions to important tasks come not from providing subsidies but from providing wisdom and competences in responsibility. Climate Change and the subsequent meteorological threats—for instance, long-lasting droughts even in areas known as rich in rainfall events - are striking examples of the shortcomings and the insufficient progress in mainstream economics. Required is the development of a widespread understanding that economic growth depends on the preservation of resilience at large, and on functioning ecological systems over the long term.

6 Resilience Thinking: Fundamental of Sustainable Development

Sustainable development is to be understood as a process of change in favour of the long-lasting well-being of society, economy and ecology alike. The definition already points to the fundamentals of resilience thinking which reads: "resilience thinking is a concept dedicated to the achievement and maintenance of the ability of a system to absorb disturbances while retaining its basic function and structure" (see above). In this process, utilization of resources, financial investments, implementation of innovative technologies and governance must be kept in harmony with the basic requirements of the functioning of the local and the global ecology and human societies. The process anchors the security of life on Earth and must therefore be focused on the functioning of marine as well as terrestrial ecosystems. The self-organizational capacity of ecosystems must be confirmed. Humans are subordinated to the primacy of the ecosystem—the intrinsic responsibility of humankind for the whole must be understood as the uppermost goal of the Anthropocene [9].

The "whole" consists of the three interlinked subsystems: society, economy and ecosystems, forming a triad—in our context a "sustainability triad". The term "triad" is used in numerous scientific disciplines to explore and describe the relationships between the three subsystems—also named "monads". In the interpersonal realm, such relationships are often conflictual. Triadic relationships have been particularly researched in psychology. A conflict-free triadic relationship arises from mutual empathy (empathy with others), introspection (perception of one's own inside) and the ability to look to the partners of concern from outside (perception from an external, quasi-objective point of view (Lothar Katz cited by [5]). This creates a paradoxical unity of identity and difference, three are one and yet different".

The three rings shown in Fig. 5 represent the three pillars of sustainability, namely ecology, economy and society, their governmental organization included. Each of these pillars (subsystems) is affected by classes of state variables. Examples are listed in Fig. 5. To maintain sustainable development it is crucial to keep the subsystems of

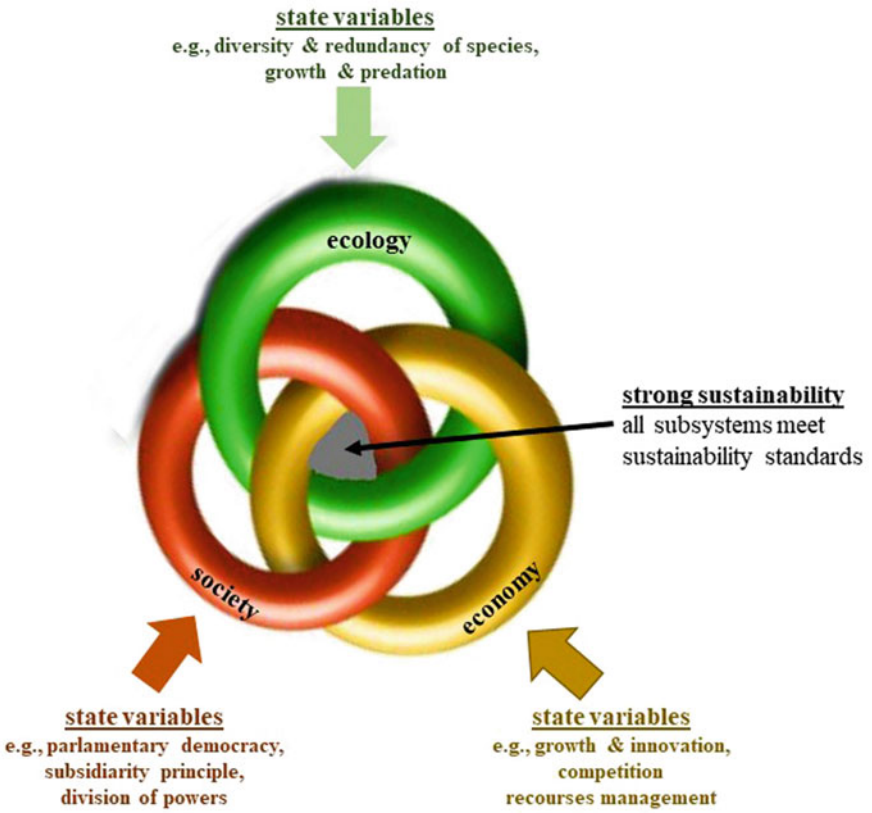

Fig. 5 Visualization of the sustainability triad affected by examples of classes of state variables

the triad as well as the triad as a whole in a state of resilience. Consequently, the interconnection between sustainable development and resilience has been increasingly discussed in the literature (e.g. [3]).

As already mentioned above, diversity and redundancy of species are the most important state variables governing the stability of ecosystems—or in other words the resilience of ecosystems. A high level of diversity allows the system to respond proactively to the variation of external factors like Climate Change. Redundancy describes additional functions to increase the system´s resilience. In case one important species get eliminated another species is ready to fill the niche.

As illustrated in Fig. 4, growth is one of the drivers to keep an anthropogenic system revolving. In ecological systems, predators are important to keep the size of certain species limited and in balance with the locally available resources. Thus, human intervention in the form of hunting or spraying pesticides to control excess growth for unwanted species is an expression of human´s pure understanding of ecological control mechanisms.

Likewise, human intervention in economic systems to respond to changing state variables needs a comprehensive understanding of causes and long-term effects. As shown in Fig. 4, growth is an important kick that triggers the development of any entrepreneurial system. Continuous revolving of an economic system requires awareness of innovative developments inside and outside of the company´s environment as well as careful observation of the changing availability of resources and of the activities of the competitors. Also here, redundancy aspects come into play, for instance, by filling the niche once a competitor vanishes from the scene.

In contrast to ecosystems, problems arise, for example, when growth is accompanied with greed for profits at the expense of resources. Certainly, a company cannot exist without making financial profits. Here, however, we talk about profit generation from products of a limited life expectancy, for instance, fashion wear (clothing, shoes, kitchen appliances, etc.). By aggressive advertisement, customers are forced to buy products, which may correspond with seasonal trends but can get outdated and wasted within months.

In some regions of Europe, the death of a person is circumscribed by "he or she put the spoon away". This saying dates back to the time when especially poor people owned lifelong just one spoon for eating. When passing away this spoon was given to one of the most beloved family members for further lifelong usage. Translated into modern times, it is absurd to consider passing our tape or CD recorder over to our grandchildren when nowadays music comes no longer from any recorder but is streamed by Spotify. And what comes next? And what should we do with the piles of CDs other than throwing them away? In essence, sustainability starts with environmentally sound production, consumption and responsible advertisement.

The third ring in Fig. 5 deals with societal issues. We just pick one aspect, governance. Referring to Fig. 1 the resilience of a societal system depends on the freedom, which the government provides to people, the economy and the remaining close-to-nature areas governed by ecological principles. Likewise to ecology and economy the societal system gains resilience through diversity of its components, and by respecting geographical particularities. It appears, that the parliamentary democracy compared with other forms of state governance offers a solid basis for sustainable development provided the subsidiarity principle is given priority over central governance.

As mentioned above, ecosystems are self-controlled in response to the conditions given in specific areas. A unified control on the global level would not function. Likewise, problems arising on the local scale can be best understood and solved by local authorities. This type of diversion of governmental responsibility is called the subsidiarity principle. This principle is an integral part of the Treaty on the European Union. Some interventions of the European Commission, however, violated this concept and were criticized by the member states and moreover by local people affected by unappropriated regulations. Division of Powers is a further important control mechanism. It provides the basis of stability in a world of rapid changes of challenges and opportunities, and it is the basis of sustainability as it remains embedded in the entire triad.

The seven postulates which are resolved at an IESP workshop held in 2003 in the premises of Kloster Banz summarized by Wilderer et al. [10] are still noteworthy, ready to be considered nowadays:

Sustainability cannot be achieved without eradication of poverty, and poverty eradication cannot be achieved without education. Poverty includes spiritual as well as economic poverty.

Measuring economic activity and quality of life with appropriate indices is necessary. Economic objectives must be balanced with sustainable ambitions.

Education must be based on indigenous cultural knowledge, implemented by local human resources and adapted to local present and future needs. A principal task of education is to develop sensitivity for the gift of life and the natural resources in the heads and hearts of people.

Culture includes religious endeavours. The principles and values common to many religions—such as thankfulness for all goods on which humans depend, sensitivity for all living beings, compassion, humility and solidarity—should be utilized in the formation of concepts of sustainable development.

Economic globalization must be based on local economic activities. Indigenous knowledge about the material and spiritual value of natural resources must be taken into consideration and adequately rewarded.

Sustainable development requires that local societies and economies have adaptive capacity. Local participation in planning and decision-making is necessary to develop adaptive capacity. To strengthen the adaptive capacity of the various societies and economies of the world, participation methods should be further developed and rigorously implemented.

Science and technology are to be understood as an important means to sustainable development. However, technological transfer and technological innovation must be integrated into the local cultural knowledge.

7 Towards a New Enlightenment

Sustainability encompasses widespread responsible utilization of material and immaterial resources. The latter category includes services and rights, education and health, ethical values and arts. Over-extraction of resources as well as pollution of soil, water and atmosphere counteract efforts to establish a world that provides reasonable conditions for a healthy environment, for a healthy human life, and for a functional economy and society. As mentioned in the introduction, Ernst Ulrich von Weizsäcker and Anders Wijkman (2018) propose a new Enlightenment focused on a change of humanity´s behaviour disrupting our common home, the Earth. In other words we may assume, they propose an enlightenment which is based on the concept of resilience thinking, and which globally transforms anthropogenic activities in favour of the continuation of life on Earth.

The former Enlightenment, also known as the Age of Reason, was driven mostly by philosophers and a multitude of intellectuals. It culminated in the eighteenth

century and lasted until the beginning of the nineteenth century. The movement was not ordered by anybody but developed by virtue of intrinsic intelligence. The ideas and concepts brought forward were massively directed against the authority of the absolute monarchies in Europe and against the dogmas of the Catholic Church, set as the primary source of knowledge. The scientific methodology of today was formulated at that time as a cornerstone of technology development and industrialization. Over-exploitation of natural resources and environmental pollution which we are suffering nowadays were and are the negative effects of the first enlightenment.

Initiatives for a new enlightenment can hardly be ordered. Similar to the first enlightenment it is to be understood as a process with uncertain results. Could it be that the new enlightenment is already in progress? Some observations support this assumption:

Mobility:

A certain fraction of the young generation favours functionality over possession of goods. For instance, getting comfortably and in time from A to B does not require owning a car or an e-scooter. The alternative services are nowadays provided by companies such as Uber or by car-sharing enterprises. In essence, this type of behaviour contributes to a decrease in the utilization of fossil resources for manufacturing instruments for mobility.

Communication:

Instead of writing a letter, chat services are faster and do not require elaborate handwritten letters. Using icons expresses warm wishes or respectful answers reasonably well. It appears that writing gets gradually outdated.

Global warming:

Through the "Fridays for Future" demonstrations, the young generation stands up, worldwide, to protest against the hesitation of the established leaders of economic and political institutions to take action. As mentioned above, discussions and postponement of the implementation of changes do not save our concurrent vital problem. The young generation, fed of reluctance, insists on taking action before it is too late.

These tree observations might be an indication for new thinking which goes beyond movements initiated, for instance, by Descartes's statement "*cogito ergo sum"*. It might indicate the beginning of a new enlightenment based on resilience thinking and the essence of sustainability.

8 Summary and Conclusions

Over billions of years, nature, more precisely self-organized ecosystems, demonstrated the power inherited in life itself. In contrast, the anthropogenic system since not being self-organized needs knowledge-controlled efforts. To be effective, these must be kept free of emotions and free of greed.

The concept of resilience thinking offers a number of mechanisms, which can assist the process of system control. The adaptive cycle is considered the most powerful instrument of resilience thinking in economic entities. Those being in charge of the respective subsystem are advised to keep a close eye on developments outside and inside of the system´s limits, and react to challenges and opportunities with the courage of release from outdated business, reorientation, reorganization and the readiness to start proper activities all over again.

Keeping the anthropogenic systems revolving is only one of the aims to maintain the system's resilience, however. As important is the task to keep each of the three subsystems, namely societies and economies, but also ecologies on the local and on the global scale simultaneously in the state of sustainability.

Sustainability must not be narrowed to conservation. It is a process of change in response to entire classes of state variables affecting the performance of each of the subsystems. Sustainable development requires monitoring of changes and the courage to react timely and appropriately.

Nourishing and expanding knowledge is one of the most important tasks of the "New Enlightenment", provided the "new" conforms to the principles of resilience and sustainability.

A new Enlightenment cannot be ordered by any authority, it must evolve by itself. Recent development suggests that the process towards a new enlightenment is already in progress. This, in fact, raises hope for our common future.

Appendix

On March 28 to 30, 2012, a group of 47 scientists, representatives from regulatory agencies, NGOs, businesses and from media assembled in Wildbad-Kreuth, Germany, to explore whether and to what extent the resilience theory is applicable to sustainable development in general and in particular to finding solutions to tackle global warming, resource limitation, loss of biodiversity and human well-being.

The workshop was entitled: "Resilience as Requirement for Sustainable Development. A contribution to tackle the Earth crises". It was organized and conducted by the International Expert group on Earth System Preservation (IESP), an institution of the European Academy of Sciences and Arts (EASA).

In the following, the messages compiled and resolved by the participants of the workshop[1] are presented.

[1] Friedrich Barth, Werner Bauer, Dr. Franz Bischof, Dr. Josef Bugl, Elena Davydova, Dr. Patrick Dewilde. Dr. Timi Ecimovic, Dr. Helmut Fluhrer, Dr. Jürgen Geist, Dr.-Ing. Martin Grambow, Dr. Hartmut Grassl, Dr. Wolfgang Haber, Dr. Slav Hermanowicz, Dr. Jörg Imberger, Dr. Tara Chandra Kandpal, Dr. Claudia Klüppelberg, Dr. Amitabh Kundu, Dr. Eva Lang, Dr. Anton Lerf, Dr. Tobias Luthe, Dr. Anastassia M. Makarieva, Dr. Franz Mauelshagen, Dr. Hamish McGowan, Dr. Chin Man Mok, Dr. Ulrike Potzel, Dr. Armin Reller, Dr. Axel Schaffer, Helga Schubert, Dr. Yong Hui Song, Dr. Rao Surampalli, Dr. Orhan Uslu, Tom Vereijken, Dr. Norbert Vogt, Dr. Michael von Hauff, Dr. Gisela Wachinger, Dr. Raoul Weiler, Dr. Peter A. Wilderer.

Climate Change and energy demand

The combustion of fossil fuels during the industrial era has become a major disturbance of the global environment—unprecedented in human history. It contributed significantly to the observed unfavourable changes in climate and ecosystems that are currently occurring on a global scale.

Existing energy regimes of industrialized and even more in developing countries are unsustainable and must be transformed. Without a clear pathway to sustainable energy regimes, the Millennium Development Goals are obviously in conflict with targets to reduce GHG emissions. As long as economic growth is dependent on greater amounts of energy consumption based on fossil fuels, sustainable development cannot effectively proceed. The resilience of the climate system is greatly related to human populations, their numbers and their consumer lifestyles. While it is desirable that wealth will be shared more equally among developed and developing countries in the future, it is unlikely that this goal can be achieved in a sustainable way as long as economic growth is considered the key to development, and greater wealth the key to stop the growth of human populations. Energy regimes need to be transformed in the first instance and carbon emissions must be reversed to remove excess carbon from the atmosphere.

It is crucial for industrialized countries to better understand their vulnerability as well as the adaptability of complex social structures and networks to Climate Change in order to be able to make robust decisions towards self-protection. For the greatest part of history on Earth, *Homo sapiens* have lived in small groups and adapted culturally to Climate Change. Its cultural capacity to create new ecologic niches has enabled spread of all landmasses on the globe. Human adaptability created a great variety of cultures making humankind as a whole extremely resilient to changes in the global ecosystem. Today, as a global society emerges, mass extinction of species is paralleled by a loss of cultural diversity. This raises serious concerns about the human capacity to adapt to global change in the future.

Water and food

Water and food supply systems have a unique role since they are vital for human survival and for societal developments. Unlike other commodities, water and food have no substitutes although food sources and supplies are much more varied than those of water. Water and food, including fertile, unpolluted soil, can be considered common goods that benefit whole humanity. The productivity of these systems must be protected. Value of water and food must be fully and appropriately reflected in the economic systems (tiered pricing—"some for free or at low cost, pay for more"). Currently, water and food values are biased worldwide by direct and indirect subsidies. Full accounting (but not necessarily full-cost pricing) of water and food that includes externalities (such as pollution) would provide more socially resilient systems of production, distribution and consumption. This issue may be especially important in the growing energy-water-food nexus. Biofuel production competes for water and land with direct human needs and biofuels are often supported by their own subsidies. If not managed properly, expansion of biofuel production may decrease the

resilience of the water and food system because they are pushed toward monoculture plantations.

Water supply and sanitation systems are typically local in scale with a few regional examples (California, Australia). In contrast, food supply systems vary from extremely localized (farming for individual needs) to completely globalized complex networks. Thus, it is likely that resilience enhancement may take different forms for water and food. Multi-scale systems are likely to be more resilient and can be applied to the water and food sector (e.g. distributed water reclamation versus large-scale centralized treatment, small urban garden farming versus agro-business) although the range of scalable solutions will be smaller for water supply than for food. Redundancy and lower extraction ratios (ratios of actual use of water or actual food consumed to their respective maximum potential availabilities) should be beneficial for resiliency although these approaches may make systems less efficient with respect to energy and other resources but less fragile, presumably.

Oceans play a special role in water and food systems. They are not only the source of fresh water in the hydrologic cycle and climate regulator but also a final receptacle for pollutants (e.g. plastic garbage, nutrients, pesticides, sediments, radionuclides). Thus, degraded ocean environments indicate possibly even more severe problems on land. Many people feel emotional attraction to the oceans and the slogan "Do not trash the ocean" might resonate well as a focal point of an awareness-raising campaign.

Ecosystems

Sizeable natural ecosystems are needed as reference points to study the sensitivity of ecosystems with respect to anthropogenic influences and impacts. Human intervention has resulted, mainly due to a long agricultural and forest tradition, in a worldwide disturbance of the functioning of natural aquatic and terrestrial ecosystems. On a major part of the Earth's surface, natural ecosystems have been replaced by artificial biological systems to provide food and biomass to human society. Such systems lack resilience that is inherent to natural ecosystems; by human intervention, they can be maintained in a short-term quasi-resilient state only. At the same time, there still remain vast ecosystems on Earth, including boreal and tropical forests and some regions of the open ocean, that, while disturbed by humans to a varying degree, still operate in the natural regime, retain much of their integrity and resilience and continue to provide particular regional and global environmental services, including the regulation of the terrestrial water cycle. Disruption of these last frontiers of resilience by uninformed human intervention is dangerous but a common practice. Modern clear-cutting of boreal forests in Eurasia is a striking example of this. Governmental institutions are called upon to exercise responsibility for the common. Another example is the misinterpretation of the links between biodiversity and resilience. Research has to be undertaken to not only consider the conservation of rare target species but to better integrate ecological functions and to simultaneously consider producers, consumers and reducers as the three principal functional groups of ecosystems.

It is important to make decision-makers as well as the public aware that our contemporary knowledge is by far insufficient to fully replace the auto-regulative

capacity of ecosystems by technology. It is beyond human competence to continuously change and adapt ecosystems to changing climatic conditions and anthropogenic land-use strategies, and thus keep ecosystems resilient. Neglecting intrinsic natural auto-regulation services is very likely to lead eventually to destabilization of ecosystems, and with it societies and economies. Ecosystems provide green space for human well-being. Taking responsibility for ecosystems is greatly facilitated by having a personal relationship with nature. We need innovative methods to deliver information about the importance of fully functioning ecosystems to the society (from childhood on) and to let the public participate in protection work.

Society and economy

Contemporary economies are driven by economic growth. Following the growth paradigm, we tend to forget, however, that within the eco-social triad economic activity has no ends in itself but should serve the needs of the society being a part of the ecosystem. Consequently, the economy should be directed to the well-being of people and to the functioning of ecosystems rather than to quantitative growth for the sake of growing. Among others, human well-being relies on educational achievements, health, easy access to freshwater, clean air and healthy food, safe neighbourhood, physical and/or virtual mobility and intact nature.

Transformation from growth to well-being-driven economies requires the ability and willingness of stakeholders to change and adapt. We need a new understanding of economic progress. Key issues include, but are not limited to the distribution of income, knowledge, as well as the successful management of global commons. Uneven distribution of income and wealth and unequal access to resources affect the resilience of the Earth System directly. While instability in the growth dynamics is a major factor affecting ecological sustainability, even stable and high growth rate is no guarantee of guarding resilience. It would be important to identify the region and context-specific factors impinging on this process and plan for interventions at different levels. Demography, resources, economic growth and societal structure should be considered as key drivers, and local, regional and global aspects may be taken to define spatial levels of articulation of concerns and of intervention.

Considerable research is required to better understand the interaction of drivers and levels and of the interdependence among the drivers and levels. It is necessary to identify indicators pertaining to Climate Change vulnerability and resilience of the Earth System, and quantify economic and social changes taking place across countries, including policies and strategies of intervention. The work may be started on a pilot basis for Asian countries, for instance, and may gradually be expanded to other regions.

Priority recommendations

The resilience theory is likely to provide a sound basis of the development of powerful strategies to drive sustainable development. In order to keep the Earth System resilient, efforts must be made to sustain its auto-regulative capacity.

The resilience of societies and their economies should be strengthened in response to global changes through robust decisions.

The triad of sustainability formed by the three major subsystems, nature, society and economy should be considered the dominant expression of the Anthropocene period. Resilience of this triad is considered the most important precondition for sustainable development and its longevity.

To foster the auto-regulative capacity of the triad, it is of crucial importance to strengthen its ability to continuously change and adapt to the ever-changing site-specific ambient conditions. Continuous re-orientation of the triad must replace conservation of the *status quo.*

Since the site-specific conditions, capacities and limits vary, a mix of local, regional and global, centralized and de-centralized approaches towards resilience and, thus, sustainability is to be favoured over approaches focusing on global governance alone.

Existing energy regimes should be transitioned across a variety of energy sources and technologies, adapting energy systems to local circumstances and de-centralizing energy production.

The vulnerability of complex societal systems (urban agglomerations, communication and mobility infrastructures, industrial societies) to Climate Change needs to be better understood. It is insufficient to base vulnerability assessments predominantly on statistics of national GDP per capita.

Resilience of tropical and boreal forests is to be valued not only because of their capacity to sequester carbon, but even more so because of their capacity to regulate the hydrological cycle.

Water, energy, natural resources, agricultural land, forests and wetlands must all be considered, and treated, as vital common goods.

Technology is an important anthropogenic means to support resilience, but technology-based remediation and control systems must be resilient themselves. Rebound effects must be considered when choosing technology as a means to strengthen the resilience of marine and terrestrial systems.

Efforts to maintain the resilience of the eco-social triad must be communicated at the earliest stage of decision making in order to reach a consensus that the proposed development strategies serve the self-interest of the region and its inhabitants and natural environment.

To better understand and manage the complexity of the relevant eco-social systems within our societies, new inter- and transdisciplinary approaches and methods are required. Efforts must be undertaken to extend the knowledge of qualitative and quantitative dynamic network models and analysis of human–environment systems, in order to find leverage points for effective intervention, and transfer such insights into practice.

Urgent research tasks and questions.

How to identify and which are the most effective points of leverage and drivers to alter complex eco-social systems towards higher resilience and sustainable growth?

Taking the world economy as such a main driver, ways to internalize external effects while de-coupling economic growth from resource degradation should be found; thus, developing a functioning world carbon market must be of utmost importance to self-regulate economies.

How do sustainable energy regimes interact with local and regional environments, and how can they be set up in a most resilient manner?

In which way and to what extent are complex social structures and infrastructures in urban areas and industrial structures vulnerable to Climate Change? What are the feedbacks of Climate Change in these structures?

In what way does the loss of cultural diversity, caused by globalization, affect human adaptability to Climate Change and global environmental change in general?

If re-orientation and innovation are accepted as major driving forces of continuous change and adaptation, which methods are to be generated and deployed that provide knowledge-based orientation? Which methods and strategies are to be developed and implemented to optimize a two-way science-society knowledge transfer?

What are appropriate measures to quantify the integrity of local and global water and food supply systems?

How to manage optimal level food supply from oceans, while the resilience of marine systems remains secure?

How to quantify the "value" of natural and human-influenced ecosystems?

How to effectively fit protected ecosystems into human land-use structures? Can the "diversity of land-use concept" serve as a framework to integrate different ecosystem functions on the regional scale? How can global commons effectively be managed at local, regional and global scale?

What exactly is the importance of biodiversity with respect to resilience of anthropogenic ecosystems? What are the links between biodiversity, the environment and its functions? What role do producers, consumers and reducers play in the context?

Under which conditions are the extinction of native organisms and intrusion of alien organisms into an anthropogenic ecosystem a threat or sign of auto-regulation?

How can an economic system based on growth be transferred into a system serving the well-being of people?

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