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SYSTEMIC THINKING FOR POLICY MAKING – THE POTENTIAL OF SYSTEMS ANALYSIS FOR ADDRESSING GLOBAL POLICY CHALLENGES IN THE 21st CENTURY

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Resulting from collaboration of OECD and the International Institute for Applied Systems Analysis (IIASA), this publication (in pdf format only) demonstrates the potential of systems analysis and systems-based strategies to address critical global issues and guide policy options, drawing on innovative methodologies, models and tools for research and policy analysis. It is presented for comments and contributions of policy communities to stimulate discussion on how systems approaches could be implemented in policymaking.

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Systemic Thinking for Policy Making

The potential of systems analysis for addressing global policy challenges in the 21st century

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1. Introduction to the OECD-IIASA strategic partnership

By Gabriela Ramos (OECD Chief of Staff and Sherpa to the G20) and Martin Lees (Chairman, OECD-IIASA Task Force)

The issues we face in the 21st Century are of an unprecedented scale; they are essentially connected and in processes of rapid, dynamic change; and they are fundamentally systemic. We have learned from experience that we cannot manage such complex, connected systemic issues through *ad hoc*, short term, sectoral interventions. We must recognise that systems evolve and behave in ways largely determined by their own characteristics and properties. It follows that, if we are to intervene successfully, we must understand their behaviour so as to know how, where and when to intervene.

However, our established approaches to analysis and policy are heavily based on the Western scientific tradition of reductionism – where we separate complex realities into specialised disciplines, fields of research, agencies and ministries, each focused on a part of the overall truth. We are then confronted by the need to pull all these disparate views together in order to organise an effective policy response.

Systems thinking, in contrast offers a more-integrated perspective and a number of proven concepts, tools and methods to improve our understanding of the complex systemic issues which threaten the future. Thus, systems thinking can improve the prospects for successful policy outcomes.

- The systems approach offers a methodology and a range of simple tools to disaggregate, understand and act on connected systemic issues – while taking proper account of the critical linkages between them.
- This can enable us to understand better the behaviour of complex, dynamic systems so as to anticipate their future evolutions, to assess and manage risks and to decide how and where to intervene through selected, targeted policies.
- This also helps us to identify and understand critical linkages, synergies and trade-offs between issues generally treated separately and thus to reduce unintended consequences.

Systems thinking is not simply a means to improve multidisciplinary, cross-sectoral collaboration. Beyond this, it can provide vital insights into systems behaviour and management by rigorous analysis of such aspects as: systems dynamics, feedbacks, sensitivity and non-linear responses; the “emergence” of systems behaviour driven by intrinsic properties; control theory and the optimisation of systems performance over different time horizons or for different groups; the anticipation and assessment of systemic risks; and the strengthening of resilience to external change and shocks.

As demonstrated in this publication, the application of systems thinking extends beyond the fields of analysis, modelling and the formulation of policy. It includes the design and management of organisations and institutions: clearly, more integrated, science-based analysis, if it is to become effective in the real world, must be implemented through reorganised and more integrated policies and institutions. And, systems thinking has immediate application in the field of human resource development, through education, training and team building to implement a systems approach.

The material discussed is disparate and perhaps at times lacking full coherence but this more accurately reflects the types of complex challenges we are grappling with. Perspectives are drawn from a range of disciplines and methodologies, from economics, social science and policymaking of course, but also from the physical, biological sciences and engineering. The publication shows how cross-sectoral, multidisciplinary collaboration can take account of the crucial linkages between issues generally treated within different specialisations and scientific and institutional “silos”. It provides valuable evidence to demonstrate the value of combining “hard” sciences and physical evidence with the social sciences and the humanities, to strengthen the basis of public policy. Naturally, the authors don’t all agree with us or with each other on the approach and value of systems analysis, but a number of common views have emerged and a coherent work programme based on shared priorities is evolving.

For all these reasons, there is growing recognition of the relevance and potential of systems thinking to complement established approaches to policy analysis and implementation by providing greater insight into the complex, dynamic systems of the modern world.

In December 2017, OECD Secretary General Angel Gurria and Pavel Kabat, Director General of the International Institute of Applied Systems Analysis (IIASA), signed a Memorandum of Understanding establishing a Strategic Partnership which should “tighten links between science and analysis on the one hand with policy and action on the other to better address global challenges through the development of systems approaches.”

This joint publication, initially proposed in June 2018 by Prof. Pavel Kabat, has been prepared through intensive collaboration between authors from the two organisations. Its purpose is to demonstrate the relevance and power of the systems approach to understand and act on a number of the critical systemic issues which confront policy-makers today.

This publication is a first step to establish strong practical collaboration between the two organisations. It is principally focused on the strategic level, that is, the relevance of systems thinking to the formulation, implementation and evaluation of national policies in line with the main focus of OECD. In fourteen short, focused chapters, it shows that the methodology and tools of systems thinking can respond to the concerns and priorities of OECD Member States by providing valuable insights into policy choices, trade-offs and synergies, improving the effectiveness of policy interventions and facilitating the proper assessment and management of risk.

The Strategic Partnership is laying the foundations for a concerted effort which will combine the sound economics and diverse capabilities and access of OECD with the scientific expertise of IIASA to strengthen the evidence basis of policy and advance the systems approach. A joint OECD-IIASA Task Force on Systems Thinking, Anticipation and Resilience has been initiated. It brings together 25 senior experts from the two organisations: at present, eight OECD Directorates are represented, some by several members. On the IIASA side, all nine scientific programmes participate.

The Programme of the Task Force is organised through a systems approach, such that the connections between the different activities will be analysed within an overall theme and purpose. Substantive activities are organised around the following seven themes: (i) systems-based strategies to address global Issues; (ii) improved analytical methods; (iii) governance and institutional innovation; (iv) systems leadership; (v) extending existing joint activities; (vi) initiating specific new topics for collaboration; (vii) extension and outreach.

In this perspective, this Joint Publication shows through the practical applications outlined in its fourteen chapters, that the systems approach can:

- Promote cross-sectoral, multidisciplinary collaboration to underpin the process of policy formulation by taking proper account of the crucial linkages between issues generally treated separately - within different specialisations and scientific and institutional "silos";
- Achieve a productive collaboration of the "hard" sciences and physical evidence with the social sciences and the humanities, to strengthen the basis of public policy;
- Provide a methodology to manage systems behaviour, risk and complexity and achieve a better understanding of the non-linear behaviour of complex systems and thus improved assessment of the consequences of policy interventions.

New Paradigms, Approaches and Methodologies

2. New paradigms and approaches for economic growth and well-being

By William Hynes, Martin Lees, Alan Kirman, Karl Naumann (OECD), Jesùs Crespo Cuaresma, Alexia Fürnkranz-prskwets and Elena Rovenskaya (IIASA)

Since the 2008 crisis the debate as to where economics is headed has erupted, and whether the discipline is in need of a "paradigm shift" or whether our existing models and analysis can be incrementally adapted to incorporate the many existing ideas that were missing and the new insights that have emerged. The philosophy of science literature seems to have settled for a compromise between Kuhn's original argument for the dramatic and complete change point of view and a more incremental point of view.

The purpose of this chapter is to argue that economics will not be able to avoid a radical change since the socio-economic system is changing and self-organising itself in a way which is difficult, if not impossible, to reconcile with existing theory. Even in the "hard sciences" it is very difficult to come up with encompassing theories that satisfactorily deal with, and explain quite simple systems of interacting particles, molecules or cells. An apparently very simple, but, in reality, extraordinarily complex, example is the evolution of patterns in John Conway's Game of Life. It is even more difficult to argue that we can treat a complex system like the socio economic one in the same way that we can treat systems of interacting particles for as Murray Gell-Mann is supposed to have said: "Imagine how hard physics would be if electrons could think". We can learn a lot from the way complex physical systems evolve but as Richard Feynman noted, "In physics the truth is rarely perfectly clear, and that is certainly universally the case in human affairs. Hence, what is not surrounded by uncertainty cannot be the truth."

We have been led down a path which has been traced by many economists and which had as its goal to establish an overall theory, with laws that Walras claimed would be as "incontrovertible as those of astrophysics". This theory has been honed and modified over time to include many insights from other disciplines but without putting into question the basic "bench-mark" model. The latter, epitomised by the "perfectly competitive" economy and regarded as an idealisation of a real economy, still dominates the field, and deviations from its assumptions are regarded as "imperfections", "frictions" or due to some mysterious exogenous "shocks" which periodically knock it off course.

In other disciplines there are phenomena which exist and evolve but which are thought of as being governed by some basic underlying laws. A paradigm shift occurs, as Kuhn suggested, when a major change in this underlying system of laws is proposed and when that change is accepted and adopted by the members of that discipline. We are seeing such a shift now in the theory of evolution with a replacement of the simple idea of individualistic survival and competition between individuals with a much more subtle view of evolution with selection at various levels, competition AND co-operation occurring at various levels from the very micro level to that of large groups. This change, epitomised by the work of Corning (2005), Sloan Wilson (2016) and other evolutionary biologists, undermines the basic evolutionary analogy that economists have long used. The view of evolution espoused by the evolutionary biologists in question is that of a complex adaptive system. As Corning (2005) says, “the emerging new paradigm is focused on a different set of questions: How have “wholes” evolved over time? How do they work, and what is their significance in evolution? Indeed, the new paradigm is more about competition via co-operation than some conflict between them.

Yet, even though we may now understand better the nature of evolution, we are faced with a system which is changing fast, in part in response to the conscious choices of those that make it up and that makes it even less predictable than biological or physical systems. Worse, the onset of the Anthropocene era has meant that we can no longer afford to ignore the relation between the environment and the individuals that inhabit it. We are now in the twenty first century, and the whole socio-economic system bears little or no relation to that which existed in the preceding centuries. It is vain to believe that there is some overarching framework based on 19th century liberal principles embodies the rules by which the system functions. Below are several examples of developments which have taken our system away from that portrayed in theory, even with all the “epicycles” that we have developed to include the systematic deviations from the underlying model.

Paradigm change

There are three distinct ways of thought for the future development of economic modelling, theory and philosophy. Firstly, there is the consideration that the current state of economic models sufficiently accurately captures reality. Hence, no further changes should be made. The second school of thought is centred on the belief that while current economic models may not be perfect, their limitations can be overcome through incremental improvements. For instance by incorporating some bounded rationality. This appears to have been the case since the stagflation of the 1970s and the global financial crisis of 2008 showed that the original neoclassical and Keynesian pictures of the economy did not entirely capture its features. Since then, we have come a long way in making economic models more complicated.

The third school of thought on the development of economics would consider the current state of theory and modelling are heading down the entirely wrong path, and there is a pressing need for a paradigm shift. Without disregarding how far economic thought has already taken us, the idea behind this school is that the underlying principles of rationality and general equilibrium no longer serve to accurately represent current reality. While this might have been more applicable in the 18th and 19th century during the development of these original theories by economists such as Smith and Walras, today the world is an entirely different place. Globalisation and digitisation have driven the world to become more interconnected and interdependent. Linkages exist across both time and space, within the economic system and from the economic to the social, political, financial and environmental systems. The global financial crisis of 2008 highlighted the some of the shortcomings of then state-of-the-art economic models in the sense that, with the exception of some non-traditional economists, the crisis was by and large not predicted to happen. The crisis emerged endogenously from within the financial system and spread into the world economy. The crisis emerged endogenously from within the financial system and spread into the world economy. This went against economic predictions which frequently consider only exogenous shocks perturbing a general equilibrium, and only barely included the financial system into macroeconomic models. What is required is a systems approach to incorporate the non-linearities, evolution, interlinkages, tipping points, emergence, trade-offs, synergies and other characteristics of the systems we inhabit. This would be a paradigm shift in economic thought towards a systems-based approach. One of the implications is a shift in the basis of economic models towards promising avenues in agent-based modelling, network models and machine learning. In these models, non-linear relationships can be determined and addressed. Furthermore, agent-based models reflect the bottom-up nature of the economy by considering the interactions of individually modelled agents (such as households or firms) and through large scale simulation determine the emergent macroeconomic trends. In this way, the broad implications of policy implementations on a variety of emergent properties can be studied and the complex outcomes of policy proposals recognised. Additionally, realisation of the multitude of network structures that exist in various systems will help identify key risks and allow policymakers to bring about resilience improving policy. For instance, there is the consideration of financial networks and transaction risk (see chapter 13 of this publication). Such a framework also allows easy adaptation of new insights in behaviour, the environment, sociology, and economics.

The orthodoxy in economics is not as clear-cut as in the natural sciences, such as physics, and thus multiple perspectives are simultaneously present and pursued, consequently the underlying economic narrative has frequently changed. In the last century, there have been two dominant trains of thought. The 1929 stock market crash and the Great Depression gave rise to the Keynesian school of economics as the ruling paradigm. Keynesian economics set full employment as its major goal and established the welfare state. This also gave rise to a wider spectrum of government intervention in the market and in the creation of the welfare state. However, during the 1970s the economy experienced stagflation, which is the simultaneous occurrence of economic stagnation and high inflation. Keynesian economics was unable to provide solutions for this problem, nor was it able to provide explanations for the oil crisis and other disasters. The Chicago school proposed the alternative and new paradigm of neoclassical economics.

Under the auspices of the free-market economic theory led by the Chicago school much focus has been on the idea of market efficiency and how this can be achieved. One approach, that appears widely implemented, is the deregulation of business and the reduction of taxation. This, so the argument goes, reduces frictions to competition, and the more “perfect” competition is, the better. However, this has neglected to fully consider the environmental or social implications of such policy. As evidenced in the period from the 1970s until today, inequality has not improved, and in many cases, has become more extreme. Furthermore, the effects of human-created emissions on the planet are having severely negative consequences. In effect, the linkages between such systems were not thought about deeply in the pursuit of productivity growth. Systems thinking purports to consider fully such interconnections by treating these individual systems as intra- and inter-connected. Such an approach, that can be seen implemented through the development of agent-based modelling, network analysis, and machine learning, treats the interactions of these systems and has the potential to generate a more holistic picture of these varied cross-effects. A concrete example would be the ability of agent-based models to endogenously reproduce the characteristics of the business cycle without external effects such as supply or demand shocks.

The current state of global affairs presents the opportunity for another paradigm change in economic thinking. A paradigm change centred on the idea of the economy as a complex adaptive system. Such a new approach requires not only a theoretical framework but also an expanded set of tools that can reflect the paths and outcomes of the current world, and allow for research and policy into how to improve it. The predominant experts in systems analysis, IIASA, have already developed a plethora of models that can guide and aid the development of further tools and policy.

Highlights in Systems Thinking

Recent work conducted by IIASA scientists concentrates on understanding how economic outcomes are affected by modelling societies which are populated by heterogeneous agents. On the one hand, the effort carried out at the institute in order to reconstruct and project populations by age, gender and educational attainment (see Lutz et al., 2014) has led to a deeper understanding of new stylised facts concerning the interaction of human capital formation, economic growth and inequality in heterogeneous societies. Such results have enabled us to gain empirical knowledge about how the educational attainment of the different cohorts which coexist in a given point of time affect economic development trends (Lutz et al., 2008), inequality (Rao et al., 2018) or political outcomes such as democratisation processes (Lutz et al., 2010).

On the other hand, pure theoretical modelling frameworks aimed at embodying the complexity of the interactions among economic agents in economic growth models have also been developed in interdisciplinary initiatives within IIASA. The degree of interconnectedness of the global economy implies that understanding the systemic characteristics of the existing trade and financial linkages, as well as recognising the importance of their system-level network properties, is central to assess economic growth and the disruptive power of crises in a globalised world. The portfolio of recent research projects at IIASA includes the use of network analysis to provide evidence on the degree of resilience of global commodity trade (Kharrazi et al., 2017) and to provide a general theoretical structure to study the international mobility of labour and capital (Wildemeersch et al., 2019). By using multi-layer networks and combining control theory and system dynamics, the complex interdependencies between labour and capital flows, as well as their contribution to economic growth and well-being, can be captured and the welfare implications of different policy options can be evaluated.

These are only a few of the promising tools developed by IIASA. The remainder of the publications highlights the plethora of new methods that have been created and are ready to inform policy in the understanding and guidance of the complex adaptive system known as the global economy.

All over the world, new concepts, models and methodologies are being explored to move beyond GDP so as to meet the concerns and challenges of sustainable and equitable development in the new conditions of the 21st Century. And, as the centre of gravity of the world economy shifts towards Asia, differing views of social and economic policy are gaining in influence. OECD has also been deeply engaged for some years in reconsidering established models of economic growth so as to master the complex systemic challenges of the 21st Century.

To position economic growth in a wider systems perspective requires both innovation of the tools, methodology and policy within the field of economics, and also the repositioning of the field of economics in relation to other critical fields such as the environment, social affairs, and political affairs - not only at the analytical and rhetorical levels but through the difficult integration of policies in practice. In the worldwide ferment of new economic thinking, there is an important opportunity for OECD to concert the expertise of its substantive Directorates and policy committees with the scientific capabilities of IIASA and its Member institutions to take a lead in developing the integrated systems-based approaches for sustainable progress so urgently required.

Conclusion

A number of things become clear. We are faced with a system which is increasingly complex and interdependent. In such a system the aggregate phenomena that emerge do so as a reflection of the interaction between all the participants in the system. The system is constantly evolving and is neither in, nor converging towards a steady state. Thus, forecasting cannot be based on extrapolations from the past nor on the analysis of the behaviour of an isolated individual.

Perhaps the most important lesson from the crisis is that our socio-economic system is evolving fast and becoming more and more distant from our old basic economic model. Making efforts to “reform” the economy so that it resembles the model more closely, through increasing flexibility and deregulation may not be helpful. We need to develop better analysis of the system as it is and not as we might have liked it to be.

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3. Improved methodologies, data and tools for modelling

By Alan Kirman, Rob Dellink and Sebastian Barnes (OECD), Elena Rovenskaya, Ulf Dieckmann, Bas van Rujiven, and Fabian Wagner (IIASA)

Introduction

The world economy is a complex system consisting of multiple interacting agents, each having their own goals, only partially consciously realised and admitted and in which the present and future (even the past) is uncertain and the dynamics are non-ergodic. There critical features of the real world should be incorporated into modelling tools. This calls for improved methodologies to implement systems-based strategies. By linking together the flagship modelling tools of IIASA and OECD, and improving existing approaches, important new avenues of interdisciplinary policy questions can be addressed.

It will be possible to more seriously address systemic barriers to economic growth by analysing feedbacks from environmental degradation and feedback effects between demographics, education and economic activity. There is also great potential for IIASA and the OECD to take advantage of the revolution in the social sciences, the natural sciences and policy to develop new analytical tools and techniques such as network models and Agent-based Models (ABM).

Mathematical/quantitative modelling of real-life socio-environmental systems can enhance our understanding of a complex system and generate reliable policy advice.[1] There are several major classes of models: (i) qualitative models (visual constructs illustrating interactions between elements of a system in a qualitative manner), (ii) simulation models, (iii) statistical models, and (iv) optimisation models.

In economics, statistical models and optimisation models are used to generate insights for policy. For example, general equilibrium frameworks (implemented through DSGE or CGE models) can provide useful insights into the behaviour of economic, social and environmental systems. Besides providing insight, understanding and scenario development, an important function of a model is to organise and structure discussion on a policy problem.

The current generation of models mainly relies on simplified assumptions.[2] Clearly, these assumptions ignore significant dimensions of systems behaviour. In particular, the structure of these models – which assumes a relatively narrow set of simple interactions between

[1] A modelling effort begins with the creation of a conceptual (qualitative) model skeleton, which defines the system's boundaries, elements/variables, and connections between them. It also specifies variables, which are subject to choice by a decision maker (control variables or decision variables) and output variables/indicators, which can also serve as objective functions. Next, the qualitative skeleton is turned into equations or transition rules, which usually are "calibrated" using past data.

[2] The most critical of which are the following: Rationality of decisions (minimising costs, maximising welfare), full information, perfect foresight, continuation of current trends into future, linearity or quasi-linearity, and a sectorial focus.

agents and relies heavily on linearity – does not mirror the premises required to generate realistic behaviour of systems. Existing models have therefore not been able to explain important phenomena and predict important events e.g. endogenous financial cycles.

Any modelling effort involves a compromise between the intention to represent the properties of the problem adequately, and the need to remain feasible (in terms of implementation) and interpretable. Indeed, models are useful precisely because they are simplified representations of reality.

Mainstream approaches often focus on tractability and allowing for closed-form analytical solutions, but do so at the expense of system complexity. With the current computing power and accumulated knowledge on bounded rational behaviour of economic agents, there is a temptation to relax the mainstream model assumptions to better reflect reality. From the experience, the following relaxations seem to be particularly promising:

- In terms of *foundations*, focus on interrelated and interdependent agents operating within the appropriate boundaries of the system.
- In terms of system *properties*, models should be able to generate interactions within the system, giving rising to phenomena such as emergence and adaptation.

In this regard, these new approaches alleviate the need for the strong assumptions more typical in mainstream approaches. These often include the existence and tendency towards an equilibrium, the rationality of individual agents (comprised of foresight, taking expectations, and maximising utility), and the representativeness of an individual agent of a large group of agents (linear aggregation) amongst other model-specific assumptions.

In the efforts to pursue the relaxations related to foundations and system properties, one needs to make sure that the resultant model remains sufficiently sound and convincing. The following are the desirable properties of a "good" model:

- A model should operate with appropriate proxies of real life objects, i.e., it should be interpretable
- A model should be feasible in the sense that it should be mathematically tractable or should be open to simulation; the cost to construct and use the model should be aligned with its ambition
- A model should ideally be tractable in the sense that the implications can be traced back to properties of the model (rather than a "black box')
- A model should ideally have a theoretical basis and/or empirical basis
- Depending on the purpose and other details, one needs to define the (minimal) validity requirements, which the model should pass, such as the ability to reproduce the past
- A model should be "useful" and should inspire trust of end users
    - Here an important aspect is co-design of models with decision makers; one needs an efficient methodology for it given that they don't understand the language of researchers, don't have much time and generally don't have much willingness to engage in such exercises

These and other features should guide the development of improved modelling approaches to systems.

Extending existing tools to better model systems

One approach to improve the modelling of systems is to extend the application of existing tools. A promising approach to modelling sustainable development strategies is to integrate (in whatever form) existing modelling tools from different fields, such as integrating environmental models with economic growth and trade models, or integrating demographic and economic models. This extends the boundaries of what is modelled and allows for wider range of interactions that help reveal indirect vulnerabilities or strengths of policy interventions.

Both OECD and IIASA develop and operate a wide array of modelling tools, which are largely complementary to each other. The tools at IIASA have a more physical focus and describe long-term dynamics in, for instance, population, energy demand and supply and agriculture and land use. The OECD has a long tradition in more economy-focused models that describe interactions between macroeconomic growth, and interlinked sectoral and regional economic activity.

Over the past years, researchers at both IIASA and the OECD have been deeply involved in the development of socioeconomic scenarios for climate change assessment, the Shared Socioeconomic Pathways. IIASA developed population and education projections for five long-term scenarios. These were then fed to an OECD macro-economic growth model (ENV-growth), which explicitly accounted for the energy revenues for fossil-fuel exporters.[3] In a third step, the economic projections from the OECD were fed back to the Integrated Assessment Modelling framework at IIASA (MESSAGEix-GLOBIOM) to produce projections of energy demand, energy supply, land-use and greenhouse gas emissions under different levels of mitigation.

Several other efforts have focused on coupling energy models and macroeconomic tools. Energy systems models have added macro-economic feedbacks for the changes in energy prices, and CGE models have linked to energy systems models to bring in more detailed information on energy sector transformations. While methods for these model linkages have been well established (Klinge Jacobsen 1998, Messner and Schrattenholzer 2000, Böhringer and Rutherford 2008, Böhringer and Rutherford 2009, Kypreos and Lehtila 2015), they focus on a limited number of variables that are harmonised and exchanged between the coupled models. This limits the types of analyses that can be performed with these linked frameworks and leaves room for major mismatches between the energy system and economic modelling tools.

[3] N.B. These economic projections were not official OECD forecasts, and not approved by OECD governments. Rather, they were unofficial projections made using the OECD modelling framework (Dellink et al., 2017).

A second example on recent collaboration was the use of IIASA's GAINS model to produce air pollution emission factors that were then used in OECD's ENV-Linkages model to project air pollution emissions and the damages from air pollution until 2060.

The very fruitful collaboration produced a widely used set of climate change assessment scenarios that are distributed through IIASA's community databases as well as a report on air pollution that has been instrumental in increasing policy attention to air pollution. However, these are also one-directional exercises that left out several key-interactions that are important to explore into the future. These include, for instance: feedbacks from changes in energy production and consumption and land use to economic activity; feedbacks from economic development on population and migration; and feedbacks from climate change impacts on energy and agriculture on economic activity and population.

Developing novel methods to link the economic modelling tools of the OECD with the physical system models of IIASA would add great value to both institutions. Methodologically, there is room for improvement of these methods, especially when the exchanged information between the models is expanded to cover not only energy supply, but also investments, distributional consequences for different household groups and minimum energy consumption requirements (such as for decent living standards, see Rao). Furthermore, such linking would open up the possibility to link economic activity, ecosystem services and biodiversity loss (see Karousakis et al. elsewhere in this report).[4]

Newer methodologies and tools

In this section of various desirable features reflecting the reality described above, we address a few, which in our view can be dealt with by methods and approaches which have been developed, piloted and in some cases applied.

- **Explicit accounting for uncertainty**. Stochastic optimisation can be used in decision support tools to derive so-called "robust" decisions, which sometimes are also informally referred to as "no-regret" decisions. Robust decisions allow to achieve a satisfactory outcome of a process no matter what realisation of uncertainty actually is observed. In IIASA, we have tested this approach to problems of insurance market against natural disasters and land use planning.
- **Multiplicity of agents with own goals, strategic interactions, tragedy of the commons.** Evolutionary game theory can be used to simulate more realistic behaviour of agents, whereby they make decisions based on observation of their local neighbourhood. Importantly, one can address use this framework to model particular instances of the tragedy of the commons phenomenon, which include climate change mitigation and mitigation of systemic risks, among other issues.

[4] Technically, the open database platforms of IIASA are proving to provide an excellent model linkage framework, in which these new approaches could be implemented.

- **Bounded rationality, including consumption preferences and consumer choices.** Behaviour economics and agent-based modelling (ABM) emphasise and make use of the fact that individuals act in ways that are not fully rational, including by following simple heuristics rather than optimising behaviour. An aspect of this for systems is that people may take their decisions based on the actual/perceived behaviour of others, rather than by acting independently as assumed in mainstream economics. For example, decisions about changing to more sustainable behaviours may depend on whether neighbours are perceived to be taking similar measures. If they thresholds in people's reactions and depending who else is in their neighbourhood, this can lead to a wide range of outcomes at the systems level. ABMs are built from the assumption numerous agents following interacting following simple behaviour rules in a well-defined environment. Individual behaviours, their interactions and the structure of their relationships gives rise to rich systems properties, including emergence and complexity. These models captures heterogeneity across agents that plays an important role in how the systems evolve. They also trace out the implications across the distribution of agents. ABM models can typically only be solved through simulation rather than through analytical solutions, but increased computer power has made this a more viable approach even on a large scale. ABMs could be applied to a vast array of policy problems, but have already proved insightful in the areas such as finance and trade. As they do not depend on concepts of equilibrium or strong assumptions about individual behaviour of the structure of the economy, they can provide very different insights from mainstream models.
- **Complexity and interconnectedness.** Network theory suggests that the system's structure in terms of the links between its components is important in defining how the system will react to various exogenous disturbances. Also, it suggests to use the information about the position of an agent in the network to specify a policy or an action. Compared to mainstream models that rely on very simple or uniform interactions between agents, network theory yields insights from more realistic relationships, for example where some nodes are much better connected to other nodes or more central to the network than would be the case in the simplest configuration of interconnections. The structure of the network can determine whether interactions tend to transmit the effects of shocks broadly to achieve a stabilising effect or whether effects move down narrower paths. It can also suggest what states emerge in the system, for example whether effects are internalised across the system or within a narrower neighbourhood of connected agents. In policy terms, interventions can be designed that work with the structure of the network to yield good outcomes. Alternatively, models can be developed to show how policy can change the structure of the network itself to yield better outcomes.

The potential role of newer tools and methods

The extension of existing tools and the application of new methods clearly has the potential to bring new insights from modelling to analysing-systems based strategies. The picture they present may be radically different from that under existing models – for example showing an economy that is non-ergodic rather than tending to a steady-state equilibrium – or, at least, reveal new aspects of the systems properties or the linkages between aggregate and agent-level behaviour. They can help to map out linkages that were not previously well articulated in models, for example the feedback between economic activity and the earth's resources.

These modelling approaches are increasingly feasible as computing power increases, making it easier to solve complex models or to simulate the behaviour of a large number of agents. The techniques themselves have developed alongside technology, notably in disciplines beyond social science such as physics, biology and engineering. Improved data, including big data, and growing understanding of many aspects of the behaviour of parts of the system, including human behaviour, can be used to calibrate and enrich these models. The newer tools can be more flexible than models designed to tractable using analytical techniques as they can more closely follow the actual structure of the problem, which also makes it easier to expand and extend the models as thinking progresses.

However, the use of the newer approaches is much less developed than for mainstream models and they present challenges of their own, which will need to be mastered over time. In particular, the systems level properties can be sensitive - as with other models – to specific modelling assumptions about agents' behaviour, the structure of the model and calibration choices that all involve important aspects of simplification relative to the real world. Given the current understanding of behave, assumptions about the heuristics that people follow may be *ad hoc* and need to be treated carefully given the potential impact on the results from models that assume them.

The interpretability of increasingly ambitious models can be more challenging than for conventional models. As they become complicated, models become harder to understand and to trace through the origins of specific results. This interpretability is important to gain insight and also to help understand whether models results are driven by a plausible set of drivers or by undesirable features of the underlying assumptions. This calls for greater efforts to explore and communicate the properties of these richer models. Furthermore, the behaviour of systems can be less intuitive than in other models, such as representative agent models that are based on thinking about a single agent. Lack of intuition about the properties of systems can make it harder for people to understand and interprets model such as ABM that take strong systems-focussed approach.

Techniques such as networks and ABMs raise specific issues of interpretability relative to mainstream models because non-linearity leads to much richer ranges of outcomes that generate range or distributions of possible outcomes rather than focussing on point estimates. While this is a valuable feature of these models, it can make them more difficult to interpret. A more fundamental issue is that complex systems may have a very wide range of outcomes and it may be effectively impossible to predict how they will evolve other than in a probabilistic way. This problem arises very clearly, for example, in forecasting future outcomes of complex system, where they may be no meaningful set of point estimates.

New methods can be used in different ways to inform systems-based strategies. Simple theoretically-focussed models can provide useful qualitative insights and help to build researchers' and policymakers' intuition about how economic, environmental and social systems behave. Simple "toy" models can yield specific insights based on relatively simple modelling. A more ambitious approach is to develop large-scale models which more closely capture the full behaviour of the real world. This approach requires models that are much more developed, particularly in terms of careful calibration and being closely informed by data. This makes such models more difficult to build and potentially harder to interpret.

Validation and relationship to data

A key question for any model is validation against data. Like other models, yielding testable predictions allows the validity of theory to be assessed and rejected where appropriate. This is challenging given current econometric tools that may lack precision and may be more challenging for newer models that have non-linear implications or predict wide distributions rather than narrow estimates.

At the same time, the growing availability of data, including smart and big data, provides much richer information that can be used to calibrate existing models and, especially, network and ABM models. These models may have many more features that can be matched to the data – both cross-sectional and aggregate - than mainstream models and may in principle be more open to validation.

The development of machine learning techniques creates new possibilities to explore data without strong assumptions of linearity. It can also be helpful to calibrate these models from big data.

Conclusion

Improved modelling capabilities, methods and approaches would facilitate the development of systems-based strategies for sustainable development. This could be achieved by extending existing modelling techniques and by applying newer tools, such as network analysis and ABM. Much remains to be done to advance these new approaches. While refining existing techniques is likely to yield new insights more rapidly, fundamental innovation would ultimately lead to the type of novel insights which a systems approach promises. The need for different models with their own strengths and weaknesses will remain and a diverse, pluralistic approach will be needed.

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The Environment and Sustainable Development

4. Developing pathways to sustainability: fulfilling human needs and aspirations while maintaining human life support systems

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Introduction

In 1987, the “Brundtland Report” of the World Commission on Environment and Development began with the following observation: “Those looking for success and signs of hope can find many: infant mortality is falling; human life expectancy is increasing; the proportion of the world's adults who can read and write is climbing…. But the same processes that have produced these gains have given rise to trends that the planet and its people cannot long bear” (WCED 1987).

A growing body of subsequent research suggests that human activities are already pushing the Earth’s system outside the stable planetary boundaries, with damaging and even catastrophic consequences (Rockstrom et al. 2009). Developing pathways that meet the challenge of fulfilling human needs and aspirations while ensuring human life support systems has thus become even more urgent, three decades after the Brundtland Report.

Long-term pathways are a useful instrument for governments to identify expectations for the future and as a reference to set up transitional changes to match multiple policy objectives. In this sense, they can be viewed as ‘normative’ backcasting exercises with desirable future goals. For example, pathways have been developed specifically for greenhouse gases (GHGs) emission reduction and stabilisation of greenhouse gas concentrations. More recently, pathways have been developed to achieve multiple policy objectives that can for instance help achieve different Sustainable Development Goals (SDGs).

Reference pathways are projections used to illustrate the likely future consequences of current trends and policy choices based on specification of underlying drivers. Hence, they are usually referred to as the “business-as-usual” or “baseline” scenarios. Traditionally, reference pathways are based on a stepwise procedure, starting with specific demographic projections that are used as an input to develop economic projections. These are then used to quantify projected environmental consequences.

This chapter presents a brief overview of some key recent developments of pathways analysis in the context of sustainability. First, the Shared Socioeconomic Pathways (SSPs) are introduced. Thereafter, integrated population and human capital scenarios for joint analysis of human development, the capacity for coping with environmental changes and securing human life support systems are considered before closing the loop on incorporating environmental feedbacks on economic growth. Lastly, these scenarios are linked with the Sustainable Development Goals as highlighted by the World in 2050 initiative (TWI2050). The chapter concludes with a discussion of how a systems approach could lead to further progress in using pathways to inform policy makers.

Recent progress on defining sustainable pathways

Shared Socio-economic Pathways (SSPs) for Climate Change

Long-term scenarios have been used by the Intergovernmental Panel on Climate Change (IPCC) since the 1990s to analyse possible climate change, its impacts and mitigation options. Initially the IPCC relied on greenhouse gas emission scenarios. However, projecting longer-term climate change impacts and costs is complicated because greenhouse gas emissions depend on demographic, economic, technological and institutional factors, which change over time (Rosenzweig and Wilbanks, 2010). Consequently, scenarios were improved to reflect coherent narrative storylines to describe consistently the relationship between emissions and their driving forces. The resulting product was the set of scenarios described in the Special Report on Emissions Scenarios (SRES) (IPCC, 2000), which included demographic, economic, social, technological and environmental aspects as part of the storylines.

More recently, a new set of scenarios - the Shared Socioeconomic Pathways (SPPs) - was developed to better describe different climate futures, including the role of both mitigation and adaptation challenges (Field et al., 2014). While the SRES were developed as joint storylines between the future emission and economic development, the SSPs were developed separately from the climate scenarios, or the so-called representative concentration pathways (RCPs).[5]

The SSPs respond to the need of the Integrated Assessment Modelling (IAM) community to put climate impacts and responses into the context of evolving socioeconomic conditions (see Rosenzweig and Wilbanks, 2010). The SSPs not only focus on pathways to achieve emission reductions and mitigation, but respond to the rising concerns on vulnerabilities, impacts and adaptation. These, in turn, are strongly linked to socio-economic developments and human wellbeing.

The SSPs consist of five scenarios, based on narratives describing alternative socio-economic developments and the corresponding challenges for mitigation and adaptation (O'Neill et al., 2017), as illustrated in Figure 4.1. The SSPs narratives were associated with quantitative descriptions for key scenario drivers, such as population (KC and Lutz, 2017), economic growth (Crespo Cuaresma, 2017, Dellink et al., 2017, Leimbach et al., 2017), and urbanisation (Jiang and O'Neill, 2016). The narratives were also further developed to describe the implications for energy and land use (Riahi et al, 2017). For each SSP there exists a single population and urbanisation scenario (by IIASA and NCAR). Meanwhile, GDP three different GDP scenarios have been developed, with the OECD's used as an illustrative case. The

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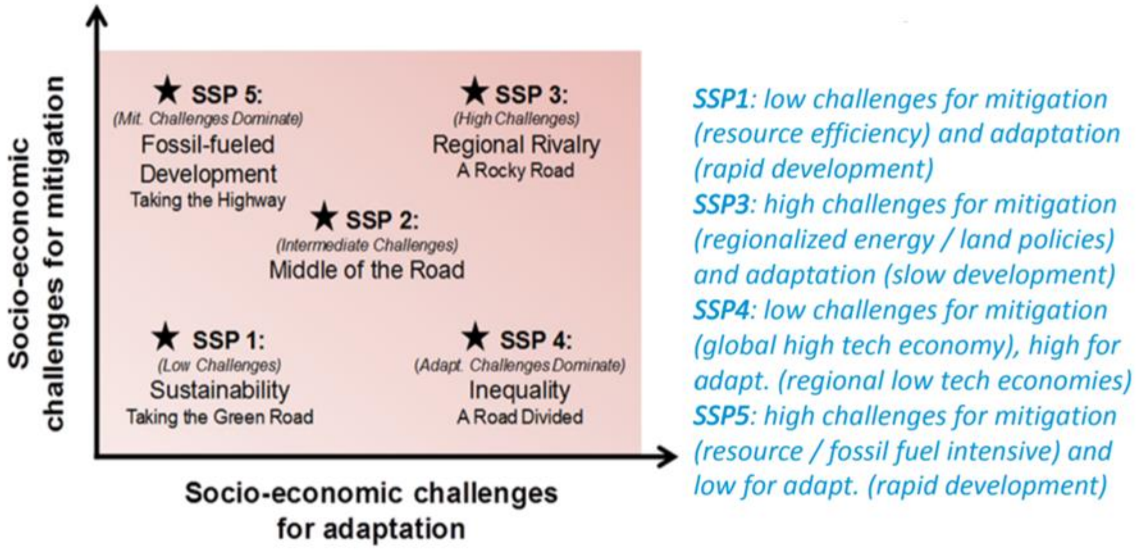
[5] As a parallel process to the development of the SSPs, the RCPs were developed to describe a range of possible climate scenarios (Van Vuuren et al., 2011). Four RPC scenarios - RCP2.6, RCP4.5, RCP6, and RCP8.5 - are labelled after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively). The two extremes of the RCPs (RCP2.6 and RCP8.5) would therefore lead to very different changes in climate, with RCP8.5 leading to much higher temperature increases and changes in precipitations. A matrix has been developed to map SSPs and RCPs (van Vuuren et al., 2014).

methodology behind the creation of the SSPs ensures the two-way causality between demographics and economic projections is accounted for.

Figure 4.1. Overview of the five different SSPs



Source: O'Neill et al., 2017.

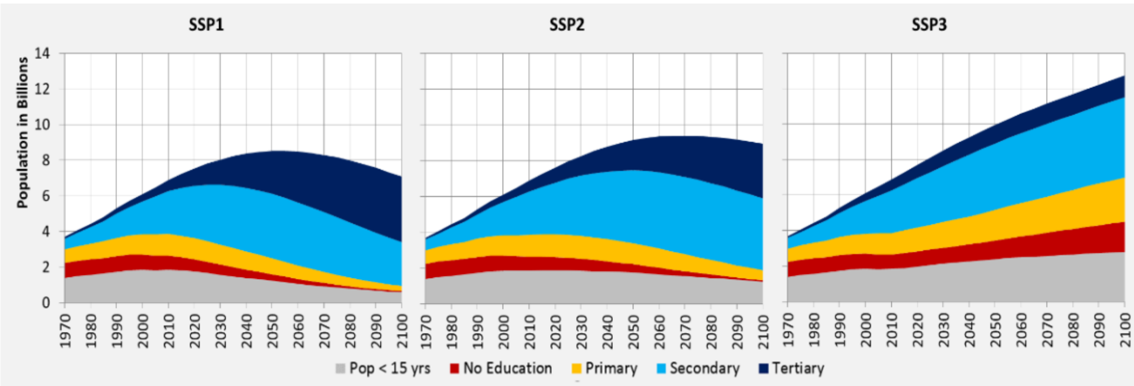
Integrated population and human capital scenarios

The SSPs were an important achievement but they have also been the starting point to explore further ways to exploit pathways for the study of future human development. Unlike the previous generation of scenarios that only considered total population size this new set of scenarios provides population projections by age, sex and six levels of education for all countries.

Beyond economic growth, education as a basic force of empowering people. Providing access to information has been shown to matter to a large range of important aspects in the context of sustainable development. There is overwhelming evidence that education is a key determinant of infant mortality (Pamuk et al., 2011) as well as adult health and mortality (KC and Lentzner, 2010). Beyond individual benefits, improving education by age and sex has also been shown to matter for countries in transition towards modern democracies and the rule of law (Abbasi-Shavazi et al., 2008: Lutz, 2009; Lutz et al., 2010). Furthermore, it has been demonstrated that basic education of the agricultural labour force is a key factor in agricultural production, therefore facilitating food security (Hayami and Ruttan, 1971). Finally, in the context of adaptation to climate change, a series of empirical studies on differential vulnerability to natural disasters in different parts of the world have confirmed the importance of education (Frankenberg et al., 2013; Hegelson et al., 2013; KC, 2013; Sharma et al., 2013; Striessnig et al., 2013; Wamsler et al., 2012). Education is shown to be an empowering factor that reduces vulnerability and enhances the adaptive capacity to the negative consequences of climate change. These effects show the interlinkages of education into the wider economic, political and climate systems, and thus should be accounted for as such.

The integrated population and human capital scenarios shown in Figure 4.2 also show alternative trajectories of world population growth. They are based on the most extensive summary of expert arguments on future fertility, mortality, migration and education trends as published in Lutz et al. (2014) and as recently updated by the European Commission (2018). Population trends matter greatly for assessing how many people will be potentially at risk of suffering from environmental changes. SSP1 demonstrates a scenario of rapid education expansion that will be associated with both lower fertility and mortality. This leads to world population peaking around 2050 at a level below 9 billion followed by a decline, which in 2100 may reach a global population size comparable to the one of today. The medium scenario, SSP2, will peak around 2070 at level of around 9.6 billion and only shows modest declines by the end of the century. Finally, the stalled development scenario sees little to no progress in education. This is associated with a much slower fertility decline, which will result in a world population of over 13 billion in 2100. As the colours in Figure 4.2 show, the Sustainable Development Scenario SSP1 will not only have lower population growth but also a significantly better-educated population. Both aspects together will make it more likely that under such a pathway human needs and aspirations will be better ensured than under the other two scenarios. SSP3 could be disastrous for future human well-being.

Figure 4.2. World population scenarios by level of educational attainment to 2100 based on Shared Socioeconomic Pathways (SSP1, SSP2, SSP3)



Source: European Commission 2018.

Links with the Sustainable Development Goals

One important development of the recent literature is the movement from a single to multiple policy targets. The recognition of the need to consider multiple policy goals has been highlighted by the Sustainable Development Goals (SDGs). Indeed, it is not just important to achieve a climate goal but also that the goal is met for instance in an inclusive way, without affecting the most vulnerable parts of the populations.

This new approach is key to on the international scientific initiative “The World in 2050” (TWI2050, 2018), which has been led by IIASA.[6] The TWI2050 aims to provide fact-based knowledge to support the policy process and implementation of the SDGs. It is a first attempt to explore transformational pathways that take a comprehensive people and planet approach to attaining the SDGs – with a view of ensuring a prosperous and healthy future for all on a resilient and healthy planet in the long-run.

Using an integrated and systemic approach, TWI2050 addresses the full spectrum of transformational challenges related to achieving the 17 SDGs, to avoid potential conflicts among them, reap the benefits of potential synergies, and reach the desired just and safe space for people and planet by 2050 and beyond. This approach is the first goal-based, multi-model quantitative and qualitative integrated analysis that encompasses the full set of SDGs. The successful identification of sustainable development pathways (SDPs), which are rooted in the SSPs, requires a comprehensive, robust approach that spans across disciplines and methodologies, and that can deal with non-linearity.

The TWI2050 framework (Figure 4.3) includes qualitative and quantitative elements and consists of the following: (i) a broad transformational narrative; (ii) targets and indicators for 2030, 2050 and beyond; and (iii) specific sustainable development pathways (SDPs), which include quantitative elements based on modelling approaches and complementary narratives.

In its 2018 report, TWI2050 identified six exemplary transformations which are needed to achieve the SDGs: (i) Human capacity and demography, (ii) Consumption and production, (iii) Decarbonisation and energy, (iv) Food, biosphere and water, (v) Smart cities, and (vi) Digital revolution (Figure 4.4).

While the TWI2050 2018 report is only the beginning of a long-term effort to understand sustainability pathways, it provides interesting key policy messages and research gaps. These include the need for early ambitious policy action to achieve the SDGs. The integrated framework highlighted the need for a holistic perspective, with an effective and inclusive governance, combining action at local and global level.

Towards an agenda for further work on sustainability pathways

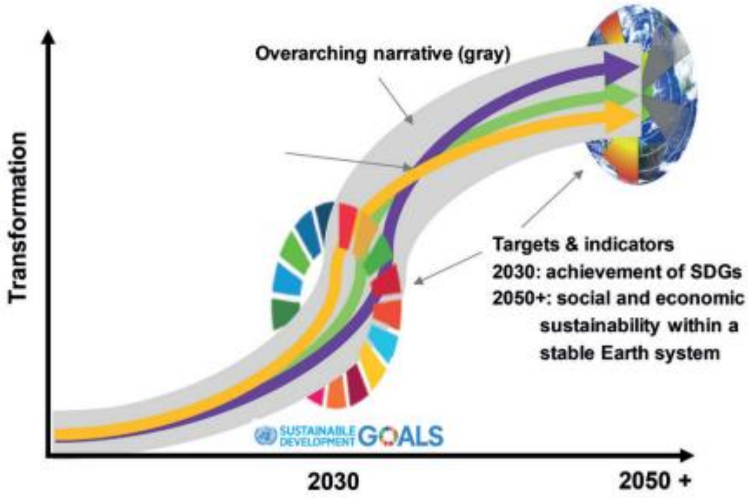
The new approaches outlined in Section 4.2 highlight the movement from disciplinary, central baselines to tackle one specific policy objective towards more holistic approaches that acknowledge that different elements in a system are interlinked, and that robust policy advice hinges on a full systems approach. To obtain more integrated sustainability pathways, a number of major developments are needed. Joint activities by OECD and IIASA can help bridge these remaining gaps.

One new direction would be to integrate feedbacks from environmental damages into demographic and education projections. As the OECD’s CIRCLE project has shown, environmental feedbacks can be significant already in the coming decades. Pathways that

[6] See: www.twi2050.org

ignore the mortality and morbidity effects (including e.g. learning and cognitive capabilities) of pollution and climate change lead to biased results. The OECD and IIASA could collaborate in preparing impact assessments of pollution feedbacks on specific demographic groups, differentiating between mortality and morbidity effects; these can then be used in IIASA's demographic projections to provide integrated pathways that encompass environmental feedbacks.

Figure 4.3. The World in 2050 Framework



Source: TWI2050 (2018).

Figure 4.4. Six Exemplary Transformations

Source: TWI2050 (2018).

Another new direction could consist of further integrating demographic, education and income projections. Education projections are currently made without reference to expenditures on education, making them less policy-relevant than they could be. Identifying how demographics, education and income projections can be constructed in a mutually consistent and highly granular manner, as pioneered in the SSPs, will enhance the insights to policy makers on how policy interventions affect the various parts of these linked systems. A gender aspect could also be considered to contribute to the understanding of the crucial role of gender-balance education for economic development. The OECD and IIASA could work together on enhancing policy scenarios for education systems that are consistent with economic projections of government budgets.

There is also a clear need for linking education levels to occupational skill categories. While (re)training programs can alter occupational skillsets of employees, the main driver of occupational skills are the education received by the employees when they grow up. However, the links between investing in education systems and the resulting changes in occupational skills is relatively weak, leaving governments with imperfect information on how to best prepare the work force for changes in skill sets demanded by economic sectors that transition towards sustainability. OECD and IIASA could first work on better mapping educational and occupational skills, potentially in collaboration with ILO, and then improve and integrate the tools used for making education pathways at IIASA and for pathways of labour supply and productivity at OECD.

Finally, modelling assessments of sustainability pathways can be further enhanced. Quantitative scenarios for SDGs related to human development are still scarce and can be improved and better integrated with indicators for other SDGs. This would help to achieve a more integrative approach and to obtain a full overview of the consequences of different scenarios and policies on a wider range of SDGs. Similarly, societal changes, the evolution of human needs and changes in governance could be better integrated into modelling work. For instance, changes in consumption patterns towards a more service-based economy could contribute to achieving sustainability while limiting the impacts on resources and the environment. Further integrating the available modelling tools at IIASA and the OECD could help mainstream sustainability considerations into the long-term projections.

Key points and conclusions

- Human activities are already pushing the earth's system outside stable planetary boundaries with damaging and even catastrophic consequences. Further degradation of the environment and natural capital can compromise prospects for future economic growth and human well-being. Developing pathways that meet the challenge of fulfilling human needs and aspirations while ensuring human life support systems has thus become even more urgent.
- Long-term pathways are a useful instrument for governments to identify expectations for the future and as a reference to set up transitional changes to match multiple policy objectives. In particular, reference pathways are projections used to illustrate the likely future consequences of current trends and policy choices based on specification of underlying drivers.
- This chapter presents a brief overview of some key recent developments in pathways analysis in the context of sustainability at the global level:
    - The *Shared Socioeconomic Pathways* (SSPs) include the role of both mitigation and adaptation in describing different climate futures; putting climate impacts and responses into the context of evolving socioeconomic conditions.
    - *Integrated population and human capital scenarios* for the SSPs highlight the importance of education as an empowering factor that reduces vulnerability and enhances adaptive capacity to climate change. They provide population projections by age, sex and six levels of education.
    - *The economic consequences of environmental feedbacks* are incorporated in projections to 2060. These projections go beyond current measures of GDP and take a wider welfare perspective. Taking account of feedbacks from environmental degradation requires substantial development of economic tools as well as additional data.
    - "*The World in 2050*" is an international scientific initiative, which addresses the need to consider multiple policy goals, for example in the framework of the SDGs. This project which has identified different exemplary transformations needed to achieve the SDGs.
- IIASA and OECD are ideal complements in further strengthening integrated systems analysis in environment-economy interactions. Further development of OECD-IIASA collaboration can generate robust policy advice based on a full systems approach in integrated pathways for green growth and sustainable development.

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5. A concerted approach to biodiversity, water, food and trade

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Introduction

Systems analysis and systems-based strategies have the potential to examine critical, interlinked and complex global issues, evaluate implications and, therefore, help inform policy options and guide decision-making processes. Systems analysis and systems-based strategies draw on innovative methodologies, models and tools for research and policy analysis.

The value-added of these approaches are crucial in areas such as biodiversity, water, food and trade, where comprehensive integrated approaches are needed to evaluate first-order and second-order effects, including on the economy, and the feed-back loops these may have. Understanding potential interactions, and the synergies and trade-offs across these - and other - areas, can help to inform political and policy issues. This is particularly relevant for example, in the context of the Convention on Biological Diversity, where the 2011-2020 Strategic Plan for Biodiversity including the Aichi Biodiversity Targets, are due to expire in two years, and a new post-2020 framework will need to be delivered. The CBD COP 14 Decision CBD/COP/14/L.30 on Scenarios for the 2050 Vision for Biodiversity "invites the scientific and other relevant communities working on scenarios and related assessments to take into account the following issues which are relevant to the development of the post-2020 global biodiversity framework", inter alia (i) the broad range of underlying drivers and systemic and structural issues related to biodiversity loss; (ii) combinations of policy approaches at multiple scales and under different scenarios; (iii) potential synergies, trade-offs and limitations in order to identify effective policies and measures to enable the achievement of the Sustainable Development Goals; (iv) identification of short- and medium term milestones in pursuit of the long-term goal. The value-added of such scenario and modelling analysis is also recognised by international initiatives such as IPBES (2016).

Policy coherence is also an increasingly prevalent message at the national level. For instance, under an original framework developed in response to agriculture ministries of the G20 countries, the OECD has been asked by agriculture authorities in ten OECD and non-OECD countries to conduct policy reviews covering all policies affecting agriculture innovation productivity and sustainability (from education to taxation and environmental regulations). The Republic of Korea also supported an OECD water policy dialogue which focused on policies covering the Land-Water-Food-Energy nexus, with the intent to help guide their new Water Law and water governance in a coherent manner.

Illustrative cases of the benefit of systemic approaches

OECD and IIASA have already applied in the past integrative approaches covering different parts of the biodiversity, water, food and trade system. In the context of biodiversity and water, systems analysis has been used in the OECD (2012), OECD Environmental Outlook to 2050: The Consequences of Inaction. By combining the OECD CGE model ENV-linkages with PBL modelling framework IMAGE-GLOBIO, analysis was undertaken to project business-as-usual scenarios of the state of the world in 2050, and various policy simulations (e.g. increase in terrestrial protected area coverage; climate change mitigation scenarios with reduced impact on biodiversity). More recently for the OECD (2017) report, The Land-Water-Energy Nexus: Biophysical and Economic Consequences, both PBL and OECD modelling teams collaborated to deepen the integration of the two models in a way that could be promising for an eventual linking between OECD and IIASA modelling tools. This report dealt with interconnections between scarce resources by highlighting the nexus between land, water and energy (the LWE nexus). The report provided projections for the biophysical and economic consequences of nexus bottlenecks until 2060, highlighting that while the LWE nexus is essentially local, there can be significant large-scale repercussions in vulnerable regions, notably on forest cover and in terms of food and water security.

Models and scenarios are increasingly promoted as relevant tools to support various stages of the policy cycle, [from framing (via quantification of explorative scenarios) through intervention design (via target seeking and policy screening scenarios) to evaluation,] in particular in the context of biodiversity, water, food and trade (IPBES, 2016) [and across multiple scales (Rosa et al. 2017)]. In addition to contributions to major IPBES reports on related methodological issues (IPBES, 2016), IIASA recently lead two innovative initiatives. First, in the “Bending the curve” initiative (Leclere et al. 2018), IIASA coordinated an international effort to couple four global land use models to ten global biodiversity models but also design and quantify new scenarios exploring how more ambitious targets for biodiversity (reversing the decline in global biodiversity indicators induced by land use change) could be achieved within the 21st century (Leclere et al, submitted). Besides extending the conservation efforts, the role of technological progress in agriculture, international trade liberalisation, human diets, and food waste reduction, was considered. This initiative involved multiple IIASA models – the global agricultural and forest sector model, GLOBIOM, and global terrestrial biodiversity models, INSIGHTs and cSAR – with the aim to feed into the preparation of the post-2020 biodiversity framework. Second, IIASA developed new modelling tools to look at the Land, Water and Energy (LWE) nexus, allowing to tackle spatially explicit analysis of hotspots of nexus issues (Byers et al 2018). These modelling tools allow for better targeting of future research and policy intervention, going beyond more traditional analysis that remains on a rather aggregated scale.

See https://www.oecd-ilibrary.org/agriculture-and-food/oecd-food-and-agricultural-reviews_24114278

Systems analysis was also undertaken in the OECD (2019) *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences* publication. The analysis presents global projections of materials use and their environmental consequences, including on land use and acidification, eutrophication and freshwater, and provides a quantitative outlook to 2060 at the global, sectoral and regional levels for over 60 different materials (biomass resources, fossil fuels, metals and non-metallic minerals). It explains how economic drivers help in determining a partial decoupling of economic growth and materials use, and assesses how the projected shifts in economic sectors and regional economic activity explain changes in the use of different materials. The projections include both primary and secondary materials used for metal productions, which provides a deeper understanding of what drives the synergies and trade-offs between extraction and recycling.

Recent OECD reports have also used modelling to explore the sector-specific links between agriculture, food, water, climate change and trade. Simulations using IFPRI's IMPACT model have been used to look at scenarios for climate change adaptation options in agriculture (Ignaciuk, A. and D. Mason-D'Croz (2014), "Modelling Adaptation to Climate Change in Agriculture", OECD *Food, Agriculture and Fisheries Papers*, No. 70) and to explore the global impacts of water stress in three water risk hotspot regions of Northeast China, Northwest India and the Southwest United States on national and international agriculture production and prices (OECD, 2017, *Water Risk Hotspots for Agriculture*) with and without climate change. Ongoing work using a set of different models, including the IIASA GLOBIOM model, is exploring the economic and trade consequences of agriculture engaging into GHG mitigation internationally and in different countries. Additionally, the recent report of the OECD to the G7 highlights the business case for action on biodiversity, which shows some of the direct interconnections between the economic and environmental systems. Specifically, "Business impacts and dependencies on biodiversity translate into risks to business and financial organisations, including ecological risks to operations; liability risks; and regulatory, reputational, market and financial risks." (OECD, 2019).

The issue of systemic risk is of particular importance nowadays when global trade networks become more and more interconnected. Countries and regions become exposed to risks of undersupply of food, energy or other critical resources, which can be caused by disturbances along supply chains happening in the other part of the world. A few recent IIASA publications quantified the systemic risk in global trade networks (Gephart et al 2016; Klimek et al 2015) and explored whether diversification as a means to reduce risks trades off with the long term turnover growth (Kharrazi et al 2017).

Systemic analyses may also be useful to conduct micro scale ex-ante assessments of the impacts of specific policies. For instance, recent work has explored the impact of specific types of core agriculture subsidies on agriculture productivity, mitigation and adaptation in Finland (Lankoski, J., et al. (2018), "Modelling Policy Coherence between Adaptation, Mitigation and Agricultural Productivity", OECD Food, Agriculture and Fisheries Papers, No. 111). Ongoing work is being carried out to explore how those policies may affect GHG emission, nutrient balance, water quality and indicators of biodiversity at the farm level.

OECD and IIASA already began collaborating also on capacity development in the area of water. In 2018, a project to assist policy makers in the Eastern Partnership (EaP) countries to develop or update a national water strategy aligned with the EU's Water Framework Directive and other official documents was implemented. Policy makers from Belarus, Georgia, Moldova, and Ukraine participated in the stakeholder workshop held at IIASA, in which they acquired knowledge and practical experience in using qualitative systems analysis and foresight to develop a comprehensive water strategy, which recognises the systemic and cross cutting nature of the water sector.

There are also several examples of the implementation of the systemic approaches to water related issues carried out at IIASA. The study A Continental-Scale Hydro-economic Model for Integrating Water-Energy-Land Nexus Solutions (Kahil et al. 2018) presents a new bottom-up large-scale hydro-economic model; the Extended Continental-scale Hydro-economic Optimisation model (ECHO). ECHO works at the sub-basin scale over a continent and integrates a detailed representation of local hydrological and technological constraints with regional and global policies. Results of this framework provide critical assessments of future investment needs in both supply- and demand-side water management options, economic implications of contrasting future socioeconomic and climate change scenarios, and the potential trade-offs among economic and environmental objectives. In another study, Global assessment of water challenges under uncertainty in water scarcity projections (Greve et al. 2018), IIASA applied a probabilistic approach to assess global water scarcity projections following feasible combinations of Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) for the first half of the twenty-first century. The results showed that median water scarcity and the associated range of uncertainty are generally increasing worldwide, including many major river basins. On the basis of these results, we have developed a general decision-making framework to enhance policymaking by identifying representative clusters of specific water policy challenges and needs. Finally, the study “Robust management of multipurpose reservoirs under hydro-climatic uncertainty” (Ortiz-Partida et al. 2018) focused on evaluating the performance of robust operation of multipurpose reservoirs under uncertainty in hydro-climatic conditions. To achieve this objective, we have formulated a novel two-stage stochastic optimisation model that maximises regional economic benefits from reservoir deliveries and integrates stochastic inflows into a water allocation system with multiple demands and various physical and institutional constraints. The model derives a robust set of monthly reservoir releases that perform well under a wide range of hydro-climatic conditions. This model has been applied to the case of the Big Bend Reach of the Rio Grande/Bravo, a transboundary river basin of high importance for the United States and Mexico.

Vision for the integrated OECD-IIASA systemic analysis

The previous examples show case the existing capacity of IIASA and OECD to carry out systemic analysis independently. However, there are many other potential studies which would benefit from integration of approaches, data and tools available at the respective institutions. This section provides elaborates on three of them.

Globally consistent national efforts for biodiversity in the post-2020 framework

Approaches such as the “Bending the curve” initiative provided relevant insights into the formulation of the post-2020 frame for biodiversity, such as what targets might be achievable and what pathways might allow reaching them. However, models and scenarios can be used to support policy decisions on a shorter time scale. While targets based on biodiversity outcomes (e.g., Mace et al 2018) might be adopted in the post-2020 framework – in an analogy to the +2 Celsius degree limit in the case of climate change – it will most likely be complemented by targets on conservation actions (e.g., targets on the extent of protected areas, or of 'other effective area based conservation measures' OECMs) and supply-side or demand-side measures (e.g., sustainably closing yield gaps or promoting diet shifts). In the post-2020 framework, IIASA models could be used to estimate the extent to which on-going efforts (e.g., actions) should contribute not only to the action targets but also to the overarching goals (i.e., biodiversity outcomes). Such a modelling could be used to assess the efforts of various countries (e.g., as was done by Forsell et al. 2016 for land based climate mitigation), but this would best perform when informed by current and likely medium-term efforts. The knowledge OECD has accumulated on various areas of policy for more sustainable use of resource, such as the PINE database, could be pivotal in making credible short-term scenarios related to the progress towards realising the post-2020 objectives. Statistic and econometric approaches can be used in conjunction with OECD expertise on policies to build scenarios of policy efforts across countries in the course of the next two or three decades.

Exploring the role of trade in climate risks resilience

Climate change is expected to impact countries' relative comparative advantage to produce agricultural commodities, potentially altering production patterns and trade flows across the globe, giving rise to new hotspots of agri-environmental pressures and posing sustainability challenges. However, although first effects of climate change impacts on agriculture and the food system have been reported in many places globally, the exact magnitude of future impacts and their location are still not precisely known, due to uncertainties related to future temperature and precipitation patterns prediction, to the way the environmental system will respond and to the extent to which farmers will be able to adapt. International co-operation through intensified and diversified trade relations could facilitate adaptation and help increasing the resilience of the global food markets. At the same time, it could increase the exposure of countries and regions to risk triggered by production shortages in distant localities through new independencies. For this reason, it is necessary to identify effective trade policy strategies combined with robust land use strategies capable of mitigating, in the face of various future climate realisations and extreme events, the most adverse impact for food security and the environment.

A modelling framework could be developed to address this problem, taking advantage of IIASA's experience in integrated assessment modelling tools and OECD's past research and policy insights. IIASA has already developed tools to support decisions and derive scenarios on land use change, also under impact of climate change, notably GLOBIOM, representing the agricultural (crops, livestock) and forestry sector, including a representation of water availability for irrigation. Such tools represent agricultural markets with bilateral trade and explicitly account for trade barriers, and would more precisely characterise most resilient trade policy approaches in the face of climate change, using different metrics, such as economic welfare, food security, GHG emissions, water stress, and/or other SDG dimensions. Policy insights from previous OECD work on the role of market integration on growth and employment, the impacts of climate change on international trade, fostering adaptation in the agricultural sector, the environmental impacts of agricultural policies and agri-environmental indicators would enable to better inform the model and increase its relevance and capacity for policy design. IIASA has some experience in expanding GLOBIOM to stochastic analysis to explicitly account for uncertainty in its inputs (precipitation, temperature regimes etc.) and examine risks of extreme events. Such approach could be expanded using so called quintile risk measures, co-dependent risks and risk evolution over time. Advanced statistical approaches including those based on machine learning are relevant for this purpose. This approach would allow identifying trade policy option robust to different future possible climate realisations, and emphasise no-regret pathways. Trade policy options to be tested could include restricted trade up to trade wars and embargos vis-à-vis free trade regimes covering large parts of the global economy (for example, one could analyse consequences of free trade agreements (FTAs) associated with China's Belt and Road Initiative, of the launch of TTIP, TPP and other initiatives of this kind currently being planned). In this part of the analysis, it is important to pay attention to both tariff and non-tariff trade barriers (NTBs); the latter, which includes regulatory frameworks and standards (including sanitary and phytosanitary standards; SPS) are much more difficult to estimate and reduce, yet it is broadly known that generally they play a bigger role in defining the trade flows. The OECD has recently developed a methodology to estimate the trade impacts of NTBs which can be used in combination with more standard methods to incorporate trade barriers and assess both. Thus, the proposed modelling framework should be able to use reliable estimates of tariff and non-tariff barriers, as well as realistic scope of countries' and regions' convergence. Eventually, by conducting an extensive analysis of possible combinations of trade policies in different parts of the world, this modelling exercise would be able (i) to reveal an "optimal" level of economic/trade connectivity, which would ensure highest level of food security globally, (ii) elucidate trade-offs in terms of food security between regions and (iii) minimise the environmental impacts.

National policies for SDG compatible development pathways compatible with the Paris Agreement

Climate change stabilisation "well below 2 degrees" as stipulated in the Paris Agreement represents an unprecedented challenge for the humanity – according to the IPCC Special Report on 1.5 degree (2018), global emissions would need to be reduced by 45% by 2030 and carbon neutrality would need to be achieved by 2050. This cannot be left as a project for isolated country participation, but rather all OECD countries should contribute to maintain chances of success. This challenge would uniquely combine some of the complementarities between OECD and IIASA such as

- Short-term/medium term focus (OECD) and long-term modelling capacities (IIASA)
- Real world policy instruments assessment (OECD) and foresight and sustainable development pathways (IIASA)
- Bottom-up approach with very detailed representation of the supply side of agricultural and forestry sectors together with related environmental impacts (IIASA) and recognised position in economic impact assessment OECD

OECD and IIASA already started collaboration on GHG mitigation in the agricultural around the AGLINK-COSIMO and GLOBIOM models. Furthermore, SDG 12 (Responsible consumption and production) is being increasingly recognised as one of the major prerequisite to achieve ambitious sustainability targets for the land, water and energy nexus (Obersteiner et al. 2016, van Vurren et al. 2015). However, the broad economic aspects (such as distributional impacts across regions and sub-sectors of the value chain within the food system, or employment effects) of such transitions are not well captured. IIASA and OECD have large and complementary experience in modelling future trajectories and impact of policies with respect to LWE nexus issues.

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6. Integrated policies for climate, air, ecosystems, energy and transport

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Introduction

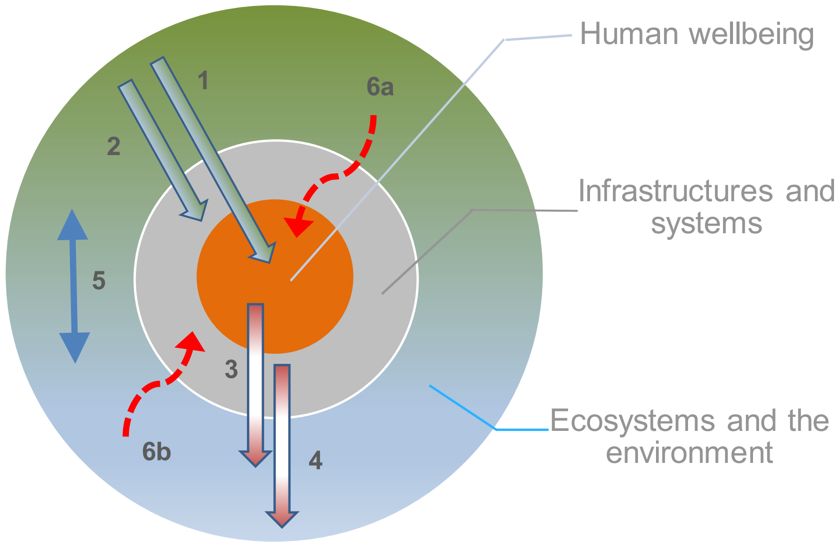
Human well-being is dependent on both human and natural systems, with ever increasing fractions of the earth actively managed for human benefit (see for example, Haberl et al (2007) and Vitousek et al (1986). The focus on this chapter is on the interplay between these systems and human-wellbeing viewed through the lens of the climate and ecosystems, focusing on the critically important mitigation challenges in the energy and transport systems.

This chapter provides three different perspectives on the complex of problems around climate and energy use, and their relationship both to healthy ecosystems and human well-being in terms of air pollution. Understanding the interactions between the natural and human systems on the global, national and local scales is essential to formulating effective sustainable policies and strengthened IIASA-OECD collaboration can make a valuable contribution on each level. The next section takes a macro or global level perspective on the trade-offs implicit in climate mitigation and ecosystems. Section 3 zooms in to the level of an individual jurisdiction or country, to understand the balance between climate policies and development while section 4 takes a sectoral perspective and examines some of the interlinkages between human wellbeing, transport and air quality.

The conceptual framework for this chapter is inspired by a paper by Waage et al (2015), but significantly modified to illustrate these key interlinkages (Figure 6.1). The “well-being” SDGs, such as SDG 1 on ending poverty and SDG 3 on good health and well-being, are at the (orange) centre of the figure. These ‘well-being’ SDGs depend on the achievement of other SDGs, such as food security (SDG 2), access to reliable, affordable, sustainable and modern energy for all (SDG 7) and clean water and sanitation (SDG 6). Of course, the achievement of these SDGs is critically dependent on the availability and effectiveness of different types of infrastructures and systems, which are represented by the middle (grey) ring.

The analysis needs to go beyond human systems however, since these are critically reliant on ecosystems and the environment – the outer ring of the diagram, shaded both green and blue to reflect the importance of both terrestrial and marine ecosystems, as well as the climate system. This dependence is both direct (Arrow 1), for example in terms of provisioning services (fuel or water abstraction), and indirect (Arrow 2) since ecosystems also provide services that we might think of as infrastructure services, such as water purification or flood protection (Millennium Ecosystem Assessment (MEA), 2005). Of course, human activities are also affecting in many ways the ecosystems, reducing the scale and range of ecosystem services they can provide in different and often radically changed contexts (MEA, 2005).[7] Some of these impacts – like the waste of water – may be ameliorated by the infrastructures we construct (Arrow 3), such as water treatment plants.

Figure 6.1. Conceptual diagram of the interlinkages between human well-being, infrastructures and ecosystems



Source: adapted from Waage et al 2015, http://dx.doi.org/10.1016/S2214-109X(15)70112-9

Similarly, the operation of the infrastructures, systems, and associated technologies that provide us with so many benefits may also cause environmental damages (Arrow 4), for instance, the emissions from a petrol or diesel car. Some of these damages are local, confined to a district or a city, but many have long-ranging or even global consequences such as the emission of carbon dioxide and other greenhouse gases (GHGs), which are still rising rapidly despite international efforts to reduce GHG emissions. An additional level of complexity is the different time-scales on which different impacts may occur and their degree of temporal persistence.

Of course, there are relationships and feedbacks (Arrow 5) within the environment – or the "earth systems" – such as the atmosphere, oceans, ice sheets, soils. For example, climate change is fundamentally modifying the global water cycle changing the distribution and intensity of rainfall as well as affecting the services that ecosystems can provide to us. In the other direction, ongoing, large-scale deforestation and forest degradation results in the emission of large amounts of CO_2 and reduces the potential for these forests to safely store

[7] The Millennium Ecosystems Assessment (2005) defined four categories: (i) provisioning; (ii) regulating; (iii) supporting; and (iv) cultural.

carbon dioxide emitted in the future.[8] Not to mention that tropical forests are also biodiversity hotspots and so deforestation contributes directly to the sixth mass extinction event.

These human impacts on ecosystems and the environment are not cost-free, even if there are some - possibly transient - benefits for some regions. The Arrows 6a and 6b in Figure 6.1 illustrate the fact that changes to the climate and ecosystems will in turn impact on human well-being, either directly (6a), or mediated through their effect on infrastructures (6b, e.g. damages from extreme weather).

The dependence of human wellbeing on the closely linked human and natural systems is increasing, both in intensity and in pervasiveness. At different temporal and spatial scales, these interdependencies may have very different characteristics and are likely to require different approaches, in terms of how we model and understand them as well as the economic and policy approaches used to manage these complex interactions and dependencies.

Macro-level interdependencies and trade-offs

Regarding the climate, human activity is driving the planet into completely uncharted territory, out of the comfortable climatic regime in which humans and their societies evolved over the last 10,000 years (IPCC 2014). The risks of severe, pervasive and irreversible damage will increase unless we invest in sustainable infrastructures (IPCC, 2014). In the absence of further policy action, climate change has strong impacts on the environment, but also on the economy.[9]

There are very real benefits that are expected if we can limit the global temperature increase from climate change to below 2 degrees Celsius, as is made clear from the recent IPCC Special Report on 1.5 degrees (IPCC 2018), in terms of reduced heatwaves and flooding, greater food security and lower levels of water stress. There would also be benefits in other environmental domains, including water quality, ecosystem services, and air quality.

However, the way in which we try to achieve such stringent mitigation goals will determine the macro-level risks and trade-offs between the climate system, ecosystems and human well-being. The following characteristics of global emissions reduction pathways will be critical:

- **The stringency of the mitigation goal**, if achieved, will determine the scale and extent of climate impacts on both human and natural systems. A recent IIASA study (Byers et al., 2018) found that global exposure to multi-sector risks (in water, energy and land) approximately doubles between 1.5C and 2C global mean temperature change.

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[8] In recent years estimated around 4.8 GtCO2-eq per year, comparable to the GHG emissions from Europe (Harris 2016)
[9] Climate change impacts could lead to economic costs that can rise up to 3% of global GDP by 2060 and up to around 6% of GDP in most damaged regions, such as South and South East Asia and Sub-Saharan Africa (OECD, 2015). However, as the report notes, there is a still a lot that cannot be quantified, so this could be a serious under-estimate should, for example, we push the climate beyond critical tipping points/

- **The rate at which the climate changes** will also have implications for how quickly natural and human systems can adapt to the changes, which in turn has policy implications in terms of how mitigation policy is implemented. For example, there is strong evidence that a focus on mitigating the effects of some short-lived climate pollutants in a targeted way could both reduce the pace of climate change over this century and provide significant benefits in terms of avoided damages from air pollution to both human health and food production (Shindell 2012 etc.). Indeed, the health co-benefits of climate policy from improved air quality have been found to outweigh or at least counterbalance the policy costs (Markandya et al., 2018; Vandyck et al., 2018).
- **The extent to which pathways depend on bio-energy and biomass**, either as a primary fuel or as a component of carbon dioxide removal technologies such as biomass-enhanced Carbon Capture and Sequestration (BECCS). The greater the extent of dependence, the greater risks to ecosystems, the services they provide and the underlying biodiversity on which they depend. Hasegawa et al. 2018 show that if the climate stabilisation policies were implemented through a uniform carbon tax across sectors and regions, the number of undernourished in the low warming scenario could be higher than in the climate stabilisation scenario. At the same time, Frank et al. 2017 show that through remunerating carbon sinks in addition to taxing the emissions, large part of the negative impacts on food security could be avoided. Finally, Havlik et al. 2014 demonstrate that because of the widely differing GHG efficiencies across the regions, international trade can be an effective mitigation measure. This can lead to increases in agricultural production in GHG efficient regions to compensate for reduced production in GHG intensive regions.

Evidently, outcomes will not solely be determined by climate policy action. There is significant uncertainty over what sort of world humans will be living in in 2050, and this is even truer of 2100. Scenario analysis is one of the key tools for trying to understand what the range of possible future worlds might mean for efforts to manage the simultaneous challenges of ensuring human well-being in the face of rapid economic and population growth and urbanisation while simultaneously trying to limit the extent of the climate risks we face. The latest set of state of the art scenarios, the Shared Socioeconomic Pathways (SSPs), were the outcome of a collaboration between several different research teams, including OECD and IIASA. They aim to capture the severity of the challenges to both mitigation and adaptation action in five different storylines for how the world might develop and can be combined with pathways for the future development of GHG concentrations and other climate forcing agents to create a matrix of scenarios out to 2100.

The SSPs economic pathways that are at the foundation of this scenario work were developed based on the OECD economic projections (Dellink et al., 2017). IIASA provided demographic pathways, which were used by the OECD to produce the economic pathways. These were then used by IIASA and other teams as a reference for scenario comparisons and studies encompassing such issues as energy and land-use futures under different levels of climate action. They also informed the OECD's recent work on climate change and economic growth (OECD, 2017a), which underlined the value of well-aligned policy packages in mobilising investment and social support for the low-emissions transition and sustaining economic growth.

Country, regional and local transformations and vulnerabilities

While climate considerations alone would argue for the maximum level of stringency in mitigation action to reduce both the extent and pace of climate change, this has major implications for the transformation of human social and economic systems and well as the extent of climate impacts. The rapid transformations required to meet stringent goals are likely to incur greater adjustment costs, offset by reduced climate impacts and other benefits, including savings, facilitated by more rapid technological advances. This could in turn influence development opportunities and paths, which reduce the welfare, adaptive capacity and flexibility of societies to deal with the impacts of climate change. These effects, and the balance between development and mitigation, will be context specific and while they are often addressed at a country level, the issues are likely to be most acute and intensely felt at smaller regional, city or even local scales.

The ambition of mitigation action at a global level will determine the intensity of potential trade-offs between mitigation measures and their potential (in)direct impacts on ecosystems and human wellbeing at smaller scales. A particularly acute challenge will be the interdependencies between water, energy and land (WEL). Over the past years, the nexus approach of integrally analysing these three domains has gained traction. A nexus approach gives equal weight to each sector (including the environmental needs) and strives to identify the interactions among sectors to better understand the synergies and trade-offs involved in meeting future resource demands in a sustainable way. The ultimate objective is to identify solutions that capitalise on potential synergies and co-benefits, minimising counterproductive policies.

Policymakers and researchers have come to understand that treating each domain in isolation risks policies with unintended consequences through system interdependencies. A nexus approach has the potential to avoid these, as it gives equal weight to each sector (including the environmental needs) and strives to identify the interactions among sectors to better understand the synergies and trade-offs involved in meeting future resource demands in a sustainable way. However, these approaches greatly increase analytical complexity.

IIASA has developed open-access scientific computing frameworks designed to aid decision-makers with complex choices regarding the development of water, energy, land resources and infrastructure in a given river basin or administrative region. These tools link engineering-economic models representing investment and allocation decisions across water, energy and land-use sectors to water resource models, representing the detailed biophysical processes at high spatial and temporal resolutions. The tools can be applied in interactive stakeholder meetings, gaining comprehensive insights into the synergies and trade-offs of policies, technological solutions and investments across water, energy and land decisions.

For its part, the OECD has analysed on the economic aspects of land, water and energy nexus, focusing on the economic consequences of possible restrictions to the availability of land, water or energy (OECD, 2017b). Separately, in a policy dialogue with the government of the republic of Korea (OECD, 2018a), the OECD identified a number of areas where progress could be made in managing the water-energy-land-food (WELF) nexus in Korea. The tools and approaches of the two organisations are complementary. OECD economic and policy analysis and approaches can provide insights that build on the detailed biophysical and technology modelling, which can be provided by IIASA.

Turning to the risks associated with climate change, future populations will be exposed to a range of climate change hazards of varying intensities that will alter from place to place, with some 'hotspots' exposed to more risks than others, compounding the challenges (Diffenbaugh and Giorgi, 2012; Diffenbaugh et al., 2007; Piontek et al., 2014; OECD, 2017). Risks are dependent both on the severity of climate change and subsequent hazards as well as, critically, on the population's spatial distribution (exposure) along with their vulnerability and capacity to prepare for and manage changing risks (IPCC, 2012). Stakeholders increasingly demand better tools and information to assist long-term decision-making and policy development. However, the capacity of regional, national and local planners to develop and analyse socioeconomic projections and climate change impacts information varies widely. Recent efforts at IIASA seek to quantify the impacts of a variety of future climates (Byers et al., 2018) by holistically compiling and analysing spatially explicit hydrologic, climate, and socioeconomic data based on the SSPs.

This state-of-the-art analysis provides a basis for performing novel vulnerability assessments at fine spatial scales and at the country level. The approach brings new levels of consistency across socioeconomic and climate scenarios – as well as through the range of spatial scales. This allows both adaptation and mitigation responses to be informed by more immediate, tailored descriptions of risks and impacts. There is a clear opportunity to complement these modelling insights with the economic and policy analysis capabilities of the OECD to improve our understanding of how to manage complex and adaptive coupled human and natural systems under conditions of uncertainty (Nicholson et al, 2009).

Climate mitigation, transport and air quality

Efforts to mitigate climate change are likely to be more successful and less costly when there is a two-way alignment between climate actions, broader goals of human well-being and sustainable development (OECD, 2019 forthcoming). Human mobility, provided by passenger transport systems, can bring access to employment and income (SDGs 1, 8, 10), education (SDG 4), and health care (SDG 3). Yet, some systems—for instance, those dominated by private, fossil-fuelled light duty vehicles—provide that mobility in ways that undermine progress on these and other sustainable goals. These negative impacts occur:

- within the system, for instance, by limiting accessibility for women or other disadvantaged groups (SDG 5, 10); or by exposing people to road injury (SDG 3);
- through infrastructures, for instance by misallocating land to parking and roads instead of other uses (SDG 11); and
- via natural systems, including by worsening climate change (SDG 13) through use of carbon-intensive energy (SDG 7); through damage to ecosystems (SDG 6, 14, 15), and through local air pollution (SDG 3).

Analysis of key issues such as the environmental impacts of transport, illustrate the need for multi-scale and linked-systems analysis. Emissions from fossil fuel burning in vehicles affect human health locally, but electrified alternatives may cause distant emissions with different health impacts, if the electricity comes from fossil sources. Therefore, policies to reduce these impacts need to go beyond inducing manufacturers to produce cleaner and electric vehicles to, for instance:

- reducing individual drivers' use of existing vehicles at the local level, including by providing public transit and active transport alternatives;
- supplying cleaner electricity (at the local, regional, or national level) or alternative (e.g. bio-) fuels based on internationally-sourced feedstock.

Each instrument to enact these different policies has economic impacts that reverberate across scales and the linked systems; and each has different effects on the emissions of the GHGs that drive climate change. This argues for a systems approach to integrally analyse the policy measures, co-benefits and trade-offs and costs.

Overall, shifting the policy focus to enhancing accessibility can better align decisions in the sector with well-being and sustainable development goals; helping as well to generate the two-way alignment between climate action and other priorities. First, because it is improved access to opportunities and activities, rather than higher physical movement that is directly linked to generating well-being. Secondly, focusing on improving accessibility (through enhancing physical access to opportunities, ensuring affordable services, and improving road safety) recognises the relevant role of sustainable modes and of creating proximity, which could also support governments in delivering climate change mitigation, as well as reducing air pollution and associated health impacts. Ensuring accessibility through alternative modes is key to, on the one hand achieve the shift from car to sustainable modes, which transport demand management policies (e.g. road, parking and fuel prices) aim to achieve, and which will bring important GHG emission reductions. On the other, it is also central to avoiding transport-related social exclusion and/or causing disproportionate economic transport costs for the population. This approach can also support governments in better ensuring that new technologies (e.g. "on-demand" shared mobility services) are introduced in a way that they can contribute to climate and wider well-being and sustainability goals.

Changes in transport mode will require infrastructure but also behavioural changes, which can be stimulated by policies. A recent study at the OECD focuses on the effect of congestion pricing on the demand for clean transport modes, drawing on an empirical analysis of the effect of Milan's congestion charge on the use of bike sharing. It finds that congestion pricing significantly increases bike sharing in the time windows when it is applied. On the other hand, recent work from IIASA (McCollum et al. 2017) shows that the emission reduction potential from the transport sector could be reduced once consumer behaviour is taken into account in the modelling work.

The multiplicity of combinations for possible responses requires integrative and multi-scale analysis to highlight which development pathways bring greatest progress towards the air quality/human health, climate, and other goals at lowest cost. However, the relevance of information from these streams of work would benefit from greater IIASA-OECD collaboration. In particular, as urban-scale interventions spread in countries with a mix of rural, suburban, and differently-scaled urban areas, their benefits and trade-offs will vary. By carefully linking insights from fine-grained urban models and analysis of good practice in policy design and implementation [OECD] to aggregate impacts and economic feedbacks [IIASA], broad and local progress towards human development goals can be studied at once, helping policymakers spot and avoid trade-offs.

Future directions

There are several future directions that should be pursued to further develop the understanding of these integrated system. Firstly, the nexus modelling of complex, adaptive inter-linked systems under conditions of change and uncertainty, with a range of specific spatial, climatic and socio-economic contexts and policy approaches should be expanded. Furthermore, there should a be concerted effort to combine modelling tools and data at different spatial levels to develop insights that are reliable, including at smaller spatial scales. The development of these models may then be used to inform and assess strategies and policies using models and developing indicators that put well-being and sustainability at the centre of decision-making.

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7. Systemic approaches for sustainable cities

By Joaquim Oliveira Martins (OECD), Michael Thompson, Wei Liu, Brian Fath and Bruce Beck (IIASA)

Urban metabolism, ecosystem services, and the circular economy

In the grand, global sweep of things, cities are where flows of resources — energy, water, plastics, carbon-, nitrogen-, phosphorus-bearing materials, and so on — come to interact with each other in the most intensive and complex of all possible ways. They end up woven together into tightly bound knots. In the socio-economic life of the city, supplies of goods embodying these resources pass around and among diverse economic sectors (food, water, energy, and so on) and are engaged in equally diverse patterns of household consumption. Cities are the end of resource supply chains; they are the start of waste generation and assimilation chains. So we could readily conceive of ***cities as the problem***: as "blots on the landscape"; or, to use another metaphor, as "bulls" charging about in the marvellous variety of vulnerable "china shops" that make up our natural environment.

On the other hand, we may choose to re-conceive of cities as the solution. Households, building clusters, and neighbourhoods may instead be conceptualised as nodes receiving flows of pre-consumption resources (from an upstream node) and duly passing on flows of post-consumption resources (to a downstream node), within a circle, not a broken chain. Indeed, better to say, households and cities may be re-thought of as "prosuming" systems. They produce goods, such as energy and feedstocks of water and fertilisers, and consume goods. As the flows of post-consumption resources pass onwards and outwards from the city, they may progressively be converted back to pre-consumption resources — given, that is, well-nourished and adequately supported ecosystem services in the environment. The unsympathetic knots of intense resource interactions can be unwound or rewound more sympathetically. The urban metabolism can be made altogether smarter. Those metaphorical bulls can be bestowed with deftness of movement and intelligence: to preserve, enhance, and service the displays of metaphorical china in the shops of nature. Cities are then imagined as net generators of ecosystem services; as positively performing nodes in the Circular Economy; and ones most mindful of promoting the same at every other resource-manipulating node in the circle.

This is a "re-thinking of the system": cities as not just the problem but also the solution. Moreover, this re-thinking has to do with visualising the very small and local (prosumption patterns in the intimate spaces of households) and at the same time visualising the global (every other node of metabolism in the circle, along with climate change and sustainability). It is thinking across scales, in size, in space, and in time of stability or instability, of city and regional economies, of infrastructures in the short term and resilience in their behaviour over the longer term, come what may. We may visualise systems in block-and-arrow diagrams to reveal the interactions, controls, feedback and feedforward loops among their parts. Cybernetics and operations research come to mind, along with computational models. The re-thinking is to think across boundaries: those that separate social communities, those that separate institutions and arms of government; those that separate the engineering and management of one piece of infrastructure (sewer network) from the next (wastewater treatment), those that separate finance from the real economy and both in turn from the environment, and finally those that separate the disciplines, economics from anthropology, engineering from ecology, and on and on. In short, all this re-thinking amounts to the systems approach. It is that continual defining and redefining of the problem, hence shaping, re-shaping, and adapting the solution. It is the kind of thinking that encompasses examination of the problem from all manner of points of view. And few things in life demand greater such holistic thinking than sustainability, with its triple bottom line, its economic policies for much more than mere efficiency, environmental policies for generating social and economic advances, and social policies that do good for the economy and the environment (OECD, 2011; Beck, 2011). If the re-thinking is to be about "busting silos" of policy formation or of thinking in a "joined-up" way, "outside the box", then let us not forget that those creating the walls of the silos and delimiting the boxes are indispensable to the systems approach (otherwise we should have no silos to bust nor boxes outside of which to think). The systems approach must thrive on that duality — in fact, plurality (no less) — in problem-framing and problem-solving.

IIASA's systems approach

IIASA's work on cities goes under the banner "Cities as Forces for Good in the Environment" (CFG), while the OECD's is framed in terms of the "Circular Economy" (CE). Both are focused on material flows – of food, water, energy, building materials, and greenhouse gases and so on – and therefore concern themselves with what is called *urban metabolism.* Apart from some small differences (which we will come to in a moment), our two teams are therefore remarkably closely aligned in their interests and aspirations. Thanks to this fortuitous convergence, we can move straight to the question: what, if anything, can applied systems analysis bring to this work? A great deal is our initial answer, but it does raise a second, and crucial, question: what *kind* of applied systems analysis?

Put simply, there is *hard* systems analysis (in which the analyst tries to get directly to grips with the system that is "out there") and there is *soft* systems analysis (which sets off by acknowledging that whatever it is that is "out there" is always mediated by "lenses", "perspectives", "Weltanschauungen", "social constructions", "myths of nature" and so on). As we shall explain, a consequence of this is that, while governance does not really come into the hard approach, it is absolutely central to the soft one and it is soft systems analysis that we need if we are to get to effective grips with the city. After all, even a cursory glance will reveal that, when citizens look at their city, they do not all see it in the same way. Some see rat-infested slums that need to be demolished and replaced with modern housing, others see a sadly neglected, but glorious, heritage that needs to be preserved and cherished. In much the same way, some are intent on creating the *smart city* (traffic-lights responding to real-time information on traffic flows, closed-circuit television cameras on every corner, self-driving cars summonsed by mobile 'phone apps and so on) while others yearn for the *liveable city* (walking or cycling everywhere, streets filled with children playing and neighbours gossiping, roof-top vegetable gardens, bees gathering nectar from the ivy-clad walls of office buildings and so on). Although we can have elements of each, we cannot have all of both!

Nonetheless, let not our use of the adjectives "hard" and "soft" suggest that soft systems analysis entails no hard (if non-quantitative) thinking nor any use of quantitative models. For it surely does, on both of these accounts. We are, however, circumspect in our use of the terms "circular economy" and "sustainability". For when all is said and done, *everything* goes in circles; it is just that human interventions often result in some of those circles being re-routed in ways that are socially undesirable and/or environmentally degrading. On top of that, there is the paradox that, as social actors, we are much exercised by those wastes while, as is often observed, there *is* no waste in nature. Nevertheless, waste is cultural: a categorisation that is imposed, and at times withdrawn, by processes that are entirely social: soft, that is, in conventional systems terms (Thompson and Beck 2017).

"Sustainability" too is a word to be used with due care and attention, not least because it is far from being a neutral and objective concept, especially when coupled with the word "development", i.e., as in "sustainable development". If you refer to our Figure 7.1 – the core of our soft systems argument – you will see that it really only makes sense in terms of the hierarchical school of engineering thought's "icon": developments that are within the pocket between the two peaks are sustainable; those that are outside those "boundaries" are unsustainable. This view of things is *not* shared by the upholders of the other three schools, and it is the constructive and argumentative engagement of all four schools that is needed if we are to find our way to *clumsy solutions*: the decisions that will get all those troublesome flows going in the right circles, thereby transforming our cities into forces for good in the environment.

With these cautions in place, then, let us look at our two approaches to the city and its metabolism.

The OECD team's prescriptions for achieving the circular economy

Cities, at present, are far from being forces for good in the environment. Indeed, they are estimated to be responsible for 50% of global waste (UNEP 2013) and up to 80% of greenhouse gas emissions (World Bank 2010). Agriculture makes up a further 30%, with the total coming in at 100%, not 110%, once we realise that roughly a fifth of the world's food is grown in cities (Harvey 2019). But some cities are much worse than others (Delhi's air pollution, for instance) while others are much better (London, for instance, is one of the world's most forested cities).

Figure 7.1 The four schools of engineering thought

Nature Capricious

A *fatalistic* school of engineering thought which requires that *learning is simply not possible* might seem rather improbable.

After all, anyone who was convinced that the world operates with neither rhyme nor reason — the ball on the flat surface — would surely have no incentive to become an engineer. However, a qualified and practising engineer could *become* fatalized and such people, it turns out, do exist. How else can we explain all those recurrent engineering failures — the Hattisunde Barrage among them — that are so liberally distributed across the Nepalese countryside?

Nature Perverse/Tolerant

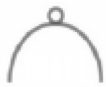
The *hierarchical* engineering voice is *pro-control* and is quick to point out that what is rational for the parts may be disastrous for the whole. Development, according to this school's icon, is sustainable only in the stable pocket between the two peaks. Hence the need for certified experts (IPCCs, Royal Societies, etc) to determine just where those peaks are located, along with statutory regulation to ensure that firms and individuals remain on the right side of them.

There is a marked bias towards complex, carefully planned, capital-intensive, centralized and *large-scale* solutions (with economies of scale being emphasised and diseconomies back-grounded).

Nature Benign

The *individualist* engineering voice is *pro-market*, calling for de-regulation, the freedom to innovate and take risks, and for the internalization of environmental costs so as to "get the prices right". Since nature is mean-reverting — a ball in a basin — there is no chance our actions will trigger catastrophic collapse. Exuberant trial-and-error, with the resulting technological solutions then being put in competition with one another, will ensure we quickly find our way along the best possible path. Since there are both economies and diseconomies of scale out there, the most profitable option (i.e. the one with the lowest "unit cost") is likely to be located somewhere between the extremes of "big is best" and "small is beautiful". Whoever comes closest to that *appropriate scale* will profit handsomely, and Adam Smith's "invisible hand" will then ensure that everyone else also benefits.

Nature Ephemeral



The *egalitarian* engineering voice tends to be *critical and strident*, often arguing for zero-growth and much concerned with "the poorest of the poor". With the least jolt, in its icon, likely to provoke catastrophic collapse, the overriding imperative is that we all "tread lightly on the earth". Our profligate consumption has to be brought down within the limits set by Mother Nature. Common-pool goods — such as those brushwood dams in Nepal — are what are needed, together with *small-scale*, decentralized and "empowering" technologies.

Note: The four "icons" are the social constructions of nature that support and justify each of these schools, while also serving to distance them from the others. More complete accounts of these four schools, in relation to the technologies of wastewater infrastructure and resource recovery, are set out in Beck et al (2018a) along with an explanation of how they are derived from the *theory of plural rationality.*

Source. Thompson et al 2018.

Cities are also part of the solution. Metropolitan areas accounted for half of the economic growth of the OECD countries between 2000 and 2010. While the countryside is not unproductive, cities that are the engines of these economies. Cities are also laboratories for innovation: from the "fintech" start-ups around London's "Silicon Roundabout" (the individualist school of engineering thought) to the greening of that same roundabout by "guerrilla gardeners" (the egalitarian school of engineering thought). And the increasing devolution of public services in OECD countries – in which local government becomes responsible for transport, solid waste, water, energy and so on (the hierarchical school) – further enhances this propensity towards experimentation, adaptation and change.

Material flows in cities are so dense, and so intricately interwoven, as to render "policy silos" increasingly unviable. Problems in the water sector, for instance, are often caused by decisions made in other sectors, while many of the solutions to that sector's problems are to be found in other sectors. In consequence, a "whole of government" approach capable of reaping all these synergistic benefits is more easily achieved than is the case at higher levels: national, regional or global. The urgent addressing of London's health problems, stemming from the nitrogen oxides and particulates emitted by fossil-fuelled vehicles, for instance, is massively accelerating the transition to renewables, thereby, if replicated across other cities, mitigating climate change much more effectively than has been the case with all those laboriously negotiated international agreements over the past 40 or so years.

In contrast to, say, the IPCC (Inter-governmental Panel on Climate Change) which, as its name makes clear, is restricted to just state actors, cities, of their very nature, are "ecosystems" in which local government actors are inevitably in interaction with market actors (e.g. those fintech start-ups) and with civil society actors (e.g. those guerrilla gardeners) and also with fatalist actors (for example the homeless "rough-sleepers" blocking the entrances to local council offices). With decisions being arrived at through governance, rather than through government, cities are well-placed to respond to the various desires of those who live and work in them. And, since there are lots of cities – all different and all going about their governance in differing ways – there is a sense in which cities are in competition for citizens (Frederick the Great's Berlin being, perhaps, the prime example).

With cities having these remarkable characteristics, it would be wrong to be pessimistic about the possibilities for them implementing the circular economy. And, of course, it is already happening, in differing ways and to different extents, in many cities: Amsterdam, for instance, with its profitable re-cycling of the construction chain and of its organic residuals, London with its food, textiles, electricals and plastics, Copenhagen with its rapid transition to carbon neutrality, Vienna with its "city mining", on and on.

The presence in these cities of "bazaars" – universities for learning and research, for instance, and Wall Streets and Cities of London for finance and investment – boosts the potential for circularity even further. Indeed, that potential, once it has been effectively harnessed through the afore-mentioned vibrant governance, is truly formidable.

How, then, does IIASA's approach address this whole question of the city and its material flows?

The IIASA team's prescriptions

This work dates from 2007: a little essay, at the request of the US Academy of Engineering, by Paul Crutzen (an atmospheric chemist), Bruce Beck (a control engineer) and Michael

Thompson (a social anthropologist). All three, at that time, were Institute Scholars, and our title was “Grand challenges for engineering. Turning cities into forces for good in the environment” (Crutzen et al 2007).

Our optimistic idea is to re-engineer city infrastructure to progressively reduce a city’s “ecological footprint” to the point where, eventually, it disappears completely and the city is “floating on air”. Hence, our idea of making ourselves “more good”, in contrast to framings such as the SDGs, or that framing in terms of “planetary boundaries” that claims to have defined a “safe operating space for humanity”, which are limited to making ourselves “less bad”.[10] Imagine we find ourselves faced with a watershed that is in a really bad way. What should we do? “Put a city in it”, is our answer!

What was asked of us, systems analysts, in our little essay, amounts to an expansive agenda of work, one stretching well into the future. That agenda is elaborated at length, and responded to in significant parts, in a companion Sustainability Concepts Paper (Beck 2011). We touch upon (therein) how a Multi-Sectoral Analysis (MSA) computational model has been developed and deployed to explore ways in which engineering problem-solving and technological innovations can lessen the “linearity”, hence increase the circularity, of the urban metabolism and economy. More specifically, MSA accounts for how energy, water, C-, N-, and P-bearing resource flows circulate around and amongst the energy, water, food, forestry, and waste sectors of the city. Thus far, it has been applied to case studies of Atlanta, USA, Suzhou, China, and London, UK (see, for example, Villarroel Walker et al 2017). The Concepts Paper also illustrates the interplay between governance and computational foresight models in a procedure of Adaptive Community Learning (Beck, 2011; pp 83-101).

Of course, for the suggestion of building a city to clean up a degraded agricultural watershed to be taken seriously, we will have to be able to point to a way of reaching decisions that is far superior to the time-honoured way, with its four *precepts of policy analysis*.

1. Ensure a single and agreed definition of the problem.
2. Clearly distinguish facts and values.
3. Set up a “single metric”, such as dollars or lives saved, so as to be able to compare and assess options.
4. Optimise around the best option.

Our candidate is the institution of a deliberative process that, starting by inserting the words “do not” in each of these precepts, enables the emergence of *clumsy solutions*: a process, that is, in which all the four schools of engineering thought in Figure 7.1 (each of which is intent on imposing its own *elegant solution*) are (a) able to make themselves heard and (b) are then responsive to, rather than dismissive of, the other three.

Unsurprisingly, much of our effort, in the years since 2007 (much of it archived at www.cfgnet.org) has been devoted to finding instances in which clumsy solutions have emerged and, more recently, to developing participatory processes in which clumsy solutions can be “discovered”, rather than just stumbled upon. Many of these, moreover, are concerned

[10] These framings are essentially hierarchical in nature; indeed, that safe operating space for humanity is nothing more than the rotation, through 180 degrees, of the hierarchical “icon” in our Fig. 6.

with cities and their infrastructures: an instance of a clumsy solution *by happy accident* is the siting, in the London Borough of Islington, of Arsenal Football Club's new stadium (Thompson and Beck 2015). And more recently, the re-engineering (by way of a 2-year participatory process) of the landslide mitigation measures for the southern Italian town of Nocere Inferiore has provided an instance of a clumsy solution *by design* (Linnerooth-Bayer et al 2015). Alongside these "proofs of concept" we would also mention the ambitious (major step in the "more good" direction, that is) proposals for taking human waste out of the water cycle completely while, in the process, transforming it into valuable resource (Beck et al 2018a).

Therefore, that is how the IIASA team is getting to grips with cities: an approach by way of systems analysis, certainly; but *soft* systems analysis: one that takes account of contending "social constructions of reality". Hence, the emphasis on *governance* in the true sense of the word: the constructive interplay at multiple levels (in this instance, the city level) of state, market, civil society and marginalised actors.

Addressing the wicked problems of cities

Cities, as our OECD policy documents acknowledge, are confronted by *wicked* problems. Each of those four archetypal actors is framing the challenge of achieving the Circular Economy and smarter urban metabolisms within its own favoured style of "box", which box is so very well suited to its own favoured, elegant style of problem-solving. But there are plural boxes, with the accompanying richness of the plurality of thinking outside those boxes, where each actor — in the ideal of elevating deliberative quality in policy formation, governance, and technological innovation (Thompson, 2008; Ney, 2009) — should heed the other's candidate prescription and be responsive to it. In short, achieving what we seek will be a matter of "wicked problems, uncomfortable knowledge, and clumsy solutions" (Thompson, 2019).

The changes we would like to catalyse through our systems approaches are radical, yet simply stated: to shift the flows of resources through cities (and the wider global economy) from a linear to a circular form; and to turn on its head the negative of the massive ecological footprint of the city. It may well call for vision and leadership, which may arise in novel guises, such as those so effective in regenerating the economy of North-east Ohio (Katz and Bradley 2013; pp XX-YY). If need be, we may start small and go big. We know the aphorism of "Think Globally; Act Locally". It has a complement (Beck, 2011; p xvii):

Engineers "Acting Most Locally" to engender a community eager to engage in "Thinking Globally"

Among other cross-disciplinary collaborations, we wish to pursue the following distinctive lines of thinking and practising applied systems analysis (as more fully elaborated in Beck et al 2018b).

Anthropology for engineers

Though we make much of governance, it is never just a matter of “better governance” (more systematic qualitative logic, as in that participatory process in Nocere Inferiore) instead of “better engineering and technology” (as in the various city models we have built of London, Atlanta and so on) or *vice versa*. Both have to be melded in a mutually supportive and stimulating manner: something that is not easily done but which, we argue, should be the USP (Unique Selling Point) of applied systems analysis (Beck et al 2011).

Cities not nations

Applied systems analysis, at present, can be overly focused on the global level (as in IIASA’s tag-line: “Science for Global Insight”). The result is that it “never reaches the ground”: it cannot say anything useful about the lower levels of the system: the system of the city, in particular, but also the household (every bit as systemic) which is where the changes in consumption behaviour can be implemented; the sorting out of waste so that it can be more easily re-cycled, for instance, or the adoption of USTs (Urine Separating Toilets).

Hard thinking about soft systems

Hard systems analysis, so dominant at the time of IIASA’s founding (in the 1970s), needs its complements too. Not only is it that cities may be more important units of analysis than nation states, but that qualitative evidence (narratives, storylines, case studies, “toad’s eye science” and so on) may be more believable than quantitative evidence (statistics, that is) in guiding the way we make decisions. “Fewer data, more anecdotes”, you might say (not unlike that slogan among patisserie-enthusiasts: “less sponge, more gunge”). The qualitative and the quantitative need to be both re-balanced and better combined. The skills of such argumentation and analysis are anything but easy to acquire “hard thinking” indeed!

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8. Systems-based approaches for development co-operation to meet diverse needs and aspirations in an interdependent world

By Ana Fernandes, Rahul Malthotra, Piero Fontolan (OECD), Frank Sperling and Mauricio Lopes (IIASA)

Introduction

In 2015, the international community laid out a collective vision for the future of humanity. Framed by the Sustainable Development Goals (SDGs), 17 globally applicable goals and 169 associated targets, this extraordinary and integrated agenda seeks to integrate economic, social and environmental dimensions of development to realise an inclusive and sustainable world by 2030 (UN, 2015).

International development co-operation will have a critical role to play to ensure that the universal ambition of the SDGs is indeed realised, and no one is left behind. Yet focusing on helping advance the economic prospects of individual countries is not enough in an increasingly interconnected but also fragmented world. The global agenda of the SDGs underscores this. With human activities now leading to global scale changes of the earth's life support system, it requires integrated and long-term solutions, which are mindful of interactions between human and natural systems, from local to global scales. It requires a rethink of how we approach and plan development co-operation, as the past can no longer serve as guidance for future progress.

Entangled natural and human systems

Humankind is on the verge of falling victim to its own success story. It took well into the mid-1800s for the world population to pass the mark of one billion. Today over 7 billion people share the planet with the most recent billion added in less than a decade. No longer bound by local environmental limits through innovation, technological progress and trade, economic productivity spread around the globe. Collectively we have never been as wealthy as today. Strong progress has been made over the recent decades towards ending extreme poverty, but partly due to increase in conflicts, we see also recent reversal in the advances made over towards universal food security. For the first time in over ten years, the number of people suffering from chronic hunger has been rising again, increasing from 777 million people in 2015 to 815 million people (11 per cent of the total world population) in 2016 (UN, 2018). There remain profound inequalities within and across many countries.

Along with the socioeconomic progress, human activities are now not only reshaping the local environment, but in their collective impact are exerting a dominant influence on global scale processes of the earth system (Crutzen, 2002). Climate change, biodiversity loss, land degradation, air and water pollution, and plastic waste are signalling environmental decline that is happening across scales, undermining the very life support systems we depend on.

This signifies a profound departure from the understanding of our relationship with the environment. For much of human history, nature was vast, its resources abundant and humankind's impact marginal. This is no longer the case. As we are affecting the earth's life support system and in return will be affected by the changes, we must shift to a holistic view that recognises the entanglement of the human and natural systems. Human development ambitions need to be cognisant of their impact across scales.

Evolving perspectives on Sustainable Development

The concern about the scale and consequences of our impact on the environment is not new nor is the demand for changing human behaviour. Particularly since the report of the World Commission on Economy and Sustainable Development (WCED, 1987), also known as the Brundtland report, called for "development that meets the needs of the present without compromising the ability of future generations to meet their own needs", sustainability considerations entered the mainstream of international and national policy discourse. Yet despite growing awareness, attention and promising initiatives, there was no transformative shift towards sustainability. As Ehrlich and others observed, "humanity has never been moving faster and further from sustainability than now" (Ehrlich et al. 2012).

Part of the challenge lies in the amorphous concept of sustainable development itself (Ekins, 1993, Gomez-Baggethun and Naredo, 2015). There are diverging options of what sustainable development really means, the role economic growth plays within this framework, i.e. whether it is a necessity or whether it impedes such a transformation. This is also reflected in the general interpretations on the extent to which natural capital is substitutable by human made capital, i.e. the contrasting concepts of weak and strong sustainability (e.g. Neumayer, 2003). Schools of thought following the weak sustainability concept hold that natural resources are abundant or resource constraints can be overcome through technical progress. Hence, sustainability is given if other forms of natural capital replace the depleted natural capital. A view that garnered considerable traction in mainstream economics. By contrast strong sustainability concepts of ecological economics place limits on the substitutability of natural capital, i.e. renewable resources should not be depleted more rapidly than they can regenerate, while the use of non-renewables should be coupled with the development of alternatives prior to their depletion. The amount of pollution and waste must match absorptive capacity of the environment.

The great acceleration of socioeconomic development and the accompanying resource use during 20th and early 21st century (Steffen et al. 2015) and also the growing concern among scientists that human induced environmental changes are crossing global scale limits beyond which human existence and development may be threatened (Rockström et al. 2009), call our current measures of performance and progress into question. There is agreement that change in human behaviour, institutions and economic systems are needed. Yet there remains discord how much change is necessary or feasible.

The emergence of green growth and green economy as concepts sought to reignite the drive towards sustainable development prior to 20-year anniversary of the Rio Earth Summit. Green growth spearheaded by the OECD (2011) and the World Bank (2012) placed the spotlight on the role and quality of growth in promoting sustainable development. Other multilateral organisations adopted the concept to regional development contexts (e.g. AfDB 2012, 2013, ESCAP et al, 2012). The complementary concept of the green economy put forth by UNEP (2011) in collaboration with other UN system aimed to define and visualise an economy that achieves a balance between meeting human needs and welfare, while sustaining natural resources and processes.

There is a push to revise and update measures of economic performance. For example, there are growing efforts to assess the performance of countries in building and developing capital stocks, complementing the prevalent focus on growth as an economic performance metric. Aside from human and produced capital and financial assets, focus is increasingly being place on better assessing the state of natural capital in the context of tracking the overall wealth of nations (Lange et al. 2018). Developing such comprehensive wealth estimates can help promote more sustainable development policies and practices, but some natural capital is critical and (precautionary) limits to substitutability with other forms of capital should be considered (Cohen et al. 2018).

Consequently, the view of what constitutes development progress has grown more complex. The push for integrating the economic, social and environmental dimensions, as called for in the Brundtland report, is growing. Development means delivering on multiple objectives and requires recognising the ambition of and working across sectors. In this context, the SDGs provide the goal posts, helping to define our collective aspirations and by including environmental targets, provide also first guidance on how much natural capital should we aim to protect to ensure sustainability.

Guiding action: Comprehensive targets for sustainable development

The collective aim and ambition of the international community was laid out in the *2030 Agenda for Sustainable Development*, which was adopted by the UN General Assembly (UN, 2015) and specified through the SDGs. The SDGs build on the successes and lessons learned from the Millennium Development Goals (MDGs). They continue an emphasis on ensuring that basic human needs are met but go also beyond the scope of the MDGs. In contrast to exclusive focus of the MDGs on developing countries, the SDGs are formulated as global goals. The SDGs aim to universally advance and ensure human welfare, while emphasising also stewardship of the terrestrial, marine and climate systems. In addition, the SDGs are informed by or link to key environmental agreements, such as the Achi targets and the Paris Agreement.

Encompassing 17 global goals and 169 associated targets, the potential for trade-offs but also synergies between various economic, social and environmental objectives has been recognised (e.g. ICSU, 2017). The 2030 Agenda asks for the SDGs to be considered indivisible. No goal should be given preference; instead the SDGs should be addressed as a collective (UN, 2015).

However, at the starting point of the implementation process, it is clear that this is not the case. Countries that tend to score high concerning economic or social goals, perform lower with regards to environmental goals and vice versa. No country scores equally well across all goals (Sachs et al. 2018).

The need for comprehensive approaches to the SDGs is further underlined by the fact that these global goals need to be realized by collective actions in a more interdependent and complex world, which seems to be in a semi-permanent state of disruption (TWI2050, 2018). Changes in one part of the world may have ramifications in another. Countries may be confronted with multiple social, economic and environmental changes at the same time. Hence, this worldview of complexity and inter-dependence needs to be embraced in development cooperation.

The Implementation Challenge

Science has been very successful in describing complex and global environmental problems, such as climate change. Climate change in particular illustrates the need to work across thematic and disciplinary boundaries. To assess the consequences of increasing greenhouse gas concentrations and their impact on the climate and the environment, the climate system needs to be understood in its interplay with marine and terrestrial systems, including numerous and positive feedback loops across different spatial and temporal scales. Mitigating and adapting to climate change cuts across economic sectors and raises social questions about equity within and across societies and generations and it is hence directly linked to considerations for sustainable development (IPCC, 2014). Furthermore, strategic decisions addressing climate change have also implications for other environmental issues, such as efforts aimed at stopping biodiversity loss and reversing environmental degradation.

The challenge now lies in linking the understanding of biophysical systems with an understanding of human systems, moving from the scientific assessment of the scale of the problem to the analysis of the options for solutions. The complexities of these systems means that solutions to these problems may be associated with uncertainties, diverse benefits and trade-offs. Without understanding the embedded trade-offs and risks, how they can best be managed and synergies effectively harnessed, it remains difficult to mobilise the necessary political will and societal support.

Despite the scientific facts and general awareness, the global transformations towards sustainability have not happened, if we look at trends concerning major environmental issues. The atmospheric greenhouse gas concentration has reached new record levels (WMO, 2018), while a rapid decarbonisation of the energy system and net zero emissions towards middle of the century are required to have a chance of meeting the objectives of the Paris Agreement (Rogelj et al. 2014). There is also scientific agreement that current land-use changes in conjunction with other environmental pressures are driving biodiversity loss. From 1910 to 2005 the appropriation of net primary productivity through human activities has roughly doubled, reaching now around a quarter of net primary production of potential vegetation (Haberl et al. 2014). Because of human pressure on the environment, species are going extinct at rates that exceed the natural background extinction rates by several orders of magnitude.

To solve these problems while further advancing human welfare, solutions are required that do not take singular perspectives, but instead relate to and account for diverse development needs and ambitions. Yet to a large extent, our academic, institutional structures, strategies and policies, and operational practices encourage silo-based approaches. In the sphere of national public policy making, the business delivery model has not kept pace with the increasing complexity and inter-dependence of our world (Oatley et al. 2019). The business model for development co-operation is often predicated on short-term, measurable outputs and not in relevant outcomes. This inevitably works against taking a more holistic view of development cooperation and shapes how diagnostic, measurement and decision-making tools are established (OECD, 2018a). Even the international bodies emerging from the Earth Summit, such as the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the UN Convention on Combating Desertification (UNCCD) reflect this fragmented approach of thinking, where major global environmental challenges are tackled separate from and complementary to major mainstream economic questions.

A compounding trend is that more of the programming decisions are being made in donor headquarters, with declining trends in country programmable aid and declining use of local actors as partners (OECD, 2018a). The growing number and also diversity of financial actors has made the landscape of financing for sustainable development more complex, leaving the international community unsure how those financial flows interact, support or undermine each other. Further clarity is also needed how the economies of scale can be harnessed through the multilateral system and how this can be utilized for investments in global public goods as well as national development processes (OECD, 2018b).

The obvious conclusion is that national and international policy environment for development cooperation needs to embrace reform in order to contribute effectively towards a more sustainable world (Yan and Yifu, 2018). Policy coherence for development (PCB) is focused on avoiding or minimizing negative spill-over effects of various policies on developing prospects of developing countries. For example, this may entail avoiding situations in which Official Development Assistance (ODA) supports agricultural development of a recipient country, while tariffs and subsidized agricultural production in in the donor country simultaneously undermine that country's export opportunities. Further expanding this focus on policy coherence for sustainable development (PCSD) takes this a step further, moving beyond a "do-no-harm" approach towards a partnership approach based on "win-win" solutions, thereby helping to foster synergies between economic, social and environmental policies (OECD, 2016).

Political will is fundamental to advance change. One aspect is to rethink how development cooperation between countries can be approached includes rethinking the relationship between donors, recipients and other stakeholders. This is illustrated by an example on triangular co-operation (Box 1). Another aspect includes rethinking how an integrative policy environment can be underpinned by strong analytics, so that the dynamics and interdependencies can be better captured and inform development cooperation. Da Silva et al (2017) argue that development cooperation should embrace complexity, thinking of "the economy as being composed of a rich set of interactions between large numbers of adaptive agents, all of which are co-evolving".

Box 1: Triangular cooperation between Morocco, Costa Rica and Germany for Sustainable Development

Triangular cooperation is an example where different partners that bring different resources and expertise are engaged to scale up impact and innovation for better development results (OECD 2019). The beneficiary partner usually solicits support to tackle a specific development challenge, while the pivotal partner provides expertise and other resources, and the facilitator helps connect all partners, supporting the collaboration financially and technically. In this example of a triangular co-operation project between Costa Rica, Morocco and Germany the complementary strengths of the country partners were used when formulating three objectives for the project: an overall objective and two separate objectives for Costa Rica and Morocco. In the project Improving the Management and Sustainable Use of Forests, Protected Areas and Watersheds (2013-2016), Morocco and Costa Rica, with support from Germany, implemented a number of pilot projects that aimed to improve watershed management, to prevent forest fires and to protect biodiversity.

Both recipient countries provided knowledge and received inputs from the other partners on managing forests and protected areas in a sustainable manner – an area where for example many Costa Rican state institutions and non-governmental organisations have vast experience and knowledge. Germany brought its knowledge in the management of processes and gave methodological and organisational impetus to the project. The project components involved representatives of governments, other state authorities, NGOs and the private sector in order to identify best practices and apply and institutionalize the lessons learned. Costa Rica implemented two pilot projects to improve watershed management, based on the Moroccan experience. Morocco implemented two projects in national parks and adopted Costa Rica's system of payment for environmental services to design a financing system and a collaboration association to tackle forest issues. Germany, on the other hand, provided knowledge of bilateral co-operation in the management process and offered organisational and methodological impulses. All partners contributed financially in equal measure.

Source: Case story shared by the Ministry of National Planning and Political Economy (MIDEPLAN) of Costa Rica and by Germany.

Identifying and Managing Trade-offs: The case for systems analysis

An understanding of the solution space for sustainable development pathways is required, which considers the interplay between diverse objectives at global, regional, national and subnational scales. Long-term perspectives need to iteratively inform and respond to near term planning processes and investment processes. In short, there is a need for integrated and strategic planning processes across spatial and temporal scales that overcome the currently fragmented decision-making landscape.

Scientists have set out to provide guardrails that can guide human action at the global scale. These are scientifically informed value judgements. Rockström et al (2009) have proposed planetary boundaries. The focus here is on sustaining biophysical conditions that are supportive to human life. Raworth (2017) has related the planetary boundary concept to necessary socioeconomic targets. The SDGs further describe goals and targets related to the social, economic and environmental dimensions of sustainable development. These can serve as ingredients for visualising desirable futures.

With its emphasis on finding robust and adaptive solutions to given problems, systems analysis pays special attention to the interactions among multiple dynamic systems and the risks and uncertainties faced by policymakers. Essentially, systems analysis is a process that aims to understand complex, multi-layered problems. It is about "solution science" that can serve as an analytical tool to decision-makers on how to reconcile multiple objectives, which relate to the social, economic and environmental dimensions of sustainable development.

The strength of system analysis lies in its ability to provide an integrative and systemic perspective to complex problems, in understanding how they interact, how threats and risks can multiply, where feedbacks might exist making it possible to anticipate surprises or tipping points. Also, systems analysis provides a pathway to effective translation of research into impacts, by developing new tools and instruments to bridge sectors and actors, as well as temporal, social, and spatial scales from global to regional, national and sub-national, thus facilitating the task of policy and decision makers to address global and national challenges.

Framing the global sustainable development pathways

Faced with the challenge to identify smart pathways to meet our collective needs while respecting planetary boundaries and the growing interdependencies between nations and economies, it also becomes clear how valuable a systems approach can be in charting a course toward a sustainable future for all. At the global level, systems analysis can be employed to assess the degree of transformation of social and economic systems that is required to realise such future. IIASA has been at the forefront of such scenario driven analysis to determine the implications of different development trajectories for meeting energy, climate, food security and environmental objectives.

The World in 2050 (TWI2050) initiative, for example, has been launched to further consolidate our understanding of the level of transformation that is globally required to collectively meet the SDGs and sustain progress thereafter. To do so, TWI2050 has conducted a first review of transformations related to six themes, which are considered to encompass major dynamics and drivers of development. These include: (i) human capacity and demography, (ii) consumption and production, (iii) decarbonisation and energy, (iv) food, biosphere and water, (v) smart cities, and (vi) digital revolution (TWI2050, 2018).

While science can provide important guidance, transformations cannot be designed and imposed from the top down. Broad public support and buy-in are also needed for each transformation, and their implementation must draw on a broad range of communities and sectors (Sachs et. al. 2019). The scientific community should take on the challenge of developing tools and methods for multi-stakeholder engagement and co-design that help identify perceived trade-offs, ensure technical feasibility of long-term pathways and explain the urgency to act. Owing to the large number of stakeholders involved and the distribution of responsibilities between national and local levels it is a must to define integrated strategies and ensure participatory design and implementation of transformations at the national and subnational levels.

Embedding local solutions in global sustainability contexts

Having a global perspective on sustainability is a necessity. But it is alone insufficient for implementation. Implementation predominantly happens at the national and subnational levels.

The need for collaboration to address global sustainability challenges runs counter to current political trends, which emphasise national level priorities over international collaboration. Therefore, policy and economic solutions may be advocated to address the needs of an individual country, which may ultimately prove detrimental by ignoring the international implications of those measures and their longer-term consequences.

It is therefore critical that a dialogue between national and global level concerns is established and through this dialogue, development pathways are being evaluated. The challenge lies in capturing the heterogeneous conditions that drive local or national decision-making processes and relating these to global level concerns, such as climate change, and collective ambitions, such as the SDGs.

The Food Agriculture Biodiversity Land and Energy (FABLE) Consortium, which brings together knowledge institutions from developing and developed countries, for example recognises the absence of long-term integrated planning capacities in the land-use space. The aim of FABLE is to strengthen model-aided, integrated analyses to support decision-making processes in advancing the transition to sustainable food and land-use systems. Co-chaired by IIASA and SDSN, FABLE works with country teams in developing national development pathways in the land-use space and assessing their compatibility with global sustainability concerns (FABLE, 2019).

With the need to integrate global and local level concerns to advance sustainable development capacities, it is important to advance the capacity of countries to carry out context specific, multi-layered analyses. Global analyses can provide a general framework, but it is in dialogue with national and subnational context, where integrated analysis become relevant for guiding programmatic and project level initiatives. In Brazil, efforts are underway to build the infrastructure for integrating spatial information at levels most meaningful for operational decisions (Amann et.al. 2018).

The concept of *Strategic Territorial Intelligence* (STI), which currently being implemented by the Brazilian Agricultural Research Organization, Embrapa, and is further explained in Box 2 seeks to combine various geospatial methods of analysis to link information from environmental, agrarian, agricultural, infrastructure and socioeconomic frameworks of the rural area, capturing interactions and also developing and disseminating methods, protocols and generic instruments and practices for territorial information access, organization and analysis, not only by highly specialised experts but also by territorial actors themselves

(Embrapa, 2019). Opportunities to further link local and regional realities with global modelling efforts should be considered. This will help to accommodate different context and scale specific functions in support of decision-making processes on sustainable development pathways.

Box 2: The concept of strategic territorial intelligence (STI)

Strategic Territorial Intelligence (STI) is a concept that employs multidisciplinary knowledge on territories, looking at their configurations, strengths and dynamics to generate information to empower research organisations, policy and decision makers and communities in the promotion of relations, interactions and synergies conducive to sustainable development. STI considers that cities, forests, rivers, farms and infrastructures such as roads, railroads, ports, energy networks, etc. are components of the geographic space in constant interaction at different levels and scales and in diverse functional arrangements. Therefore, these components should be understood and considered in a more systemic, integrated way - as analogs of components of the metabolism in living organisms.

One of the major tasks of STI is the access, organisation and integrated analysis of territorial information on natural, agrarian, agricultural, infrastructural, logistical, social and economic dimensions, and at various temporal and spatial scales. Also, it aims the development and dissemination of methods, protocols and generic instruments and practices for territorial information access, organisation and analysis, which can be used not only by highly specialised experts but also by territorial actors themselves. STI could also become a powerful tool of communication, allowing the development of narratives to increase public awareness of the dimensions and complexity of development - beyond the economic use of resources - but also covering aspects such as landscape, culture, traditions and many peculiarities and values that can be found or developed from a functional territory. Considered in larger scales or even at country scale, STI can become a powerful tool to clarify the multiplicity of functional spaces (territories) in a certain geography and the heterogeneous needs that must be taken into account in order to build good, ethical governance and sustainable development in such spaces. In summary, STI can be seen as a way to bring geographic and functional reasoning to planning and to promote governance improvement at regional and national levels.

Systems analysis could become key to bring STI to reality, considering its power to explore the main interlinkages among systems operating in territories, with their broad range of possibilities, impacts, risks and uncertainties. System analysis at the territorial level could also help indicate scientific research, models, databases and applied analytical tools useful for the solution of major problems and challenges in current or potentially functional geographic spaces. Integrated assessment, as a form of systems analysis, would help also emphasise systems interlinkages and comprehensive impact assessment of options available.

Concluding Remarks

Development is confronted with simultaneously addressing national level development ambitions while responding to global scale changes and concerns. Living in the “age of complexity”, this is a daunting undertaking. It requires the bridging of sectoral interests and recognition of interactions that may play out across different spatial and temporal scales. It requires maintaining a long-term focus on national and global objectives while maintaining the capacity to adapt and react to rapid change.

System analysis offers development co-operation an analytical framework for assessing interactions between multiple objectives. This includes insights into transformations at the global scale to attain development pathways that are in line with the ambitions of the SDGs and planetary boundaries. Embedded in this, there is the need to build the capacity for national development pathways, which allow countries to evaluate the economic and ecologic implications of strategic choices in an integrated manner.

The diagnostic support provided by systems analysis should be seen in the context of a broader push within development co-operation to visualise sustainable futures and provide a roadmap towards these futures. It requires a focus on developing narratives that guide the strategic planning and implementation processes. This has to be understood as an iterative effort where short-term investments are placed in the context of long-term strategic ambitions of countries as well as global level sustainability concerns, such as the Paris Agreement. To be effective, an emphasis on systems-based approaches needs to be matched by the appropriate enabling framework, which allows for the diagnostics to feed into integrated planning and cross-sectoral implementation efforts, overcoming the institutional fragmentation and barriers that still predominates today. It also needs to be matched with appropriate communication and outreach strategies, so that awareness and understanding of and ownership for socioeconomic transformations towards sustainable development pathways is generated, bringing to live a collective vision for sustainable future for all.

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Social and Economic Change

9. The potential of integrated education and population policies

By Tracey Burns (OECD), Wolfgang Lutz, Anne Goujon and KC Samir (IIASA)

Introduction

Education and demographic changes such as population ageing are typically treated as separate issues by different ministries and fields of research. Education research and policies mostly deal with the teaching and learning process and the systems and institutions that support them, while ageing research and policies often focus on health-related issues, such as old-age disability, and public expenditures, such as the costs of pension systems. Yet while these might seem like diverse topics, the notion of life cycle already implies that the young of today will be the elderly of the future. The skills, world views or other characteristics that children acquire will be basis for their skills and world views as they age. Better educated young cohorts will also be better educated throughout the lifespan, bringing with them important capabilities, including stronger health literacy. Linking education and ageing using multi-dimensional demographic models allows for a better understanding of the slow but certain changes in the educational composition of populations. Doing so reveals that education empowers people to be more productive, healthier and likely work longer, and we know for sure that the elderly of the future will be better educated than the elderly of today.

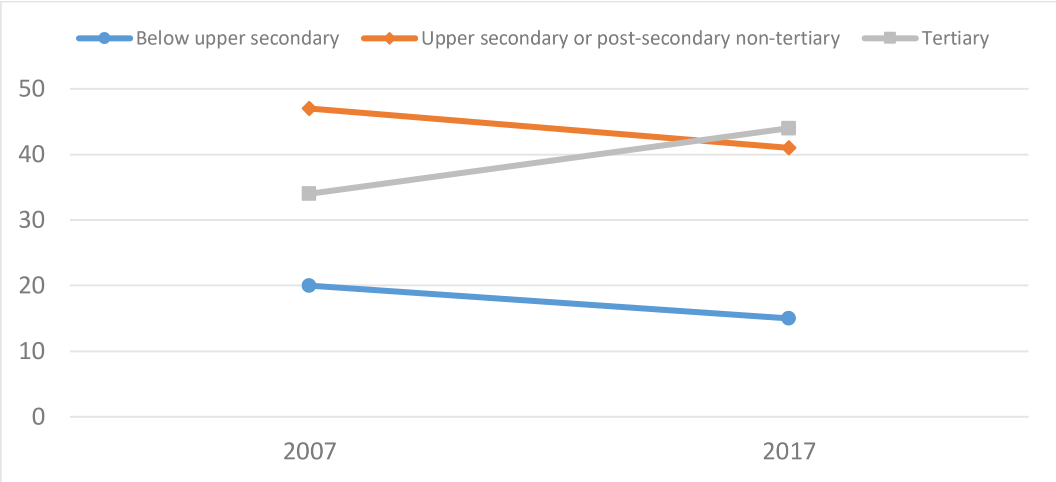
Trends in education and ageing

Populations in developing countries are ageing, with fewer young people due to decreasing birth rates and more adults living to old age. Improvements in our health and lifestyles have led to a substantial growth in life expectancy across OECD countries in recent decades. Importantly, these gains have been mostly in good health, setting the stage for an active retirement. Although the average retirement age in OECD countries has remained relatively stable since 1970, greater life expectancy has increased the amount of time in retirement, from an average of 13 years (for women and men) in 1970 to 20 years in 2015 (OECD, 2019).

At the same time, the level of education of the population has been increasing. In most OECD countries, the large majority of younger adults (age 25-34) had at least an upper secondary qualification in 2017. The proportion of 25-34 year olds with tertiary education also increased, from 34% in 2007 to 44% in 2017 on average across the OECD. In just a few decades, upper secondary schooling has been transformed from a vehicle for upward social mobility into a minimum requirement for life in modern society (OECD, 2018a).

Figure 9.1 Trends in educational attainment, 2007-2017

Percentage of 25-34 year-olds with a given level of education as the highest level attained.



Note: In most countries, there is a break in the time series as data for 2017 refer to ISCED 2011 while data for 2007 refer to ISCED-97.

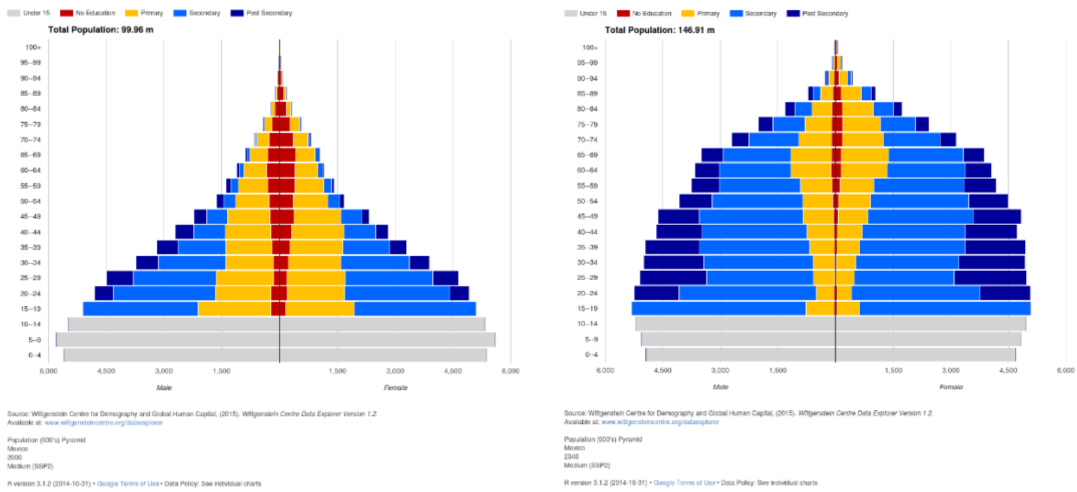
Source: OECD (2018), Education at a Glance, Table A.1.2

Analysis of education/ageing nexus

Education is typically acquired at young age and after a certain age your (formal) educational attainment does not change any more over the rest of the life cycle. A doctorate, once attained stays with you until death. But education does not only give us a degree, it also changes the structure and functioning of our brains in important ways that will stay with us for the rest of our lives. There is abundant scientific evidence that education has a robust effect on executive functioning and cognitive abilities (Lutz, Crespo Cuaresma, and Sanderson 2008; Butz, Lutz, and Sendzimir 2014; Lutz, Muttarak, and Striessnig 2014). Neuroimaging studies have demonstrated strong associations between adaptive changes in the brain and learning experience in classrooms. Abstract cognitive skills such as categorisation and logical deduction start to be acquired during early childhood and are further strengthened through schooling (Bruine de Bruin, Parker, and Fischhoff 2007; Peters et al. 2006). There is no doubt that formal education can significantly improve knowledge, planning horizons and understanding complex information that is key for health-related behaviour, economic productivity and the general capacity to adapt to new situations. These capacities, once acquired, tend to be maintained throughout life and may only decline if mental disability increases in old age.

Given this clear association between the level of education acquired early in life and the associated greater mental capabilities in later life combined with the fact that the future elderly will be more educated than todays elderly provides a rather positive outlook in the context of population. As indicated above, in virtually all countries the young cohorts today are better educated than the older ones. And we can forecast the future educational attainment for different age groups with near certainty for decades into the future. If we know how many women at age 20 in 2000 had completed secondary education, we know how many 60 year old women in 2040 will have secondary education (with only minor uncertainties due to migration and mortality). Figure 2 illustrates this for the case of Mexico, where the education-age pyramid for 2040 shows a much older population but also a much better educated older population than in 2000. Given all the positive effects of education ranging from better health to higher labour force participation to higher productivity, this has significant implications.

Figure 9.2 Education-age pyramids for Mexico, 2000 and 2040



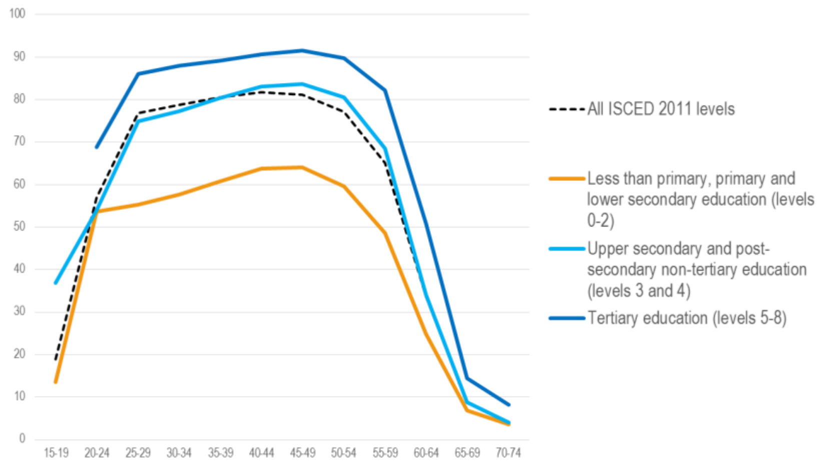
Source: WIC (2015)

Link to labour force and productivity

Education also greatly matters for labour force participation. Empirical data show that in virtually every country, less educated adults have lower participation rates and tend to retire earlier. This pattern is particularly pronounced for women and in the Southern European countries. Figure 1.3 shows the female labour force participation rates for all EU-28 member states combined around 2015.

Simulations show that when keeping this pattern constant, the fact that younger cohorts of women are better educated and therefore will have higher participation rates in the future will result in markedly higher overall labour force participation in the future (Loichinger, 2015). If it is assumed that by 2030 all Europeans will have those age- and gender-specific participation rates that are observed in Sweden today, then the overall size of the labour force in Europe would not even decline by the middle of the century, despite of the strong baby boom cohorts reaching retirement age. Hence, under this scenario even without additional migration into Europe the labour force dependency rate could stay at the same level as it is today. Since there is a huge body of literature demonstrating the positive effects of education on productivity and wages there is reason to assume that in addition to higher labour force participation due to the better education of young cohorts those better educated workers will also be more productive (CEPAM 2019).

Figure 9.3 Female labour force participation rates by level of education in the EU-28



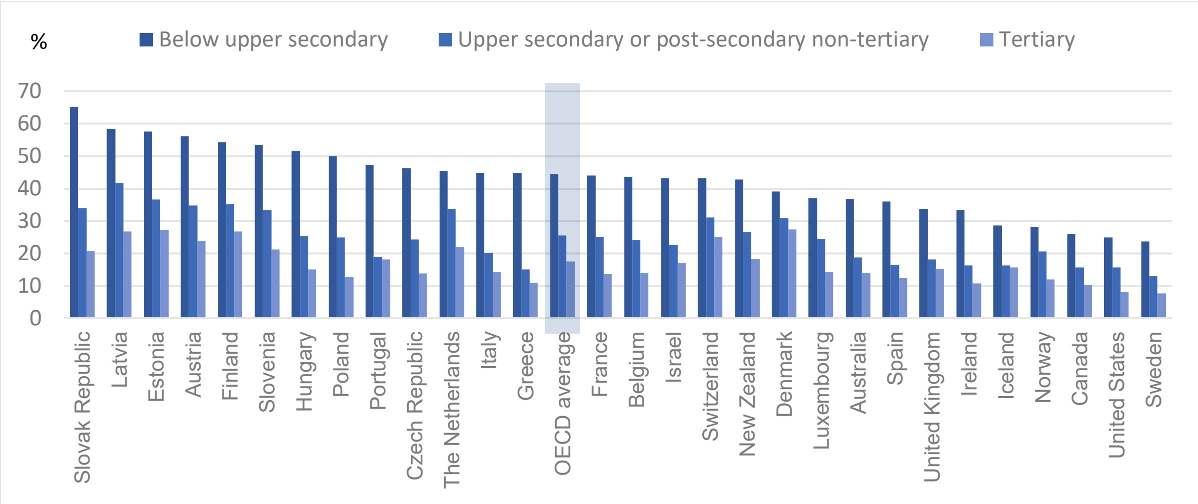
Source:

Link to health

Education can also protect health. Better-educated individuals have better health later in life and stronger labour market prospects. Education can help reduce risk-taking behaviour by developing knowledge, capacity to process information, and social and emotional skills (Ashton, 2018; Moreira, 2018; Conti, Heckman and Urzua, 2010).

As shown in Figure 1.4, activity limitations in adult life due to health problems are more common among those with lower levels of education. On average across OECD countries, 44% of those with an education attainment level below upper secondary education report some activity limitation, while this figure is reduced to 26% for individuals with upper secondary or post-secondary non-tertiary education, and 18% for those with tertiary education.

Figure 9.4 Percentage of adults (25 years+) with activity limitation due to poor health, by educational attainment, 2014



Note: Switzerland: Year of reference 2013.

Source: Table A8.2a in OECD (2016), Education at a Glance 2016: OECD Indicators, https://doi.org/10.1787/eag-2016-en.

The importance of health literacy

Health literacy is made up of a combination of cognitive, social and critical analysis skills. Individuals with low health literacy tend to have lower income, rate their health as poor, are more likely to have a high body mass index, and are less likely to exercise regularly (Ashton, 2018). There is, thus, increasing pressure to improve health literacy in OECD countries. However, this is easier said than done: health needs change over the life course, not only due to changes from ageing but also because the health system itself is continuously evolving. Hence, a large and growing group of those in need of health literacy development are adults, particularly older adults (Connolly & Crosby, 2014).

The combination of the facts that the future elderly will be better educated than todays, and that better education leads to better health and lower disability at any given age results in the more optimistic forecast that despite of an increasing number of elderly the future number of people with disability is not expected to increase as strongly as merely age-based projections suggest. It has also been shown that in some countries this education effect on health can even fully compensate for the ageing effect on future disability prevalence (KC & Lentzner, 2010).

What does this mean for education research and policy?

Given the importance of education in improving healthier behaviours and preferences, as well as effects on income, opportunities and self-confidence, it comes as no surprise that improving the quality of and access to education is a top policy priority for OECD countries. Investing in children, from high-quality early childhood education and care to primary and secondary education, leads to strong personal, social and economic returns (OECD, 2017).

Our ageing populations have also increasingly placed the spotlight on the education of adults. Governments across the OECD have been promoting a lifelong learning culture through policies aimed at improving work-based skills development, vocational training and adult education. This effort is needed: results from the Survey of Adult Skills demonstrate that proficiency reaches a peak at around 30 years of age and then declines steadily, with the oldest age groups displaying lower levels of proficiency than the youngest age groups, with variations by field of activity.

An example of how lifelong learning can be promoted comes from Japan, a rapidly ageing society with the highest life expectancy at birth among the OECD countries. In 2006, the government amended its Basic Act on Education to integrate the concept of lifelong learning, ensuring support for its municipalities with funding and guidance. Lifelong learning councils were established at the prefecture level and by 2012, 18 metropolises and 996 municipalities had action plans in place to promote lifelong learning. Japan’s education ministry is maintaining the programme’s momentum by providing information on good practices, and at the local level, some municipality leaders have formed an alliance for information-exchange and policy research. Despite this, making this work in practice and across workplaces is a real challenge: a recent review found that Japan’s system of lifelong learning is less well developed than in many other OECD countries (OECD, 2018b).

Success of education programmes designed for an ageing society will greatly depend on how well the teaching methods and curriculum adapt to the needs of mature workers. This could include, for example, programmes with short, modular courses that build on students’ previous learning and experience or online education (OECD, 2006). Another example of this are education programmes that help seasoned professionals at the end of their careers develop new skills as “knowledge brokers” to allow them to transmit their valuable experience and skill sets to younger generations of workers (OECD, 2014).

In addition to this immediate need of a stronger focus on learning programs for mature workers, there is also need to continue enhancing early childhood cognitive development and quality of schooling at all levels. Poor quality initial education has a significantly negative effect on long-term prospects for lifelong learning and healthy ageing. Studies have shown that the utilisation and effects of lifelong learning programs depends on the level of education received at young age. Hence the earlier and the better the process of learning how to learn starts, the more successful learning throughout life will be (Ref. Leopoldina Ageing Statement).Because the human life cycle in OECD countries is already round 80 years, investments today in effective learning in children and youth will have significant positive effects over the rest of this century.

This short piece has argued that, by connecting education with the process of demographic renewal and inter-cohort changes in society, we can generate new and important knowledge that will help guide both research and policy. While this is relevant for virtually all countries and different aspects of development, here we chose to focus on the challenges associated with ageing in OECD countries. The results suggest that the strong emphasis currently placed on early childhood cognitive development is key, as it establishes the basis for future learning over the rest of an increasingly extensive life cycle. Because cognitively more empowered individuals are not only more productive but also tend to have better health and stronger social networks, access to and participation in formal and informal education throughout the lifespan will keep our populations healthier, more physically and cognitively active, and more connected to society.

In this context, systems approach is a valid tool to analyse education within the continuum of the life cycle to understand the interrelationships with other components such as the health and labour force participation of individuals, to identify alternative strategies and foresee their impact. IIASA's multistate population and education modeling can inform the OECD's strategic and policy oriented mission to create better policies for better lives. This will be of tremendous importance in in poorer countries where the education, particularly of girls and women is a key instrument to reduce poverty and improve gender equality.

Key points and conclusions:

- The multiple benefits of education extend to the well-being of the elderly in terms of cognitive skills, health and disability.
- Education fosters labour force participation and increases age at retirement.
- Because levels of education have been increasing across generations, OECD countries might have a more positive future in terms of ageing than expected.
- In order to promote healthy aging, key strategies related to educational development are needed over the life cycle, from early childhood to adult learning

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10. Long-term strategies for employment and well-being in the digital age

By Herwig Immervol, Duncan MacDonald (OECD), Elena Rovenskaya and Leena Ilmola (IIASA)

Systems analysis facilitates policy responses to complex labour-market changes, including from digitalisation and technological progress.

A rise in alternative work arrangements has accompanied the digitalisation of work processes. Less stable, non-standard forms of work create new demands on social protection, which existing policy configurations may not be ready to meet. As social protection provisions were frequently designed around traditional full-time employee-employer work relationships, non-standard workers may not have access the support that they would need in order to succeed in a dynamic labour market. Moreover, a greater availability of non-standard employment contracts can create strong incentives for workers or employers to reduce costs by opting out of social support provisions. These opt-out opportunities can undermine the foundations of risk sharing and lead to a declining reach of social protection, and rising costs for remaining participants.

Responding to this emerging challenge requires considering both the direct and indirect effects of digital transformations on labour markets, including linkages between non-standard work, social protection systems, and technological progress. For example, digitalization promotes the further adoption of technology. However, it also facilitates alternative work arrangements with lower labour costs, which, in turn, may discourage further technology adoption in some sectors.

Qualitative system mapping can provide the holistic perspective that is needed for understanding the resulting policy challenges. It enables a systematic exploration of connections between elements of a complex system. From this, policy makers can obtain a broad view of the drivers of policy outcomes.

Agent-based modelling (ABM) can complement a systems mapping approach. These models, including one maintained by IIASA, can simulate systemic effects that result from linkages and feedback effects as visualised in a systems map. Such simulations allow policy makers to anticipate and explore policy outcomes, and to examine the resilience of policy configurations in a context of changing and uncertain circumstances.

Introduction

Automation and digitalisation are driving labour market transformations across OECD countries. These transformations bring about opportunities for increased productivity, new products and novel ways of organising production (Graetz and Michaels, 2015[1]; Acemoglu and Restrepo, 2017[2]). However, there is also concerns that the speed of this transformation may overwhelm societies' ability to adapt effectively (Brynjolfsson and McAfee, 2014[3]; Ford, 2015[4]). In particular, technology adoption creates risks that, for some workers, job losses will outpace the creation of new employment opportunities.

Fears regarding the social and economic consequences of innovation and technological change are not new. Since the Industrial Revolution, there have been concerns about technology-induced job losses. In the 1930's John Maynard Keynes (1931[5]) warned of technological unemployment, and similar concerns have remained present ever since. Although, some have suggested that the present bout of technological disruption may be different (Brynjolfsson and McAfee, 2011[6]; Mokyr, Vickers and Ziebarth, 2015[7]). Technology and digitalisation have lowered transaction costs, allowing firms to outsource or automate not just jobs, but individual tasks (Nedelkoska and Quintini, 2018[8]). As a result, work via online platforms has increased rapidly in recent years, although they still account only for a small share of workers in OECD countries (Katz and Krueger, 2016[9]).

While past innovations have certainly destroyed some jobs, in the long-term they have created more than they have destroyed (Autor, 2015[10]). However, newly created jobs are by their nature different from those destroyed, and they may be of lower quality. For example, non-standard work and alternative work arrangements, such as temporary employment, own-account work and "gigs", are more likely to be low-quality jobs, and they have been on the rise in OECD countries (OECD, 2018[11]).[11]

The rise in alternative work arrangements has implications for the development of countries' social protection systems. On the one hand, more dynamic labour markets with less stable employment strengthen the case for social protection. But on the other hand, existing social protection provisions, which were typically designed around traditional full-time employee-employer work relationship, may be less effective or accessible for non-standard workers, e.g. if entitlements are conditional on regular employment over prolonged periods of time. In addition, alternative working arrangements create strong financial incentives for workers or employers to bypass the social risk-sharing mechanisms and their associated short-term costs, such as social insurance contributions. These opt-out opportunities can undermine the foundations of risk sharing, and ultimately lead to a cycle of declining reach of social protection and rising costs for those requiring insurance (Rothschild and Stiglitz, 1976[12]; Akerlof, 1970[13]).

A narrowing reach of social protection systems raises both equity and efficiency concerns, especially during periods of labour market change and elevated uncertainty. Responding to this emerging challenge is made more difficult by its novelty: when a policy problem concerns a new phenomenon about which policy makers have little intuition. For example, they may examine non-standard work, social protection systems, or technological progress in isolation, but not the systematic linkages between them. More generally, there are concerns that policy makers have difficulty applying a systems thinking approach to devising decisions by not always considering relevant interactions in full (Levy, Lubell and McRoberts, 2018[14]).

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[11] Own-account workers are those self-employed who have no employees.

A number of tools are available to aid policy makers in examining complex systems. Qualitative systems maps can help overview a system as a collection of interacting components and illuminate key feedback loops, while agent-based models can simulate quantitative scenarios emerging from these dynamic interrelationships. The remainder of this short chapter presents a proof-of-concept of the systems analysis approach applied to the social protection policy challenges. It discusses qualitative systems mapping and provides an illustrative example relating to technological progress, alternative work arrangements, and social protection systems. At the end, the chapter briefly outlines linkages to agent-based models.

Systems Mapping

A qualitative systems map helps its users to understand the nature of the system's boundaries, its elements and the relations between them. The process consists of three steps: (1) identification of the system's key elements, (2) identification of relevant interrelations between them, and (3) identification of key feedback loops that define the behaviour of the system, and of actions which can lead to desired outcomes via these feedback loops (Wildemeersch, Rovenskaya, & Ilmola, 2017). This analysis can be performed based on customised input from experts, or on evidence that is available from the literature.

Building and analysing a qualitative systems map with the involvement of decision makers can lead to unexpected, counter-intuitive results (Sterman, 2002). This makes them useful for addressing so-called *wicked problems* (Churchman, 1967[15]; Rittel and Webber, 1973[16]). These problems typically arise when addressing novel and unique problems, or when the system is so complex that it is impossible to oversee all critical factors and their interrelations (Kanter, 2018).

Ultimately, a systems map can provide insight into indirect effects between a system's elements that are relevant for a given policy question, and it helps to anticipate effects of policy interventions (including the absence of policy action). The insights gleaned from the maps aid in identifying policy issues or interventions that may be missed when focusing attention on individual components at a time.

Feedback loops are critical for understanding the system's behaviour. A feedback loop is a sequence of interactions within the dynamics of a system that begins and ends with the same component. These loops can be either reinforcing or balancing. Reinforcing loops compound the effect of previous iterations of the loop, either positively or negatively, while balancing loops resist forces that pull components away from their initial state.

The development of a systems map can be a first step for further exploration and, in particular, provide the conceptual foundation for quantitative modelling. It can also be a tool for consensus building amongst stakeholders to explore possible further actions (Tiller, De Kok, Vermeiren, & Thorvaldsen, 2017).

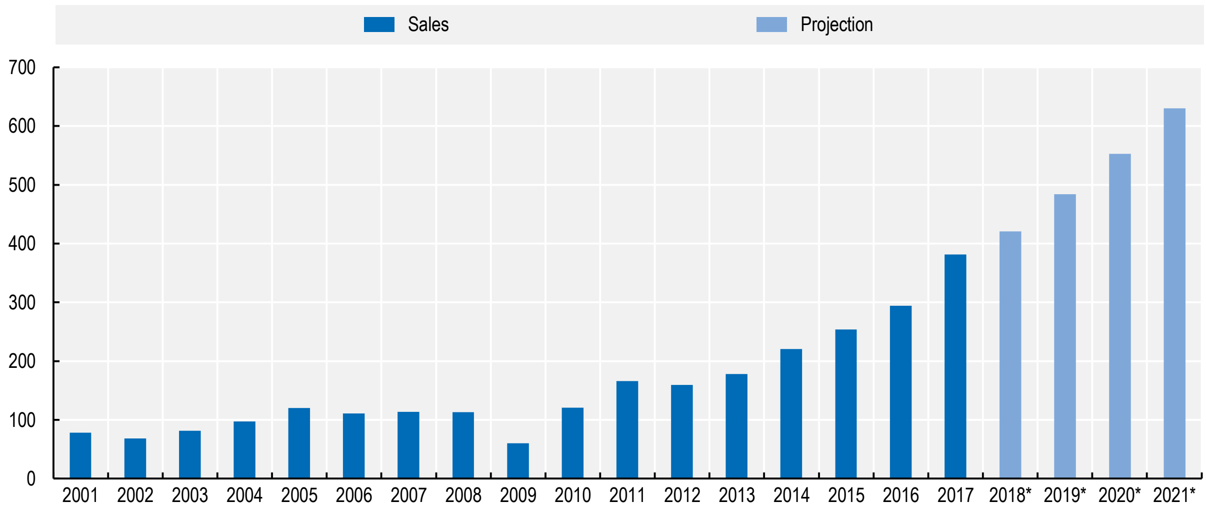
Technology and alternative working arrangements: An illustrative systems map

This section presents a simple systems map, covering linkages and interactions between technology adoption, alternative work arrangements, wages, and social protection. The impact of technology adoption is a suitable subject for a systems map because its growth has been rapid (Figure 1), and because it can give rise to multiple disruptions of labour markets that interact in complex ways.

The components and linkages are based on research outlined in the most recent OECD Employment Outlook (OECD, 2019[17]). The aim is thus illustrative; to provide a graphical mapping of the drivers featured in the Outlook to highlight some benefits of qualitative systems mapping. The illustration is thus not intended as a comprehensive full-scope systems map, which would require additional research.

Figure 1. Robots hold the potential to disrupt labour markets

Estimated worldwide annual supply of industrial robots, thousands of units



*: forecast
Source: International Federation of Robotics (IFR), https://ifr.org/.

Emerging linkages between technology and work

With technology adoption continuing at a steady pace, many studies, with varying degrees of urgency, have predicted that technological disruptions will lead to job displacement and technological unemployment (Nedelkoska and Quintini, 2018[8]; Frey and Osborne, 2017[18]; Brynjolfsson and McAfee, 2011[6]). At the same time, technology can increase worker productivity and wages (Autor and Salomons, 2018[19]; Acemoglu and Restrepo, 2018[20]; Acemoglu and Restrepo, 2017[2]; Bessen, 2017[21]). These two trends need not be mutually exclusive. With the rise of digital platforms, economies are experiencing the automation of certain tasks and the reorganisation of others. This has given rise to alternative work arrangements, which notably includes the *gig economy* (European Commission, 2017[22]; Katz and Krueger, 2016[9]; Huws, Spencer and Syrdal, 2017[23]). The impact of technology on overall employment trends remains uncertain. Some workers will lose their jobs, while new types of work will be created. So far, the net effect for most economies has been positive overall but some workers have fallen behind (OECD, 2018[24]).

Technology alters price structures and can spur the accumulation of capital, replace labour and reduce its share in national incomes (OECD, 2018[24]; Schwellnus, Pak and Pionnier, forthcoming[25]). Indeed, recent technological advances has encouraged market concentration and winner-takes-most dynamics in some sectors (Autor et al., 2017[26]). Beyond reducing demand for labour due to their capital intensity, these industries can supress wage growth owing their (labour-)market power (Azar, Marinescu and Steinbaum, 2017[27]; Benmelech, Bergman and Kim, 2018[28]).

At the same time, many workers and employers are turning to alternative work arrangements that provide flexibility of when, where and how to work. For example, online platforms can reduce job search frictions and unemployment durations, allowing potential workers to find some jobs more easily, while helping firms to locate workers with unique skill sets (European Commission, 2017[22]) (Manyika et al., 2015[29]). Alternative work arrangements are not without downsides, however. In particular, increased flexibility may come at the price of reduced legal protection for workers and higher risks of low and uncertain earnings. As technology removes barriers to finding jobs, more workers enter the labour market in some sectors, driving wages down. The digital nature of these platforms often means that employers can find workers worldwide. As labour standards and living costs continue to differ strongly across countries, this can create a "race-to-the-bottom" for workers in the sectors concerned. Indeed, workers in countries with higher rates of non-standard work tended to have lower wages, less employment protection, less access to social protection, and lower bargaining power (OECD, 2014[30]).

Downward pressure on wages can have a balancing effect on technology adoption. The apparent inexorable and uninterrupted advance of technology is not certain when workers compete with machines on cost. Lower wages can slow the adoption of automation and the related decline in the labour share. In fact, countries with relatively low labour costs have not seen the same hollowing out of routine jobs as higher-wage countries (OECD, 2017[31]).

Social protection provides a safety net for workers with low incomes and those experiencing out-of-work spells. However, in many countries, social protection provisions may be unavailable or optional for some groups of non-standard workers. When risk insurance is a choice, workers may undervalue the safety net provisions and may instead seek to minimise current costs, such as taxes and contributions to social insurance provisions. They may therefore choose the lowest protection possible or may attempt to circumvent participation in risk-sharing arrangements altogether. For example, in Latvia and Spain, two countries where the self-employed can choose their level of commitment to the unemployment insurance program, nine out of ten self-employed workers choose the minimum contribution (Arriba and Moreno-Fuentes, 2017[32]; Rajevska, 2017[33]).

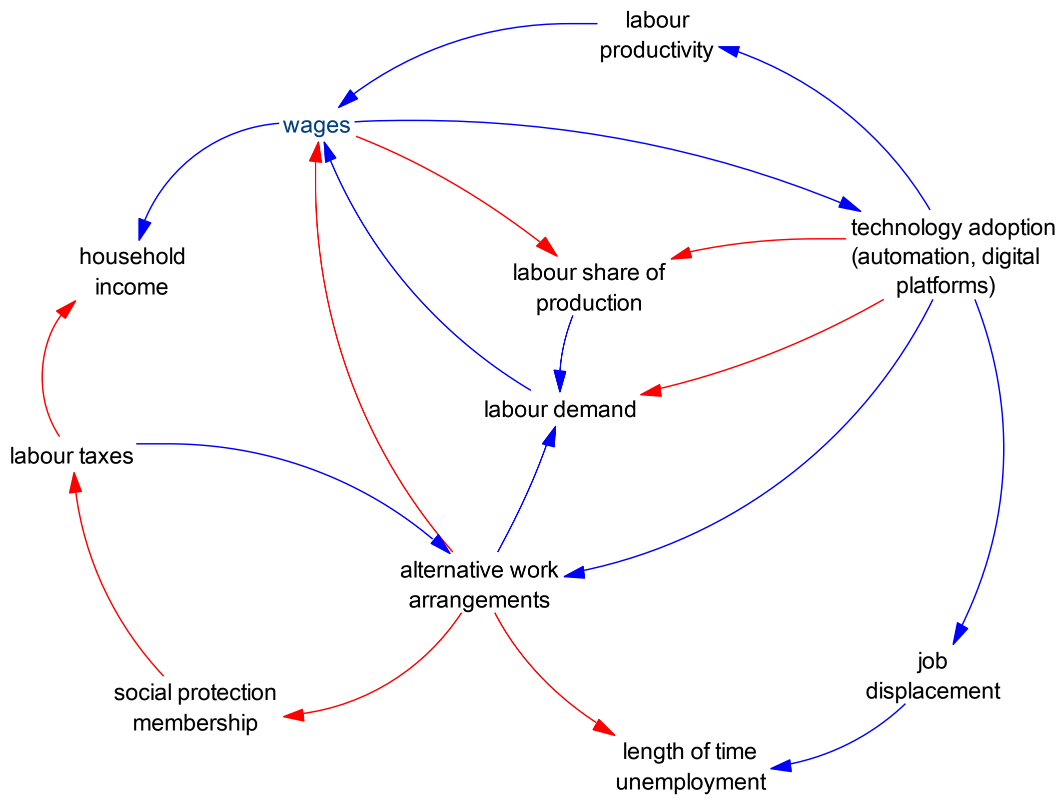
Unequal financing burdens or social protection entitlements can promote certain forms employment while discouraging others (OECD, 2019[34]). A growing incidence of non-standard work therefore creates financing and sustainability pressures for social protection, notably if financing largely relies on contributions or taxes levied on labour incomes. Without public subsidies, declining social protection membership ultimately produces a cycle of escalating costs and declining coverage (Rothschild and Stiglitz, 1976[12]; Akerlof, 1970[13]).

Technology and work: Illustration of a systems map

Figure 2 presents a simplified systems map focussing on the above linkages. Even in this comparatively system, a number of interesting feedback loops emerge; they are highlighted in Figure 3.

Figure 2. Example systems map of labour market interactions with technology

Preliminary qualitative systems map of technology, work, and social protection.



Note: Blue arrows indicate positively reinforcing links, while red arrows indicate negatively reinforcing effects. The direction of the arrow indicates the direction of the affect.
Source: OECD and IIASA analysis.

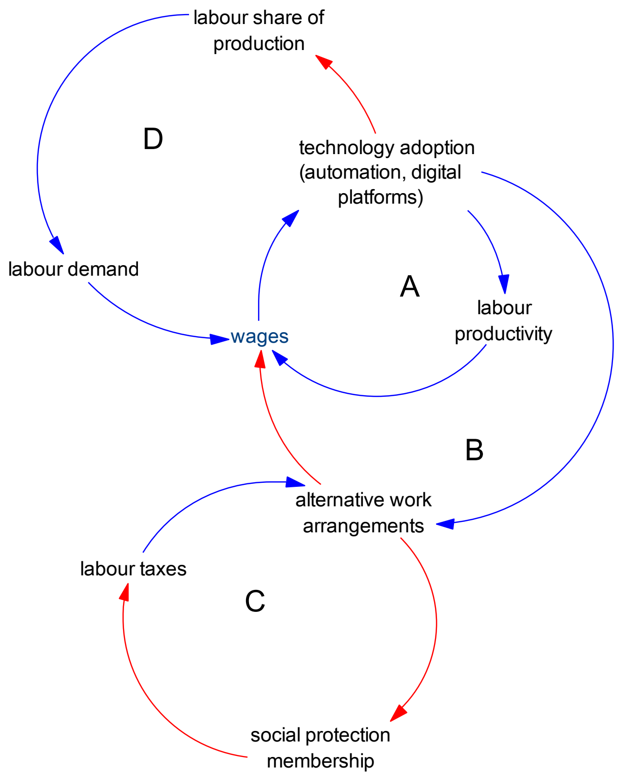
One example of a simple positively reinforcing loop is the link between technology adoption, labour productivity and wages (Figure 3, loop A). As indicated in the systems map, increased adoption of technology can increase labour productivity, which then feeds into higher wages for workers. These higher wages then provide incentives to replace labour with capital and so adopt more technology. However, a caveat is needed. Technology adoption increases productivity only for those workers with compatible skills, while often displacing those workers with substitutable (that is, automatable) skills. This displacement can be observed in the balancing loop that connects technology adoption, labour's share of production, labour demand, and wages (Figure 3, loop D). When technology adoption reduces, perhaps temporarily, labour demand, the total sum of wages declines, which in turn reduces the pay-off from further investment in automation.

Another balancing loop links technology adoption, alternative work arrangements, and wages (Figure 3, loop B). Here, new technologies encourage alternative work arrangements, which can lead to lower wages that, in turn, disincentivise further technology adoption.

A final example of a loop in this system map relates to the interaction between alternative work arrangements, social protection and taxes (Figure 3, loop C). As alternative forms of employment become more common, associated voluntary opt-in provisions can erode membership in social protection and can lead to increases in contribution rates to cover funding shortfalls. This (further) increases the labour-cost differential between standard and non-standard workers, encouraging more workers to take up alternative work arrangements. Successive iterations along this loop have negative consequences for income security regardless of the type of work arrangement, either standard or non-standard.

Naturally, national context is a key determinant of the operation of social protection systems. Both the strength of the linkages between components within a system and the configuration of the social protection system vary across countries and these differences can be notable. Risks of a self-reinforcing feedback loop of rising insurance premiums and falling coverage come to the fore when insurance membership is voluntary for all or some types of employment. Those with the greatest risks are more likely to enrol in this case, making risk sharing more costly (adverse selection). For example, opt-ins for the Canadian Special Benefits for Self-employed Workers, a maternity and parental benefit scheme, were found to be mostly women of child-bearing age and have significantly lower income than those who did not opt in (OECD, 2018[11]; Employment and Social Development Canada, 2016[35]). Likewise, an increase in the premium for voluntary unemployment insurance in Sweden in 2007-08 led to one in eight participants opting-out of the program (OECD, 2018[11]). Those who left the fund were those least likely to benefit, either older workers with little unemployment risk, or younger workers with low unemployment durations.

Figure 3. Labour market feedback loops



Note: Blue arrows indicate positively reinforcing links, while red arrows indicate negatively reinforcing effects. The direction of the arrow indicates the direction of the affect.
Source: OECD and IIASA analysis.

While illustrative, the above examples reveal a key benefit of systems analysis, which is to facilitate consideration of the behaviour of a complex system by decomposing it into sub-processes, which can be verbally described in a rather straightforward and relatively simple way. For example, *What is the net impact of technology adoption on labour?* Assessing this question in practice would require analysing all feedback loops and the relative weights of their linkages. On this basis, it is possible to identify the dominating loop and the dynamics that define the behaviour of this system.

Systems maps as an output, or an input

Further specification of the system in a national context, and with particular reference to social protection systems, can yield even further insights, however. Additional detail and specification comes with both costs and benefits. Systems are complex by nature, and a systems map can provide clarity. Attempts to make the map highly comprehensive by adding additional detail can jeopardise that clarity. In this sense, the development of a system map that focuses on the most relevant components and relationships can be the key output of a research project.

At the same time, a systems map provides a platform for further analytical development. With a clear view on the components and linkages of a system, it is possible to develop a *policy "lab" or "sand box"* based on quantification of the strength of linkages between components. Researchers can then use the map to formulate working simulations, such as agent-based models, which allows policy makers to pose "what if" type questions and undertake explicit scenario analyses.

Agent-based models

Agent-based models can quantify relationships outlined in a systems map

In examining complex systems, a natural extension to qualitative systems mapping is to use them to inform a simulation model. One such modern modelling paradigm, agent-based modelling (ABM), consists of the simulation of a number of heterogeneous agents, according to empirically based decisions rules. These models have been garnering growing attention in the aftermath of the global financial and economic crisis after 2008-2009, due to their ability to provide alternative perspectives to traditional macroeconomic modelling (Blanchard, 2018[36]; Stiglitz et al., 2017[37]).

ABM are capable of incorporating various behaviour rules at significant granularity and without relying on oversimplifying assumptions. They are therefore well-suited for modeling the feedback loops as established in a systems mapping exercise by allowing relationships to be calibrated to observed data in an economy. Such calibration is important as the strength of linkages between different individual components can shape the overall dynamics of a feedback loop. A weak link at one point of the loop can "short-circuit" (i.e. essentially deactivate) a loop, while exceptionally strong linkages amplify and drive relationships. Examining the quantitative aspects of these connections therefore produces an understanding of which parameters are crucial for the system's behaviour.

Although ABMs are complex and require considerable computational resources, a number of government institutions and international organisations have developed or are developing them as tools for informing crucial policy debates. These include the EURACE model developed with funding from the European Union (Dawid et al., 2011[38]), and a model of the Austrian economy developed by researchers at IIASA (Poledna and Thurner, 2016[39]), which have been used to examine financial fragility (Cincotti, Raberto and Teglio, 2010[40]) and worker skill upgrading (Dawid et al., 2009[40]).

Social protection in an agent-based model

As micro-models, ABMs support analysing the distributional effects of the policy changes. As governments' tax-benefit systems redistribute income and of risks, the distributional insights, e.g. from the feedback loops explored above, can be illuminating. An ABM could explore which workers may be especially likely to find themselves in non-standard employment—either by their choice, or through decisions of their employers.

In turn, policy makers could explore methods of ensuring adequate social protections for these workers. For instance, policy makers might seek to shape the financial incentives for various forms of work by altering the taxes or contribution rates that finance social protection, or through complementary policies that encourage firms to hire workers on standard contracts. More generally, policy makers can amplify or dampen feedback loops by exploring targeted policy solutions. An added benefit of these models is that, by modelling a complexly interacting system, they can incorporate realistic behaviour rules, which can be easier to communicate to decision makers. However, the added complexity often results in a model with many parameters, which can require an extensive set of assumptions.

Conclusion

Technological advances will continue to transform the world of work. Social protection systems need to be prepared to support those workers with outdated skills who are ill equipped to compete in tomorrow's job market. With an increasing variety of work arrangements, policy makers need to ensure social protection systems provide adequate risk pooling to help smooth negative outcomes for all workers. A first step in achieving this is to understand all of the ways that technology influences labour markets. Qualitative systems mapping methods provide a means to achieving this and they are especially useful when a policy problem is relatively new, when data availability is limited, or when potential interactions between different elements of the system are powerful and complex. The resulting map can itself form an insightful research output, or it can be the basis of more extensive quantitative research, such as the development of an agent-based model.

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11. Managing innovation and new technology for enabling economic and social progress

By Dominique Guellec, Mario Cervantes (OECD), and Arnulf Grübler (IIASA)

Introduction

Innovation is a force for social and economic progress. Its benefits are huge: productivity growth, new jobs, new technologies and new solutions to human needs, raising average incomes, increasing health outcomes and improving social welfare. However, a focus on the economic costs and benefits associated with innovation has blind sighted us to the environmental costs and benefits of new technologies. It has also blind sighted us to the societal impacts of new technologies, notably the exclusion it can create between those with access to capital, skills and now data, and those without. The current wave of innovation and new technology has both commonalities and differences with previous waves. Digitalisation and automation are potentially disrupting entire sectors and industries, and changing the demand for skills. The cheaper costs of automated manufacturing also suggests that developing countries, who traditionally enjoyed a cost advantage which enabled them to channel the surplus labour from agriculture, must leapfrog and find a new development path. This should be facilitated by the tremendous opportunities offered by digital technologies, e.g. mobile communication (which allows dense connectivity even in rural areas) or ecommerce (which makes global markets more easily accessible to small producers). There is now a need for steering innovation and new technology towards responding better to societal and environmental needs: developing greener energy and chemistry, transportation systems, smart cities, sustainable agriculture and food systems etc. For that to happen, market and non-market forces must be aligned around a number of goals reflecting those concerns.

Innovation and new technology have become a pervasive force, penetrating all aspects of social and personal life and influencing their development, involving all actors in society. At the same time, the dynamics of innovation itself has become more complex, diverse and unpredictable, hence more difficult for any specific actor, such as government, to anticipate, plan and guide.

Advanced systems-based analytical approaches such as system-level modelling, technology foresight and scenarios, anticipatory governance, can help policy makers better understand how technology and innovation can be better harnessed to meet the goals of sustainable development. While innovation policies and theories have long integrated systemic thinking – for example by recognising the importance of the quality of industry-science relations in the commercialisation of technologies, the role of different actors involved and the need for co-ordination, or the critical interdependencies and knowledge feedbacks between the supply and demand for innovations– they have only recently began integrating it explicitly in the context of managing the transition of socio-technical systems towards sustainability (e.g. energy, transport)). By bringing into focus the social, economic and environmental impacts, trade-offs and interdependencies generated by the introduction of new technologies, the motivations of actors and their interactions, system approaches can help identify strategies that maximise synergies as well as minimise trade-offs between different innovation and development objectives and any resulting barriers or leverage points for technology diffusion and uptake. The involvement of consumers, industry and civil society in managing these transition processes is a crucial element of systems thinking, as well as the initiative of all levels of government: local, national, and global.

Innovation studies have been among the first fields in social sciences to implement a systems-based approach. The reasons are that many students of innovation have a hard sciences background, that endows them with the appropriate technical skills, but also that innovation is particularly affected by systems-type mechanisms: it is an emergent phenomenon, it is non-linear, it is complex etc.

This note will review the evolving dynamics of innovation in various fields (digital, bio, energy) with a focus on the systemic dimension of change; and it will present the new, systems-based policy approaches that could potentially help policy makers influence these dynamics for achieving societal and environmental goals.

Sector examples

Digitalisation as catalyst for operationalising systems-based strategies (digital innovation: acceleration, data as inputs, collaboration)

The rapid and long term advance of the power of computers, the expansion of the Internet as a repository of all data and as a general connector, the increasing sophistication of software, all these forces have contributed to making digitalisation the transformative force of 21st century economies and societies. The transformation brought by digitalisation is systemic in nature. It concerns all aspects of economies (manufacturing, daily life, administration, entertainment); it affects all actors in society and their interconnections. Digitalisation changes the frontiers that structure social and economic life – between industries, between activities, between actors. Digitalisation also affects all the interconnections between actors: the circulation of information as well as the allocation of power. The phenomenon of “fake news” illustrates one negative aspect of the dis-intermediation of information management, although there are many positive aspects as well. Hierarchical and filtered relations have been replaced by more horizontal, unfiltered connections with a network shape. The functioning of a system is highly dependent on the allocation of information across the actors, and digitalisation is transforming that as well. Digitalisation for society needs also to be conducted in close coordination with other transformations: smart cities require a lot of digital tools, but also skills, physical infrastructures, regulation and corresponding evolving social relations and behaviours.

Bio economy/circular economy

Concepts like a “bio economy” or “circular economy” are often proposed as a solution for addressing environmental challenges. Systems level modelling however reveals that simple input substitution efforts are likely to be counterproductive without a radical transformation in the entire resource provisioning and consumption system in direction of vastly improved materials and energy efficiency and conservation where the technical potentials are as vast as the associated innovation and behavioural and lifestyle changes constitute formidable barriers. The development of a bio-economy is also a complex field that includes a variety of sectors and stakeholders involved in far-reaching changes in production systems and consumption patterns. Particularly the demand-side of this transformation remains under researched and the effect of policy signals remains uncertain both with respect to effectiveness as well as in terms of political and social acceptability. The transformation would require policy signals on the one hand from broad range of domains notably agriculture, energy, water, land, environment, trade, as well as research. It also would require changes in government regulations ranging from regulations on the generation and use (and re-use) of waste, to limits on emissions, land zoning, etc. In addition, most importantly, it will require organisational and changes in individual/consumer behaviours. Using a system approach can reveal the trade-offs and synergies that are likely to occur in the transition to bio-economy (OECD, 2018). However, synergies and trade-offs will have to be managed which will require stakeholder engagement (with business, policy makers, civil society, scientists, financing) and coherence across policy domains. Many countries inside and outside the OECD are attempting to develop coherent and integrated Bio economy strategies. The real value of a systems approach is to cast doubt on simplistic notions of “bio economy” (even circular economy, or all renewable energy systems). The critical interplay between demand and supply for resources needs to be a central concern. Without step changes in efficiency (that needs technological as well as behavioural and lifestyle innovations in direction of “less is more”) and changing consumption patterns any significant transition towards a bio economy risks of creating more environmental impacts that it aims to resolve. Systems based policy tools, such as agent-based modelling, could help to explore such strategies, regulations, and policies to ensure that novel concepts are tested before they are implemented.

Innovation and clean energy systems

System innovation argues that policies aimed at transitioning sociotechnical systems to more environmentally sustainable configurations differ significantly from those aimed at increasing the economic performance of existing systems with unchanged, even growing resource demands. The transition from a fossil fuel based energy system to one based on renewable and low carbon energy sources is a living case study that many countries are grappling with. Among the challenges facing policy makers in the energy transition is the need to develop a vision of what future energy systems will look like, including which technologies – and combinations of technologies - are likely to play important roles in the future system and which energy infrastructures will be needed, as well as how business models (e.g. shared urban mobility) regulations and patterns of consumer behaviour will need to change (e.g. fostering energy efficiency). Such visions have to be developed using both bottom up approaches and top down visioning. Top down, addressing such complexity requires not only lengthening financial planning and investment horizons; but also co-ordination across government Ministries and different levels of government. Bottom up means linking local and community-based initiatives to national goals and international commitments (e.g. SDGs, Paris Agreement). Systemic analytical approaches such as portfolio diversification models can help to craft appropriate diversification strategies in face of persistent innovation uncertainty and often unknowable ultimate environmental and social impacts of particular technological options considered. Integrated Assessment Models (IAMs) are increasingly becoming available to assess alternative transformation strategies on their impacts across a wide range of SDGs.

Key system based policy mechanisms

The policy response to systemic changes needs to be system itself. For that to happen, it needs both the vision and the appropriate instruments. Over the past years, older instruments have been modernised and new instruments have appeared which endow policy makers with a rich tool kit.

- **Strategic Policy intelligence.** Strategic policy intelligence can be defined as "the set of activities to search, process, diffuse and protect information in order to make it available to the right persons at the right time, so that they can make the right decisions". In the STI policy space, these includes such policy support instruments such as foresight and technology assessment, monitoring, benchmarking, regional innovation auditing, technology road mapping, horizon scanning, specialisation indices, and strategic evaluation (Acheson, H. 2008). Many governments use foresight exercises, a form of "strategic policy intelligence", as part of their priority setting procedures to stimulate dialogue. Horizon scanning is a distinct futures methodology that researches and draws out key trends on the margins of current thinking that will affect people's lives in the future. Most horizon scanning exercises aim to provide advance notice of significant new and emerging risks and opportunities, to exchange information, and to evaluate potential impacts. This involves the review of a broad spectrum of information beyond the usual timescales and sources and the participation of various sectors of society. Smaller economies have perhaps been the most active with regard to using foresight and other future-oriented studies to inform priority setting because of the need to focus and get returns from relatively small investments. Strategic policy intelligence, whether foresight or others depend on timely quantitative and qualitative data of high quality. Many OECD countries still struggle with gaps in their data especially as regards understanding of socioeconomic impact of public R&D in scientific and technological fields. The non-linearity of research impacts is not adapted to the input/output models of R&D budgeting and evaluation. For instance, mathematical research can advance science and innovation in areas as varied as AI, advanced manufacturing or synthetic biology but current systems for measuring impact of funding priorities will be unable to ascertain such effects. Improving data analysis on both the input and output side will necessarily require work to develop up-to-date definitions and taxonomies. A renewed effort for performing a range of empirical studies across technologies, countries, and the economic, social, and environmental returns of past innovation projects is also long overdue.
- **Digital Science and Innovation Policy (DSIP).** Several OECD member-countries and partner economies have started exploring the potential of exponentially increasing data volumes and advancements in computational power for science and innovation policy

by launching Digital Science and Innovation Policy (DSIP) initiatives. DSIP initiatives refer to the adoption or implementation by public administrations of new or re-used procedures and infrastructures relying on an intensive use of digital technologies and data resources, to support the formulation and delivery of science and innovation policy. DSIP initiatives are becoming increasingly instrumental in steering national science and innovation policy in a highly uncertain environment. The Japanese digital system SPIAS uses big data and semantic technologies to process data on R&D activities to guide decisions of government agencies on investments in science and innovation. The system was used to map the impacts of regenerative medicine in Japan and formulate new policy measures to promote its further development. Another example is a Welsh system Arloesiadur designed to provide policy-makers with intelligence on industrial and research strengths of the region, domestic and international networks and opportunities for the future economic growth. Arloesiadur uses natural language processing and machine learning to analyse data from administrative sources, research repositories and the web to inform decisions of policy-makers. While being mainly used for supporting a current mode of operations of STI policies, DSIP initiatives can potentially be used to facilitate the transition of socio-technical systems as well for instance, by providing analyses with high granularity and scope that are not possible to achieve using conventional methods and approaches, DSIP initiatives can effectively guide policy-makers in improving STI policy frameworks by making them more responsive to inclusiveness and other societal challenges.

- **Participatory approaches in research funding /priority setting.** Governments are increasingly involving industry and society upstream in the policy debate through participatory approaches to setting priorities (Argentina, Chile, Denmark, Greece, Netherlands and Turkey) (OECD, 2016). Rarer is the involvement of participatory approaches in the evaluation of research and innovation policies.

- **Mission innovation.** One-way governments are trying to mobilise STI for grand challenges is mission- oriented R&D and innovation programmes. Mission-oriented programmes align policies, public R&D programmes and public-private collaboration to overcome a concrete problem. This in turn helps to address a broader societal challenge or “wicked problem” – one that is complex, systemic, interconnected and urgent – such as climate change, environmental degradation and public health challenges. Mission oriented programmes often involve all stakeholders in their design, they mobilise various actors in their implementation (ministries, agencies, businesses), various scientific and technological disciplines. At the core of the mission-oriented approach is the understanding that governments must not only correct market failures, but also actively drive and direct innovation by co-creating and co-shaping markets (Foray, Mowery and Nelson, 2012, Mazzucato, 2015).

- **Smart Regulation.** From an innovation perspective, “smart regulation” approaches can facilitate the diffusion of new technologies, if they achieve consumer and environmental protection at minimum cost and maximum simplification. The challenge for governments is to design and apply regulations that do not stifle competition between new innovations (and associated actors) and existing technology (and incumbent actors): regulating too much or too soon can stifle the challenger to existing incumbents, especially when innovations have applications in other product markets with different regulatory traditions (e.g. 3D printing in automobile and health applications).

- **Systems modelling for innovation policy**. The first important role for systems modelling is to apply a systemic approach for identifying opportunities as well as potential trade-offs for policy interventions in complex coupled socio-economic and natural systems. A prominent example are the UN Sustainable Development Goals (SDGs) that suggest policy priorities along a broad range of societal objectives from economic to social development as well as environmental preservation. Systems thinking and resulting modelling can help to identify which policies offer potential for synergies among various SDGs, and which policies could lead to important trade-offs. These trade-offs do not arise between the various SDGs (policy objectives) per se, but rather from particular policies proposed to address any singular SDG in an isolated manner. For instance a climate policy objective translated into an input substitution policy, e.g. biofuels for fossil fuels in transport, almost inevitably leads to important trade-offs for competing uses of land, water, and other resources between energy production, food and fibre provisioning, as well as ecosystems services.

- Conversely a demand-side strategy, e.g. promoting comprehensive shared mobility schemes, particularly in urban settings (see e.g. the modelling work of OECD ITF, 2016 and 2018) can lower resource use, environmental impacts and mobility costs while at the same time illustrating SDG synergies that can be harnessed by integrated policy approaches, that above all first consider the most important systems interdependencies: i.e. between supply and demand. Recent advances in Integrated Assessment Modelling tools such as being in use at IIASA help to shed light on these potential synergies and trade-offs among various policy options (Nilsson et al., 2018). The potential for policy integration and holistic strategies for addressing the SDGs have been recently described in the transformation scenarios of “The World in 2050” Initiative hosted at IIASA (TWI2050, 2018) underpinned by systems modelling in the domains of food-water-energy Nexus (Parkinson et al., 2019) as well as climate policy with a focus on demand-side solutions (Grubler et al, 2018).

- A second important area of application of systems thinking is in the domain of innovation policy. Important new conceptual models of innovation systems have been developed that describe the positive outcome of innovation efforts within a multidimensional, interacting space involving knowledge, actors and institutions, resource mobilisation as well as innovation outcomes (Gallagher et al., 2012). These interacting dimensions of innovations systems are not substitutive, but rather complementary and need to be addressed simultaneously by policy. As a simple example, consider for instance an enhanced R&D program for large-scale carbon capture and sequestration. In absence of corresponding policies that put a price on the carbon externality, these innovation efforts will be stymied by a lack of market deployment incentives. In other words, the R&D efforts remain in the proverbial innovation “valley of death” (viable prototype technologies cannot be brought to market). Currently data limitations preclude a formal model representation of entire innovation systems, but the approach has been fertile in explaining relative success or failure of innovation initiatives across different technology fields and across countries (see the case studies assessed in Grubler and Wilson, 2014) as well as has enabled to identify systemic biases in innovation policies for climate protection across all OECD countries, that are unduly focus on supply-side options, marginalising end-use innovations (Wilson et al, 2012).

- Lastly, formal systems modelling can also assist innovation policies to tackle the perennial problem of deep innovation uncertainty. The biblical quote of "many are called, but few are chosen" describes the inherent uncertainty of innovation outcomes, despite well-funded innovation efforts and aligned market incentives. Drawing of portfolio theory, new models have become available that can assist innovation policy via a quantitative framework of the economic value of risk diversification via a portfolio approach (Grubler and Fuss, 2012, for methods see Krey and Riahi, 2013). A novel feature of these models is that those different degrees of risk aversion (to innovation failure) become an input variable specified by policy makers. "Optimal" diversification portfolios given pre-specified innovation uncertainties and policy-specified risk aversion can be determined mathematically, albeit computational limitation currently restrict the application of these approaches to portfolios of less than two dozen innovation projects. A robust finding from the modelling studies is that expanding innovation portfolios is a direct function of innovation risks. The higher the risks, the more diversified the portfolio should be. In many cases, such diversification might not be possible within the limited resources available for national innovation strategies. International co-operation and joint risk hedging can thus be proven to be an economically rational and optimal innovation strategy.

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Systemic Risk and Resilience

12. Understanding and evaluating resilience to systemic risks

By Igor Linkov (USACE), Elena Rovenskaya, Ulf Dieckmann, Reinhard Mechler, Stefan Hochrainer, and Michael Obersteiner (IIASA)

How does systemic risk arise?

Systemic risk is the potential for a threat or hazard to propagate disruptions or losses to multiple nested or otherwise connected parts of a complex system. Systems prone to systemic risks are highly interconnected and intertwined with one another. Such interconnections contribute to complex causal structures and dynamic evolutions – typically nonlinear in their cause-effect relationships, often stochastic in their effect structure, and potentially global in their reach (in the sense that they are not confined within borders; IRGC, 2018). Systemic risks overwhelmingly do not follow normal risk distributions, but tend to be fat-tailed, i.e., there is a high likelihood of catastrophic events once contagion starts to unfold.

Systemic risk occurs in a wide variety of natural and human-made systems. It is the risk that a large part of the system ceases to function and collapses with potentially dramatic consequences for the system and its constituting parts. One of the most prominent examples of systemic risk today occurs in financial networks. Systemic risk in financial systems implies that a significant fraction of the financial system can no longer perform its function as a credit provider and collapses. A recent example of the Great Recession started from the failure of a financial institution and propagated through the financial system reaching also the real economy. In a broader sense, systemic risk also includes the risk of system-wide shocks that affect many financial institutions or markets at the same time.

Systemic risks in financial markets generally emerge through two mechanisms, either through synchronization of the behaviour of agents (e.g., through fire sales, margin calls, or herding) or through interconnectedness of agents. The former can be measured by a potential capital shortfall over periods of synchronized behaviour, during which many agents are simultaneously distressed. The latter is a consequence of the network nature of financial claims and liabilities. Systemic risk is potentially extremely harmful because of the possibility of cascading failures, meaning that the default of a financial agent may trigger defaults of others. Secondary defaults might cause avalanches of defaults percolating throughout the entire network and can potentially wipe out the financial system by a de-leveraging cascade. The fear of cascading failure is generally believed to be the reason why financial institutions under distress are often bailed out at tremendous public cost.

Financial systemic risk must not be confused with the default (single) risk of nodes or links in a networked system. The risk that financial agents primarily take into account is the so-called “credit default risk,” i.e., the risk that obligations, such as loans, are not paid at the agreed time, or not at all. This risk affects the lender immediately, but does not necessarily have systemic relevance. There exists an extensive literature on the understanding, regulating, and modelling credit default risks. Present-day regulations of the financial system are almost exclusively focused on this type of risk. Credit default risks exist between two parties once they engage in a financial transaction, and usually no network aspects are considered.

The inability to see and quantify financial systemic risk arising from interconnections poses concerns of considerable financial and economic losses to society at large, and the failure to manage such systemic risk has been proven to be extremely costly. Systemic risk has become a focus of recent academic research, not only because of its societal importance, but also because of the availability of high-precision data enabling its qualitative assessment and because the financial system is human-made and can in principle be changed and engineered to improve it.

The financial crisis of 2007–2008 was triggered by the default of a single investment bank. The consequences of this default propagated through the financial system, bringing it to the brink of collapse. Because of close links between the financial system and the real economy, the financial crisis spread quickly and triggered a global economic downturn, the so-called Great Recession. The majority of losses were indirect, such as people losing homes or jobs, and for the majority of people, income levels have dropped substantially. Despite such impacts, the mechanisms of how a financial crisis may lead to an economic recession, and vice versa, are not yet adequately understood at a fundamental level.

These developments have spurred research on systemic risk and financial networks. The clarification of the structure, stability, and efficiency of financial networks has become a hot research topic over the past decade. It has been shown that the topology of financial networks can be associated with probabilities of systemic collapse. In particular, network centrality measures have been identified as appropriate for quantifying systemic risk.

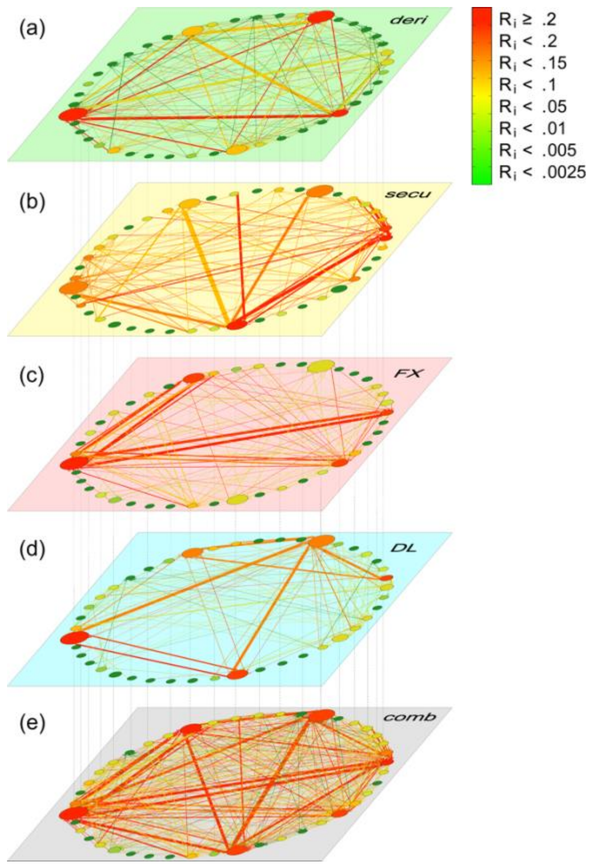
How to evaluate systemic risk?

Systemic risk and financial contagion are to a large extent related to synchronized behaviour and correlated portfolios of financial institutions. In this context, several econometric measures of systemic risk have been proposed that focus (mainly) on statistics of losses, accompanied by a potential shortfall during periods of synchronized behavior, during which many institutions are simultaneously distressed. In particular, four statistical measures have been proposed recently: conditional value-at-risk (CoVaR), systemic expected shortfall (SES), systemic risk indices (SRISK), and distressed insurance premium (DIP). CoVaR is defined as the value at risk (VaR) of the financial system, conditional on institutions being in distress. The contribution to systemic risk of an institution is the difference between CoVaR conditional on that institution being in distress, and CoVaR conditional on that institution being in its median state. SES measures the propensity to be undercapitalized, given that the system as a whole is undercapitalized. SES is related to leverage and the marginal expected shortfall (MES). SRISK is closely related to SES and as such a function of the size of an institution, its degree of leverage, and its MES. DIP measures the price of insurance against systemic financial distress in the banking system and is closely related to SES.

As an alternative to statistical measures of systemic risk, it is also possible to take interactions directly into account and measure systemic risk in financial networks. Until recently, this alternative has been practically ignored by the mainstream economic literature. Research on systemic risk and financial networks has progressed only through the availability of high-precision empirical network data providing information on interbank networks, financial flows, or overnight markets. Several recent studies examine the evolution of financial networks and the network formation process. Their findings indicate that during the Subprime Crisis, a structural break appeared only after the collapse of Lehman Brothers; otherwise, interbank networks remained stable during this crisis. Research suggests that network measures can potentially serve as early warning indicators for crises. Several network-based systemic risk measures have been proposed recently. All approaches are based on quantifying the systemic importance of a node (institution) within a financial network. It has been reported consistently across many studies that the most relevant types of network measures for quantifying the systemic risk of a financial institution are network centrality measures. A disadvantage of such centrality measures is that their value for a particular node has no clear interpretation as a measure of losses due to systemic risk. An alternative to centrality measures that solves this problem is the so-called “DebtRank,” a recursive method suggested by Battiston et al. (2012) to quantify the systemic importance of nodes in terms of the losses a node would contribute to the total loss in a crisis. IIASA researchers have used DebtRank in a variety of studies to quantify systemic risk and have generalized DebtRank for multi-layer networks (Poledna et al., 2015).

Generally, empirical data on financial networks is not publicly available and is typically collected and owned by central banks or other government agencies. Because of the confidential nature of financial transactions, these agencies are reluctant to allow researchers access to this data. As a result, research on financial networks has mainly focused on credit networks between financial institutions. However, financial systemic risk is not only the property of a single network, but usually is determined by multiplex (or multi-layer) networks resulting from institutions being connected through various types of qualitatively different links, representing different types of financial contracts. Specifically, the layers of a financial multiplex network consist of the borrowing-lending contracts (obligations, i.e., counterparty exposures, and implicit relationships, such as roll-over of overnight loans), insurance (derivative) contracts, collateral obligations, market impact of overlapping asset portfolios, and networks of cross-holdings (holding of securities or stocks of other banks). Research on multiplex financial networks has appeared only recently. In collaboration with researchers from the Banco de México, the Mexican Central Bank, IIASA researchers from the ASA and RISK program analysed a financial multi-layer network. This work is based on a unique dataset containing various types of daily exposures between the major Mexican financial intermediaries (banks) over the period 2004–2013 (although for this work, data from 2007-2013 was used). Data were collected and are owned by the Banco de México, and various aspects of the data have been extensively studied. By evaluating contributions to systemic risk from four layers – (unsecured) interbank credit, securities, foreign exchange, and derivative markets – of the national banking system of Mexico, IIASA researchers have shown that focusing on a single layer significantly underestimates the total systemic risk (Poledna et al., 2015). Figure 1 shows the multi-layer financial network of Mexico, and Figure 2 shows how systemic risk evolves over time.

Figure 12.1 Banking multi-layer network of Mexico on 30 September 2013



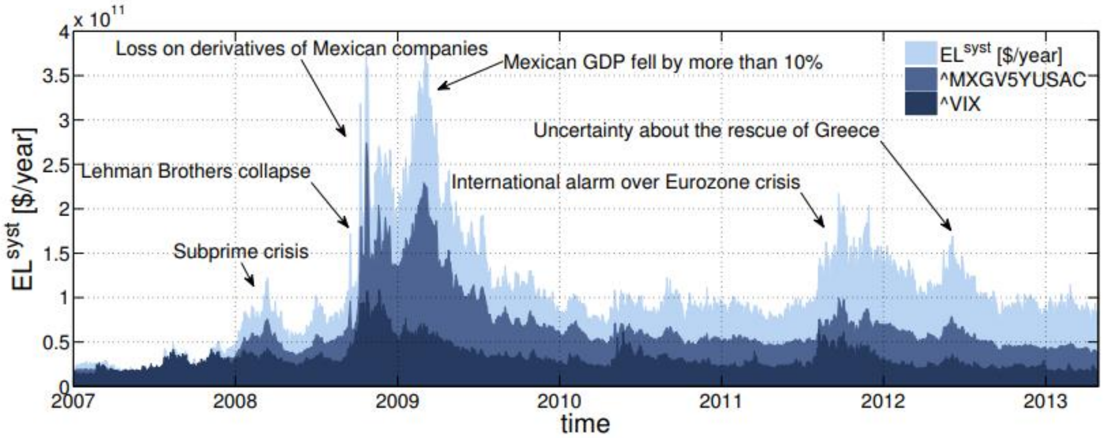
(a) Network of exposures from derivatives, (b) security cross-holdings, (c) foreign exchange exposures, (d) deposits & loans and (e) combined banking network.

Nodes (banks) are coloured according to their systemic importance in the respective layer: from systemically important banks (red) to systemically safe (green). Node size represents banks' total assets. Link width is the exposure size between banks, link colour is taken from the counterparty.

Source: Poledna et al (2015)

Another network layer of systemic risk emerges through common asset holdings of financial institutions. Strongly overlapping portfolios lead to similar exposures that are caused by price movements of the underlying financial assets. Based on the knowledge of portfolio holdings of financial institutions, Pichler et al. (2018) and Poledna et al. (2018a) quantify the systemic risk of overlapping portfolios. In particular, Pichler et al. (2018) present an optimization procedure that enables the minimization of systemic risk in a given financial market by optimally rearranging overlapping portfolio networks under the constraint that the expected returns and risks of the individual portfolios are unchanged. The developed approach has been applied to the overlapping portfolio network of sovereign exposure between major European banks by using data from the European Banking Authority's stress test of 2016. It has been shown that systemic-risk-efficient allocations are indeed feasible. In the case of sovereign exposure, systemic risk can be reduced by more than a factor of two without any detrimental effects for the individual banks. The reduction of systemic risk is achieved by a dramatic decrease of the probability of contagion.

Figure 12.2 Expected systemic losses (EL^{syst}) in Mex$ per year, in comparison to the volatility index VIX and the CDS spreads of 5-year Mexican government bonds in USD (MXGV5YUSAC).



To allow comparison the MXGV5YUSAC and the VIX are scaled such that the data points coincide on 2 January 2007. Several historical events are marked. Market-based indices relax fast to pre-crisis levels, whereas expected systemic losses does not, indicating that the expected systemic losses are indeed driven to a large extent by network topology and are consistently underestimated by the market. Expected losses in 2013 are about four times higher than before the crisis.

Source: Poledna et al (2015)

Not only financial firms, but also non-financial firms, such as vehicle manufacturers or energy companies, contribute to systemic risk in financial systems, in the same way as financial institutions as banks do. Poledna et al. (2018b) are the first to study the systemic importance of non-financial firms to shed light on mechanisms of how a financial crisis may lead to an economic recession, and vice versa. This work analysed data on nearly all financial and non-financial firms in Austria that included 80% of firms' debts to banks. The researchers reconstructed the financial network between 796 banks and 49,363 firms, effectively representing the Austrian national economy in 2008, which is the most comprehensive financial network ever analysed. The researchers identified a number of mid-sized firms, with assets worth less than 1 billion Euros that are systemically important in the Austrian economy. This was previously unknown. Overall, the paper found that in Austria, non-financial firms introduce more systemic risk than the financial sector – 55% compared with 45%, respectively. This finding speaks strongly in favour of introducing regulations, similar to the Basel III rules imposed on banks to reduce the financial systemic risk they generate, also for non-financial firms. The results of this work could be the basis of a new approach to bank stress testing exercises that takes into account feedback effects between the real economy (goods and services) and the financial economy. Currently, bank stress testing exercises only assess the impact of risk drivers on the solvency of banks and are typically conducted without considering feedback effects among banks or between banks and the real economy.

How to manage systemic risk?

In current financial regulation, systemic risk is regulated indirectly through capital requirements and other restrictions on financial institutions. On the regulators' side, only in response to the financial crisis of 2007–2008, broader attention is now directed to financial systemic risk. A consensus is emerging on the need for a new financial regulatory system including a potential redesign of the financial sector: new financial regulations should be designed to mitigate the systemic risk of the financial system as a whole.

In the regulatory framework of Basel III currently under discussion, the importance of networks is recognized. In an effort directed at the reduction of systemic risk, the Basel Committee on Banking Supervision (BCBS) recommends future financial regulation for systemically important financial institutions (SIFIs). The Basel III framework recognizes SIFIs, and in particular global and domestic systemically important banks (G-SIBs and D-SIBs), and recommends increased capital requirements for them, the so-called "SIFI surcharges." By doing so, institutions are expected to alter their market behaviour and to internalize contagion externalities. Instead of using quantitative models to measure systemic importance, the BCBS suggests an indicator-based approach that includes the size of banks, their interconnectedness, their substitutability, their global (cross-jurisdictional) activity, and their complexity. In Poledna et al. (2017), IIASA researchers from the ASA and RISK Programs, in collaboration with a researcher from the University of Oxford, studied and compared the consequences of different options for the regulation of systemic risk with an agent-based model and showed that Basel III would not reduce systemic risk in a substantial way.

Linkov et al. (2018) and Larkin et al. (2015) characterize the various strategies that United States federal agencies, as well as multiple directorates and affiliate agencies within the OECD, respectively assess and discuss systemic risk and threat. They individually frame the regulation and discussion of resilience through a disciplinary lens, where threat and system resilience are categorized into infrastructural, social, informational domains. Both pieces find that resilience is framed differently, with US Federal agencies placing greater emphasis upon infrastructural risk and resilience Linkov et al. (2018) with OECD placing greater emphasis upon social and economic concerns and systemic threats (Larkin et al., 2015).

Unlike for management of credit risk, proposals for management of systemic risk appeared only recently. While credit risk is relatively well understood and can be mitigated through several methods and techniques, management of systemic risk requires an understanding of the system as a whole. While it is evident that financial institutions as lenders have strong incentives to mitigate credit risk, it is less clear in the case of systemic risk as it involves externalities. In general, financial institutions manage their risks but do *not* consider their impact on the system as a whole. Management of systemic risk is, therefore, foremost in the public interest and must require financial institutions to internalize costs of systemic risk or otherwise create an incentive to minimize risks that are borne by the public.

Several authors have, therefore advocated various taxation schemes to manage systemic risk, while others are in favour of regulation due to the inherent difficulties of measuring systemic risk. Taxation schemes and the related measures for systemic risk are typically based on the notion of the systemic importance of financial institutions that need to be subjected to a Pigouvian tax. The idea is that institutions internalize contagion externalities if they are "taxed" based on their systemic importance. Levied taxes are typically collected by a rescue fund that can be used for bail-outs. In Poledna and Thurner (2016), IIASA researchers introduced the notion of the marginal systemic risk, i.e., the systemic risk increment of an individual financial transaction, that is, its contribution to the overall systemic risk. Knowing the marginal systemic risk of individual transactions opens the way to an entirely new approach to managing financial systemic risk by reshaping the topology of financial networks. To apply this new approach, the researchers proposed a tax on individual transactions between financial institutions based on the marginal systemic risk that each transaction adds to the system and showed that this policy could essentially eliminate the risk of future collapse of the financial system.

In Leduc et al. (2017), an alternative mechanism to mitigate systemic risk by using credit default swaps (CDS) is examined. Considering that a CDS has the effect of transferring the default risk from one bank to another, the researchers showed that a CDS market could be designed to rewire the network of interbank exposures in a way that makes it more resilient to insolvency cascades. In Leduc and Thurner (2017), the authors used an equilibrium concept inspired by the matching markets literature to prove that the systemic risk tax proposed by Poledna and Thurner (2016) allows the regulator to effectively rewire the equilibrium interbank network to make it more resilient to insolvency cascades without sacrificing transaction volume.

IIASA research has also been used to study the economic and financial ramifications of crisis resolution mechanisms (Klimek et al., 2015). The authors of this study used an agent-based model, finding that, for an economy characterized by low unemployment and high productivity, the optimal crisis resolution concerning financial stability and economic productivity is to close the distressed institution. For economies in recession with high unemployment, the bail-in tool whereby debt of a financial institution is written off or converted into equity without shifting the burden to taxpayers, provides the most efficient crisis resolution mechanism. Under no circumstances do taxpayer-funded bail-out schemes outperform bail-ins with private sector involvement.

The International Risk Governance Center's *Guidelines for the Governance of Systemic Risk* offer a risk governance approach that tackles the dynamic nature of complex adaptive systems (IRGC, 2018). Complex adaptive systems are in constant flux, and transitions between regimes are natural processes. Traditional probabilistic risk assessment methodologies cannot be successfully applied to risks that arise in such systems and may even have counterintuitive and unintended consequences. Since a system can be hampered by factors that reside inside or outside of its functioning as a complex system, dealing with systemic risks requires a dual process of identifying both problems and their interactions. Such notions are consistent with OECD discussions on systemic risk management and governance, such as the need to address global shocks and cascading failures, strengthen resilience, and create capacity for improved agility. Specifically, the IRGC Guidelines recommend a seven-step approach that is intended to help organizations identify, analyse, manage, and communicate their susceptibility to systemic risks:

1. Explore the system in which the organisation operates; define the boundaries of the system and the organisation's position in a dynamic environment.
2. Develop scenarios, considering ongoing and potential future transitions.
3. Determine goals and the level of tolerability for risk and uncertainty.
4. Co-develop management strategies to deal with each scenario and the systemic risks that affect or may affect the organisation, and to navigate the transition.

5. Address unanticipated barriers and sudden critical shifts that may come up during the process.
6. Decide, test, and implement strategies.
7. Monitor, learn, review, and adapt.

Similar to IRGC's approach, Linkov and Trump's *The Science and Practice of Resilience* (Linkov and Trump, 2019) characterizes systemic risk as a property of an organization's or system's resilience. They use a definition proposed by the National Academy of Sciences (NAS, 2015) that frames resilience as the ability of a system to plan and prepare for, absorb and withstand, recover from, and adapt to adverse events and disruptions. Such disruptions can be sudden one-off events (shocks) or slow and even nearly imperceptible impacts (stresses). Linkov and Trump argue that systemic risk can be managed only by first understanding the core interdependencies and resilience (or lack thereof) within the various nested dependencies and critical functions of a given system, and then crafting countermeasures or system redundancies/fail-safes to ensure that a disruption to any given critical function will not trigger a cascading system failure. Specifically, systemic capacity to overcome systemic threat is framed as a particular measure of recovery and adaptation (Linkov et al., 2018).

How could IIASA and OECD collaborate to enhance their analytical capabilities and rigor of policy advice in the area of systemic risk?

As demonstrated by the review presented above, IIASA and OECD develop very complementary approaches to financial systemic risk. IIASA has a strong capacity in quantitative methods to measure, model, and manage systemic risk of financial systems using network theory and agent-based modelling. OECD looks into how to operationalize the concept of resilience to systemic risk to equip policy makers with an effective and efficient resilience management framework. IIASA's quantitative methods can inform and enhance OECD's framework by making available simple and transparent systemic risk indicators that can be monitored in real real-time, as well as tools to test alternative policy interventions to reduce systemic risk. For example,

- Currently, financial regulations focus primarily on credit default risk ignoring risks generated through interconnections among banks or between banks and the real economy. New financial regulations, so called macro prudential regulation, should be designed to mitigate the systemic risk of the financial system as a whole and must require financial institutions to internalize costs of systemic risk or otherwise create an incentive to minimize risks that are borne by the public.
- Current macro prudential regulation focusses almost exclusively on the financial sector. IIASA's research indicated that in Austria non-financial firms introduce more systemic risk than the financial sector. This finding speaks strongly in favor of introducing regulations also for non-financial firms.
- Bank stress testing exercises typically only assess the impact of risk drivers on the solvency of banks and are typically conducted without considering feedback effects

among banks or between banks and the real economy. New approaches to bank stress testing should take feedback effects among banks and between banks and the real economy into account.

Approaches and models developed to deal with financial systemic risk may also have the potential to be useful to deal with systemic risk in other networked systems, for example, supply chains. Agent-based modelling framework developed by IIASA can be used to evaluate systemic economic consequences and indirect effects of natural disasters, whose frequency and severity are expected to increase due to climate change putting at risk economic growth and citizens' well-being.

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13. Strategies to govern systemic risks

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Introduction

Governments, businesses and civil society worldwide more and more realize that the risks that modern societies face have become increasingly systemic, complex, potentially irreversible and in some cases existential. They present governance institutions with cross-cutting and diverse challenges that may result in disruptive consequences and require integrated and innovative thinking and solutions. *Risk* typically refers to uncertain outcomes the negative consequences of which need to be addressed by governments (Hochrainer 2006). The financial crisis of 2007/2008 brought home the significance of the systemic nature of risks, that is, the potential for impacts to cascade through economic, social and ecological systems, to irreversibly breach system boundaries, and to cause instability or even system collapse (Pflug and Kovacevic 2014). A distinguishing feature of systemic risk is that it emerges from complex interactions among individual elements or agents (and their associated individual risks); therefore, systemic risk is sometimes called network risk (Helbing 2013, see also Box 1 in Florin et al. 2018).

Governments play a central role in managing systemic risks; yet governance is more than government. Public governance covers the formal and informal arrangements, including institutions, tools and processes that determine how public decisions are made and how public actions are carried out. As witnessed in many risk policy issues (e.g., the transformation needed to break free from the world's dependency on fossil fuels) civil society and businesses exert their influence across the whole policy cycle. Indeed, forming strategic alliances across governments, businesses, and civil society organizations has become the new operating norm in democratic societies. The blurring of boundaries makes it increasingly necessary to view governance as a system rooted in policy networks or 'soft' systems that can encompass complex and ill-defined problems with multiple interacting actors, often with conflicting interests and values (sometimes called "wicked" problems) (Checkland and Holwell 1998).

A key lesson learned from the 2007/2008 financial crisis was that risk governance – the institutions, rules, conventions, processes and mechanisms by which policy decisions about risks are taken and implemented (Florin et al. 2018) – is critical, yet sorely underdeveloped for existential and systemic risks. While it can be argued that the global financial system was well understood and institutionally mature in comparison with many global governance regimes, the institutions failed to predict or prevent the financial crisis (Goldin and Vogel 2010). This is not surprising considering the challenges facing institutions that manage financial risks: the complexity of rules and regulations in place with corresponding gaps and loopholes, difficulty in identifying contributing actors, unavailable or highly uncertain information on cascading impacts, undefined responsibility for taking systemic risk management decisions, and little attributable accountability for the consequences.

Wicked issues require more innovative and comprehensive approaches to problem solving through system thinking. This applies by extension for systemic risk problems, for which traditional linear methods of societal problem solving (i.e., actors agree on the problem and objectives, experts gather and analyze data and formulate a solution, public or private actors implement the solution) do not seem to work. Indeed, risk assessment and management as conventionally practiced often fail to find social consensus on highly contentious issues (note, for example, recent debates on the risks of genetically modified foods, nuclear power, financial regulation, smoking, cell phone radiation, food safety, migration, and even climate change). What's more, the very fundamentals of society's risk governance institutions may not be adequate for managing ill-defined and potentially irreversible risks that increasingly require transformational changes in system attributes: social behaviors; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biophysical systems (O'Brien et al. 2012).

This chapter is a brief foray into the challenges for governing the array of systemic risks facing modern interconnected economies and societies, and the potential of systems analysis to address these challenges. Following an elaboration of the governance challenges in the next section, we turn to briefly discuss the inroads made by the OECD and IIASA in their applications of systems analysis to selected governance issues. These range from the OECD's 'whole of society' approach applied to critical infrastructure management to IIASA's methodological innovations that apply network theory and agent-based models to risks in complex financial systems. Following the distinction made by Jentoft et al. (2007) between the system to be governed and the governance system, we emphasize the importance of inclusive and trustworthy governance processes that co-generate policy options for systemic risk governance, and we illustrate OECD's 'good governance' principles and IIASA's inroads into the design of stakeholder co-generation processes.

Challenges for governance of systemic risk

A fundamental challenge to governing systemic risk is understanding the system as a complex network of individual and institutional actors with different and often conflicting interests, values and worldviews. Superimposed on this governance network are the potential risk events with ill-defined chains or networks of interrelated consequences and impacts. While the agreed objective may be mitigating the risk, the differently perceived and constructed solutions can have far-reaching and often highly uncertain differences in their costs, effectiveness, and distribution across winners and losers. Because in a systems approach there may be many competing solutions with no clear first best, the challenge for their governance is to assure transparency, accountability and inclusiveness of the risk management process, and effectiveness, stationarity, equity, and sustainability of the outcome.

For assuring greater accountability, responsibility and awareness on the part of individual and institutional actors, Helbing (2013) has proposed a principle of collective responsibility as one central cornerstone of systemic risk governance, which echoes the OECD's whole of society approach to risk governance underpinning the OECD recommendation on the governance of critical risks.[12] However, this shared responsibility approach raises challenges. Responsibility relies on establishing attribution across the often complex geospatial and sectoral distribution of stakeholders and dealing with the large uncertainties that exist in determining the causal effects, while governments keep fundamental responsibilities. This is complicated by the fact that systemic risk can evolve up to the global, macroscopic scale through disruptions at the microscopic scale or through behaviour that is only indirectly linked to the disruption it causes (Poledna and Thurner 2016). Even in cases where the attribution question can be tackled, the complexity of the networks may diffuse responsibility, for example, it is difficult to identify the responsible institutions and risk managers in trade networks (Centeno et al. 2015). Consequently, attributing accountability limits the solution space for systemic risk mitigation, as responsibilities and liabilities are unclear; it also hampers the development of a joint vision defining clear common targets for systemic risk management.

Other governance challenges arise in assuring the stationarity and equity of the risk being managed. As a start, this will require understanding or even assessing systemic risks and their differentiated burdens, that is, identifying the triggering events, and understanding their potential for cascading impacts, exposure to the risks (and distributional aspects), and vulnerability to the impacts. Among many other considerations, risk assessment will require identifying the risk drivers, which can include financial, political, technological, and natural phenomena, and also human agency, behaviour, and even culpability (Hochrainer-Stigler et al 2018). More subtly, the human risk drivers may be actions of individuals and/or groups existing outside of recognized or established institutions, and outside of effective governance structures, for example, rogue traders, aggressive financial innovators, or terrorists. Frank et al. (2014) refer to these challenges as 'femtorisks' and stress their importance in propelling systems down paths of increasing instability and challenging standard approaches to risk assessment.

As society confronts increasingly complex risks, the governance system itself becomes more complex. According to sociologists, modernity relies on increasing complexity to manage the very risks it creates, which in turn can generate risks embedded in the construction of social organizations and institutions (Centeno et al. 2015). For example, the benefits and efficiencies that resulted from specialization of labour, economies of scale, collective knowledge, and information sharing have dramatically increased exposure to disastrous outcomes (Beck 1999).

Strategies to govern systemic risk: IIASA and OECD experience

IIASA and the OECD have pioneered strategies that build on systems analysis for the purpose of understanding, assessing, managing and generally governing systemic risks. Selected examples are briefly discussed below.

OECD's 'whole of society' approach: The OECD has focused extensively on "critical risks" as identified in its 2011 publication 'Future Global Shocks' (OECD 2011). Critical risks are threats

[12] https://www.oecd.org/gov/risk/Critical-Risks-Recommendation.pdf

and hazards that pose the most strategically significant risks as a result of (i) their probability or likelihood and of (ii) the national significance of their disruptive consequences. Critical risks are often ‘critical’ because of their cascading effects, impeding the capacity of societies and citizens to live fulfilling lives and undermining the functioning of public institutions. These risks include sudden onset events (e.g. climate extremes like hurricanes, earthquakes, industrial accidents, terrorist attacks), gradual onset events (e.g. pandemics), and so-called “steady-state” or pervasive risks. Risks of disruption to critical infrastructure systems have received special attention, both because of the potential for their effects to cascade through interlinked subsystems of economies and also because governments generally have primary responsibility for the safety of public infrastructure. Governments invest in prevention, preparedness and disaster response to protect wellbeing, competitiveness and sustainable economic growth. The OECD recently assessed country progress in the governance of “critical risks” (OECD 2019) starting with a stocktaking of the governance arrangements that underpin risk management, including a mapping of OECD governments’ self-assessments as well as of the risk governance functions of lead institutions.

From this analysis, the OECD has developed a framework for *Good Governance for Critical Infrastructure Resilience* (2019), which takes into account the systemic and interconnected aspects of critical infrastructure systems. This framework recognizes the essential systemic nature of the risks involved in core infrastructure systems that can have rippling effects through the economy and society, and the advantages of a systems-based approach to risk governance in this area combined with close interaction with critical infrastructure actors for enhancing resilience. Most importantly, this analysis underlined the importance of a “whole of government” and even a “whole of society” approach, with a systems’ perspective on the governance of critical risks.

To achieve this holistic governance approach, governments need to invest more in understanding complex interdependencies, and adopt methodologies and metrics to identify the critical functions, systems and assets that pose the greatest systemic risks. To achieve this, the OECD recommends that governments establish information-sharing platforms with operators of critical infrastructure for a comprehensive and shared understanding of risks and vulnerabilities. There is a need to consider a mix of policy tools, informed by cost-benefit analysis, to encourage operators to invest in resilience and achieve resilience objectives. Government should monitor implementation and evaluate progress in attaining resilience objectives, with a clear accountability framework for operators.

IIASA’s methodological advances: While many conventional approaches (like cost-benefit analysis) for mitigating and responding to critical risks are well established in policies and practices, the expert-led analyze-prioritize-implement approach will likely confront difficulties in assessing cascading impacts in interlinked, networked systems, characterized by a lack of historical experience and relevant data (Frank et al. 2014). For this reason, methodologies that account for systemic properties, such as complexity theory, network science, and agent-based modeling, are emerging (Florin et al. 2018; OECD 2018).

In response to the 2007/2008 financial crisis, IIASA developed and applied systems methodologies, including network analysis and agent-based models (ABMs), for understanding, assessing and mitigating systemic risk. As one application, IIASA researchers explored the idea of a ‘systemic risk tax’ that would be levied on financial transactions that contribute to systemic risk (Poledna et al. 2017; 2018). To identify these transactions, IIASA and collaborators developed an agent-based model where agents were financial actors in a dense network of financial institutions. Estimating the marginal systemic risk of individual transactions opens the way to a novel approach for managing risk by re-shaping the topology of financial networks. Based on this new approach, the authors proposed a tax on individual financial transactions proportional to their marginal systemic risk, and showed that this policy could significantly mitigate the risk of future collapse of the financial system. Another idea introduced and analysed by Leduc et al. 2017 is to use credit default swaps (CDS), which transfer the default risk from one bank to another, to rewire the network of interbank exposures in a way that makes it more resilient to insolvency cascades.

IIASA researchers have also examined the risk of cascading impacts from disasters, or indirect risk, which might emerge from the loss of critical infrastructure or supply chains. The indirect losses from disasters have been especially thorny to estimate. IIASA's unique approach is based on an agent-based model of a networked national economy (Austria). The Austrian ABM is the first to couple the macro economy with the financial system by representing financial contracts between nearly all firms and banks in Austria as a network of direct exposures, and incorporating a 'big data' representation of agents in a national economy that agrees reasonably well with real-world economic observations. The model shows how not only banks, but also firms, make a significant contribution to systemic economic and financial risks. It also shows to what extent to expect cascading indirect losses from major floods (Poledna et al. (in preparation). Based on the copula approach, a novel statistical methods, for estimating the frequency of flood extremes, the model shows that a large-scale natural disaster can have entirely different economic effects than moderate events due partly to the different financial transmission channels. This result is also due to financial limits on the reconstruction effort owning to fiscal constraints facing public officials and liquidity constraints facing private bank lenders. Importantly, the model shows how flood impacts differ substantially across industries and economic sectors. Beyond disaster losses, the model is useful for quantifying systemic risk in various economic networks, predicting responses of the economy to endogenous shocks, e.g., from the financial system, and to exogenous shocks, like transformative technological innovations or unintended consequences of political interventions such as subsidies and tax policies.

From science to evidence informed policy to risk governance

The question is how to make use of complex models and other analytical information in the policy process, or how to cross the barrier between risk science and policy. This question was prevalent in the early 1970's debates surrounding use of nuclear power, and continues today with the emergence of new, controversial technologies in and in scientific debates surrounding climate change. A confounding feature of most controversial risk issues is that 'science-to-policy' is far from a straightforward linear process, as illustrated by the need for scientific advice during crises and the need to address unknown unknowns as part of strategic crisis management (OECD 2015, 2018). For one, the uncertainties inherent in any risk estimation – and prolific in systemic risk assessments – mean that experts frequently differ on the very nature and seriousness of the risk. More troubling, in the case of systemic risks the 'unknown unknowns' can dominate 'known unknowns', meaning probabilistic estimates may be intractable, and become even more problematic where network dynamics and social processes intertwine. In this context, when policy cannot be justified on 'objective' risk estimates, the importance of a credible and trustworthy social decision process becomes apparent.

A policy context steeped in uncertainties and unknowns, and diffuse actors across political boundaries, might call for an adaptive, evolutionary and participatory learning process. If an iterative process can muster acceptance and trust across stakeholders, it might help bridge the gap between expert analyses and implementation llenges (Schinko and Mechler 2017). The importance to tackle systemic risks on a continuous and pro-active basis (such as envisioned usually in adaptive approaches) is of especial importance due to the special nature of systemic risk that may realize due to small disturbances (Hochrainer-Stigler et al. 2019). Another related suggestion is to combine systemic risks with other types of risk so that they can be tackled together (Hochrainer-Stigler et al. 2018). For example, direct risks due to extreme hazard events (e.g. monetary losses due to asset damages) can be combined with systemic risk considerations (e.g. business interruptions that cause large scale repercussions on larger levels due to affected supply chains, one prominent example is the Thailand floods of 2011). However, any collaborative effort requires interaction among heterogeneous individual, group and national actors - risk imposers and risk bearers. Current approaches are often piecemeal, presenting an ensemble of perspectives on specific aspects of systemic risk. One single perspective may inappropriately bias the view of the whole system. Hence, the OECD has emphasized the 'whole of society' approach that might naturally embrace a participatory, adaptive process with continuous monitoring and iterative evaluation on different levels, as many countries also engage in comprehensive National Risk Assessment exercises which reflect and integrate a participatory and iterative process (OECD 2018b).

Engaging multiple actors with their alternative problem frames for systemic risk is now recognized as essential for effective governance processes and ultimately for robust policy implementation (Verweih and Thompson, 2006). It is also fundamental to a systems approach. It is for this reason that stakeholder engagement has become common parlance in policy research. Indeed, Churchman (1968) recognized early on that a systems approach to policy processes actively 'folds in' as many factors as possible and looks at the issues from different viewpoints or, as he first coined the term, 'worldviews'. In this latter aspect, in Churchman's words – "A systems approach begins when first you see the world through the eyes of another" (Churchman 1968, p. 231).

Taking the example of critical infrastructure, while operators and governments typically agree on the need to protect critical assets and maintain service, their views may differ on the level of resilience required, the means to achieve it, and the regulatory requirements that should apply, given the financial implications. The key aspects involve establishing trust, ensuring secure information sharing, developing cost-sharing mechanisms and strengthening international co-operation, which require appropriate governance mechanisms. The OECD has identified up to 22 tools that governments and countries are using in this area, from prescriptive regulatory tools and compensation mechanisms to voluntary frameworks based on partnerships (OECD 2019).

The OECD also recognizes that risk governance requires the combined efforts of government, market and civil-society actors. Recent risk controversies have highlighted the critical role played by non-state actors, for example, non-smokers in raising smoking risk to political agendas, anti-nuclear advocates in changing many national energy agendas, and, more recently, public demonstrations for climate-change actions or major infrastructure projects. Still, some are calling the 21st century the post-participation era because of the growing recognition that stakeholders need not be merely participants in expert-generated policy strategies, but experts can be participants in stakeholder-generated strategies – what is termed co-generation which is key to public sector innovation. IIASA is on the forefront of developing and implementing stakeholder co-generation processes that apply system concepts to co-design and co-assess policy options, and at the same time respect the plural perspectives and frames of stakeholder groups. As one example, IIASA carried out a three-year co-generation process for landslide mitigation in Italy, where experts worked with three stakeholder groups holding very different perspectives on the landslide problem and its solution. Ultimately, a compromise solution was co-generated, agreed upon and implemented (Linnerooth-Bayer et al. 2016; Scolobig et al. 2016).

Conclusion and Outlook to the future

The importance of applying a systems approach to both the system to be governed and the governance system was recognized early on by Elinor Ostrom who saw 'the great divide' between market, state and civil society actors, and who warned that 'contrived walls separating analysis of potentially synergetic phenomena into separate parts miss the potential for synergy (Ostrom, 1996, p. 1073)'. OECD and IIASA are contributing to dismantling the "contrived walls" by developing and applying systems approaches that strengthen risk governance systems as well as improve understanding of the social and economic networks through which the risk impacts proliferate.

OECD and IIASA concepts and applications can serve as testing ground for the huge effort needed to effectively and fairly govern risks from climate change, financial transactions, biodiversity loss, and many other complex and systemic risks facing the world. Recognizing that systemic risk governance is still in its infancy, there is an opportunity to explore systems thinking in structuring local, national and global governance regimes. This chapter has provided brief ideas on this exploration, including the OECD's 'whole of society' approach for managing critical infrastructure risk and IIASA's suggestions for establishing triple learning loops to reframe or even enable transformative changes and focus attention on the critical nodes that are key to ensuring resilience of economies and societies. This chapter (as well as others within this book) has also illustrated the powerful role that methodologies, like network analysis and agent-based models, can play in understanding network behaviours and the critical network nodes that can be targeted for effective reduction of the risks. Importantly, methodologies are also under development for meaningfully involving stakeholders in the governance of systemic risks by co-generating solutions that respect the plural framings of the issues.

As systemic risks increasingly spread across political, institutional and sectoral boundaries, broad partnerships and collaborative efforts are needed between governments, businesses and civil society – between those who gain and lose from the activities generating the risks - to maintain a country's constitutional values under changing environments and evolving problems. Reducing such risks is a major public interest, and we therefore call for further institutional changes, mutual learning mechanisms and robust methodologies to enable the effective handling of systemic risks in the future. Countries can benefit from inter-governmental sharing mechanisms as well as establishing close partnerships with cutting edge academic networks to facilitate take-up of new innovative measures and foster shared investments in economic and social resilience.

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Proposals for the Way Forward

14. Public sector innovation: adapting institutions to systems thinking

By Edwin Lau, Piret Tõnurist (OECD), Elena Rovenskaya, Reinhard Mechler, Ulf Dieckmann and Fabian Wagner (IIASA)

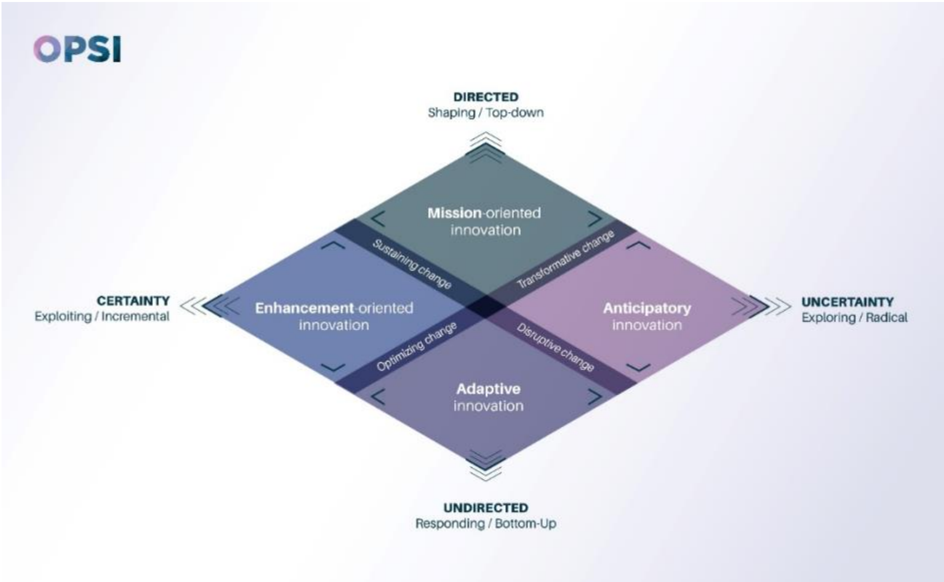
Introduction

Complexity is the core feature of most policy problems today. Globalisation has introduced new interdependencies in most policy areas, meaning that governments do not have the sole control over the success or failure of policies, or how citizens perceive their actions. Moreover, societies remain to be characterised by wicked problems – problems that do not have a single cause or a solution. Furthermore, digitalisation of society and economy is both creating new business models, services and demands, but also destroying existing practices, skill-sets and thus, producing new inequalities that the public sector has to contend with. To put bluntly, governments are dealing with a volatile and shifting policy context, where interventions that previously worked do not work anymore and where government has to be reflexive in action as policy solutions by default create unforeseen and unintended effects. This means that 'how' public sector works becomes increasingly more important than 'what' it specifically does, because the idea of permanence and best practise is disappearing. The ability to adapt to change and see systemic effects rippling through policy domains becomes critical to long-term success. Are today's public sector institutions and systems equipped to adapt to this change? Probably not.

The public sector management systems that were created over the last decades under the New Public Management concentrated on precision-target systems, focussing on the performance of programs/agencies on the 'frog view' (Bouckaert and Peters, 2002): rather than on the cross-organisation outcome level. Thus, the effects of interventions were analysed within their specific domains, policy silos, while the broader interdependencies and outcomes received little attention. This has created a lot of critique under the rise of new mission-oriented policies, which are horizontal by nature and require different capabilities and working methods from the public sector (Kattel and Mazzucato, 2018). Indeed, government capacity should not remain static; it needs to adapt to societal and technological changes (Tõnurist, 2018). Thus, public sector intuitions need to invariably change their working methods and innovate the functioning of the public sector itself. How should the sector accomplish the former and how could systems thinking help?

There are of course diverging capabilities that the public sector needs to cultivate. For example, the Observatory of Public Sector Innovation has proposed a new model for public sector innovation based on the level of uncertainty and directionality of (desired) change (Figure 14.1). The model defines four different facets – enhancement oriented innovation, mission oriented innovation, adaptive innovation and anticipatory innovation – and all these different facets require diverging strategies and working methods to be successful. Systems thinking works best in the context of purpose-driven change, when the goals and problems are known or can be collectively defined (OECD, 2017).

Figure 14.1 Public sector innovation model



Note: The model is developed as part of the work of the Observatory of Public Sector Innovation, OECD.

Source: OECD.

Applying a systemic lens to complex problems can help map the dynamics of the system, explore the ways in which the relationships between system components affect its functioning, and ascertain which interventions can lead to better results. Thus, systems thinking can help clarify the need for innovation in the public sector itself. Therefore, systems thinking tools and methods could be the solution for 21st century missions, where the public problems and purposes are shifting and methods to adapt the institutions need to also reflect the former.

Systems thinking practice in the public sector

While systems thinking as the methodology behind purpose-driven change could be used to deliver on the 21st century missions, it does not mean that public sector is interested or ready to use it for that aim. Systems thinking inside the public sector has been so far used as a ‘sense-making’ tool to make interconnectedness visible (usually with the help of outside experts – see box 1) rather than a day-to-day practise that helps guide everyday action and decision-making.

Box 1. Systems thinking in the practise of IIASA

Strategic planning of water resources and water infrastructure in the context of conflicting stakeholder interests, high risks and uncertainty.

In July-December 2018 IIASA and OECD conducted a gamified participatory capacity building exercise for policy makers and experts from the EU's Eastern Partnership countries. Its aim was to present to participants how a strategic planning process in the water sector can be organised to come up with robust water strategies by eliciting collective wisdom of relevant experts and stakeholders. The approach builds on a fusion of a number of qualitative systems analysis methods, including multi-criteria decision analysis, systems mapping, morphological analysis, scenario building, and robust decision-making. It enables a group of stakeholders and experts to collectively produce a set of agreed strategic objectives, analyse enabling factors, which allow to achieve these objectives, understand key uncertainties involved in the underlying processes and derive robust policies.

In this project, IIASA involved individuals representing relevant stakeholders from Belarus, Georgia, Moldova and Ukraine and ran a process implementing the participatory strategic planning approach for an imaginary country. As a result, the process participants, facilitated by IIASA researchers, worked out a prototype of a national water strategy of this imaginary country. This particular process was designed to help participants to acquire a deeper understanding of the role of uncertainty in decision making, to enhance their experience in developing resilient water strategies and to raise their awareness about strategic planning methods taking into account the nexus of water with other sectors, notably, food and energy. In this way, this exercise strengthened the capacity of the participants in strategic planning, which was its primary purpose.

IIASA put forward this participatory strategic planning approach as a tool to support a sustainable water management in a country by recognising and operationalising systems thinking, which allows to reduce the risks of unintended consequences and optimises the use of water by multiple consumers.

Source: IIASA.

Yet, sense making or visualisation of the system alone does not a priori lead to more systemic action or increase understanding of what needs to be changed in practice (OECD, 2017). If the systems thinking capacity in the public sector is not high or there is no mandate or window of opportunity to change things, it falls under the complexity-decision making paradox: systems thinking exercises are viewed as 'interesting' to policymakers, but not useful for them in their specific context.

Systems thinking becomes a source of innovation in the public sector when there is actually room to change the structures and functioning of government in line with systemic needs. Otherwise, the public sector cannot do anything but ignore the complexity connected to policy problems, because they do not have efficacy to do anything about it. Alternatively, public servants start to concentrate heavily on selected technical details – the frog view – that civil servants feel that they can control and deliver on, creating a false sense of certainty and purpose of action. Sometimes a number of incremental changes becomes a source of cumulative change; however, often many layered policy interventions, well intended they may be, will not make any difference at all, because they do not address the interconnected issues or the scale of issues adequately. This is not to blame policymakers or civil servants: the existing performance management and budgetary systems influence them to be reductionist in their work. Thus, part of the inability to use systems thinking in the public sector comes from the fact that established systems and government silos are created to deliver on goals and problems defined by a previous mass-production era and they are highly path-dependent in nature. Hence, systemic reform of the public sector is needed (towards more adaptive, reflexive processes), so, that systems thinking can be effectively applied in specific policy fields.

What makes the application of systems thinking even more difficult in the public sector is that existing systems cannot be turned off, redesigned and restarted, because there is high need for continuous service provision (e.g. healthcare, education). Although an interesting exercise, there is no luxury in the public sector to do zero-based budgeting with the help of systems thinking every year. Thus, the government needs to learn to introduce change in an iterative manner even if the change itself is contradictory to current practice.

Making systems thinking actionable in the public sector

Creating room for open-ended processes and synergistic feedback – more holistic practises inside the public sector – is not easy; yet it is not impossible. The Observatory of Public Sector Innovation has been working with OECD member countries to introduce systems thinking methods in the public sector starting with Slovenia, Scotland and Finland. The methods have been applied to review existing systemic reforms: for example the introduction and implementation of the National Performance Framework (NPF) in Scotland (Box 2). The Scottish experience showed that even if from the top-down the need for systems change is acknowledged and supported, it does not lead to uniform effects if the government and its capacities are not internally reformed to support action in a systemic manner.

Box 2. From sense-making to roadmaps: building collective scenarios for the Scottish NPF

Outcome-based management has been a trend in many OECD countries in the last decades, supported by performance-based budgeting and whole-of-government approaches. This has also led to more nuanced and welfare-oriented national goals. Many countries (e.g., Ecuador, France, Italy, New Zealand, Sweden, and the United Kingdom) are moving to measure welfare beyond-GDP and Scotland has been one of the early movers in this arena. Yet, there are many – political, process, measurement etc. – barriers connected to the adoption of such goals and their measures in policymaking. Consequently, even though more and more national governments have taken on the challenge of developing well-being measures and frameworks, and these are often well-documented in reports and websites, much less has been recorded about how, or even if, these indicators are actually being used to inform their policy decision-making.

The Scottish government's NPF was first published as part of the 2007 Spending Review, and was refreshed in June 2018. The aim of the NPF was to unite the government under a single overarching purpose connected to sustainable, inclusive growth and wellbeing of its citizens and set high-level, measurable targets for the government (figure 1). The content (the underlying values, aims, and national indicators), can be accessed on a central website, where the government reports on the performance of the framework.

Figure 2. Scottish National Performance framework

11 national outcomes

Source: Source: https://nationalperformance.gov.scot/.

It sets out a vision for Scotland, which uses an outcomes-based approach to measuring government's achievements, rather than inputs and outputs. During its establishment, the Scottish government tried to forgo existing silos by getting rid of departmental divisions and structuring action based on the NPF. Consequently, the NPF started to form the basis of performance agreements with public service delivery bodies, and is used to monitoring their effectiveness. Yet, it did not mean that uniform progress across the NPF goals were made. Some fields, including environment and justice adapted their institutions, while others carried on as usual.

In 2018, the Scottish government worked together with the Observatory of Public Sector Innovation using systems approaches to find out how much progress had been made over the ten years and what the systemic barriers inside the government were. The work culminated with a collective workshop on scenario-building to address some of the systemic barriers in the government. This enlightened new and innovative approaches to some of the issues faced by the public sector and the potential to push the transformation process further. Thus, systems thinking can be used as a way to spur on collective innovation around missions.

Source: OECD.

The OECD's practice (see Box 3) has shown that making systems thinking actionable in the public sector is, however, not only reliant solely on capacity – public sector institutions and their eco-systems themselves need to be adapted to new types of missions/challenges to be fit for purpose (budget cycles, organisational silos, feedback mechanisms etc.). Sometimes there are very concrete issues – such as political mandates, constitutional structures and behavioural influences from political interest (e.g., coalition governments) – that cannot be changed, but influence systemic change profoundly. This does not have to paralyse action, but these should be analysed as boundaries for action – the borders of the innovation sandbox – that need to be designed around.

Designing cumulative systemic processes becomes even more important when different levels of governance are needed to make interventions effective. The case of air pollution is one of the most indicative here, because its determinants and effects transcend the usual areas of interventions (Box 5).

A case for soft systems thinking?

Decision processes have often been one way, meaning experts provide facts and a preferred decision option to responsible authorities, which may be chosen or not. This is opportune when there is a clear societal objective and various methodological approaches for illuminating policy paths to these goals. In contrast, when policy issue are ill-defined, even "wicked" in the sense that there are irreconcilable views on the problem and its solution – what cultural theorists refer to as "contested terrain," multi-actor involvement can be essential for policy legitimisation and implementation. IIASA has been unique in structuring expert-stakeholder deliberative processes that bridge the gulf between systems models and practical policy options, what has been called *soft systems science*. The methodological approach encompasses a process of interaction, communication, and policy-making among the complex web of actors involved, including governments, international negotiators, businesses, conservationists, and civil society. As a IIASA-contributed book demonstrated across more than ten cases that policies made without participation from "all the voices" were significantly less robust than those with inclusive deliberation (Verweij and Thompson, 2011[41]).

Box 3. Local policy impact by implementing inclusive stakeholder processes

Soft system science for informing disaster risk management in Nocera Inferiore, Naples, Italy

In the city of Nocera Inferiore located at the base of the landslide-prone Mount Albino close to Naples, Italy experts worked with the municipality and jointly decided to build a landslide protection wall at the foot of a mountain, which was met with intense public protest (Amendola, 2013[42]). The municipality welcomed a IIASA-led public participatory process to resolve the issue as there had been little guidance on how to institutionalise a two-way model for disaster risk management; that is, how to design deliberative processes that involve stakeholders and scientific experts for the purpose of eliciting their worldviews and co-producing knowledge for the policy process. The core feature of the IIASA-designed Nocera Inferiore process was the interactive coupling of expert-formulated policy options (including hazard and risk modelling) with stakeholder discourses. To generate alternatives to the wall, and ultimately resolve the issue of how to protect residents against landslides, IIASA designed and led a three-year process that made use of extensive stakeholder interviews, a public questionnaire, public meetings, an interactive web platform, and an extended citizen deliberative process. Based on respect for diverse stakeholder views and rejecting the notion of "consensus," the process ended with a workable compromise in terms of a set of risk management measures to reduce landslide risk that were accepted by the municipality and other responsible authorities and are seeing implementation.

Sources: (Scolobig and Linnerooth-Bayer, 2016[43]) (Linnerooth-Bayer, 2016[44])

Conclusion

This chapter highlights that the public sector itself needs a systemic change to be ready to use systems thinking tools for not only sense-making, but also as a methodology to deliver on the 21st century missions. It is not enough to talk about what types of systemic change are needed in different policy fields without connecting it to the ability of public sector institutions to implement the desired changed. As such, systems approaches cannot be introduced in the public sector through theory alone – they need to be learnt by doing and their implementation has to be continuous and inclusive, not ad hoc. This is needed as systems thinking is necessary to tackle complex problems and help reach compromise on complex public sector goals (such as missions) as it helps avoid or deal with continuously with unexpected and unwanted consequences. Consequently, systems thinking is a practice, not a theory; hence, civil servants and public sector partners should learn to apply it in actual examples.

Nevertheless, even if policy makers as individuals are systems thinkers, it does not mean that policies they fabricate are systemic; one needs institutions to support systems policy making. Yet, clearly systems thinking, hard and soft, is and will continue to be an important part of the public sector toolbox in dealing with complex challenges and upcoming missions. OECD's and IIASA's work in this field has shown that the public sector leaders face an uphill battle: there is little clarity on who should promote systems thinking in public organisations and who should assure their capacity.

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15. Human capabilities for systems leadership: disseminating systems thinking through education and training

By Martin Lees (OECD), Ulf Dieckmann, Gerid Hager and Fabian Wagner (IIASA)

Systems thinking

Frequently, people do not encounter the principles of systems thinking in their formal education. Consequently, without the necessary tools at their disposal they cannot apply systems thinking to understand and evaluate systemic issues that affect their lives and futures.

Yet we live in a systems world, in which systems thinking is increasingly indispensable. Four trends over the past few decades have enhanced the need for individual and collective actors to understand and engage with challenges of a systemic nature:

- **Interconnectedness**. Humanity is confronted with an array of deeply interconnected difficulties and objectives. These often involve linkages between local, regional, and global scales and extend across the economic, social, environmental, and security facets of human activities. Long-term trends toward economic, political, and digital globalisation are intensifying these interconnections.
- **Speed**. The processes associated with these challenges are dramatically accelerated by new information and communications technologies supporting finance, economic and trade systems, just-in-time production chains, food production and distribution, and research and innovation in an interdependent world. This implies that the consequences of interventions cannot just be analysed in paced iterations, as was the traditional practice, but must often be anticipated and integrated holistically in the very design of such interventions, requiring step changes in the systemic scope of the underlying analyses.
- **Data**. The technological systems enabling this acceleration often make it possible to measure, monitor, and memorise an incredible and highly heterogeneous amount of data across many spatial and temporal scales. In principle, this unprecedented stream of data can enable systems analyses and systems solutions of a qualitatively different kind and reach than was possible before.
- **Computing**. The computing power and algorithmic prowess available for processing all this data have risen to a level at which fundamentally new practices of analysis are emerging, e.g., using machine learning and artificial intelligence, that enable data scientists to harvest the available information in innovative ways. Through the arrival of potent software, the power to conduct such analyses in moving from the hands of a select crowd of experts to a much larger group of data analysts and citizens.

Together, these trends have led to a revival of systems thinking, following in the wake of an earlier golden era that started about 50 years ago. Today, the demand for systems thinking is widely articulated and it is seen, sometimes perhaps even with too much optimism, as critical for overcoming an overly technocratic, reductionist, and compartmentalised traditional approach, and is thus deemed apt for tackling the most difficult challenges of the 21st century.

While systems thinking offers a coherent, rigorous, and balanced approach to analyse and understand complex, interconnected, and dynamic issues, the character and ambition of systems thinking have been changing over time. After innovations in operations research during and after World War 2 broke new ground in terms of recognising feedbacks, nonlinearities, and networks, simple early applications of systems analyses have nowadays often become integrated into disciplinary analyses. Through decades of development, today's ambitions have risen considerably with needs and capabilities. In this understanding, systems thinking – by definition – is pushing the envelope, going further than established disciplinary approaches toward the integrated, interdisciplinary, and holistic analyses of complex systems. Likewise, challenges at the cutting edge of contemporary systems analysis can be expected eventually to recede into the disciplinary background of mainstream practices, to be replaced by ever new challenges arising at the forefront of devising integrated approaches to addressing issues in complex, interconnected, and dynamic systems.

Based on these considerations, disseminating systems thinking through education and training will always be a moving target. With the functioning of institutions and the formulation and implementation of policies critically depending on the knowledge, skills, and motivations of people at every level, self-innovating education and training in systems thinking will be central to produce a new generation of public- and private-sector leaders, experts, and teachers – and an informed public – competent to understand and act on the systemic challenges of the modern world. Such competences in systems leadership are also essential for the effective and efficient design of institutions facilitating the development of multidisciplinary teamwork and interdepartmental strategies and programs, supported by innovative modelling, scenario analysis, and the tools of systems thinking.

OECD and IIASA are both in the vanguard of institutions addressing these challenges, pursuing their missions bolstered by considerable track records of past and present achievements.

Target audiences

Building human capabilities for systems leadership is a highly multifaceted challenge, as a wide variety of target audiences can benefit from the dissemination of systems thinking through education and training:

- **Practitioners**. Policy makers, public administrators, ministry officers, business leaders, diplomats, negotiators, and development-aid officials need systems thinking to arrive at more integrated solutions to many pressing policy issues. Such solutions, when devised and implemented appropriately, are superior to traditional approaches by addressing problems more robustly (since systems boundaries have been drawn comprehensively), covering more loopholes and opportunities for gaming the system (since the underlying feedbacks have been recognised), and gaining acceptance among larger segments of the relevant constituencies (since complementary views of multiple stakeholder groups have been taken into account).

- **Experts**. Policy analysts, systems analysts, and education analysts often use systems thinking as a core part of their professional toolbox. Typically, these experts need to train in and subsequently apply concepts, methods, models, and tools at the cutting edge of systems thinking. Achieving a higher degree of integration and using a more modern suite of systems-analysis tools are likely to make their research stand out from the mainstream and help generate additional impacts beyond their immediate peer audiences.
- **Teachers**. Academic teachers, school teachers, and adult-education teachers have an important responsibility to lay the groundwork of systems thinking in the minds of learners, enabling next-generation systems competence and systems leadership. Their general objective in teaching systems thinking is to communicate transferable knowledge, qualitative approaches, and flexible heuristics. Such teaching enables learners personally to experience successful applications of systems thinking before taking such approaches into the contexts of institutional decision making and scientific research.
- **Learners**. Academic students, school students, and adult-education participants will initially experience the growth of their competences in simple applications of systems thinking. Once the power and versatility of systems thinking has thus becomes tangible to them, they are more likely to infuse the underlying approaches – depending on the direction in which their professional responsibilities develop – into institutional decision making and scientific research.
- **General public**. The broadest audience for the dissemination of systems thinking is the general public, which not only includes the aforementioned groups, but further extends to all citizens interested in understanding the complex systems in which their lives unfold. Also for members of the general public, systems thinking can be highly beneficial, helping them to avoid pitfalls of reasoning when managing everyday situations or engaging in debates about contentious policy issues.

The high diversity of relevant target audiences underscores why the successful dissemination of systems thinking cannot follow a one-size-fits-all strategy. Instead, there will be more and less successful ways of communicating the concepts, methods, models, and tools of systems analysis to each of these audiences. More successful training and teaching will take into account from which level of knowledge the training commences, highlight those benefits of systems thinking that are particularly attractive for motivating the given audience, and use examples and applications that are close to the target audience's experiences and needs.

Inclusive framing

The key to systems thinking is inclusive framing. This means that systems approaches display a higher level of ambition than traditional approaches toward overcoming overly compartmentalised methods of analysing complex phenomena. It also means that the standards of systems analysis are constantly rising: what may have been an adequately ambitious level of inclusive framing, and thus part of systems analysis, decades ago, often becomes part of disciplinary analyses once widely accomplished. Systems analysis, understood in this way, keeps raising its standards.

Two recent examples may serve to illustrate this general trend. First is the widespread drive towards so-called nexus research in the earth-system sciences, through which analyses of anthropogenic impacts on land, energy, and water – and, possibly, additional targets – are becoming increasingly intertwined. This drive can be seen as a natural response not only to the need for such integration, which has existed for decades, but also to the fact that such an ambitious degree of integration has gradually transitioned into the realm of operational feasibility during the last decade. A second example is the rise of research on network dynamics and systemic risk in the wake of the Global Financial Crisis of 2008. This development can be interpreted as a swift and still expanding movement toward applying the advances of decades of research on network theory and complex adaptive systems to the new set of highly integrative system-level questions that have quickly gained prominence and momentum through this crisis.

When striving for the inclusive framing of a particular challenge in the spirit of systems thinking, many aspects need to be considered, some of which may be fairly problem-specific. Yet, there are at least five dimensions of inclusivity that are consistently helpful for structuring the perspectives on essentially any challenge to which systems thinking can usefully be applied:

- **Impacts**. Maybe the most obvious dimension in which systems thinking requires inclusive framing concerns the impacts of the considered dynamics. This is where system boundaries feature prominently and detrimentally affect the quality of analysis when drawn too narrowly: in the latter case, important impacts are left on the outside and therefore cannot be accounted for as part of an integrated analysis. It is by now widely acknowledged, if perhaps not yet widely remedied, that what economic analyses refer to as externalities are almost always critical components of the wider problems to be solved. The notion of externalities results from drawing narrow boundaries around a system's economic components in general, and around the processes affecting and affected by prices through market forces in particular, while leaving the system's environmental and social components on the outside. If changes in market dynamics negatively impact those other components – be it through pollution of the environment, losses of biodiversity, overexploitation of non-traded natural resources, or anthropogenic climate warming on the environmental side, or through declines of trust or precaution, reductions of public safety, rises in infection risks, or degradations in public health on the social side – these impacts fall outside the scope of market-based analyses. While it is sometimes possible to internalise externalities through taxes, many externalities cannot easily be regulated in such market-based manners. In such situations, it is therefore crucial to draw system boundaries widely enough so as to capture the externalities as part of a sufficiently holistic accounting of impacts.
- **Feedbacks**. Crucially, the various impacts occurring throughout a system may all be part of feedback loops. Ignoring such feedbacks in an overly narrow style of analysis is particularly hazardous: while short-term predictions may well be accurate,

potentially inspiring an erroneous sense of confidence, long-term predictions may be far off the mark. A prominent example are the feedbacks between a society's status in regard to demography, education, and affluence. Curbing demographic growth often helps promote education and raise affluence, which, in turn, further curb demographic growth. Overlooking those potent feedbacks has led to the notion of demographic explosion staying at centre stage in many discussions of sustainable development during the past decades. In general, feedbacks can be positive or negative. Positive feedbacks occur when the rise in one indicator stimulates the rise of another, and vice versa. Such positive feedbacks are destabilising certain components of a system. Negative feedbacks, in contrast, are stabilising and occur when one indicator's rise causes another indicator's reduction, and vice versa. Evidently, overlooking positive feedbacks is particularly harmful to the quality of systems analysis.

- **Trade-offs**. When specifying the objectives of a particular policy intervention, trade-offs and synergies naturally come into play. The reason is that such objectives at the system level typically have multiple components, and advancing in the direction of one component may make it harder (in the case of trade-offs) or easier (in the case of synergies) to advance in the direction of another component. It is even possible that under a sufficiently broad perspective a trade-off can turn into a synergy, and vice versa. The notion of green growth is tightly linked to broadening the framing of the apparent competition between economic growth and environmental protection to a level of inclusivity at which it becomes possible, or at least plausible, that investments in environmental protection become important drivers of economic growth. When trade-offs or synergies are not well reflected in an analysis, either because some of their components are left outside the drawn system boundaries or because the relationships specifying the trade-offs or synergies are poorly quantified, major errors in the predictions derived from such analyses are inevitable.

- **Emergences**. Many systems of sufficiently high complexity have the capacity to self-organise in ways that lead to newly emergent phenomena and dynamics. Such emergences mean that the rules of the game played in the system are qualitatively altered, in ways that were difficult to anticipate before the change happened. Typical examples are broad political developments, such as the emergences of revolutions, new parties, or social movements, which are notoriously difficult to predict in analyses until they have started to unfold. These emergent phenomena are often associated with behavioural, social, and institutional dynamics. Since culture, psychology, and beliefs thus profoundly affect real-world systems, the human and social dimensions of systems thinking are of fundamental importance. Hence, including such aspects in system models can be a critical, if not sufficient, antidote against overlooking emergences. Other examples of emergent phenomena arise from tipping points in natural systems, such as a lake's sudden eutrophication, the closure of the ecological niche of an overexploited species, or the breakdown of the thermohaline circulation driving the Gulf Stream. The quality of a system's analysis rises with recognising and accounting for a wide range of emergent phenomena that can act as game changers.

- **Stakeholders**. When a policy challenge involves many stakeholder groups, the inclusive framing of solutions, or of processes suitable for collectively identifying them, is essential for the subsequent degree of policy acceptance. In contrast, when solutions are sought with insufficient inclusivity – for example, when governments and market actors cooperate while excluding environmentalists or indigenous people – the acceptance, implementation, and longevity of the resultant measures tend to suffer. Starting out from a sufficiently wide framing in terms of stakeholder groups will thus be costly initially, but may pay off in the longer run in terms of establishing solutions that enjoy a higher degree of endorsement and robustness.

Complementary perspectives

Beyond the five key dimensions of inclusivity in systems thinking outline above, three additional perspectives help avoid overly narrow framings. Each of these perspectives can be thought of as providing a mental checklist systems analysts can use to minimise the risk of overlooking important aspects of a problem and consequently framing it too narrowly:

- **Sectors**. Good systems thinking often requires multi-sectoral approaches. Scanning through the economic sectors that are related to a particular challenge is therefore helpful to ensure that no important impacts, feedbacks, tradeoffs, emergences, or stakeholders have been overlooked. As part of this scrutiny, care should be taken to ensure that the resultant analysis is not unduly dominated by economic perspectives alone.
- **Disciplines**. Good systems thinking often requires interdisciplinary approaches. Including – or, at least, consulting with – representatives from different disciplines in the framing of a particular analysis can thus substantially reduce the otherwise high risk of arriving at an overly narrow framing. As part of this scrutiny, care should be taken to ensure that the resultant analysis is not unduly dominated by natural-science perspectives alone.
- **Scales**. Good systems thinking often requires multi-scale approaches. This is important since the impacts, feedbacks, tradeoffs, emergences, and stakeholders associated with one scale can differ, subtly or substantially, from those associated with another scale. Regarding spatial scales, revealing teleconnections or conflicts among the interests of local, regional, global stakeholders are only two benefits that are likely to accrue from an awareness of how scales are connected in the context of a particular problem. Regarding temporal scales, the analogues of the aforementioned conflicting interests are central for understanding intergenerational equity, but also have a bearing on appreciating how incentives to policy makers and business leaders are affected by the durations of their terms of office.

Avoiding pitfalls

Common cognitive pitfalls can impede good systems thinking. According to Benson & Marlin (2017), the following suite of mental heuristics can aid practitioners in side-stepping these pitfalls:

- **Broad perspective**. The authors advise to take a sufficiently broad perspective on the problem at hand, by examining connections within and between systems, seeking to understand the big picture, changing perspectives to increase understanding, and resisting the urge to come to quick conclusions.
- **Careful scrutiny**. The authors advise to invest careful scrutiny in framing the approach to a particular challenge, by observing how system elements change over time, understanding how a system's structure generates its dynamics, revealing unintended consequences of actions, and challenging how hidden assumptions and mental models may impinge on the analysis.
- **Nonlinearity awareness**. The authors advise to pay particular attention to how nonlinearities affect the considered system dynamics, by identifying complex cause-effect relationships and recognising the impacts of time delays and cumulative processes.
- **Enlightened management**. The authors advise to use a modern approach to managing complex systems, by focusing on possible leverage actions, monitoring the outcomes of actions, and iteratively adjusting the actions accordingly.

Training dimensions

Training in systems thinking can take many forms, the best choices of which strongly depend on the intended target audience. As a starting point for designing specific interventions, it may be helpful to recognise the following five universally relevant training dimensions, as summarised in the adjacent figure:

- **Qualitative principles**. Most training interventions for promoting systems thinking among non-experts will de-emphasise technicalities and instead emphasise the qualitative principles that are characterising good systems thinking. The main aspects of these qualitative principles have been laid out above: good systems analysts systematically strive to frame their approaches inclusively (with regard to impacts, feedbacks, trade-offs, emergences, and stakeholders), proactively consider complementary perspectives (in terms of sectors, disciplines, and scales), and carefully avoid cognitive pitfalls (by adopting a broad perspective, careful scrutiny, nonlinearity awareness, and enlightened management). Teaching these principles in the abstract can only go so far: it is therefore helpful to embed their teaching in the broader context of the following four additional training dimensions.
- **Quantitative methods**. Quantitative methods are part and parcel of any real-world systems analysis. Consequently, the training of systems-analysis experts has to give high priority to teaching a broad range of salient methods. For non-experts, in contrast, the teaching of quantitative methods can raise undesirable barriers, because it requires sufficient time, depends on adequate background training, and risks frustration. For such target audiences, it will be more appropriate to provide information about the existence of salient methods and about how they are used in systems analyses, rather than build detailed skills to apply these methods. The

portfolio of quantitative methods to be covered in the teaching of systems thinking would typically include elements of the following: scenario analysis, causal-loop analysis, statistics, machine learning, dynamical systems, stochastic processes, game theory, agent-based modelling, bifurcation analysis, and control theory.

- **Simple models**. Building awareness of the consequences of nonlinearities and feedbacks is another central dimension of training in systems thinking. This poses particular challenges, since real-world experiences leave most people ill-equipped to assess and understand nonlinearities and feedbacks. Simple models can play an important role in addressing this training need, enabling the target audience to explore – and thus, ultimately, to understand – such complex dynamics in minimalistic settings. The range of specific phenomena to be covered in the teaching of systems thinking aided by simple models would typically include the following: exponential and logistic growth, positive and negative feedbacks, time delays and lagged responses, emergence of oscillations and chaos, clustering and percolation, contagion and systemic risk, strategic interactions and best responses, tipping points and bifurcations, collective phenomena and phase transitions, as well as pattern formation and self-organisation.
- **Complex models**. Contemporary systems analysis heavily relies on complex models, whose development and maintenance requires long-term commitments by sizable teams of researchers. The models themselves may involve, for example, agent-based dynamics or optimisation principles based on linear programming, but commonly are so extensive that specifying them in the short space of a scientific paper's methods section is impossible. Accordingly, introductions to the use of such models often have the character of demonstration sessions, in which trainees are shown what the model can accomplish, how model inputs are specified, and how model outputs are extracted. Since such complex models are, therefore, not well amenable to teaching, it is critical, for the purpose of training non-experts in systems thinking, to explain how the design and operation of such models are related to the aforementioned more comprehensible qualitative principles, quantitative methods, and simple models.
- **Examples**. The fifth training dimension is highly important and involves success stories, application narratives, and case studies. By grounding the more general and abstract first four dimensions in the context of more specific and concrete challenges, approaches, and solutions, the practices of systems analysis are becoming tangible.

For teaching systems thinking to non-experts, the approach indicated by the three red arrows in the figure above seems most appropriate. This approach works by illustrating quantitative methods, simple models, and complex models through success stories, application narratives, and case studies, to instil in the target audience a clear understanding of the qualitative principles of systems analysis as the primary objective of the training.

Training instruments

Mirroring the diversity of target audiences and the richness of training dimensions, many instruments are suitable for disseminating systems thinking through education and training. The two principal characteristics according to which these training instruments can be organised are the target audience (ranging from practitioners and experts over teachers and learners to the general public) and the training duration (ranging from minutes to years). The following list attempts to inventories the broad range of possibilities:

- **For practitioners**. In typical settings, practitioners have preciously little time to devote to learning about systems analysis and systems thinking. Training interventions that are suitable for members of this target audience thus have to be relatively compact and particularly relevant in serving their professional needs. Short courses and professional training sessions lasting for a few days may be most suitable. Other options include written briefing materials such as policy reports that combine high accessibility with high information density. Such materials can draw on practical, focused examples, to convey the realities of systems dynamics and the associated risks to policy makers, public administrators, ministry officers, business leaders, diplomats, negotiators, and development-aid officials who are not familiar with the concepts and tools of systems thinking. In view of the relevance of systems thinking for supporting longer-term processes of institutional design and transformation, special training interventions for practitioners could be envisaged in the contexts of developmental aid and institutional management. Such interventions could be arranged over a longer time period, potentially accompanying the relevant design and transformation processes.

- **For experts**. Training instruments for enhancing the systems-analysis skills of experts in narrowly defined thematic areas are already well established and typically comprise training workshops and collaborative research activities. Where broader introductions for these audiences are useful, they can take the forms described above for practitioners.

- **For teachers**. To promote the ability of teachers to enhance skills in systems analysis and systems thinking, materials can be developed that make it easier for them to integrate such objectives into their teaching portfolios. At the most ambitious and comprehensive level, this can take the form of curricula for academic students, school students, and adult-education students. At the next level, teaching modules can be developed that enable teachers to combine multiple such modules as building blocks according to their needs. At the most concrete level, specific course materials can be offered. When the goal is to interest teachers in systems thinking by highlighting its potential as part of their teaching activities, broader introductions, as described above for practitioners, can be considered.

- **For learners**. To benefit academic students, curricula for bachelor's, master's, and PhD degrees can be adjusted toward communicating the concepts and tools of systems thinking and systems analysis, potentially supported by the aforementioned teaching modules and course materials. A comprehensive approach to building societal competences in systems thinking must start with students at school or even earlier. Training elements suitable for academic students therefore need to be adjusted and re-developed for learners with less advanced academic backgrounds, before being incorporated, for example, into school projects and adult education. For many learners, especially in developing countries and rural regions, the availability of such opportunities through online courses and distance learning will be essential. For advanced academic students, teaching should ideally be complemented by hands-on practical exercises and mentored research.

- **For the general public**. Many of the aforementioned instruments are also suitable for other target audiences and the general public. In particular, briefing materials can be developed at all levels, tailored to specific target audiences. A particular approach with broad relevance and wide current appeal are experiential games. Such games enable immersive group experiences that can be highly valuable for instilling in the minds of participants key insights about the functioning and management of complex systems. Details about this promising non-traditional approach are provided in the next section.

The various training instruments outlined above can all benefit from a maximally clear understanding of what constitutes the essentials of systems thinking and systems analysis. Surprisingly, such an understanding often remains implicit in the work of many practitioners and experts. While the associated plurality of opinions may be enriching, it can also engender confusion. For this reason, it would be beneficial to distil the essentials of systems thinking and systems analysis into what may be called a foundations course, with the aim that the design of such a course can serve as a foundation for the design of more specific interventions. Ideally, the foundations course would thus provide two levels of specification: first, it would identify the essentials of systems thinking and systems analysis to be covered, and second, it would identify alternative means of coverage that are differentially geared to the needs and capabilities of alternative target audiences.

Experiential games

Experiential games are an innovative way to train systems competence, i.e., the ability to understand and assess the interlinked nature of a highly connected human-earth system. This includes the ability to deal with uncertainty and incomplete information at multiple levels, as well as skills to communicate and make joint decisions across departments, industries, sectors, and stakeholders.

What is needed are learning and training situations based on real-life scenarios that offer the possibility to test actions, boldly try and explore new strategies, and reflect on the resulting consequences within a safe, simulated environment. *"The World's Future – A Sustainable Development Goals Game"* is an innovative experiential game[13] jointly developed by the Centre for Systems Solution[14] and IIASA. It combines the benefits of systems analysis and

[13] https://worldsfuture.socialsimulations.org
[14] https://systemssolutions.org

simulation techniques with the dynamics of group-based scenario building and creative role playing. The experiential-game approach thus offers a highly immersive and transformative learning experience.

Within about six hours, game participants gain considerably broad and deep insights into the complexities of and multi-level interactions among the Sustainable Development Goals (SDGs) within the human-earth system, which cannot be achieved as easily and deeply using conventional training instruments. The experiential-game approach deliberately does not offer how-to-guidelines or solutions, but instead creates a space within which participants can better understand and learn how to deal with incomplete information, feedback processes, and how to face complex challenges together. It offers tangible experiences that can greatly improve the systems-thinking skills of participants, allowing them better to grasp interlinked social-ecological complexity.

Since 2017, participants from the Directorate General DEVCO of the European Commission, the European Parliament, the European External Action Service (EEAS), and the OECD have successfully engaged in the *"The World's Future – A Sustainable Development Goals Game"* gameplay, amongst others, offering the following testimonials:

- *"It was a humbling and eye-opening experience for me as a policy writer – to be confronted with the complexity of policy making in action and trying to find sustainable solutions, even in a simplified version of reality."* – Participant from the Directorate General DEVCO of the European Commission
- *"I got a much clearer insight that policy making is actually very messy based on imperfect understanding of the system and incentives, and on imperfect information of what others are doing."* – Participant from OECD
- *"As an industry, why would we really care about climate impacts or try to avoid them? But down the line, we experienced the effects on our infrastructure and workforce. We didn't think about that connection in the beginning."* – Participant from OECD

References

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16. Outlook: towards an OECD-IIASA Multiannual Work Programme

By Martin Lees, William Hynes (OECD) and Jan Marco Müller (IIASA)

A whole series of scientific and analytical reports– supported by growing evidence in the real world – have underlined the increasing scale, intensity and urgency of the issues and vulnerabilities we face in the world economy, in international finance, in society and politics and in regard to the environment, the climate and resources. As outlined in this publication, these issues are intrinsically complex, connected and systemic.

The challenge set to the Strategic Partnership and its Task Force – and, in a wider perspective, the challenge to OECD and IIASA – is to develop systems approaches which can combine scientific rigour and evidence with economic and social realism to propose innovative strategies to address such global issues. This is the international context in which the field of economics is facing both challenges and opportunities to adapt to the new imperatives of the 21st Century.

OECD and IIASA together can provide an international focus and intellectual leadership to stimulate and support transformative change towards inclusive and sustainable societies. There is an important opportunity to develop cross-cutting recommendations and briefing materials for policy makers and OECD Committees through coordinated presentations and modern techniques of communication. A key objective must be to explain the tools and insights of systems thinking in simple terms. This will enhance the ability of non-experts, including in many cases, policy makers themselves, to understand and anticipate better the risks and opportunities of systemic challenges and to act effectively in response.

The Strategic Partnership has been consolidated during 2018 and 2019 and is recognised as a credible, innovative and useful initiative by a growing number of OECD Permanent Representatives and in the capitals of some Member States. At its second meeting in January 2019, the Task Force endorsed an indicative multi-year Programme of Work as a broad basis for the development of its future activities and a necessary foundation for consultations with Member States. This includes the formulation of substantive proposals for strategies to contain critical global issues, drawing on innovative methodologies, models and tools for research and policy analysis. *(See Draft Programme of Work, SPTF1//18/11.)*

The substantive activities of the Programme of Work are organised around the following seven themes which will form the basis of collaboration between the two institutions: (i) Systems-based strategies to address global Issues; (ii) Improved analytical methods; (iii) Governance and institutional innovation; (iv) Systems leadership; (v) Strengthening and extending existing joint activities; (vi) Initiating specific new topics for collaboration; (vii) Extension and outreach.

It is expected that the programme of the Strategic Partnership will be financed mainly through voluntary contributions from donor governments, contributions from intergovernmental organisations and from non-governmental sources and specific contributions to support carefully designed joint projects. The Government of Sweden, through the Agency for Innovation Systems, VINNOVA, has committed early financial support through a voluntary contribution of €200,000 to advance the work of the Strategic Partnership. Extensive consultations are now in progress with other potential donors.

Future Activities to Extend the Systems Approach

The work of the Task Force will be linked through its Members to the mainstream activities of the OECD Committees so as to facilitate the application of systems thinking to practical policy issues. In this way, the Partnership can promote policy innovation and anticipation, recognising the behaviour and dynamics of the complex systems of the modern world. This should lead to more coherent strategies, more successful interventions and better analysis of systemic risk, complexity and uncertainty, all of real value to OECD Member States.

At its second meeting, the Task Force agreed in broad terms on the main aims and themes for its future activities. Subject to the availability of funding, these could include:

- **Research and Collaboration on Specific Priority Issues,** such as: systems-based strategies to guide the trajectory of human progress on to a sustainable path; new paradigms and approaches for sustainable and inclusive growth and well-being; critical linkages between finance, investment and climate change; concerted policies for the climate, ecosystems, energy, and water nexus; longer-term strategies for employment as a primary objective of progress; managing the interactions between technological innovation and economic progress; a concerted approach to water, food and trade; systems-based approaches for development co-operation to meet diverse needs and aspirations in an interdependent world; strategies and governance to assess and manage systemic risk; improved methodology and tools for modelling; and adapting institutions to systems thinking to meet new challenges.

- **Presentations to OECD Committees on Identified Priority Issues**. A number of issues will be identified for discussion with the relevant OECD Directorates and substantive Committees. The Task Force can then undertake targeted activities to demonstrate how the systems approach can provide valuable insights into specific issues in line with the priorities and interests of key committees. This could include in particular, the possible introduction of a systems approach into selected National Economic Reviews undertaken by OECD.

- **Extending the Systems Approach across the OECD**. A growing number of Directorates are participating in the work of the Task Force. Presentations and seminars on systems thinking will be organised with Directorates to generate wider understanding and interest in the systems approach across the OECD.

- **Collaboration with other Prestigious Research and Policy Institutions**. A number of institutions have already expressed interest in participating in the work of the Strategic Partnership. Efforts will continue to build on the existing connections of OECD and IIASA in the policy and scientific communities to develop a worldwide network of institutions and experts so as to diversify its substantive base and to make the initiative visible and connected with influential stakeholders.

- **Disseminating Systems Thinking through Education and Training.** Drawing on the unique expertise and accumulated knowledge of OECD and IIASA, there are important opportunities to develop teaching modules, briefing materials and short courses to advance systems thinking for the international community – including OECD itself - and a wide public.

The major outputs proposed from the Programme of the Strategic Partnership to be discussed with Members and Committees at the OECD and IIASA may include:

- A "flagship" OECD-IIASA publication defining and consolidating new systems approaches to policy, "Systems-based strategies for sustainable progress and peace" *(title tbd).* This publication will present substantive proposals for strategies to contain critical global issues, drawing on the analytical capacities and modelling tools of IIASA and OECD through multidisciplinary teamwork;
- interim results and policy recommendations on key systemic issues to be presented to OECD Committees and Member States and to the National Member Organisations of IIASA as short policy notes and research findings;
- briefing materials and coordinated presentations for policy makers, OECD committees and other actors;
- Outreach and the dissemination of information to selected partners and the public;
- Training courses for OECD officials;
- Short courses and training materials to advance education on systems thinking, anticipation and resilience.

In coming years, the Strategic Partnership between OECD and IIASA should gradually engage the participation of Member Countries and Institutions, Partners and Donors, and of course, of OECD Directorates and Committees. It should make use of the opportunities offered by modern techniques of presentation to communicate the potential of systems thinking through the development of innovative briefing materials and presentations for policy makers and Committees.

It can also encourage wide interest within OECD and its Member States in the role and potential of systems thinking to achieve a better integration and cross-fertilisation of the expertise and experience of the OECD Directorates. In parallel, it can stimulate within the high-quality scientific programmes of IIASA, greater interdisciplinary collaboration and awareness of the economic and policy considerations which can enhance the impacts of their analyses and proposals.

We live in a systems world, accelerated and enabled by information and communications technologies and rapid technological, economic and geopolitical transformation. Systems thinking, coupled with improved anticipation and strengthened resilience, provides a coherent methodology and the necessary tools to develop the new approaches to the management of global issues which are so urgently required.

This initiative can help Member States, institutions and other actors to understand the complexity of the interconnected issues we face and to manage rising levels of risk and vulnerability under conditions of uncertainty. It can provide a focus and intellectual leadership for the evolution of the diverse ideas and approaches now emerging across the world to manage systemic global issues and thus to improve the prospects for inclusive, stable and sustainable progress and peace.