

New Approaches to Economic Challenges

Systemic Thinking for Policy Making

**THE POTENTIAL OF SYSTEMS ANALYSIS
FOR ADDRESSING GLOBAL POLICY CHALLENGES
IN THE 21ST CENTURY**

Edited by William Hynes, Martin Lees and Jan Marco Müller



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Preface

In policymaking, we hear the word “system” all the time. The economic system. The education system. The financial system. The political system. The social system... However, we rarely hear the word system attached to the word “approach”. But unless we adopt a systems approach, unless we employ systems thinking, we will fail to understand the world we are living in. Our world is made up of complex systems, systems of systems interacting with each other, and changing each other by that interaction and the links between them.

The global economy now has a greater number of links than ever before. The global nature of supply chains; new ways of exchanging goods, services and ideas; increasing migration; and ever-greater digitalisation, all increase our global connectedness. Such interconnectedness, in turn, gives rise to complexity, and this can be good or bad. However, within mainstream economics, the understanding of why and when interconnectedness may increase stability or instability has remained fragmented.

Complexity science helps us to understand the main features of the most important systems we have to deal with. Features such as emergence, when the overall effect of individuals’ actions is qualitatively different from what each of the individuals is doing. Radical uncertainty is another important aspect. It describes surprises—outcomes or events that are unanticipated, that cannot be put into a probability distribution because they are outside our list of things that might occur.

But despite radical uncertainty and the unanticipated, the future is born by anticipation. We take decisions and perform actions to influence the future, as individuals, societies or governments. And the imagined, probable, or expected outcomes influence our decisions and actions in the present. Even things that may never happen, or will only happen decades from now, can have an impact on what we do today. That is why we plan our day, buy insurance, and pay into pension funds. That is why we try to forecast everything from GDP to the weather to the results of elections or football matches.

Of course, not all our decisions about the future are in tune with what economic rationality would like us to do. We promote evidence-based decision-making, but of course there is no evidence about the future. Moreover, experience shows that simply extrapolating from the past can be ridiculous, dangerous or at best misguided.

A complexity approach helps us to avoid these errors. We are dealing with a world characterised by nonlinearities, tipping points, and asymmetrical relations where a small cause can have a big effect. In a systems approach, global issues need global solutions. Environmental problems do not respect borders. You need to import some goods and services to be able to export others. The digital revolution is making it hard to define what the “domestic” in “gross domestic product” is. Growing inequalities are creating discontent.

If we are to tackle these issues, governments must change the ways in which they design and implement policies. An acceptance of complexity shifts governments from a top-down siloed culture to an enabling culture where evidence, experimentation, and modelling help to inform and develop stakeholder engagement and buy-in.

Unfortunately, bad things will still happen, and this brings us to another aspect of systems, resilience. To traditional economic thinking, resilience means the capacity to resist downturns or to quickly get back to a desirable situation. Today, we need approaches to resilience that focus on the ability of a system to absorb, recover from, and adapt to a wide array of systemic threats and shocks.

That is the motivation behind this publication, and the broader strategic partnership between IIASA and the OECD. By joining forces to work on the environment, growth, inequality, population, energy, future shocks, and other central issues, we gain a more thorough understanding of the systemic and dynamic linkages among the major trends shaping our world, as well as the impact that different policy measures have on them.

The nature of the challenges means that no country can overcome them on its own. And for issues such as climate change or trade, a single country acting alone can potentially make things worse for everyone, including its own citizens. That is why the response has to be co-operative, multilateral and systemic – complementary outcomes that collectively contribute to a better world.

In short, the challenges we face have origins and consequences ranging from the individual to the global, the psychological to the political, the social to the economic. That is why we need systems thinking to understand the issues, anticipate the consequences of our decisions, and build resilience. Together we can shape a brighter future, for our economies, our societies, and all of our citizens.



Angel Gurría
Secretary-General
OECD



Albert van Jaarsveld
Director General and Chief Executive Officer
IIASA

Foreword

OECD and IIASA have cooperated on topics of mutual interest for many years. At a meeting in Paris on 24th May 2017, Prof. Dr. Pavel Kabat, then Director General of IIASA and Mr Angel Gurría, Secretary-General of OECD, agreed to establish a Strategic Partnership for co-operative activities between the two organisations. In December 2017, they signed a Memorandum of Understanding “to tighten the 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.” The Memorandum indicated a number of domains where the two organisations would co-operate, including:

- Developing new approaches to economic challenges to enhance understanding of the complexity of the global economy, society and environment.
- A systems approach to the analysis of economic performance and exploration of how far systems thinking could be taken in understanding the evolution of a national economy.
- Analysis of risk and resilience, and the recognition of uncertainty in the management of complexity.
- International co-operation in science, technology and innovation to advance knowledge and address grand challenges.
- Investigation of connections between climate, energy and international finance

The Strategic Partnership between OECD and IIASA can help Member States, institutions, and other actors to understand the complexity of the issues we face and manage rising levels of risk and vulnerability under conditions of uncertainty. It can provide a focus and intellectual leadership for the evolution of the new ideas and approaches so urgently required to improve the prospects for inclusive, stable, and sustainable progress and peace.

Within the OECD, responsibility for implementing the Partnership falls to the New Approaches to Economic Challenges (NAEC) Unit, overseen by Gabriela Ramos, Chief of Staff and G20 Sherpa. Within IIASA, the co-ordinator is Jan Marco Müller, Acting Chief Operations Officer. The Memorandum of Understanding provided for the establishment of the OECD-IIASA Task Force on Systems Thinking, Anticipation and Resilience, which “shall identify and coordinate areas of work of mutual benefit.” Both OECD and IIASA have designated senior expert members for the Task Force, chaired by Martin Lees.

This publication summarises joint work by members of IIASA and OECD on how systems thinking can improve policymaking. It focuses on four main areas of mutual interest, presented in chapters co-authored by officials from both organisations: new economic paradigms, approaches and methodologies; the environment and sustainable development; social and economic change; and systemic risk and resilience. William Hynes, Head of the OECD New Approaches to Economic Challenges (NAEC) Unit and Jan Marco Müller co-ordinated the publication. Angela Stuart (OECD) and Patrick Love (OECD) provided editorial and technical assistance.

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Acronyms and Abbreviations

ABM	Agent-based Models
CBD	Convention on Biological Diversity
CDS	Credit Default Swaps
CGE	Computable general equilibrium
COP	Conference of the Parties [of the UN Framework Convention on Climate Change]
DSGE	Dynamic stochastic general equilibrium
GHG	Greenhouse gases
GLOBIOM	Global Biosphere Management Model
IAM	Integrated Assessment Modelling
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRGC	International Risk Governance Center
LWE	Land, Water, Energy
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goal
SSP	Shared Socioeconomic Pathway
STI	Strategic Territorial Intelligence
TWI2050	The World in 2050

Executive Summary

To tackle planetary emergencies such as climate change, and the trends and issues shaping today's and tomorrow's world, we have to understand their systemic properties, such as tipping points, interconnectedness and resilience. The OECD and the International Institute for Applied Systems Analysis (IIASA) have expertise and experience in applying systems thinking to propose new approaches to achieving this understanding.

The systems approach can promote cross-sectoral, multidisciplinary collaboration in 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". The approach provides a methodology to achieve a better understanding of the non-linear behaviour of complex systems and improve the assessment of the consequences of policy interventions.

Key findings

Next-generation systems analysis models have to better integrate real-world dynamics such as social and behavioural heterogeneity. This will help to represent social dynamics and complex collective decision-making and facilitate the evaluation of the effectiveness of policies and their systemic impacts.

Systems thinking inside the public sector is generally a 'sense making' tool to make interconnectedness visible (usually with the help of outside experts) rather than a day-to-day practice that helps guide everyday action and decision-making. Even if policymakers as individuals are systems thinkers, it does not mean the policies they design are systemic; one needs institutions to support systems policy making.

A systems approach is a valid tool to analyse education within the continuum of the life cycle to understand the inter-relationships with other components such as the health and labour force participation, and to identify alternative strategies and foresee their impact. IIASA's multistate population and education modelling can inform the OECD's strategic and policy-oriented mission. This will be important in poorer countries where the education, particularly of girls and women, is a key instrument to reduce poverty and improve gender equality.

Five dimensions of inclusivity are consistently helpful for structuring perspectives on challenges to which systems thinking can be applied: impacts; feedbacks; trade-offs; emergencies; and stakeholders. Universally relevant training dimensions include systems principles; qualitative and quantitative methods; simple and complex models; and examples.

Developments to obtain more-integrated sustainability pathways could include integrating feedbacks from environmental damages into demographic and education projections; and further integrating demographic, education, and income projections. A gender aspect could also be considered.

The need for collaboration to address global sustainability challenges runs counter to current political trends, where solutions advocated to address the needs of an individual country may prove detrimental by ignoring their international implications and longer-term consequences.

Formal systems modelling can assist innovation policies to tackle deep innovation uncertainty. Models drawing on portfolio theory provide a quantitative framework of the economic value of risk diversification. In these models, different degrees of risk aversion (to innovation failure) become an input variable specified by policymakers. “Optimal” diversification portfolios given pre-specified innovation uncertainties and policy-specified risk aversion can be determined mathematically.

Agent-based modelling (ABM) can complement a systems mapping approach. Agent-based models, including one maintained by IIASA, provide a “sandbox” for exploring the consequences of linkages and feedback effects for individual agents and for the system as a whole.

Studies that would benefit from integration of IIASA and OECD’s approaches, data, and tools include: (1) Globally consistent national efforts for biodiversity. IIASA’s statistical and empirical approaches combined with OECD’s policy expertise to build scenarios of policy efforts across countries. (2) Exploring the role of trade in climate risks resilience to identify trade policy strategies combined with robust land use strategies capable of mitigating the most adverse impacts for food security and the environment. (3) National policies for SDG-compatible development pathways compatible with the Paris Agreement on climate.

Recommendations

Conventional policy analysis contains four precepts that should be reversed. Do not: insist on a single and agreed definition of the problem; distinguish facts from values; set up a single metric for comparing and assessing options; optimise around the most promising option.

A systems approach should be applied to both the system to be governed and the governance system itself. The OECD’s ‘whole of society’ approach for managing risk could incorporate IIASA’s suggestions for establishing learning loops to reframe or enable transformative changes and focus attention on the critical nodes that are key to ensuring resilience of economies and societies.

Systemic issues IIASA and OECD could collaborate on include sustainable and inclusive growth and well-being; linkages between finance, investment, and climate change; concerted policies for the climate, ecosystems, energy, and water nexus; longer-term strategies for employment; 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; 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.

1 Introduction to the OECD-IIASA Strategic Partnership

By Gabriela Ramos (OECD Chief of Staff and Sherpa to the G20)
Jan Marco Müller (Acting Chief Operations Officer, IIASA)
Martin Lees (Chairman, OECD-IIASA Task Force)

The rationale and objectives of the OECD-IIASA Strategic Partnership are outlined. The Partnership underpins an effort to combine the OECD's strengths in policy analysis and dialogue with the scientific expertise of IIASA, to strengthen the evidence base of policy and help provide better strategies and advice. The systems approach can promote cross-sectoral, multidisciplinary collaboration in 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". The approach provides a methodology to achieve a better understanding of the nonlinear behaviour of complex systems and improve the assessment of the consequences of policy interventions. A joint Task Force is organised around systems-based strategies to address global issues; improved analytical methods; governance and institutional innovation; systems leadership; extending existing joint activities; initiating new topics for collaboration; and extension and outreach.

We are living in a period of profound systemic change, and as in similar periods in the past, there is bound to be considerable instability and uncertainty before the new society and economy take shape. We have to identify actions that will shape change for the better, and help to build resilience to the inevitable shocks inherent in, and generated by, the system of systems constituted by the economy, society, and the environment. We are facing issues whose complexity, scale, interconnectedness, and pace of change are unprecedented, affecting entire economic, social, and natural systems as well as the relations between them. Experience shows that we cannot manage such systemic issues through established approaches to analysis and policy based on a tradition that separates complex realities into specialised disciplines, fields of research, agencies, and ministries, each focused on a part of the overall truth. We need to pull these disparate contributions together to organise an effective policy response. We need to be aware that ad hoc, short-term, sectoral-based interventions and isolated solutions in one policy area may have unintended and unpredicted consequences in other areas. We must understand system behaviour and evolution as a whole if we are to know how, where, and when to act to change them positively.

Systems thinking offers a more-integrated perspective and a number of proven concepts, tools, and methods to improve our understanding of potentially threatening complex, systemic issues. Systems thinking can improve the prospects for successful policy outcomes by offering 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 evolution, assess and manage risks, and decide how and where to intervene through targeted policies. Systems thinking also helps us to identify and understand critical linkages, synergies and trade-offs between issues generally treated separately, and thus to reduce unintended consequences of policies. Systemic thinking also helps decision makers to spend public money more wisely because integrated solutions tend to be cheaper than sectoral ones due to the synergies created.

Systems thinking not only improves multidisciplinary, cross-sectoral collaboration, it can also provide insights into systems behaviour and management by rigorous analysis of such aspects as system dynamics, feedback, sensitivity, and non-linear responses; the emergence of systems behaviour and properties; the optimisation of system 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, because if more-integrated, science-based analysis is to be effective, it must be implemented through reorganised and more-integrated policies and institutions. Systems thinking also has immediate application in developing human capital through education, training, and team building.

It could be argued that by isolating a problem, policymakers can focus their thinking and design responses tailored to the specific issue. Often, however, the outcome of such an approach will not be as hoped for due to unintended consequences, unforeseen spillovers, and unsatisfactory trade-offs, because the challenges are interconnected, multidimensional, and complex. At the same time, trying to adjust all the parameters of a problem simultaneously is likely to lead to confusion and paralysis. Systems thinking offers a solution to this dilemma. It allows us to identify the key drivers, interactions, and dynamics of the economic, social, and environmental nexus that policy seeks to shape, and select points of intervention in a selective, adaptive way.

The material discussed in the following chapters accurately reflects the types and diversity of the 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 and 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 demonstrates 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 do not always agree with each other on the best approach to the issues discussed, other than that it should be systemic, but a number of common views have emerged and a coherent work programme based on shared priorities is evolving.

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 Gurría and Pavel Kabat, then Director General of the International Institute for 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, first proposed in June 2018 by Professor Kabat and the Chief of Staff and Sherpa of the OECD who oversees the NAEC initiative, 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 that confront policy-makers.

This 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. The authors show how the methodology and tools of systems thinking can respond to the concerns and priorities of governments by providing valuable insights into policy choices, trade-offs and synergies; improving the effectiveness of policy interventions; and facilitating the assessment and management of risk.

The Strategic Partnership is laying the foundations for a concerted effort that will combine the OECD’s strengths in policy analysis and dialogue with the scientific expertise of IIASA to strengthen the evidence base of policy and help provide better strategies and advice. A joint OECD-IIASA Task Force on Systems Thinking, Anticipation and Resilience has been formed, bringing together 25 senior experts from across the different areas of activity of the two organisations. 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 framework. Activities are organised around the following themes: systems-based strategies to address global issues; improved analytical methods; governance and institutional innovation; systems leadership; extending existing joint activities; initiating new topics for collaboration; and extension and outreach.

The practical applications outlined in the following chapters show that the systems approach can be applied to a number of domains, as illustrated below.

Modernising economic analysis

The socio-economic system is changing and self-organising itself in a way that is difficult, if not impossible, to reconcile with existing theory. In an increasingly complex and interdependent system, the aggregate phenomena that emerge do so as a reflection of the interaction between all the participants. 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 or analysis of the behaviour of an isolated individual.

Next-generation systems-analysis models have to better integrate real-world dynamics such as social and behavioural heterogeneity. This will help to represent social dynamics and complex collective decision-making and facilitate the evaluation of the effectiveness of policies and their systemic impacts. A

promising approach is to integrate existing modelling tools from different fields, for example linking environmental models with economic growth and trade models. This extends the boundaries of what is modelled and allows for broader ranges of interactions to assess policy interventions. Going beyond the integration of existing tools may involve pioneering applications and innovative methodologies and tools in several areas, including explicit accounting for uncertainty; multiple agents with strategic interactions; bounded rationality, including consumption preferences and consumer choices; and network effects linked to complex interconnectedness and systemic risks.

The environment and sustainable development

The environmental challenges facing policymakers are not only systemic, complex and nonlinear, they are regressive, in that they will affect the poorest regions and poorest people most. Adequate response to the environmental issues associated with sustainable development requires acting on several scales, from global to city. For macro-level interdependencies and trade-offs, the stringency of global mitigation will determine climate impacts on human and natural systems. The rate of climate change has implications for how quickly systems can adapt, as does dependence on bio-energy and biomass. Concerning country, regional, and local transformations and vulnerabilities, mitigation actions 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 well-being at smaller scales, notably concerning the water, energy, land nexus. Adaptation policies will be better informed as long as we include the broader set of phenomena that will derive from the interaction of the social, environmental, and economic system. The growth maximisation paradigm may need to be revisited to ensure growth is sustainable, while at the same time contributes to improving the well-being of people.

Responding to transport's impacts on the environment, notably climate change, shows how a number of policies and interests have to be considered simultaneously. For example, electrified transport causes non-exhaust emissions and may cause distant emissions with different health impacts if the electricity comes from fossil sources, so policies must go beyond inducing manufacturers to produce cleaner and electric vehicles. Policies could aim to reduce individual drivers' use of existing vehicles at the local level, including by providing public transit and active transport alternatives; and to supply cleaner electricity at the local, regional, or national level, or alternative fuels based on internationally-sourced feedstock.

Social and economic change

In order to promote positive social and economic change, a range of policies have to be integrated, including education, demographic, employment, well-being, and technology and innovation policies. Lifelong education, for example, will keep populations healthier, more physically and cognitively active, and more connected to society and the labour market. However, the content and quality matter, as well as how aligned education systems are with societal and environmental goals. System mapping is one tool to facilitate consideration of the behaviour of a complex system by decomposing it into sub-processes that can be verbally described in a straightforward and relatively simple way. From this, policymakers can obtain a broad view of the drivers of policy outcomes. Agent-based modelling can complement a systems mapping approach.

Systemic risk and resilience

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.

The 2008 crisis illustrated why a systems approach offers the best possibility of understanding the nature of global challenges. The crisis started in the US financial sector but quickly became global and evolved into an economic recession that gave rise to social and political crises too. It proved the level of interconnectedness of our economies, and the channels of contagion of a highly integrated financial sector. The financial system also illustrates potential benefits of OECD-IIASA collaboration. IIASA has quantitative methods to measure, model, and manage systemic risk of financial systems using network theory and agent-based modelling. OECD looks into how to operationalise the concept of resilience to systemic risk to give policymakers an effective and efficient resilience management framework. IIASA's methods can inform and enhance OECD's framework by making available simple and transparent systemic risk indicators that can be monitored in real-time, as well as tools to test alternative policy interventions to reduce systemic risk.

Insights of this first deliverable of the OECD-IIASA Strategic Partnership and next steps

In advancing systems thinking, some features of conventional policy analysis could be reassessed. There is no single and agreed definition of a problem; distinguish facts from values; set up a single metric for comparing and assessing options; optimise around the most promising option.

A systems approach should be applied to both the system to be governed and the governance system itself. The OECD's 'whole of society' approach for managing risk could incorporate IIASA's suggestions for establishing learning loops to reframe or enable transformative changes and focus attention on the critical nodes that are key to ensuring resilience of economies and societies.

Systemic issues IIASA and OECD could collaborate on include sustainable and inclusive growth and well-being; linkages between finance, investment, and climate change; concerted policies for the climate, ecosystems, energy, and water nexus; longer-term strategies for employment; 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; 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.

Part I New Paradigms, Approaches and Methodologies

2 New Paradigms and Approaches for Economic Growth and Well-being

By William Hynes, Alan Kirman, Patrick Love and Karl Naumann (OECD)

It is argued that economics needs to change radically 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. In an increasingly complex and interdependent system, the aggregate phenomena that emerge do so as a reflection of the interaction between all the participants. 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 or analysis of the behaviour of an isolated individual. To position economic growth and analysis in a wider systems perspective requires both innovation of economic tools, methodology and policy, and the repositioning of the field of economics in relation to other critical fields such as the environment, society, and politics at the analytical and rhetorical levels and through the integration of policies in practice.

The 2008 crisis has provoked a debate on whether our existing economic models and analysis can be incrementally adapted to incorporate the many ideas that were missing and the new insights that have emerged, or whether a paradigm shift is needed. This chapter argues 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 traced by many economists that 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 “benchmark” model. This model, 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 exogenous “shocks” which periodically knock it off course.

In other disciplines, there are phenomena which 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, competition, and co-operation at various levels from very micro to large groups. By viewing evolution as a complex adaptive system, 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. As Corning (2005) says, “the emerging new paradigm is focused on a different set of questions... Indeed, the new paradigm is more about competition via co-operation than some conflict between them”.

In economics, we are faced with a system that is not only changing fast, but is changing in part in response to the conscious choices of those who make it up. 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. The whole socio-economic system bears little or no relation to that which existed in the preceding centuries and it is vain to believe that there is some overarching framework based on 19th century liberal principles that embodies the rules by which the system functions. Many developments 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.

Possible pathways for economics

There are three distinct ways of thinking about the future development of economic modelling, theory, and philosophy. First, that current economic models capture reality with sufficient accuracy, so 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 capture all its features. Since then, we have come a long way in making economic models more complicated.

The third school of thought considers that current 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 is that the underlying principles of rationality and general equilibrium do not accurately represent reality. The theoretical underpinnings of traditional economic growth theory, for example, tend to build upon mathematical representations with (rational) homogeneous representative agents, derived from the theoretical setting provided by Solow (1956) and the paradigmatic structure based on infinitely-lived rational individuals proposed by Ramsey (1928). However, in spite of the large amount of knowledge about the mechanisms leading to income growth gained by using these models, the focus on homogeneous agents implies that topics such as the linkage between economic development and intra- and intergenerational inequality have been significantly under-researched.

Linkages affecting everything from trade to well-being 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 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. The crisis emerged endogenously from within the financial system and spread into the world economy. This went against economic predictions that frequently consider only exogenous shocks perturbing a general equilibrium, and only barely included the financial system in 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. 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 determine the emergent macroeconomic trends through large-scale simulation. 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 design policy to improve resilience. (See for instance chapter 13 of this publication on financial networks and transaction risk). Such a framework also allows easy adaptation of new insights in behaviour, the environment, sociology, and economics.

Change is also needed beyond modelling. For example, IIASA argues for the inclusion of age in national accounts, and the study of age-specific patterns of key economic activities. Only by considering the whole system of public and private inter-generational transfers can analysts adequately explain and project the impacts of transfers on public finances and derive evidence-based options for policy reforms.

Economic paradigms and narratives

The orthodoxy in economics is not as clear-cut as in the natural sciences, 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 schools 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 shocks. 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 systems were not thought about deeply in the pursuit of productivity growth. Systems thinking fully considers such interconnections by treating these individual systems as intra- and inter-connected. Such an approach, that could be implemented through the development of agent-based modelling, network analysis, and machine learning, 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.

Practical and theoretical examples of systems thinking

Recent work conducted by IIASA scientists concentrates on understanding how economic outcomes are affected by modelling societies that are populated by heterogeneous agents. The effort carried out at the Institute 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 give us empirical knowledge about how the educational attainment of the different cohorts which coexist at a given 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).

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. IIASA uses 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.

Conclusion

To position economic growth in a wider systems perspective requires both innovation of the tools, methodology, and policy within the field of economics, and 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.

A number of things are clear already. We are faced with a system that 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, “representative” individual or firm.

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 Methodologies and Tools for Integrated Systems Modelling

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OECD and IIASA's modelling tools are presented and the needs of a new generation of tools are outlined. Next-generation systems analysis models have to better integrate real-world dynamics such as social and behavioural heterogeneity. This will help to represent social dynamics and complex collective decision-making and facilitate the evaluation of the effectiveness of policies and their systemic impacts. A promising approach is to integrate existing modelling tools from different fields, for example linking environmental models with economic growth and trade models. This extends the boundaries of what is modelled and allows for broader ranges of interactions to assess policy interventions. Going beyond the integration of existing tools may involve pioneering applications and innovative methodologies and tools in several areas, including explicit accounting for uncertainty; multiple agents with strategic interactions; bounded rationality, including consumption preferences and consumer choices; and network effects linked to complex interconnectedness and systemic risks.

Integrated quantitative modelling of coupled socio-environmental systems is a useful way to enhance our understanding of complex systems and to generate systems-based policy advice. OECD and IIASA both develop and make extensive use of such models to devise policy options and to provide outlooks in a variety of areas, including economic growth, employment, agriculture, energy, and the environment, as well as their interrelations. Models can also help organise and structure discussions around so-called “wicked” problems¹.

Model suites at OECD and IIASA include simulation models, optimisation models, and statistical models spanning wide ranges of geographical and temporal scopes and granularities, from local to global and from annual to centennial. This chapter discusses the role of integrated systems modelling in informing policy decisions and looks at how extending existing models and developing new tools based on systems approaches could yield additional insights.

Integrated modelling to inform policy decisions

What is integrated systems modelling? In the context of systems analysis, a model is a simplified representation of reality expressed in equations and/or computer code, focusing on the key mechanisms at play. Any model builds on a conceptual skeleton, which defines the system’s boundaries, external conditions (parameters), internal elements (variables), and the relations between them. Such a qualitative skeleton is turned into quantitative equations or transition rules based on theories and data. Implemented in computer code, a model can be used for analysing outcomes and for gaining a better understanding of a system’s response to specific policy interventions. A systems approach often challenges a system’s traditionally considered boundaries, bringing in elements that may lie outside the immediate area of interest, but have the potential to impact that area of interest. For example, integrating a water model with an energy model enables a more realistic evaluation of future energy production, because water availability may limit production possibilities.

The OECD model suite. At OECD, statistical models and analytical models based on micro-foundations are two major types of models used to support economic policy. Statistical models have the advantage of often having medium complexity, as such models describe the properties of aggregate economic variables directly. This approach fell out of favour in recent decades because it may lead to unreliable results, as highlighted by the Lucas Critique that emphasised the problems caused when inferring future behaviour from the past in the presence of structural breaks (Lucas, 1976). Nevertheless, statistical modelling remains an important approach for devising large-scale macroeconomic models and empirical research on aggregate-level phenomena. Structural models have become the dominant approach to analyse macroeconomic issues, particularly through two types of general equilibrium models called dynamic stochastic general equilibrium (DSGE) models (Cacciatore et al, 2012) and computable general equilibrium (CGE) models, respectively. The use of different model types is dictated by data available and the purpose of modelling – forecasting or policy evaluation.

At OECD, some of the main applications of economic modelling to support policy include:

- Short-term macroeconomic forecasting and policy simulations are based on reduced-form large-scale macroeconomic models, such as the NIESR (National Institute of Economic and Social Research) NiGEM model (National Institute’s Global Econometric Model) (Barrell and Pain, 1997).
- Long-term macroeconomic models that provide a globally consistent set of long-run projections for potential output and other variables (Guillemette and Turner, 2018).
- Trade policy issues are analysed by using static CGE models, such as the METRO model (Modelling TRade at the OECD).
- Agriculture and food projections are produced by means of the Ag-Link model, which is a dynamic-recursive partial equilibrium model developed in collaboration with the United Nation’s Food and Agriculture Organization (FAO) and used for the annual OECD-FOA Agricultural Outlook series.

- Projections and policy analysis focused on environmental issues are done using the ENV-Linkages model, which is a large-scale dynamic CGE model with global coverage and more than 50 economic sectors, supported by the ENV-Growth model, a Solow-type macroeconomic growth model.

The IIASA Integrated Assessment Modelling Framework. IIASA has a long tradition of modelling physical systems related to energy, air pollution, land use, and water, and of developing methodologies, such as scenario analyses, to apply these modelling tools. The main large-scale IIASA modelling tools are coupled within an integrated systems framework and include:

- Global and national energy-systems modelling with a process-based, dynamic, systems-engineering, integrated assessment model of the global energy-economy-environment system.
- Air-quality modelling based on global and regional emissions and technologies with GAINS (Greenhouse gas-Air pollution INteractions and Synergies).
- Agriculture, food, and land-use modelling with GLOBIOM (GLObal BIOsphere Management Model), a global model to assess competition for land use among agriculture, bioenergy, and forestry.
- Global water modelling with CWatM (Community Water Model), including the evolution of future water demand and availability.

These tools are complemented by other models, including stylised models, medium-complexity stock-flow-consistent models, and agent-based models (ABMs).

Why is a next generation of modelling tools needed? While the suite of models outlined above has proven to be very useful in providing insights into a wide range of topics, enhancements as well as new methodological developments are needed to improve the policy realism and relevance of these tools. In particular, next-generation systems analysis models need to focus on a better integration of real-world dynamics such as social and behavioural heterogeneity, which will help in representing social dynamics and complex collective decision-making, and thereby facilitate evaluating the effectiveness of policies and their systemic impacts.

Any modelling effort necessarily involves a compromise between the intention to represent the properties of a problem adequately and the need for the resultant model to remain interpretable as well as feasible in terms of its implementation. Mainstream modelling approaches often focus on stylised assumptions that improve tractability, but do so at the expense of sacrificing some of the richness of the behaviour of the modelled systems. With current computing power, rising data availability, and accumulated knowledge on the boundedly rational behaviour of economic agents, it is tempting to relax the simplifying assumptions of mainstream models in order to reflect reality better. The following innovation dimensions seem particularly important, as detailed in the next two sections:

- Linking and integrating models through so-called nexus studies should give them the appropriate breadth to cover multiple domains together.
- The focus of modelling should increasingly move to capturing complex dynamic interrelations and interdependences among agents operating within a system's boundaries, and the resultant models should be able to describe profound changes among these interactions that give rise to phenomena such as emergence and adaptation.

An important aspect of how models meant to inform policy decisions can be developed concerns their co-design in collaboration with stakeholders and decision makers. Such an approach helps ensure that models are well designed from a technical perspective, are based on appropriate intellectual ownership and buy-in, and address relevant policy concerns in a way that effectively communicates to the associated policy communities.

Integration of existing tools

A promising approach to modelling sustainable-development strategies is to integrate existing modelling tools from different fields, such as linking environmental models with economic growth and trade models or linking demographic and economic models. This extends the boundaries of what is modelled and allows for broader ranges of interactions that help reveal indirect vulnerabilities or strengths of policy interventions.

Potential for OECD-IIASA collaboration. Both OECD and IIASA develop and operate wide arrays of modelling tools, which are largely complementary to each other, as summarised above. OECD has a long tradition in more economy-focused models that describe interactions between macroeconomic growth and interlinked sectoral and regional economic activity. The tools at IIASA have a more physical focus and describe long-term dynamics in areas such as population, energy, technology, air pollution, water, natural disasters, ecology, agriculture, and land use. In the following, we highlight several integration dimensions by focusing on examples that showcase the potential for OECD-IIASA collaboration.

Linkages with energy models. Researchers at IIASA and OECD have been deeply involved in developing socioeconomic scenarios for climate-change assessment, the so-called shared socioeconomic pathways (SSPs). First, IIASA developed population and education projections for five long-term scenarios. Second, these served as inputs to an OECD macro-economic growth model (ENV-Growth), which explicitly accounts for the energy revenues accrued by fossil-fuel exporters². Third, the resultant economic projections were used in IIASA's Integrated Assessment Modelling Framework to produce projections of energy demand, energy supply, land use, and greenhouse-gas emissions under different levels of mitigation. Several additional efforts have also focused on coupling energy models and macroeconomic tools. Energy-systems models have added macro-economic feedbacks for changes in energy prices, and CGE models have been linked to energy-systems models to incorporate 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), so far they have focused 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 within these frameworks and leaves room for major mismatches between the energy system and other economic elements.

Linkages with air-pollution models. Another example of recent collaboration is the use of IIASA's GAINS model to estimate 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. This very fruitful collaboration has produced a widely used set of climate-change assessment scenarios, 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 collaborative efforts were also one-directional exercises, which left out several key interactions that will be important to explore in the future. These include feedbacks from changes in energy production and consumption and land use on 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.

Expected benefits of model integration. Developing novel methods for linking the economic modelling tools of OECD with the physical system models of IIASA would add great value to both institutions. There is room for improvement of the existing methods, especially when the information exchanged 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 those needed for achieving decent living standards; see Rao and Min, 2017). Furthermore, such integration would open up the possibility to link economic activity, ecosystem services, and biodiversity losses (see the chapter by Karousakis et al. elsewhere in this volume)³.

By linking the flagship modelling tools of IIASA and OECD, important new avenues of interdisciplinary policy questions can be addressed. This will allow researchers to treat systems barriers to economic growth more seriously, e.g., through feedbacks from environmental degradation, interactions with energy exports for countries whose national incomes heavily rely on fossil fuels, and feedback effects between demographics, education, and economic activity. It will also allow them to improve the economic backbone of the biophysical systems analysis done by IIASA. Brought together, these advances will help produce more robust policy insights. Among other benefits, the highlighted dimensions of model integration will be important for addressing the challenges discussed in Chapter 2 (promoting different dimensions of human well-being); Chapter 4 (modelling in support of the United Nation's Sustainable Development Goals and of examining the linkages among them); Chapter 5 (understanding critical interconnections between water and food systems and their implications for biodiversity); Chapter 6 (exploring the air-pollution implications of ecosystem dynamics and energy transformations); and Chapter 10 (understanding the diverse implications of digitalisation).

Pioneering applications of innovative methodologies and tools

Opportunities for strengthening the modelling capacities of IIASA and OECD beyond the integration of existing tools may involve pioneering applications and innovative methodologies and tools in several key areas, as outlined below.

Explicit accounting for uncertainty. Stochastic optimisation can be used in decision-support tools to derive so-called robust decisions (informally referred to also as no-regret decisions). Robust decisions allow a satisfactory outcome of a process to be achieved irrespective of the particular realisation of uncertainty that is actually observed. At IIASA, this approach has been applied to designing insurance markets mitigating against natural disasters (Ermolieva et al., 2016a); land-use planning (Ermolieva et al., 2016b); and evaluating energy investment portfolios (Krey and Riahi, 2013).

Multiplicity of agents with strategic interactions. Evolutionary game theory can be used to describe the behaviour of agents pursuing their interests by making strategic decisions based on observing other agents. The resultant strategic interactions among agents often lead to social dilemmas collectively known as the 'tragedy of the commons': when agents pursue their selfish interests, collective interests typically get jeopardised. This phenomenon is of universal relevance, being germane to managing key challenges associated with the many common goods on which humankind depends. Examples are as diverse as mitigating climate change, securing clean air, preventing environmental pollution, managing sustainable land use, exploiting renewable resources, achieving prudent urbanisation, ameliorating family planning, protecting social welfare, and governing the internet. At IIASA, this approach has been applied, for instance, to designing innovative incentive systems for protecting common goods (Chen et al., 2015) and analysing the threats of institutional corruption (Lee et al., 2019).

Bounded rationality, including consumption preferences and consumer choices. Behavioural economics and agent-based models (ABMs) 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 their behaviours. In particular, people may make their decisions based on the actual or perceived behaviours 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 household neighbours are perceived as taking similar measures. If there are thresholds in people's actions depending on actions taken in their neighbourhood, this can qualitatively alter outcomes at the systems level. ABMs are built on the assumption that numerous agents interact following simple behavioural rules in a well-defined environment. Individual behaviours, their interactions, and changes to the structure of these interactions can give rise to rich systems dynamics, including emergence and high levels of complexity. ABMs can capture heterogeneities among agents that play an important role in how a system evolves. They can also

predict implications across such distributions of agents. ABMs can typically only be solved through simulations, rather than analytically, but increased computing power has made this a viable approach even for large-scale models. ABMs can be applied to a vast array of policy problems. OECD and IIASA have used ABMs and other simulation models to suggest instruments to reduce financial systemic risk (Poledna and Thurner, 2016), to analyse transport systems (ITF, 2017, McCollum et al., 2017) and the potential for the development of shared mobility, and are developing ABMs to look at other issues, including interactions between the real economy and the financial system.

Complex interconnections and systemic risks. Network theory demonstrates that a system's structure, in terms of the linkages between its elements, is important for determining how it responds to exogenous disturbances. Network theory also suggests how to use information about an agent's position in a network to specify policies or actions that are particularly suitable for that agent. Compared with mainstream models that rely on simple or uniform interactions among agents, network theory yields insights for more realistic relationships, for example, when some agents in a network are much better connected to other agents or are more central to the network as a whole than in simpler configurations of interconnections. With a network's structure determining how broadly or narrowly its interactions transmit the impacts of shocks (e.g. Kharrazi et al. 2017), policy interventions can be designed to modify this structure to yield desired outcomes.

Challenges and opportunities

The integration of existing tools and the application of innovative methods will be critically important for generating new policy-relevant insights. For example, they can help map out causal linkages that were not well articulated in traditional models, such as the feedback between economic activity and natural resources.

These improved modelling approaches become increasingly feasible as computing power keeps growing, making it easier to solve complex models or to simulate the behaviour of a large number of agents. The computational techniques themselves have developed alongside the computational technology. Improved data, including big data, and a growing understanding of the behaviour of key system elements, including human behaviour, can be used to validate, calibrate, and enrich these models.

Detailed models can be complemented by stylised models that provide useful qualitative insights and help enhance the intuitions and insights of researchers and policymakers about how economic, environmental, and social systems behave and interact.

While being essential for next-generation models, the better incorporation of social sciences and of heterogeneities among agents poses new challenges. First, behaviour is almost always context-specific, which means that data requirements for quantifying behaviour are often large and difficult to generalise. Second, system-level properties can be remarkably sensitive to detailed assumptions made about such behaviour, and modellers must hone their comprehension of those sensitivities and their implications. Given the current – still rather incomplete – understanding of human behaviour, the heuristics implemented in models may turn out to be too ad hoc and, given their potentially large impact on model results, need to be subjected to carefully designed robustness checks.

Models need to be formally validated on a routine basis. This may pose challenges due to large uncertainties and since current econometric tools often lack precision. The growing availability of salient data, however, provides a better basis for calibrating complex tools, including network models and ABMs. The development of machine-learning techniques creates opportunities to explore data without committing to rigid assumptions. In particular, machine-learning models are very versatile for detecting and investigating nonlinear features of empirical systems.

Complementing the greater availability of raw data, more empirical studies are needed to estimate causal relationships and determinants of change that can guide quantitative future projections involving human behaviour, e.g. regarding the evolution of diets, new technologies, individual preferences, or social norms.

Conclusions

Modelling tools at IIASA and OECD will continue to be essential for a systems-based assessment of the pending transformation towards sustainable development. A coherent strategy across the institutions requires the extension and integration of existing tools as well as the application of innovative methodologies to better represent real-world complexities in regard to heterogeneity, uncertainty, strategic interaction, bounded rationality, and network structure. There is a clear need for different tools that can answer different questions. It is thus important to build on existing strengths while in parallel pursuing new methodological developments.

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Notes

¹ A wicked problem is a problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognise (Rittel & Webber 1973).

² 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).

³ At a technical level, the open database platforms of IIASA are proving to provide an excellent model-linkage framework, in which these new approaches could be implemented.

Part II The Environment and Sustainable Development

4 Developing Pathways to Sustainability: Fulfilling Human Needs and Aspirations while Maintaining Human Life Support Systems

By Elisa Lanzi, Shardul Agrawala, Rob Dellink (OECD),
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Shared Socioeconomic Pathways (SSPs) are introduced, and integrated population and human capital scenarios for joint analysis of human development, coping with environmental changes, and securing human life support systems are considered. Incorporating environmental feedbacks on economic growth is discussed. These scenarios are linked with the SDGs as highlighted by IIASA's 'The World in 2050' framework (a broad transformational narrative; targets and indicators for 2030, 2050 and beyond; and sustainable development pathways). Developments to obtain more integrated sustainability pathways could include integrating feedbacks from environmental damages into demographic and education projections; and further integrating demographic, education, and income projections. A gender aspect could be considered. Modelling assessments of sustainability pathways can be enhanced. Quantitative scenarios for SDGs related to human development can be improved and better integrated with indicators for other SDGs. Societal changes, the evolution of human needs, and possible changes in governance could be better integrated into modelling.

Introduction

In 1987, the “Brundtland Report” of the World Commission on Environment and Development (WCED) 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 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.

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 gas (GHG) emission reduction and stabilisation of GHG 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 reviews developments of pathways analysis in the context of sustainability. First, the Shared Socioeconomic Pathways (SSPs) are introduced. Then 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. Finally, these scenarios are linked with the SDGs as highlighted by the the World in 2050 initiative (TWI2050, 2018). 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 Socioeconomic 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 GHG emission scenarios. However, projecting longer-term climate change impacts and costs is complicated because GHG 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.

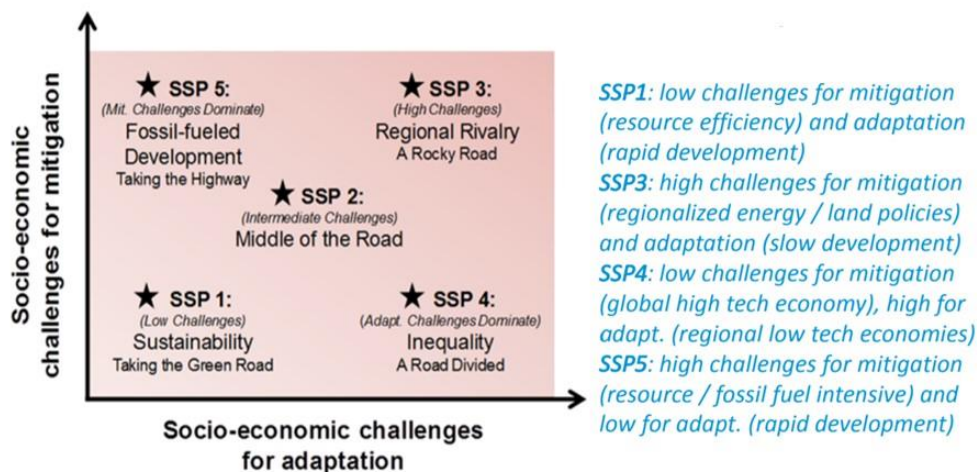
More recently, a new set of scenarios - the Shared Socioeconomic Pathways (SSPs) - was developed to better describe different climate futures, including the role of both mitigation and adaptation challenges (Field et al., 2014). While the SRES were developed as joint storylines between future emissions and

economic development, the SSPs were developed separately from the climate scenarios, or the so-called Representative Concentration Pathways (RCPs).¹

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 also respond to the rising concerns on vulnerabilities, impacts, and adaptation. These in turn are strongly linked to socioeconomic developments and human well-being.

The SSPs consist of five scenarios, based on narratives describing alternative socioeconomic developments and the corresponding challenges for mitigation and adaptation (O'Neill et al., 2017), as illustrated in Figure 4.1. The SSP 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 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, three different GDP scenarios have been developed, with the OECD's used as an illustrative case. The 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

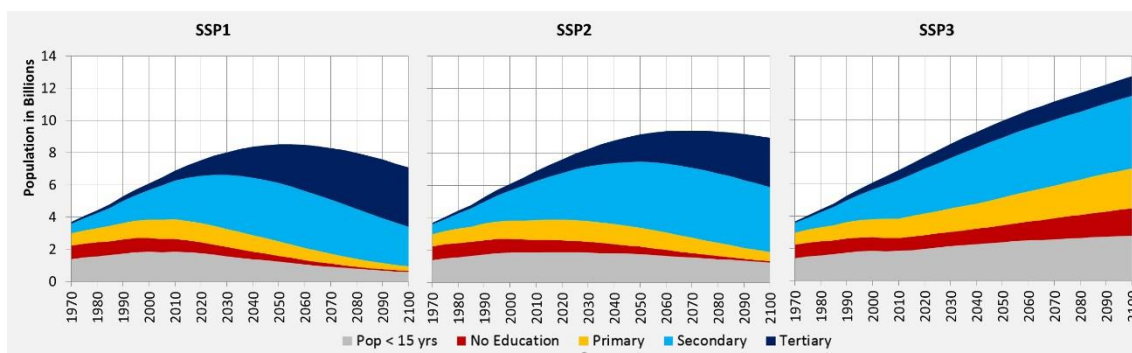
The SSPs were an important achievement but they have also been the starting point to explore further pathways for the study of future human development. Unlike the previous generation of scenarios that only considered total population size, this new set of scenarios provides population projections by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

Beyond economic growth, education is a basic force for 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, S. and H. Lentzner, 2010). Beyond individual benefits, improving education for different age groups 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, S. and H. Lentzner, 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 updated by the European Commission (2018). Population trends matter greatly for assessing the number of people 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 below 9 billion followed by a decline, which in 2100 may mean a global population size comparable to today. The medium scenario SSP2 will peak around 2070 at around 9.6 billion and only shows modest declines by the end of the century. The stalled development scenario SSP3 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. 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 in 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 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 population.

This new approach is key to TWI2050². 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 to ensure 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. 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 disciplines and methodologies, and that can deal with nonlinearity.

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

In its 2018 report, TWI2050 identified six exemplary transformations needed to achieve the SDGs: (1) Human Capacity and Demography; (2) Consumption and Production; (3) Decarbonisation and Energy; (4) Food, Biosphere and Water; (5) Smart Cities; and (6) Digital Revolution (Figure 4.4).

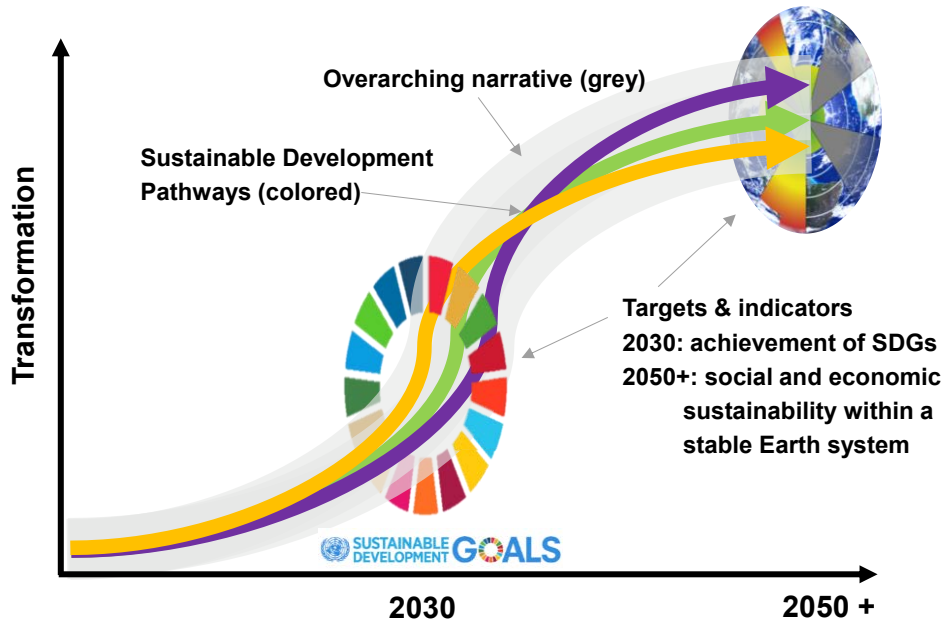
While the TWI2050 2018 report is only the beginning of a long-term effort to understand sustainability pathways, it provides interesting key policy messages and research gaps. These include the need for early ambitious policy action to achieve the SDGs. The integrated framework highlighted the need for a holistic perspective, with 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 Costs of Inaction and Resource scarcity: Consequences for Long-term Economic growth (CIRCLE) project has shown, environmental feedbacks could be significant already in the coming decades. Pathways that 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 could 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. Identifying how demographic, education, and income projections can be constructed in a mutually consistent and highly granular manner, as pioneered in the SSPs, will enhance the insights 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 in 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 to link education levels to occupational skill categories. While (re)training programmes can alter occupational skillsets of employees, the main driver of occupational skills is the education received by 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 workforce for changes in skillsets 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 the International Labour Organisation (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.

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 possible 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 to mainstream sustainability considerations into the long-term projections.

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Notes

¹ 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 RCP 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).

² See: <http://www.twi2050.org>.

5 A Concerted Approach to Biodiversity, Water, Food, and Trade

By Katia Karousakis, Guillaume Gruère, Jean Chateau, Marcel Adenauer, Santiago Guerrero (OECD), Petr Havlik, Ulf Dieckmann, Taher Kahil, David Leclere, Elena Rovenskaya, Hugo Valin, and Yoshihide Wada (IIASA)

IIASA and OECD's capacities to analyse the biodiversity, water, food, and trade systems are illustrated. Studies that would benefit from integration of their approaches, data, and tools are suggested. (1) Globally consistent national efforts for biodiversity. IIASA's statistical and empirical approaches combined with OECD's policy expertise to build scenarios of policy efforts across countries. (2) Exploring the role of trade in climate risks resilience to identify trade policy strategies combined with robust land use strategies capable of mitigating the most adverse impacts for food security and the environment. (3) National policies for SDG-compatible development pathways compatible with the Paris Agreement. Short-term/medium-term focus (OECD) and long-term modelling capacities (IIASA); ex-post policy assessments (OECD) and foresight and sustainable development pathways (IIASA); and bottom-up approaches with very detailed representation of the supply side of agricultural and forestry sectors together with related environmental impacts (IIASA) plus top-down approaches for economic impact assessment (OECD).

Introduction

Systems analysis and systems-based strategies can examine critical, interlinked, and complex global issues, evaluate implications, and 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 is crucial in areas such as biodiversity, water, food, and trade, where comprehensive integrated approaches are needed to evaluate first-order and second-order effects of policies, including on the natural and socioeconomic systems, and their feedback loops. Understanding potential interactions, and the synergies and trade-offs across these, can inform political and policy issues. This is particularly relevant, for example, in the context of the Convention on Biological Diversity (CBD), where the 2011-2020 Strategic Plan for Biodiversity including the Aichi Biodiversity Targets, are due to expire, and a post-2020 framework will be needed. 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”, including: the broad range of underlying drivers and systemic and structural issues related to biodiversity loss; combinations of policy approaches at multiple scales and under different scenarios; potential synergies, trade-offs, and limitations to identify effective policies and measures to enable the achievement of the Sustainable Development Goals; and identification of short- and medium-term milestones in pursuit of the long-term goals. The usefulness of such scenario and modelling analysis is also recognised by international initiatives such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (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 twelve OECD and non-OECD countries to conduct policy reviews covering all policies affecting agricultural innovation, productivity, and sustainability (from education to taxation and environmental regulations, OECD, 2019c). The Republic of Korea also supported an OECD water policy dialogue that focused on policies covering the land-water-food-energy nexus, to help guide their new water law and water governance in a coherent manner (OECD, 2018).

Illustrations of the benefit of systemic approaches

OECD and IIASA have already applied 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 Environmental Outlook (OECD, 2012) by combining ENV-Linkages, the CGE model of the OECD Environment Directorate, with IMAGE, the Integrated Model to Assess the Global Environment modelling framework of the Netherlands Environmental Assessment Agency (PBL). This 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 report *Land-Water-Energy Nexus: Biophysical and Economic Consequences* (OECD, 2017a), 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 also 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 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 led 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 in 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, the Global Biosphere Management Model (GLOBIOM), and global terrestrial biodiversity models, INSIGHTs and cSAR - to help prepare the post-2020 biodiversity framework. Second, IIASA developed new modelling tools to look at the Land, Water and Energy (LWE) nexus, 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.

Systems analysis was also undertaken in the report “Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences” (OECD, 2019b). The analysis presented global projections of materials use and their environmental consequences, including on land use and acidification, eutrophication, and freshwater, and provided 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). The report explained how economic structural changes and technological progress help in determining a partial decoupling of economic growth and materials use, and assessed how the projected shifts in economic sectors and regional economic activity explain changes in the use of different materials. The projections included both primary and secondary materials used for metal production, which provided 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 the International Food Policy Research Institute’s (IFPRI) IMPACT model were used to look at scenarios for climate change adaptation options in agriculture (Ignaciuk and Mason-D’Croz, 2014) 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, 2017b) with and without climate change.

Ongoing OECD work using a set of different models, including the IIASA GLOBIOM model, is exploring the economic and trade consequences of agriculture engaging in 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, 2019a).

The issue of systemic risk is of particular importance nowadays when global trade networks are becoming 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 other parts of the world. 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 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 et al., 2018). Farm-level and partial equilibrium models were used to explore how agricultural policies affect GHG emission, nutrient balance, water quality, and indicators of biodiversity at the farm level (Henderson and Lankoski, 2019).

OECD and IIASA are also collaborating on capacity development in the area of water. In 2018, a project to assist policymakers in the EU 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 systemic approaches to water-related issues 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 for many major river basins. On the basis of these results, a general decision-making framework has been developed 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., 2019) focused on evaluating robust operation of multipurpose reservoirs under uncertain hydro-climatic conditions. A novel two-stage stochastic optimisation model was formulated 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 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 showcase the capacity of IIASA and OECD to carry out systemic analysis independently. However, many other potential studies would benefit from integration of approaches, data, and tools available at the respective institutions. This section 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 insights into the formulation of the post-2020 framework for biodiversity, such as what targets might be achievable and what pathways might reach 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 agricultural 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 should contribute to the action targets and to the overarching goals (i.e. biodiversity outcomes). Such 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 data that the OECD has accumulated on policy areas relevant to the sustainable use of natural resources, including biodiversity, such as the PINE (Policy Instruments for the Environment) database, could be pivotal in making credible short-term scenarios related to progress towards realising post-2020 global biodiversity objectives. Statistical and empirical 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 in agriculture, potentially altering global production patterns and trade flows, giving rise to new hotspots of agri-environmental pressures and posing sustainability challenges. However, although climate change impacts on agriculture and the food system have started to be reported in many places, the magnitude of future impacts and their location are still not precisely known, due to uncertainties related to future temperature and precipitation patterns; to the way the environmental system will respond; and the extent to which farmers will be able to adapt. International co-operation through intensified and diversified trade relations could facilitate adaptation and help to increase the resilience of global food markets. At the same time, intensified trade could increase the exposure of countries and regions to risk triggered by production shortages in distant localities through new interdependencies. For this reason, it is necessary to identify effective trade policy strategies combined with robust land use strategies capable of mitigating the most adverse impacts on food security and the environment of future climate and extreme events.

A modelling framework could be developed to address this problem, taking advantage of IIASA’s experience in integrated assessment modelling and OECD’s research and policy insights. IIASA has developed tools to support decisions and derive scenarios on land use change, including under climate change, notably GLOBIOM, representing the agricultural (crops, livestock) and forestry sectors, including a representation of water availability for irrigation using the ECHO hydro-economic model. Such tools represent agricultural markets with bilateral trade and explicitly account for trade barriers, and would more precisely characterise the 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 indicators related to the SDGs. Policy insights from OECD work on the role of market integration on growth and employment, the impacts of climate change on international trade, the quantification of non-tariff measures, climate change adaptation in agriculture, the environmental impacts of agricultural policies and agri-environmental indicators would better inform the model and increase its relevance and capacity for policy design.

IIASA has 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 an approach could be expanded using the quintile risk measures, co-dependent risks, and risk evolution over time approaches. Advanced statistical methods including those based on machine learning are relevant for this purpose and would allow trade policy options robust to different future possible climatic conditions to be identified, and emphasise no-regret pathways. Trade policy options to be tested would include both tariff and non-tariff measures (NTMs). NTMs, which include regulatory frameworks and standards - including sanitary and phytosanitary standards (SPS) - are much more difficult to estimate and reduce, although they play a big role in defining trade flows. The OECD has developed a methodology to estimate

the trade impacts of NTMs that 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 measures, as well as realistic country and regions development paths. Eventually, by conducting an extensive analysis of possible combinations of trade policies in different parts of the world, this modelling exercise would be able to reveal an “optimal” level of economic/trade connectivity, which would ensure highest level of food security globally; elucidate trade-offs in terms of food security between regions; and 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 humanity. According to the IPCC Special Report on 1.5 degrees (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); ex-post policy assessments (OECD) and foresight and sustainable development pathways (IIASA); and a bottom-up approach with very detailed representation of the supply side of agricultural and forestry sectors together with related environmental impacts (IIASA) and a top-down approach for economic impact assessment (OECD).

OECD and IIASA have started collaborating on GHG mitigation in the agricultural sector around the AGLINK-COSIMO and GLOBIOM models. Furthermore, SDG 12 (Responsible consumption and production) is being increasingly recognised as one of the major prerequisites to achieve ambitious sustainability targets for the land, water, and energy nexus (Obersteiner et al., 2016; van Vuuren et al., 2015). However, the broad economic aspects of such transitions (such as distributional impacts across regions and sub-sectors of the value chain within the food system, or employment effects) 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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Three perspectives on the problems around climate and energy use and their relationship to ecosystems and human well-being in terms of air pollution are provided. (1) Macro-level interdependencies and trade-offs. The stringency of global mitigation will determine climate impacts on human and natural systems. The rate of climate change has implications for how quickly systems can adapt, as does dependence on bio-energy and biomass. (2) Country, regional, and local transformations and vulnerabilities. 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 well-being at smaller scales, notably concerning the water, energy, land nexus. (3) Climate mitigation, transport and air quality. Electrified transport causes non-exhaust emissions and may cause distant emissions with different health impacts if the electricity comes from fossil sources, so policies must go beyond inducing manufacturers to produce cleaner vehicles and electric vehicles.

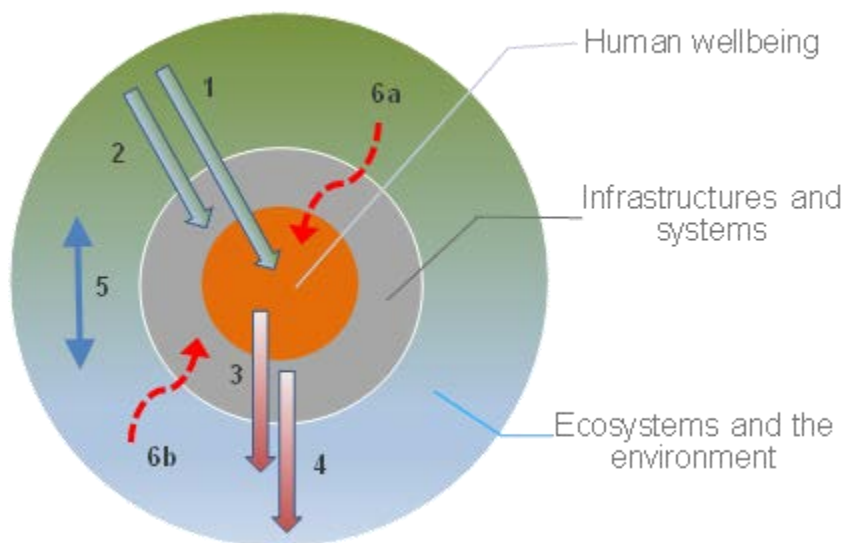
Introduction

Human well-being depends on 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 of this chapter is on the interplay between these systems and human well-being viewed through the lens of the climate and ecosystems, focusing on the critically important mitigation challenges in the energy and transport systems. The chapter provides three 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 interlinkages between human well-being, transport, and air quality.

The conceptual framework 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 achieving 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, achieving these SDGs depends critically 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 also affect these ecosystems in many ways, reducing the scale and range of ecosystem services they can provide in different and often radically changed contexts (IPBES, 2019; MEA, 2005).¹ 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](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 far-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 them. 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, which affects 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 CO₂ and reduces the potential for these forests to safely store carbon dioxide emitted in the future.² Not to mention that tropical forests are also biodiversity hotspots and so deforestation directly increases the risks of a 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. 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 well-being 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 (Nicholson et al, 2009).

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.³

Very real benefits are expected if we can limit the global temperature increase from climate change to 1.5 degrees rather than 2 degrees Celsius or higher, 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 global mitigation** 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.
- **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 by avoiding damages from air pollution to both human health and food production (Shindell et al., 2012). Interactions between climate change and air pollution are significant (Lanzi and Dellink, 2019; McCollum et al., 2013) and reduced damages from both would have beneficial economic outcomes (OECD, 2015 and 2016). Indeed, the health co-benefits of climate policy from improved air quality have been found to outweigh or at least counterbalance the costs of meeting climate policy goals (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 the implications for patterns of land-use, including for food production, and the higher the 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 broadly in line with the Paris Agreement (RCP 2.6) were implemented through a uniform carbon tax across sectors and regions, the number of undernourished people could be higher than in a scenario with greater levels of climate change (RCP 6.0). At the same time, Frank et al. (2017) show that through remunerating carbon sinks in addition to taxing the emissions, a large part of the negative impacts on food security could be avoided. Havlik et al. (2014) demonstrate that because of the widely differing GHG efficiencies across 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 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 as a reference for scenario comparisons and studies encompassing such issues as energy, water, and land-use futures under different levels of climate action. These economic projections 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 social and economic systems as 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 that 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 well-being 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 tries 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. 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 (Wada et al., 2019; Kahil et al., 2018; Vinca et al., 2019). These tools link engineering-economic models representing investment and allocation decisions across water, energy, and land-use 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 decisions⁴.

For its part, the OECD has analysed the economic aspects of the 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 IASA can provide.

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, 2017b). Risks depend 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 IASA 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.

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). 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 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).
- 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 illustrates the need for multi-scale and linked-systems analysis. Emissions from fossil fuel burning in vehicles affect human health locally, but electrified alternatives still cause non-exhaust emissions and 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 vehicles 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 transport sector with well-being and sustainable development goals. First, because it focuses attention on improved access to opportunities and activities, rather than on higher physical movement. Second, focusing on improving accessibility (through enhancing physical access to opportunities, ensuring affordable services, and improving road safety) recognises the potentially important role of sustainable transport modes and of approaches that create proximity of housing to these economic and social opportunities. Such an approach could also support government climate change mitigation policies, as well as reducing air pollution and associated health impacts. Ensuring accessibility through alternative modes is key to achieving the shift away from individual vehicles, which transport demand management policies (e.g. road, parking and fuel prices) aim to achieve. On the other, it is also central to avoiding transport-related social exclusion or disproportionate economic transport costs for the population. This approach can also help ensure 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 lower once consumer behaviour is taken into account.

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. Both the OECD and IIASA have a range of tools to look at impacts and policies. By carefully linking insights from fine-grained urban models and analysis of good practice in policy design and implementation to aggregate impacts and economic feedbacks, broad and local progress towards human development goals can be studied at the same time, helping policymakers spot and avoid trade-offs.

Future directions

Several future directions should be pursued to develop the understanding of these integrated systems. First, 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. It is also important to connect stakeholders systematically during the model development process, to ensure that interventions are accepted by stakeholders when implemented. Furthermore, there should be a 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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Notes

¹ The Millennium Ecosystems Assessment (2005) defined four categories: provisioning; regulating; supporting; and cultural.

² In recent years estimated around 4.8 GtCO₂-eq per year, comparable to the GHG emissions from Europe (Harris 2016)

³ 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 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/

⁴ See: <https://www.iiasa.ac.at/web/home/research/iswel/ISWEL.html>

7 Cities and the Circular Economy

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The importance of applying the systems approach to cities and urban policies is illustrated using the circular economy. Cities are laboratories for innovation and have the entrepreneurial impetus and links to citizens to generate the social, environmental, and economic benefits of innovation and experimentation. Many cities are implementing circular economy strategies to maintain a healthy and regenerative economy, while promoting environmental sustainability and liveability. City infrastructures have to be re-engineered and re-operated to rectify environmental “bads”, for example degraded water. If cities are to be forces of good for the environment, the traditional systems approach may not suffice. Conventional policy analysis contains four precepts that should be reversed. Do not: insist on a single and agreed definition of the problem; distinguish facts from values; set up a single metric for comparing and assessing options; optimise around the most promising option.

Introduction

Cities are important for the global system and will continue to face profound challenges due to climate change, population growth, and urbanisation. Cities are certainly causes of environmental problems, but also part of the solutions, which urban policies with the right scale, strategies, and stakeholders can provide. The approach that both OECD and IIASA pursue is a people-centred systems approach to matters of governance, but also to matters of orchestrating and mobilising the relevant knowledge bases, models, engineering and ecological thinking, technological innovations, and holistic systems approaches. This chapter argues for the importance of applying the systems approach to cities and urban policies, taking the circular economy as an example.

Why apply the systems approach to cities and urban policies?

Cities are facing and will continue to face intense challenges due to megatrends such as climate change, demographic growth, and urbanisation. Cities are where people, information, finance, and global flows of resources (energy, water, plastics, carbon-, nitrogen-, phosphorus-bearing materials, etc.) are gathered to interact with each other in the most intensive, complex, and often unexpected ways. Cities are responsible for over 70% of energy-related CO₂ emissions (IEA, 2016) and a growing share of waste - 1.3 billion tonnes of global municipal solid waste were generated in 2016, which is expected to rise to 3.4 billion tonnes in 2050 (UNEP, 2017). With an increasing population living in cities (up to 70% by 2050), together with the effects of climate change, notably sea-level rise affecting coastal regions, the environmental impacts look set to intensify.

Rich and poor urban dwellers, moreover, usually live in different neighbourhoods, with unequal access to goods and services and asymmetric experiences. Global frameworks such as the 2030 Agenda for Sustainable Development clearly recognise the need for *making cities inclusive, safe, resilient, and sustainable*: through improved access to services; novel ways of arranging human settlements; and innovative ways of re-engineering urban infrastructure to reduce and eliminate the negative atmospheric, aquatic, and terrestrial environmental impacts of cities. Indeed, systems approaches are capable of enabling cities to go above and beyond their becoming merely “less bad” for the environment and the global system.

The complexity of urban issues cannot stay in policy silos and instead requires a systems approach. In particular, since decisions are taken at every moment across multiple scales (households, firms, local, regional, and national governments), there is a need for synergies and a better understanding of how decisions are made and executed in cities. Government decisions are often made according to sectors, which overlooks a “whole-of-government” approach that can maximise synergies, while minimising overlaps and transaction costs.

A systems approach refers to a set of processes, methods, and practices that aim to affect systems change. For governments, this approach has several implications: to develop a vision and related strategies to transform the system in the face of changing circumstances; to mobilise a broad range of actors to achieve a common good rather than narrow institutional interests; to confront problems that traverse administrative and territorial boundaries in a holistic manner; and to face constant adjustment throughout the policy cycle, with implications for the ways in which institutions, processes, skills, and actors are organised. For this to happen, certain conditions should be in place, such as having a champion committed to change; capacity to experiment; ability to engage with internal and external stakeholders; and sufficient resources to delay a business-as-usual approach (time, capital, etc.). Understanding problems and needs requires identifying underlying gaps and synergies across sectors and actors and connecting the dots (OECD, 2017).

However, current methodologies can be overly focused on the global level, overlooking the local dimension. Contemporary Applied Systems Analysis (ASA) “never reaches the ground” as a result (Beck et al., 2018). What is called for, analysed, and proposed at the global level can lose its significance and political immediacy at city, neighbourhood, and household levels. The well-known aphorism, “think globally, act locally”, has its complement, first coined for engineering styles of ASA (Beck, 2011; p xvii): “Engineers ‘Acting Most Locally’ to build a community eager to engage in ‘Thinking Globally’”.

Individual actions can make the difference in our consumption behaviour. Highly local acts can have impacts on the distant destinations of post-consumption products: flushing the toilet, or sorting out the growing categories of recyclable and – still regrettably non-recyclable – household “waste” (itself an increasingly unhelpful misnomer). Cities thus present an effective focus for the design and implementation of systems-based solutions.

To take a somewhat broader stance, cities and their hinterlands are naturally interconnected and interacting systems. Together they play a key role in regional development and cohesion. Urban systems planning has ideas and problem-solving approaches to offer to rural systems development, and vice versa. Their interdependence and the need for a systems approach to them both - as one - is evident in the eloquent words of Berry (1977, p 24):

[Our cities] and our country create one another, depend on one another, are literally part of one another; that our land passes in and out of our bodies just as our bodies pass in and out of our land; that as we and our land are part of one another, so all who are living as neighbors here, human and plant and animal, are part of one another, and so cannot possibly flourish alone.

In cities, decisions are taken all the time across the multiple scales of households, firms, community groups, and local, regional, and national governments (to name but a few of the key actors in the system). To begin with, there is a need for a better understanding of decision-making and, more importantly, of the synergies and antagonisms among this host of decisions across scales.

It is possible to conceive and classify the host of decision-making actors and institutions in ways other than scale. There are public-sector government actors, private-sector market actors, civil-society actors (they have been called “.gov”, “.com”, and “.org” actors, respectively); and, just as significantly, there are science and technology communities (adding “.edu” to the list). As witnessed in many environmental and social issues of policy – the transition to a non-smoking public sphere, or the transformation needed to break free from the world’s dependence on fossil fuels – civil society and the private sector are exerting their influence throughout the whole policy cycle. Affairs amount to much more than merely joined-up government thinking. Forming strategic alliances across governments, academics, businesses, and civil society organisations is becoming a new operating norm. The blurring of boundaries makes it increasingly necessary to view urban policymaking as a networked system.

For the benefits of the systems approach to be enjoyed, certain conditions should be in place, such as having an individual who champions change (Katz and Bradley, 2013; pp 64-87), and first-followers not afraid to move the masses. A capacity to experiment, a tolerance of failure, and a capacity to learn from mistakes are needed. This requires an ability to engage with stakeholders both within and outside of government, with sufficient resources (time and capital) to resist the urge to continue with a business-as-usual approach.

“Change” according to a systems approach is thus needed. Transformative change is being sought in many places and ways, with important implications for governments. In particular, choices should be *collectively* debated and inputs from a broad range of actors need to be mobilised and encouraged in order to achieve a future collective good that spreads beyond narrow institutional interests. The scale at which problems and solutions arise should be taken into account, as well as administrative and territorial boundaries. Constant adjustment and continual adaptation will be needed throughout the policy cycle, which bears clear implications for the organisation of institutions, processes, skills, and actors.

Cities are foci of innovation, including in respect to systems approaches themselves. For what are innovation ecosystems and urban innovation districts, if not the results of deliberate systems thinking and systems design? Cities are the laboratories of the world. The very feature of their “bounded regionality” provides intimate, on-the-ground links. Cities enable the bottom-up entrepreneurial impetus for citizens to stimulate and cultivate innovative social, environmental, and economic benefits, including novel forms of businesses and entrepreneurial partnering. And yet, coordination between the local and national levels is needed for policies and incentives at the two scales to catalyse one another. National strategies play a key role in supporting cities’ unique capacity to foster entrepreneurship.

Governance at the urban level must focus on the material realities of the city and the immediacy of policy consequences for the everyday lives of city dwellers. Accountability is a proximate reality, not something vaguely distant. City managers are obliged therefore to think, invest, and act in the full glare of the longer-term perspective. Their concerns must be to anticipate and adapt to change and to strengthen resilience in the face of the inevitable shocks that cannot even be imagined, let alone anticipated. Governments at this local level should be what is desired of so many: agile. Encouraging and facilitating such nimbleness of governance must be prominent in the remit of the proposed systems approach to cities and urban policies.

The currently debated transition from a linear to a circular economy is an example of how system thinking can be applied at the city level. The circular economy, as a new socio-economic paradigm aiming at preventing waste and transforming it into resources obliges one to think yet wider still: of the sub-system of the household nested within the city, the city within the region, and the region within the supra-system of the entire globe. The circular economy in cities implies resource flows are not about merely linear supply chains. Better to say, they are supply *circles*: endless, unbroken chains, between *post*-consumption resources generated in the city and their return back to the city as *pre*-consumption resources (Thompson et al., 2019; Beck et al., 2019). To reach such an alternative conception requires summarising the necessary (and necessarily profound) re-thinking of the system of the city and its hinterland. The circular economy provides precisely the problem context needed for testing, refining, and extending the systems approach in cities.

Putting the systems approach to work: new ways of forming and implementing policy

Cities and the circular economy: the OECD’s perspective

OECD has been at the forefront of research and analysis of urban policy. It is a leading international forum for exchanging views and experience in the field. Acknowledging the importance of place-based policies, the OECD has been working on databases, country reviews, thematic studies, and standards that take into account the specific characteristics of territories, the connection across levels of government, the inclusion of stakeholders in policymaking and implementation, and the interlinkages across a wide range of policies. For example, the OECD Metropolitan Database is defined according to so-called Functional Urban Areas, which extend beyond administrative boundaries of cities, while taking into account the functionality of territories based on people’s daily movements (OECD, 2012). Countries and thematic reviews take into account multi-level governance for clear allocation of roles and responsibilities across levels of government, capacity building, and policy coherence. National Urban Policy reviews (e.g. Mexico, Chile, China) support a coordinated implementation and monitoring of global urban agendas, such as the Sustainable Development Goals, Paris Agreement, and Sendai Framework.

The OECD has also developed standards, the *OECD Principles on Urban Policy*, to provide governments with a guiding framework to deliver effective urban policies, based on scale, strategies, and stakeholders. The *Principles* define urban policies as:

“a co-ordinated set of policy decisions to plan, finance, develop, run and sustain cities of all sizes, through a collaborative process in shared responsibility within and across all levels of government, and grounded in multi-stakeholder engagement of all relevant urban actors, including civil society and the private sector” (OECD, 2019).

The role of the OECD as an intergovernmental organisation is to support governments in navigating economic challenges through innovative approaches, such as those concerning the transition to the circular economy. As such, the OECD works hand in hand with governments (e.g. Spain, the Netherlands, and Sweden) to share policy recommendations and best practices on the transition from the linear to the circular economy. Governments at different levels have shown increasing interest in the subject, and want to know more about the economic and governance conditions needed to put in place the circular economy, which is systemic by nature.

Cities are very much concerned with the transition towards the circular economy: first, as already discussed, cities are laboratories for innovation and have the bottom-up entrepreneurial impetus and links to citizens to generate the social, environmental, and economic benefits of such innovations and experimentations, including new forms of businesses and partnerships. Second, in light of the increasing trends of decentralisation of public services in OECD countries, subnational governments have greater responsibility for local public services such as transport, solid waste, water, and energy, which are key for the well-being of citizens. Third, governance at the urban level focuses on the realities of the city and the impacts of policies on the lives of citizens. Cities such as London, Amsterdam, Paris, but also smaller ones like Valladolid, Groningen, Granada, and Umeå are designing and implementing circular economy strategies, as a vehicle to maintain a healthy and regenerative economy, while promoting environmental sustainability and liveability.

At the core of OECD’s work on the circular economy in cities and regions is the 3Ps framework, which argues that for the circular economy to be implemented at local and regional level, three aspects should be highlighted, considering the complex interactions across people, policies and places (OECD, forthcoming):

- **Coordination across people** implies coordination at different levels of government and across stakeholders. Several actors (business, government, and civil society) have varying rationalities and divergent objectives in moving towards a circular economy. For this purpose, it is important to engage stakeholders for inclusive policy design and implementation; to motivate stakeholders towards common aims; and to create incentives and framework conditions for building synergies at the right scale and minimising future liabilities for society. The involvement of all stakeholders requires active, specific, and tailored communication strategies. However, information is not enough. Raising awareness about circular economy costs, benefits, challenges, and opportunities is equally important. Stakeholders need to be engaged in the projects in order to secure acceptance and commitment. The business sector is a key player in a circular economy since the transition towards a circular economy will depend on the capacity of the sector to shift towards more sustainable business models (e.g. using secondary material, recycling, sharing, etc.). Citizens make constant consumption choices and can influence production. Therefore, a behavioural change is needed. Government at different levels needs to coordinate to avoid overlaps and duplications. “Who” does “what” and at which level requires clarification in order to create synergies across national and local regulations and financing.
- **Coordination across policies** provides an opportunity to seek complementarities across sectors (e.g. environmental, regional development, agricultural, industrial policies) and enhance better planning for the use of water and energy in the building sectors or the reuse of food waste for agricultural purposes, for instance. Some of these interactions are not well-known or thoughtfully considered when designing and implementing urban policies.

- **Coordination across places** is also important to manage trade-offs across urban and rural areas, amongst others. The issue of scale is key for the circular economy in cities, as they are not isolated systems, but a space for inflows and outflows of materials, resources, and products, connected with surrounding areas and beyond. A circular economy can reinforce and create opportunities across urban and rural areas.

The variety of actors, sectors, and goals makes the circular economy systemic by nature. It implies a re-thinking of governance models based on multi-stakeholder and multi-sectoral approaches. For the circular economy to happen, policies need to be aligned, stakeholders informed and engaged, legal and regulatory frameworks updated and supportive of innovation. In addition, technical, human, and financial resources need to be adequate; new capacities need to be built; and progress and results need to be monitored and evaluated to stimulate economic growth, social well-being, and environmental sustainability.

IIASA's approach to urban metabolism and infrastructure innovation

One highlight of IIASA's work on cities has been motivated by the idea of "Cities as Forces for Good in the Environment" (CFG) (Crutzen et al., 2007). Its vision and challenge may be expressed thus:

How can city infrastructure be re-engineered and re-operated - indeed, through the participation of the plural .org, .gov, and .com actors - so as to reduce the city's ecological footprint to zero, even to go above and beyond this, such that the city may become a net generator of ecosystem services?

The challenge calls for a new mindset: making ourselves "more good", a fully intentional liberating motivation (McDonough and Braungart, 2002). It is also a mindset intended to accompany that of the framings of the SDGs and of the climate change science community. We must be mindful of our "planetary boundaries" and "safe operating space for humanity". In sum, we should progressively make ourselves "less bad" (Fiscus and Fath, 2019). In other words, the challenge is to ask how to rectify the environmental "bad" of, say, an agriculturally or industrially degraded watershed and, with a change of mindset, to build the environmental "good" of a city in the depleted watershed.

The companion Sustainability Concepts Paper significantly elaborates the complementary agenda of CFG (Beck, 2011). This agenda is people-proximate, like that of the OECD, and is supported computationally by a Multi-sectoral Systems Analysis (MSA) model. The model has been applied to case studies of Atlanta, USA, Suzhou, China, and London, UK (Villarroel Walker et al., 2017). It accounts for how energy, water, carbon-, nitrogen-, and phosphorous-bearing resource flows circulate through the energy, water, food, forestry, and waste sectors of the city and the surrounding hinterland of its watershed.

First results with MSA were published as a matter of "Understanding the Metabolism of Urban-rural Ecosystems" (Villarroel, Walker, and Beck, 2012). The framing of MSA falls well within the ambit of the circular economy. It enables the systems analyst to ask and respond to the following kinds of questions (Villarroel Walker et al., 2017): what re-engineering interventions and technological innovations might be key – under gross uncertainty – to achieving a more sustainable and less resource-intensive urban metabolism in the future; and which sectors of commerce and society (.org, .com, .gov) offer the greatest opportunity and promise for such technical and policy interventions? Indeed, the central purpose of MSA is to re-orient such interventions, from a reactive to a more proactive, people-driven task: which actors in the urban-rural communities might want to cultivate and advance which of several schools of engineering thought in order to contribute to realising CFG? The first signs of such people-proximate re-engineering and innovation are foreshadowed in Beck et al. (2011, 2013). Strategy development can be supported by foresight models, such as MSA, in the setting of Adaptive Community Learning (Beck, 2011; pp 83-101).

When the challenge requires nesting CFG within the circular economy, the traditional systems approaches may not suffice. In this instance, the much sought-after transformational change is needed in the systems approach itself. If a new systems approach is being forged, new cohorts of applied systems analysts must be trained differently. The appropriate engineers and economists will have to be given the capacity to "think

differently”, not least to exercise more systems thinking. Decisions in the circular economy will not be made “once and for all” and will always need to be adapted.

Such change implies broadening enquiry and procedure beyond customary conventional boundaries, indeed, to be somewhat disruptive of its routine. Specifically, conventional policy analysis contains four precepts that should be prefaced by the word “not”: *not* to insist on a single and agreed definition of the problem; *not* to distinguish facts from values; *not* to set up a single metric for comparing and assessing options (e.g. dollars, lives saved); and *not* then to optimise around the most promising option. When working within the common conventions, the procedure of decision analysis can be called *elegant*. Outside the conventions, the procedure would be called *clumsy* – precisely to emphasise the contrast. The two, elegance and clumsiness, are complementary.

Deciding which approach to apply depends on whether the problem is tame or wicked. Addressing the issues of cities and the circular economy requires the latter, as exemplified in the slogan, “Wicked Problems, Uncomfortable Knowledge, Clumsy Solutions” (Thompson and Beck, 2014). This means that the problems may preclude convergence to any solution, unless the overarching governance and innovation framework is shaped to enable a solution to emerge. Knowledge of the way the system works may also be plural. How civil-society (.org) actors believe the world to be may be at odds with what public sector (.gov) and private sector (.com) actors hold it to be. For any type of actor, the knowledge held by the other types is thus uncomfortable. In such settings, success in the policy process can thus be gauged along these lines: in a clumsy solution, each type of actor gets more of what they want (and less of what they do not want) than they would have got had they excluded all the other types of actors, taken no notice of their knowledge and aspirations for the future, and “gone it alone”. Governance thus has a key role to help clumsy solutions to emerge.

Some two decades of practical experience has now been accumulated in addressing wicked problems with this form of people-centred systems approach – gathered around our anthropological hypothesis of clumsiness, based on the theory of Plural Rationality (see Box 7.1) or Cultural Theory (Thompson et al., 1990). This approach has been deliberately exposed to debate, dialogue, challenge, and criticism, in a recent (November, 2019) workshop co-sponsored by the Institute for Science and Innovation in Society (InSIS) at Oxford University and the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC): “How Engineers Think — About Infrastructure, Cities, and Resource Flows” was the workshop’s title, accompanied by the sub-title “The Social Anthropology of Engineering Problem-solving and Technological Innovation”. Such practical experience is especially relevant to the people-proximate issues of resource management, infrastructure, and cities – just as argued in the foregoing, in respect of OECD’s 3Ps approach to cities and the circular economy.

Box 7.1. Plural Rationality, Computational Models, and Analytical Methods

A great deal of what has been achieved over the past three to four decades in developing and applying the theory of Plural Rationality, including indeed what was first presented as Rubbish Theory (Thompson, 1979), avails itself in practice of but three out of the theory's five rationalities: the hierarchist (.gov), individualistic (.com), and egalitarian (.org) rationales. To be able to understand and identify a fourth rationality, symptomatic of a passive "fatalised" (or fatalist) stance, is crucial to apprehending a loss of deliberative quality in governance. At a systems level, each of these (now) four rationalities may be identified by its distinctive beliefs about the stability-instability in a system's behaviour (over the shorter-term). Each may accordingly be defined by a distinctive risk-coping style (risk managing, risk seeking, risk avoiding, and risk absorbing). Elaboration of a fifth rationality, identified with the systemic property of resilience in a system's behaviour (over the longer term), will be a strategic goal of our research. Its development and application promise very substantial potential for managing the process of adaptation in governance.

Plural Rationality defines the behavioural logic of the five ways of seeing the world and acting in it. The behaviour of a community of such diverse agents (people, institutions, businesses, organisations, etc.), each interacting with each other and making choices, may be simulated in a model. The first such agent-based models were developed in the 1990s at the Santa Fe Institute. Surprising though it may seem, it is possible to conceive of implementing the resource-flow analyses of MSA according to Plural Rationality, with a view to attaining smarter urban metabolisms (Beck et al., 2013). And it is just as possible to set up plural-rationality models for achieving resilient operation (in real time) of energy management systems of distributed energy storage in community micro-grid networks, as discussed at the 2019 Oxford workshop. Case studies in such application areas should be used as "live" test beds for elaborating the four (preferably five) schools of engineering thought.

A city may also be viewed as a multi-dimensional layering of interacting networks. How resource and information flows are exchanged and overlap in these networks can inform policy analysts about the structural organisation and functional performance of urban metabolism (Zhang et al., 2016, 2018). In particular, we will encourage further case studies investigating the cycling, scaling, circulation, and trade-off between efficiency and redundancy, to give another picture of the circular and regenerative economy in cities (Fath et al., 2019).

Future directions

OECD and IIASA's approaches to cities and the circular economy are closely aligned in their interests and aspirations. Both seek impact "on the ground" and are concerned with the roles of governance in their respective systems approaches.

OECD's experience in supporting national, regional, and local governments with policymaking and place-based, multi-level governance and multi-stakeholder approaches, in exchanging best policy practices, and in dismantling siloed thinking, will shape the way IIASA articulates such experience into re-engineering strategies and cultivating technological innovations in urban policies. IIASA's experience of strategies for coping with risk and working towards resilience in policy outcomes and people's experiences of their urban and rural environments – driven by Plural Rationality and reflected in computational modelling – will add to OECD's elaboration of its 3Ps framework, applied to the ongoing OECD Programme on the Circular Economy in Cities and Regions.

Future directions include continuing exchanges between OECD and IIASA to support policymakers by developing joint research on cities and the circular economy.

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8

Systems-based Approaches for Development Co-operation to Meet Diverse Needs and Aspirations in an Interdependent World

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An approach to development co-operation based on systems analysis is advocated to help decision-makers reconcile multiple objectives related to the social, economic, and environmental dimensions of sustainable development. Systems analysis examines how complex problems interact, how threats and risks can multiply, and where feedbacks might exist, making it possible to anticipate surprises or tipping points. It provides a pathway to effective translation of research into impacts, by developing instruments to bridge sectors and actors, as well as temporal, social, and spatial scales from global to regional, national, and subnational, thus facilitating the task of policy- and decision-makers to address global and national challenges. The need for collaboration to address global sustainability challenges runs counter to current political trends, where solutions advocated to address the needs of an individual country may prove detrimental by ignoring their international implications and longer-term consequences.

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 agenda seeks to bring together 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 in 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 may 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 one billion mark. Today, over seven 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 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 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 human and natural systems. Human development ambitions need to be aware of their impact across scales.

Evolving perspectives on sustainable development

Concern about the scale and consequences of our impact on the environment is not new, nor is the demand to change human behaviour. Sustainability considerations entered the mainstream of international and national policy discourse 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". 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).

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 concerning how much change is necessary or feasible.

Part of the challenge lies in the amorphous concept of sustainable development itself (Ekins, 1993, Gomez-Baggethun and Naredo, 2015). There are diverging options as to what sustainable development really means, and 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 of 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 capital replace the depleted natural capital. This view gained 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 the absorptive capacity of the environment.

The emergence of green growth and green economy as concepts sought to reignite the drive towards sustainable development prior to the 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 proposed by UNEP (2011) in collaboration with other UN bodies 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 placed 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 we should 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 beyond the scope of the MDGs. In contrast to the 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 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 realised 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, a worldview of complexity and interdependence needs to be embraced in development co-operation.

The implementation challenge

Science has been very successful in describing complex and global environmental problems such as climate change, which 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 and moral 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 also have 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 mean 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. Atmospheric greenhouse gas concentration has reached new record levels (WMO, 2018), while a rapid decarbonisation of the energy system and net zero emissions towards the 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, now reaching 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 national public policymaking, the business delivery model has not kept pace with the increasing complexity and interdependence of our world (Oatley, 2019). The business model for development co-operation is often predicated on short-term, measurable outputs and not on relevant outcomes. This inevitably works against taking a more holistic view of development co-operation 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, 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 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, and support or undermine each other. Clarity is also needed on how the economies of scale can be harnessed through the multilateral system and how this can be utilised for investments in global public goods as well as national development processes (OECD, 2018b).

The obvious conclusion is that the national and international policy environment for development co-operation needs to embrace reform in order to contribute effectively towards a more sustainable world (Yan and Yifu, 2018). Policy coherence for development (PCD) is focused on avoiding or minimising negative spillover effects of various policies on the development 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 subsidised agricultural production 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 create synergies between economic, social, and environmental policies (OECD, 2016).

Political will is fundamental to advance change. One aspect to rethinking how development co-operation between countries can be approached includes taking a fresh look at the relationship between donors, recipients, and other stakeholders. This is illustrated by an example on triangular co-operation (Box 8.1). Another aspect includes considering how an integrative policy environment can be underpinned by strong analytics, so that the dynamics and interdependencies can be better captured and inform development co-operation. Da Silva et al. (2017) argue that development co-operation 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 8.1. Triangular cooperation between Morocco, Costa Rica, and Germany for Sustainable Development

Triangular co-operation 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 institutionalise 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 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 support 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, multilayered problems. It is about “solution science” that can serve as an analytical tool for decision-makers on how to

reconcile multiple objectives, which relate to the social, economic and environmental dimensions of sustainable development.

The strength of systems analysis lies in its ability to provide an integrative and systemic perspective on complex problems, in understanding how they interact, how threats and risks can multiply, and 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 subnational, 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 a 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 is an example of a multi-party effort 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 considered to encompass major dynamics and drivers of development: human capacity and demography; consumption and production; decarbonisation and energy; food, biosphere and water; smart cities; and the 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-led by IIASA and the Sustainable Development Solutions Network (SDSN), FABLE works with country teams in developing national land-use development pathways 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, multilayered analyses. Global analyses can provide a general framework, but it is in dialogue with national and subnational contexts where integrated analysis becomes 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 is currently being implemented by the Brazilian Agricultural Research Organization, Embrapa (Box 8.2) 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, organisation, 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 about sustainable development pathways.

Box 8.2. 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, policymakers 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. These components should be understood and considered in a more systemic, integrated way - as analogies of components of the metabolism in living organisms.

One of the major tasks of STI is the access to, and organisation and integrated analysis of territorial information on natural, agrarian, agricultural, infrastructural, logistical, social, and economic dimensions, at various temporal and spatial scales. It also seeks 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 specificities and values that can be found or developed from a functional territory. Considered in larger scales or even at country scale, STI can help 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 bringing 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. Systems 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 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 securing the capacity to adapt and react to rapid change.

Systems 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, understanding and ownership of socioeconomic transformations towards sustainable development pathways are generated, bringing to life a collective vision for a sustainable future for all.

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Part III 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)

It is argued that connecting education with ageing and inter-cohort changes can generate knowledge to guide research and policy. Emphasis on early childhood cognitive development is key. Better-educated individuals are not only more productive, but also tend to have better health and stronger social networks. Lifelong participation in formal and informal education will keep populations healthier, more physically and cognitively active, and more connected to society. A 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 health and labour force participation, as well as to identify alternative strategies and foresee their impact. IIASA's multistate population and education modelling can inform the OECD's strategic and policy-oriented mission. This will be important in poorer countries where education, particularly of girls and women, is a key instrument to reduce poverty and improve gender equality.

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 life cycle means that the young of today will be the elderly of the future. The skills, worldviews, or other characteristics that children acquire will be basis for their skills and worldviews as they age. Better-educated young cohorts will also be better educated throughout their 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 that the elderly of the future will be better educated than the elderly of today.

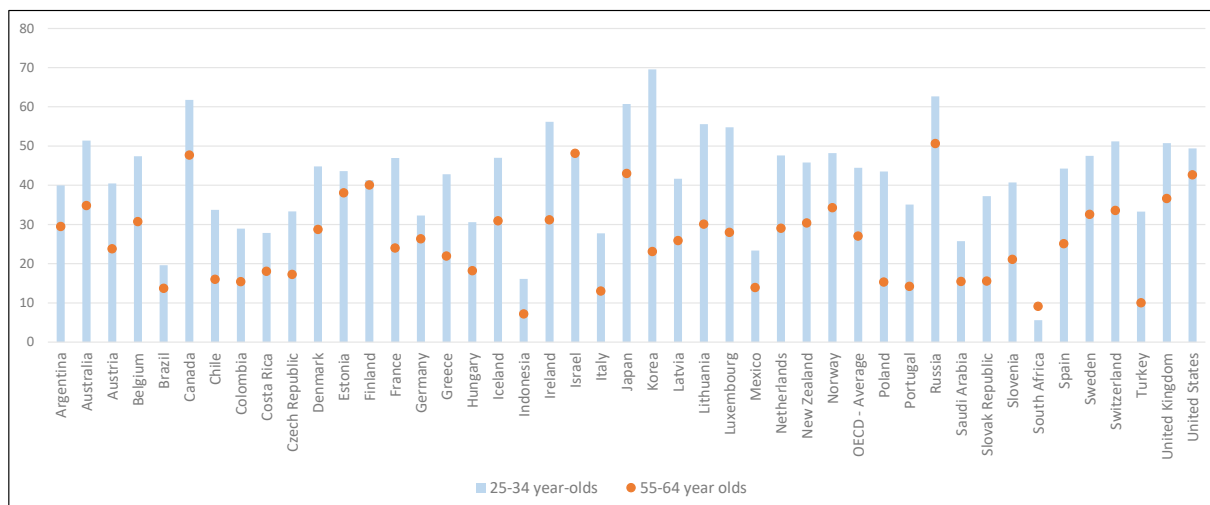
Trends in education and ageing

Improvements in 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. Population with tertiary education (2018 or latest available)

25-34 year-olds / 55-64 year-olds, percentage in same age group



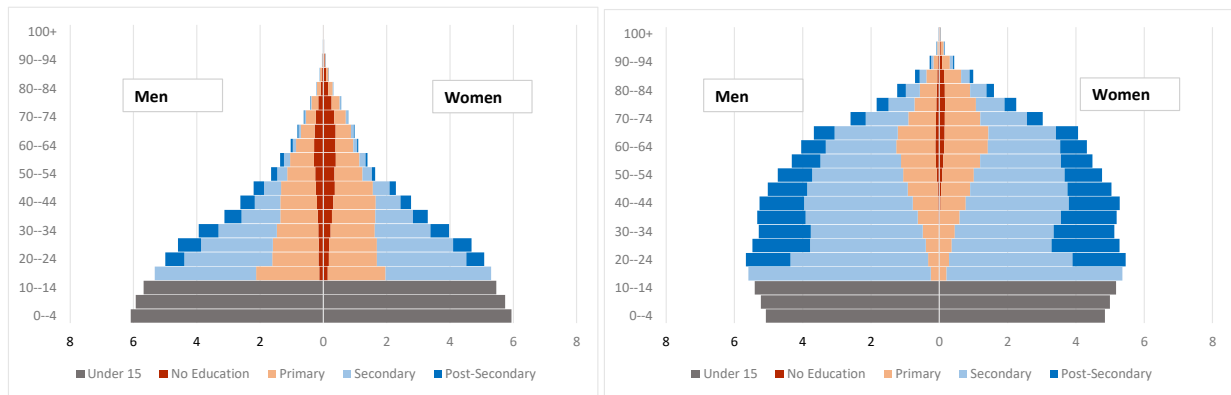
Note: In most countries, there is a break in the time series as data for 2017 refer to ISCED 2011, while data for 2007 refer to ISCED 97
 Source: OECD (2019), Population with tertiary education (indicator). <https://doi.org/10.1787/0b8f90e9-en>

Analysis of the education/ageing nexus

Education is typically acquired young, and after a certain age, (formal) educational attainment does not change over the rest of the life cycle. A doctorate, once attained, stays with you until death. But education does not only give us a qualification, 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 today's elderly, provides a positive outlook in the context of population. As indicated above, in virtually all countries young cohorts today are better educated than older ones. And we can forecast 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 9.2 illustrates this for 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 (left) and 2040 (right)



Note: Population in millions. The pyramid for 2040 is based on the SSP2 scenario assuming a continuation of demographic and education trends.

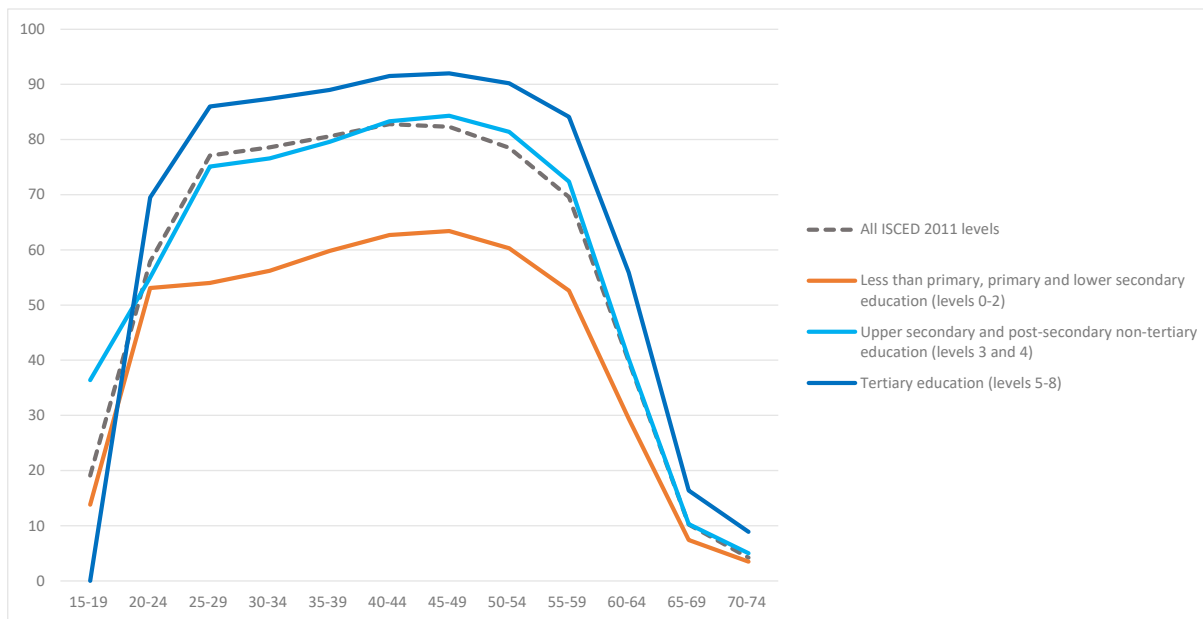
Source: WIC (2018)

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 9.3 shows the female labour force participation rates for all EU-28 member states combined in 2018.

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 (Lutz et al. 2018).

Figure 9.3. Female labour force participation rates by level of education in the EU-28, 2018

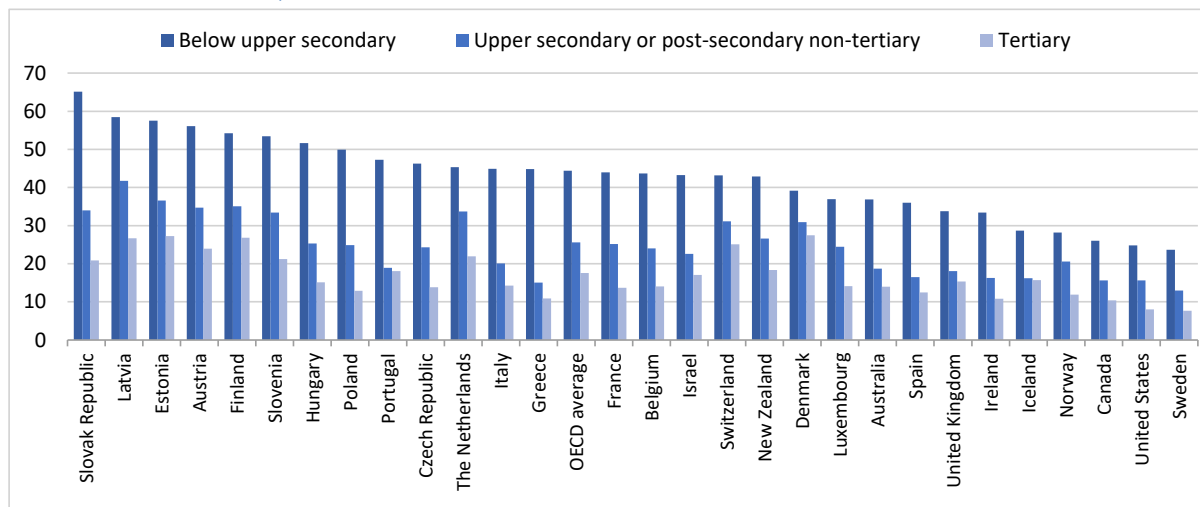


Source: Eurostat, Labour force surveys

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 9.4, 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 and Crosby, 2014).

The combination of the facts that the future elderly will be better educated than today's, 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 age-based projections alone 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, S., and H. 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 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 OECD Survey of Adult Skills (<https://www.oecd.org/skills/piaac/>) demonstrate that proficiency peaks 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. Even so, 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 is 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 programmes 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 programmes depends on the level of education received at a young age. The earlier and the better the process of learning how to learn starts, the more successful learning throughout life will be (German National Academy of Sciences, Leopoldina, 2014). Because the human life cycle in OECD countries is already around 80 years, investments today in effective learning in children and youth will have significant positive effects over the rest of this century.

This 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 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 long 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 life will keep our populations healthier, more physically and cognitively active, and more connected to society.

In this context, a 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, and to identify alternative strategies and foresee their impact. IIASA's multistate population and education modelling can inform the OECD's strategic and policy oriented mission to create better policies for better lives. This will be of tremendous importance in poorer countries where 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 encourages 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 ageing, key strategies related to educational development are needed over the life cycle, from early childhood to adult learning.

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10 Social Protection in the Face of Digitalisation and Labour Market Transformations

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It is shown how systems analysis can facilitate policy responses to complex labour-market changes, including from digitalisation and technological progress. A simple systems map covering linkages and interactions between technology adoption, alternative work arrangements, wages, and social protection illustrates how qualitative system mapping can provide a holistic perspective and enable a systematic exploration of connections between elements of a complex system. The map illustrates how systems analysis facilitates consideration of the behaviour of a complex system by decomposing it into sub-processes that can be verbally described in a straightforward and relatively simple way. 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, provide a “sandbox” for exploring the consequences of linkages and feedback effects for individual agents and for the system as a whole.

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 are concerns that this transformation is occurring too fast for societies to be able to adapt (Brynjolfsson and McAfee, 2014^[3]; Ford, 2015^[4]). In particular, a faster pace of technology adoption creates risks that job losses will outpace the creation of new employment opportunities.

Main Messages

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. Responding to the resulting labour-market challenges 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, digitalisation 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.

Likewise, less stable, non-standard forms of work create new demands on social protection, which existing policy configurations may not be ready to meet. A greater availability of non-standard employment contracts can also create strong incentives for workers or employers to reduce costs by opting out of social support provisions. Opt-out opportunities, in turn, can undermine the foundations of risk sharing and lead to a declining reach of social protection.

Qualitative system mapping can provide the required holistic perspective. It enables a systematic exploration of connections between elements of a complex system to help understand the policy challenges. 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, provide a “sandbox” for exploring the consequences of linkages and feedback effects for individual agents and for the system as a whole.

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 1930s, 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 it still accounts only for a small share of workers in OECD countries (Katz and Krueger, 2016^[9]).

While past innovations certainly destroyed some jobs, in the long-term they have created more than they 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]).¹

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 relationships, 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 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 - 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 policymakers have difficulty applying a systems thinking approach to devising decisions by not always considering relevant interactions in full (Levy, Lubell and McRoberts, 2018^[14])

A number of tools are available to aid policymakers in examining complex systems. Qualitative systems maps can help give an overview of 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 chapter presents a proof-of-concept of the systems analysis approach applied to the social protection policy challenges. It discusses qualitative systems mapping as a concept and provides an illustrative example relating to technological progress, alternative work arrangements, and social protection systems. The chapter also 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, and understand system's elements and relations between them. The process consists of three steps: identification of the system's key elements; identification of key interrelations between them; and identification of key feedback loops that define the behaviour of the system and identification of actions that can lead to desired outcomes via these feedback loops. This analysis can be performed based on input from experts or evidence from literature.

Ultimately, a systems map can provide insight into indirect effects between system's elements relevant for a given policy question and helps anticipate effects of certain policy interventions. The insights gleaned from the maps aid in identifying policy issues or interventions that policymakers can miss when focusing attention on individual components.

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

Building and analysing a qualitative systems map with the involvement of decision makers can lead to unexpected, counter-intuitive results. 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.

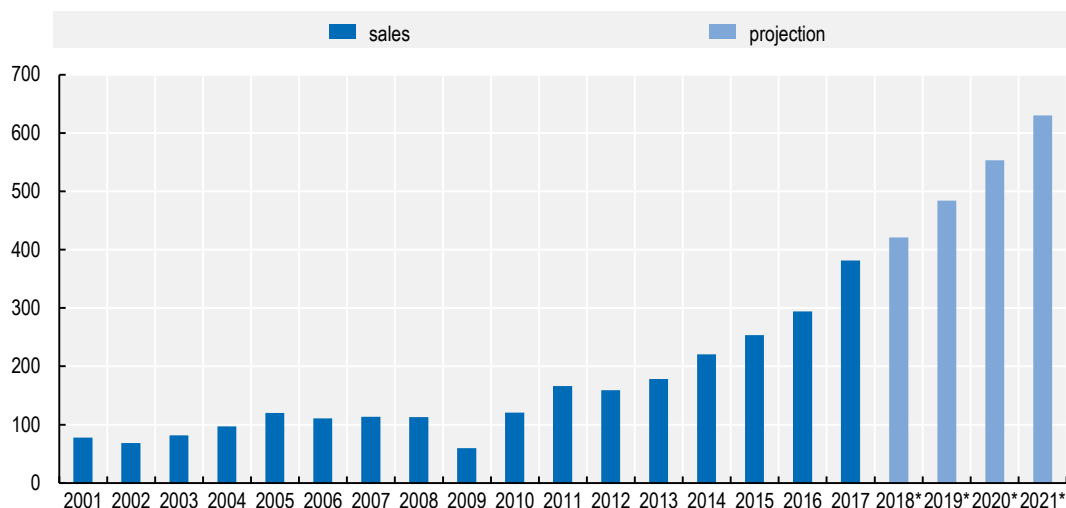
The development of a systems map can be a first step for further exploration and, in particular, quantitative modelling. It can also be a tool for consensus building amongst stakeholders to explore possible further actions.

Technology and alternative working arrangements: An illustrative systems map

This chapter presents a simple systems map, covering interactions between technological adoption, alternative work arrangements, wages, and social protection. The impact of technological adoption is a suitable subject for a systems map, as it can have diverse and complexly interacting disruptions in labour markets. Further, the pace of technological adoption is likely to continue to increase in the coming years.

This example is not intended to represent a full-scope systems map. 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 next section briefly summarises the drivers, and the following section presents the systems map.

Figure 10.1. Robots hold the potential to disrupt labour markets



Note:* = 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 these 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 workers' productivity and increase their 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]). Under these various factors, the overall trend of employment is highly uncertain. Some workers will lose their jobs, while new types of work will be created. Notably, so far, the net effect for most economies has been positive (OECD, 2018^[24]).

Technology fosters the creation of new jobs, and their destruction. It can reduce relative investment prices and spur the accumulation of capital, which in turn replaces labour and leads to a decline in the labour share (OECD, 2018^[24]; Schwellnus, Pak and Pionnier, forthcoming^[25]). Recent technology has encouraged market concentration and winner-takes-most dynamics, leading to a few large firms in some sectors (Autor et al., 2017^[26]). Beyond reducing demand for labour due to their capital intensity, these concentrated industries can further suppress wage growth owing to a lack of competition for workers (Azar, Marinescu and Steinbaum, 2017^[27]; Benmelech, Bergman and Kim, 2018^[28]).

At the same time, many people are turning to alternative work arrangements. For example, online platforms help to reduce job search frictions, allowing potential workers to more easily find jobs. With these platforms, firms can easily find workers with unique skill sets, and workers can gain increased flexibility and access a wider range of opportunities, thereby enlarging the labour market (European Commission, 2017^[22]). By reducing job search frictions, these new digital platforms can reduce time in unemployment (Manyika et al., 2015^[29]).

These alternative work arrangements are not without downsides. While workers gain increased flexibility, this comes with increased risk of low and uncertain earnings. As technology removes barriers to finding a job, more workers enter the labour market, driving wages down. The digital nature of these platforms often means that employers can find workers worldwide, and the variability in labour standards and living costs across countries can often mean a “race-to-the-bottom” for all workers. Those countries with higher rates of non-standard work also have lower wages, less employment protection, less access to social protection, and low bargaining power (OECD, 2014^[30]).

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

Beyond direct wages, social policy and tax-benefit systems can provide a safety net for workers with low earnings, or who suffer unfortunate circumstances. However, in many countries, social protection is either optional or unavailable for those in alternative work arrangements. When given such a choice, these workers often undervalue the safety net provisions and choose either the minimum amount or not to participate at all in the schemes. 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]).

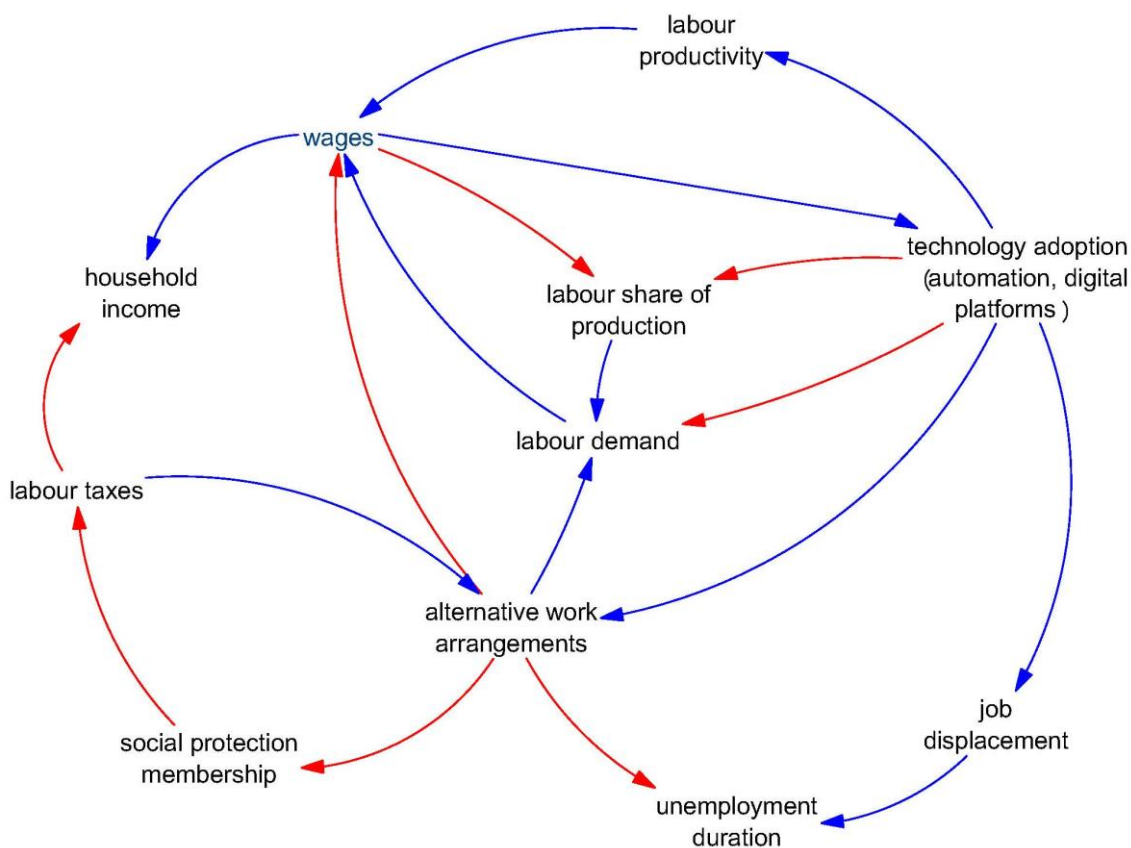
Thus, growing forms of non-standard work places pressure on the financing of social protection, as it largely relies on contributions or taxes levied on incomes from work. Without public subsidies, this incentivises further declines in social protection membership and, ultimately, a cycle of escalating costs and declining coverage (Rothschild and Stiglitz, 1976^[12]; Akerlof, 1970^[13]). In turn, unequal financing burdens or social protection entitlements can promote certain forms employment while discouraging others (OECD, 2019^[34]).

Technology and alternative working arrangements: An illustrative systems map

The trends outlined above provide only a partial picture of the interactions and effects brought on by technological progress. However, here we focus on the labour market, and more specifically, on alternative work arrangements, and present a simple systems map. Even from this simple system, there emerge some interesting feedback loops, illustrated below.

Figure 10.2. 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 effect.

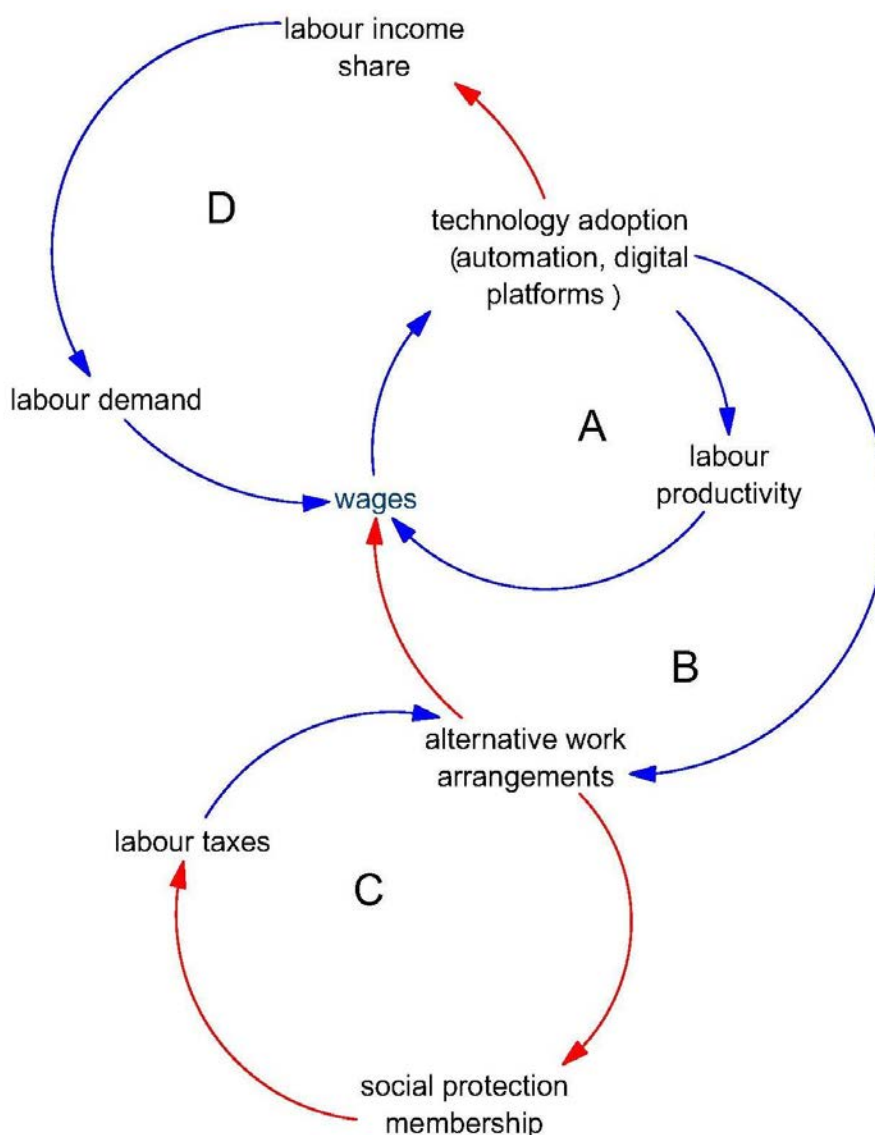
Source: OECD and IIASA analysis

One example of a simple positively reinforcing loop is the link between technology adoption, labour productivity, and wages. 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. When technology adoption decreases the amount of labour needed, the total sum of wages is decreasing which in turn decreases the motivation for investment in automation.

Another balancing loop links technology adoption, alternative work arrangements, and wages. Here, new technologies encourage alternative work arrangements, which can lead to lower wages that, in turn, disincentivises further adoption of technology.

A final example of a loop in this systems map relates to the interaction between alternative work arrangements, social protection systems, and taxes. As alternative work becomes 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. All of this increases the tax wedge differential between standard and non-standard workers, encouraging more workers to take up alternative work arrangements. Further iterations of this loop have negative impacts on overall wages and household income, regardless of the type of work arrangement, either standard or non-standard.

Figure 10.3. 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

The above examples reveal one of the benefits of systems analysis: it makes us think about 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?* To assess that, we analyse all feedback loops and their relative strengths in order to identify the dominating loop and analyse the dynamics that define the behaviour of this system.

Systems maps as an output, or an input

As shown above, a systems mapping exercise can provide clarity on key elements and interactions in a system. The identification of feedback loops is essential to understanding a system, and these loops are not always evident when examining components in isolation. The high-level perspective of the system allows policymakers to gain a conceptual understanding of key interdependencies. In the context of labour markets, this understanding then assists in the design of social protection systems.

Social protection systems provide support during episodes of low earnings capacity and economic difficulties. These systems seek to prevent the deterioration of human capital, which can lead to long-term disadvantages and exclusion. Some components of social protection systems can be seen as “triggers” that policymakers can use to influence a system. For example, income protection measures redistribute resources to groups with elevated needs and provide support during periods of low earnings, unemployment, or other types of non-employment. Additionally, promotion measures can strengthen or re-establish self-sufficiency through incentives, and by tackling individual employment and social-inclusion barriers.

Importantly, 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 infrastructure are country specific, and these specifics will dictate the behaviour of a system

These national circumstances can be notable. For instance, some countries have voluntary insurance schemes for some types of employment. Unless these schemes achieve a high coverage rate, they risk falling into a negatively reinforcing feedback loop of rising insurance premiums and falling coverage. Unfortunately, voluntary schemes suffer from adverse selection, with the most in need of insurance the most likely to enrol. 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 with significantly lower income than those who did not opt in (OECD, 2018^[11]; Employment and Social Development Canada, 2016^[35]). Likewise, an increase in voluntary unemployment premiums 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.

Gaining a meaningful understanding of a system is a useful result itself. As shown with the systems map presented above, even a simple systems map can reveal useful insights. Further specification of the system in a national context, and with particular reference to social protection systems, can yield even further insights.

Additional detail and specification comes with both costs and benefits. Systems are complex by nature, and a systems map can provide clarity. Adding additional detail jeopardises that clarity. In this sense, the development of a systems map can be the key output of a research project.

At the same time, a systems map can provide 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 playground” by specifying the magnitude of the interactions between components. Researchers can use the map to formulate working simulations, such as agent-based models, which allows policymakers to pose “what if” type questions.

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, consists of the simulation of a number of heterogeneous agents, according to empirically based decisions rules. These models have been garnering increased attention in the aftermath of the 2008 financial crisis and Great Recession, due to their ability to provide alternative perspectives from traditional macroeconomic modelling techniques (Blanchard, 2018^[36]; Stiglitz et al., 2017^[37]).

As these models are capable of incorporating various behaviour rules of agents without relying on oversimplified assumptions, they are particularly suited to quantitatively model the feedback loops discovered during a systems mapping exercise. These models add to the researcher's toolbox and they allow relationships outlined in a systems map to be calibrated to observed data in an economy. This can be important, as the strength of the linkages between concepts can heavily influence the dynamics of a feedback loop. A weak link at one point of the loop can short-circuit a loop, just as strong connections elsewhere can amplify relationships. Examining the quantitative aspects of these connections can lead to an increased understanding of the feedback loops and their most crucial parameters. However, these models come at the cost of increased complexity and computational resource requirements.

A number of government institutions and international organisations have developed or are developing agent-based models. 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, Miess and Hommes, 2019^[39]), which have been used to examine financial fragility (Cincotti, Raberto and Teglio, 2010^[40]) and worker skill upgrading (Dawid et al., 2009^[41]).

Social protection in an agent-based model

Crucially, agent-based models allow policy makers to introduce or alter policies within the model, and then evaluate the distributional effects of the changes. Governments' tax-benefit systems rely on the redistribution of cash and of risks, and so the additional distributional insights gleaned from agent-based models can be illuminating.

For instance, the feedback loop explained previously, between alternative forms of work, membership in social protection schemes, and labour taxation, could be explored in detail. An agent-based model could highlight those workers who are likely to find themselves in non-standard work (through their own choice or the choice of their employer) and policymakers could explore methods of ensuring adequate social protection for these workers.

Policymakers can vary incentives for various forms of work by changing the contribution rates that finance social protection. Although financing methods vary across countries, governments largely fund protection systems with contributions or taxes levied on work income. Using agent-based models, policymakers can explore alternative funding structures that promote certain types employment while making others less attractive. Alternatively, they could examine complementary policies that encourage firms to hire more workers using standard contracts.

With a set of realistic decision rules that mimic reality and a high-level view of the system informed by a systems map, agent-based models can be an aid to policymakers in developing optimal policies. With agent-based models, policymakers can amplify or dampen feedback loops by introducing innovative and targeted policy solutions. An added benefit of these models is that by modelling the entire economy, it is easy to observe any unintended consequences of any policy reform within the model. Further refinement can reduce these externalities, and ensure that policies have only the intended consequences.

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, policymakers 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 of 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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Note

¹ Own-account workers are those self-employed who have no employees.

11 Innovation and New Technology for Enabling Economic and Social Progress

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

The evolving dynamics of innovation in digital, bioeconomy, and clean energy are discussed, focusing on the systemic dimension of change. Systems-based policy approaches that could help policymakers influence these dynamics to achieve societal and environmental goals are presented. 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, and resource mobilisation, as well as innovation outcomes. These interacting dimensions are complementary and need to be addressed simultaneously by policy. Formal systems modelling can also assist innovation policies to tackle deep innovation uncertainty. Models drawing on portfolio theory provide a quantitative framework of the economic value of risk diversification. In these models, different degrees of risk aversion (to innovation failure) become an input variable specified by policymakers. “Optimal” diversification portfolios given pre-specified innovation uncertainties and policy-specified risk aversion can be determined mathematically.

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. But a focus on the economic costs and benefits associated with innovation has blinded us to the environmental and social costs and benefits of new technologies. It has also blinded us to the societal impacts of new technologies, notably the exclusion they 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 that traditionally enjoyed a cost advantage which enabled them to channel surplus labour from agriculture, must find a new development path. This should be facilitated by the tremendous opportunities offered by digital technologies, (e.g. mobile communication that allows dense connectivity even in rural areas) or e-commerce (which makes global markets more easily accessible to small producers).

There is now a need to steer innovation and new technology towards responding better to societal and environmental needs: developing greener energy and chemistry, transportation systems, smart cities, sustainable agriculture, food systems, etc. For that to happen, market and non-market forces must be aligned around a number of goals reflecting these 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 - which involves, inter alia, the intensive use of data and advanced modelling in prediction and decision-making combined with greater participation by citizens - can help policymakers understand more fully 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 begun integrating it explicitly in 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, as well as the motivations of actors and their interactions, system approaches can help identify strategies that maximise synergies and minimise trade-offs between 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 transnational.

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.

This note reviews the evolving dynamics of innovation in various fields (digital, bioeconomy, clean energy) with a focus on the systemic dimension of change. It presents new, systems-based policy approaches that could help policy makers influence these dynamics to achieve 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, and the increasing sophistication of software have all contributed to making digitalisation the transformative force of 21st century economies and societies. The transformation brought about by digitalisation is systemic in nature. It concerns all aspects of economies (manufacturing, daily life, administration, entertainment); and 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, between spaces. 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 disintermediation 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 evolving social relations and behaviours.

Bioeconomy/circular economy

Concepts like a “bioeconomy” or “circular economy” are often proposed as a solution to 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 provision and consumption system in the direction of vastly improved materials and energy efficiency and conservation, where the technical potentials are vast but the associated innovation and behavioural and lifestyle changes constitute formidable barriers. The development of a bioeconomy is also a complex field that includes a variety of sectors and stakeholders involved in far-reaching changes in production systems and consumption patterns. The demand-side of this transformation remains particularly 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 from a broad range of domains, notably agriculture, energy, water, land, environment, trade, and research. It would also 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 systems approach can reveal the trade-offs and synergies that are likely to occur in the transition to a bioeconomy (OECD, 2018). However, synergies and trade-offs will have to be managed, which will require stakeholder engagement (with business, policymakers, civil society, scientists, financing) and coherence across policy domains. Many countries inside and outside the OECD are attempting to develop coherent and integrated bioeconomy strategies. The real value of a systems approach is to cast doubt on simplistic notions of “bioeconomy” (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 the direction of “less is more”) and changing consumption patterns, any significant transition towards a bioeconomy risks creating more environmental impacts than 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 policymakers 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. promoting 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, it means linking local and community-based initiatives to national goals and international commitments (e.g. SDGs, the Paris Climate Agreement). Systemic analytical approaches to such portfolio diversification models can help to craft appropriate diversification strategies in the face of persistent innovation uncertainty and often-unknowable ultimate environmental and social impacts of the technological options considered. Integrated Assessment Models (IAMs) are increasingly becoming available to assess the impacts of alternative transformation strategies across a wide range of SDGs.

Key system based policy mechanisms

The policy response to systemic changes needs to be systemic 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 toolkit.

- **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 Strategic Territorial Intelligence (STI) policy space, these include 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, 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 other tools, depends on timely quantitative and qualitative data of high quality. Many OECD countries still struggle with gaps in their data especially as regards understanding and measuring the socioeconomic impact of public R&D in science and technology. The nonlinearity 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 artificial intelligence (AI), advanced manufacturing, or synthetic biology, but current systems for measuring the impact of funding priorities will be unable to ascertain such effects. Improving data analysis on both the input and

output side of innovation will necessarily require work to develop up-to-date definitions and taxonomies. A renewed effort to perform 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 countries and partner economies have started exploring the potential of exponentially-increasing data volumes and advances in computational power for science and innovation policy by launching 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 policymakers with intelligence on industrial and research strengths of the region, domestic and international networks, and opportunities for economic growth. Arloesiadur uses natural language processing and machine learning to analyse data from administrative sources, research repositories, and the web to inform the decisions of policymakers. 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 it is not possible to achieve using conventional methods and approaches, DSIP initiatives can effectively guide policymakers 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, e.g. Argentina, Chile, Denmark, Greece, Netherlands, and Turkey (OECD, 2016). The involvement of participatory approaches in the evaluation of research and innovation policies is rarer.
- **Mission innovation.** One way governments are trying to mobilise STI for grand challenges is through mission-oriented R&D and innovation programmes. Mission-oriented programmes align policies, public R&D programmes, and public-private collaboration to define priorities and set targets 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, and mobilise various actors in their implementation (ministries, agencies, businesses, 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 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 to identify opportunities as well as potential trade-offs for policy interventions in complex coupled socio-economic and natural systems. A prominent example is the 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) as such, but rather from particular policies proposed to address any single 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 and food and fibre provision, 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 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 those 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 food-water-energy nexus (Parkinson et al., 2018) 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 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, and 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 an enhanced R&D programme for large-scale carbon capture and sequestration. In the 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) and has enabled systemic biases in innovation policies for climate protection to be identified across all OECD countries, that unduly focus on supply-side options, marginalising end-use innovations (Wilson et al, 2012).
- 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 on 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 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, although computational limitation currently restricts 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.

Key points and conclusions

- There is a pressing need to steer innovation and new technology towards societal and environmental needs. A systems approach to innovation policy argues that policies aimed at transitioning socio-technical 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.
- A traditional focus on the economic benefits of innovation has blinded policymakers to the environmental and social costs and benefits of innovation and new technologies.
- Many OECD countries still struggle to understand and measure the socioeconomic impact of public R&D. The nonlinearity of research impacts is not adapted to the input/output models of traditional R&D budgeting and evaluation.
- Systems thinking and systemic approaches in the domain of innovation (such as formal system modelling, strategic policy intelligence, participatory approaches in research funding and agenda setting, digital science and innovation policies, and mission innovation) can help reduce uncertainty in R&D and innovation, and identify strategies that maximise synergies and minimise trade-offs between the different goals of innovation policy interventions.

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Part IV Systemic Risk and Resilience

12 Systemic Risk Emerging from Interconnections: The Case of Financial Systems

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Approaches to analysing and managing the potential for a threat or hazard to propagate disruptions or losses to multiple connected parts of a complex system are reviewed, and ways IIASA and OECD could enhance their analytical capabilities and rigour of policy advice on systemic financial risk are outlined. IIASA has quantitative methods to measure, model, and manage systemic risk of financial systems using network theory and agent-based modelling. OECD looks into how to operationalise the concept of resilience to systemic risk to give policymakers an effective and efficient resilience management framework. IIASA's methods can inform and enhance OECD's framework by making available simple and transparent systemic risk indicators that can be monitored in real-time, as well as tools to test alternative policy interventions to reduce systemic risk. Approaches and models developed to deal with financial systemic risk may also be useful in other networked systems, for example, supply chains.

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; International Risk Governance Center, 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 constituent 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. 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 synchronisation 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 synchronised 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 one 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 via a deleveraging 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 of credit default risks. Current 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, 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 can systemic risk be evaluated?

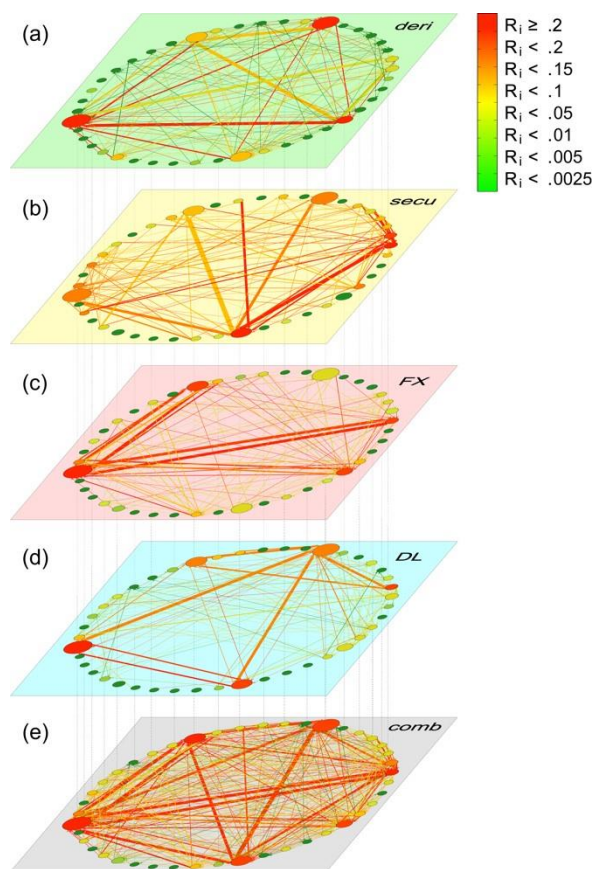
Systemic risk and financial contagion are largely related to synchronised behaviour and correlated portfolios of financial institutions. In this context, several econometric measures of systemic risk have been proposed that focus (mainly) on statistics of losses, accompanied by a potential shortfall during periods of synchronised behaviour, 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 undercapitalised, given that the system as a whole is undercapitalised. SES is related to leverage and the marginal expected shortfall (MES). SRISK is closely related to SES and as such is 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 measurements 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 generalised 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 Advanced Systems Analysis (ASA) and Risk and Resilience (RISK) programme 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 12.1 shows the multi-layer financial network of Mexico, and Figure 12.2 shows how systemic risk evolves over time.

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



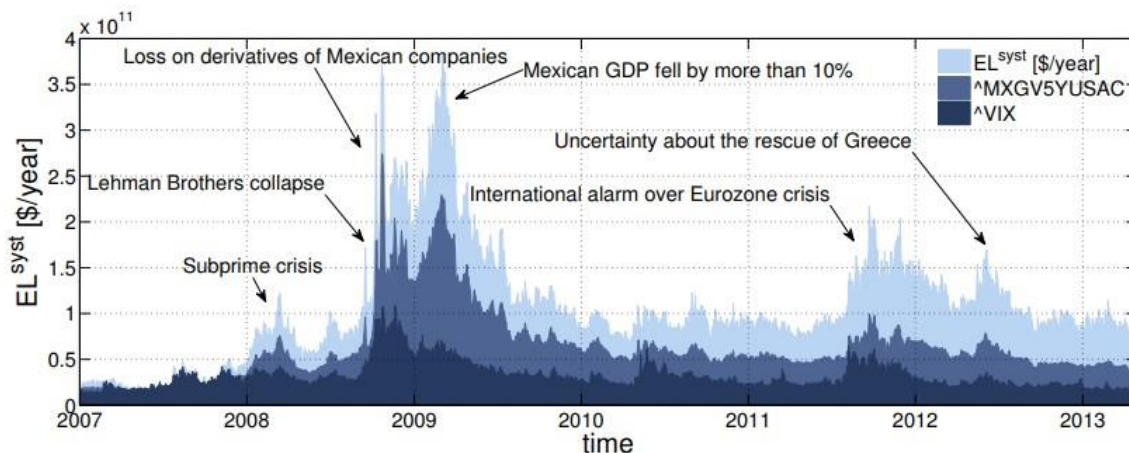
Note: (a) Network of exposures from derivatives, (b) security cross-holdings, (c) foreign exchange exposures, (d) deposits & loans and (e) combined banking network. Nodes (banks) are coloured according to their systemic importance in the respective layer: from systemically important banks (red) to systemically 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 optimisation procedure that enables the minimisation 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)



Note: 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 can systemic risk be managed?

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 recognised. 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 recognises 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 internalise 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 Programmes, 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) characterise 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 categorised 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 internalise costs of systemic risk or otherwise create an incentive to minimise 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 internalise 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 bailouts. 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 characterised 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 bailout schemes outperform bail-ins with private sector involvement.

The IRGC'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 organisations 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) characterises systemic risk as a property of an organisation'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 operationalise 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 internalise costs of systemic risk or otherwise create an incentive to minimise 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 favour 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

By Stephane Jacobzone, Charles Baubion, Jack Radisch (OECD), Stefan Hochrainer-Stigler, Joanne Linnerooth-Bayer, Wei Liu, Elena Rovenskaya and Ulf Dieckmann (IIASA)

Strategies to govern systemic risk are reviewed and the potential of systems analysis to address these challenges is assessed. OECD and IIASA's approaches are described. 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. The importance of applying a systems approach to both the system to be governed and the governance system is emphasised. The OECD's 'whole of society' approach for managing risk could incorporate IIASA's suggestions for establishing learning loops to reframe or enable transformative changes and focus attention on the critical nodes that are key to ensuring resilience of economies and societies.

Introduction

Governments, businesses and civil society worldwide realise more and more that the risks modern societies face have become increasingly systemic, complex, potentially irreversible, and in some cases existential. They present governance institutions with crosscutting 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 organisations 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 (actors agree on the problem and objectives; experts gather and analyse 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 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 behaviours; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biophysical systems (O'Brien et al., 2012).

This chapter reviews the challenges for governing the array of systemic risks facing 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, 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 emphasise 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 IASA's work on 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 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 whole of society approach to risk governance underpinning the OECD recommendation on the governance of critical risks.¹ 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 recognised 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 organisations and institutions (Centeno et al., 2015). For example, the benefits and efficiencies that resulted from specialisation 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 to understand, assess, manage, and generally govern systemic risks. Examples are 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 and hazards that pose the most strategically significant risks as a result of their probability or likelihood and of 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 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 recognises 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 analyse-prioritise-implement approach will likely confront difficulties in assessing cascading impacts in interlinked, networked systems, characterised 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 modelling, 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 ABM 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 reshaping 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 difficult to estimate. IIASA's unique approach is based on an ABM of a networked national economy (Austria). The Austrian ABM is the first to couple the macroeconomy 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 method, 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 owing 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 use 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 1970s debates surrounding use of nuclear power, and continues today with the emergence of new, controversial technologies, 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 gain acceptance and trust across stakeholders, it might help bridge the gap between expert analyses and implementation challenges (Schinko and Mechler, 2017). The importance of tackling systemic risks on a continuous and proactive basis (such as envisioned usually in adaptive approaches) is particularly important due to the special nature of systemic risk that may happen 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, such as 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 emphasised 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 recognised as essential for effective governance processes, and ultimately for robust policy implementation (Verweij 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) recognised 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).

In critical infrastructure for example, 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 recognises 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 putting smoking risk onto political agendas, antinuclear advocates in changing many national energy agendas, and, more recently, public demonstrations around 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 cogeneration, which is key to public sector innovation. IIASA is at the forefront of developing and implementing stakeholder cogeneration processes that apply system concepts to codesign 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 cogeneration process for landslide mitigation in Italy, where experts worked with three stakeholder groups holding very different perspectives on the problem and its solution. Ultimately, a compromise solution was cogenerated, agreed upon, and implemented (Linnerooth-Bayer et al., 2016; Scolobig et al., 2016).

Conclusion and outlook

The importance of applying a systems approach to both the system to be governed and the governance system was recognised 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 IASA concepts and applications can serve as a testing ground for the huge effort needed to effectively and fairly govern risks from climate change adaptation, financial transactions, biodiversity loss, and many other complex and systemic risks facing the world. Recognising 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 IASA'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 in 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 intergovernmental sharing mechanisms as well as establishing close partnerships with cutting edge academic networks to facilitate take-up of innovative measures and encourage shared investments in economic and social resilience.

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Note

¹ <https://www.oecd.org/gov/risk/Critical-Risks-Recommendation.pdf>

Part V Proposals for the Way Forward

14 Introducing Systems Thinking into Public Sector Institutions: Learning by Doing?

By Piret Tõnurist (OECD),
Elena Rovenskaya, Reinhard Mechler Fabian Wagner and J. Linnerooth-Bayer (IIASA)

The need to overhaul systems thinking in public sector management is discussed. While systems thinking as the methodology behind purpose-driven change could be used to accomplish missions, the public sector is not necessarily interested or ready to use it for that. Systems thinking inside the public sector is generally a ‘sense-making’ tool to make interconnectedness visible (usually with the help of outside experts) rather than a day-to-day practise that helps guide everyday action and decision-making. Even if policy makers as individuals are systems thinkers, it does not mean the policies they design are systemic; one needs institutions to support systems policymaking. OECD’s and IIASA’s work shows that 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.

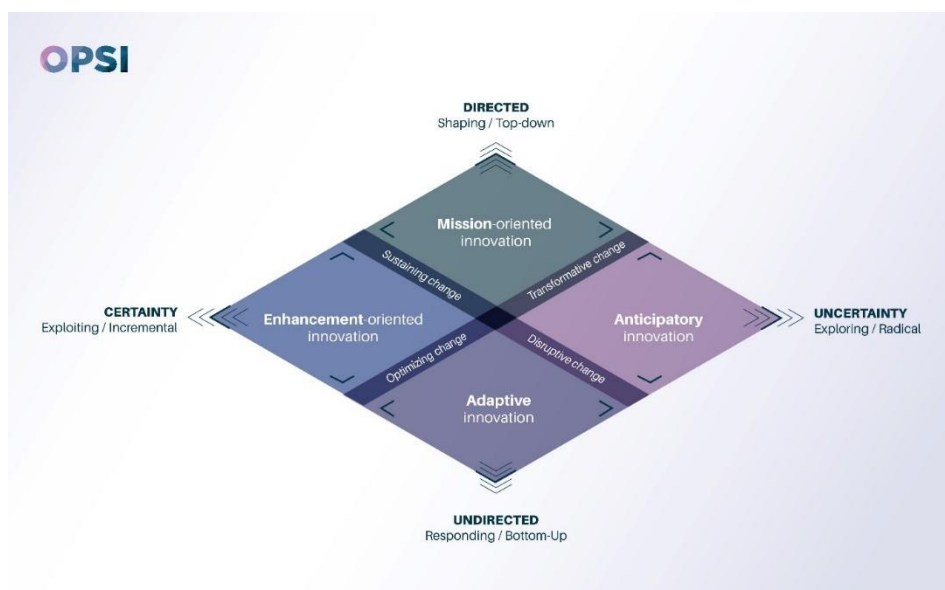
Introduction

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 are faced with wicked problems – problems that do not have a single cause or a solution. Furthermore, digitalisation of society and the 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 it 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 reactive as policy solutions by default create unforeseen and unintended effects. This means that ‘how’ the public sector works becomes increasingly more important than ‘what’ it specifically does, because the idea of permanence and best practice 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 programmes/agencies from the ‘frog view’, the view from within the system (Bouckaert and Peters, 2002) rather than on the cross-organisation outcome level. Thus, the effects of interventions were analysed within their specific domains or policy silos, while the broader interdependencies and outcomes received little attention. This has provoked a lot of critique with 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 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 (OPSI) 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, all requiring different 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 and 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 shifts.

Systems thinking practice in the public sector

While systems thinking as the methodology behind purpose-driven change could be used to deliver on 21st century missions, this does not mean that the public sector is interested or ready to use it for that aim. So far, systems thinking inside the public sector has been used as a 'sense-making' tool to make interconnectedness visible (usually with the help of outside experts – see box 14.1) rather than as a day-to-day practice that helps guide everyday action and decision-making.

Box 14.1. Systems thinking in the practice 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 policymakers 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 the collective wisdom of relevant experts and stakeholders. The approach builds on a fusion of a number of qualitative systems analysis methods, including multicriteria 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 one 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 one 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 can only ignore the complexity connected to policy problems, because they do not have means to do anything about it efficiently. 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; often however, many-layered policy interventions, well intended though 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, the public sector does not have the luxury of doing 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 practices 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 14.2). 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 14.2. 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 14.2). 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 14.2. Scottish National Performance framework

11 national outcomes

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

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 previous 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 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 has shown that making systems thinking actionable in the public sector does not rely on capacity alone. Public sector institutions and their ecosystems 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 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.

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 issues 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 book IIASA contributed to demonstrated across more than ten cases, policies made without participation from “all the voices” were significantly less robust than those with inclusive deliberation (Verweij, 2011).

Box 14.3. 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 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 the mountain, which was met with intense public protest (Amendola, 2013). 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 to elicit their worldviews and co-produce 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: Linnerooth-Bayer, 2016.

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 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 change. 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 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 policymakers as individuals are systems thinkers, it does not mean that policies they fabricate are systemic; one needs institutions to support systems policymaking. 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 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 Ulf Dieckmann, Gerid Hager, Piotr Magnuszewski (IIASA), and Martin Lees (OECD)

The need for, and content of, training in systems leadership are summarised. 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, teachers, and an informed public competent to understand and act on systemic challenges. Competences in systems leadership are also essential for the design of institutions facilitating the development of multidisciplinary teamwork and interdepartmental strategies and programmes. Five dimensions of inclusivity are consistently helpful for structuring the perspectives on challenges to which systems thinking can be applied: impacts, feedbacks, trade-offs, emergences, and stakeholders. Universally relevant training dimensions include systems principles, qualitative and quantitative methods, simple and complex models, and examples. Training instruments vary depending on the audience and duration of the training.

Introduction

Most 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. 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 flow 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 diffusion of powerful software, the power to conduct such analyses is 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 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, elitist, or compartmentalised traditional approach, and thus, 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 often become integrated into disciplinary analyses. Through decades of development, today's ambitions have risen considerably, driven by similar rises in needs and capabilities. In this understanding, systems thinking, by definition, is 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 to recede into the disciplinary background of mainstream practices, to be replaced by 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 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 achievements.

Target audiences

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

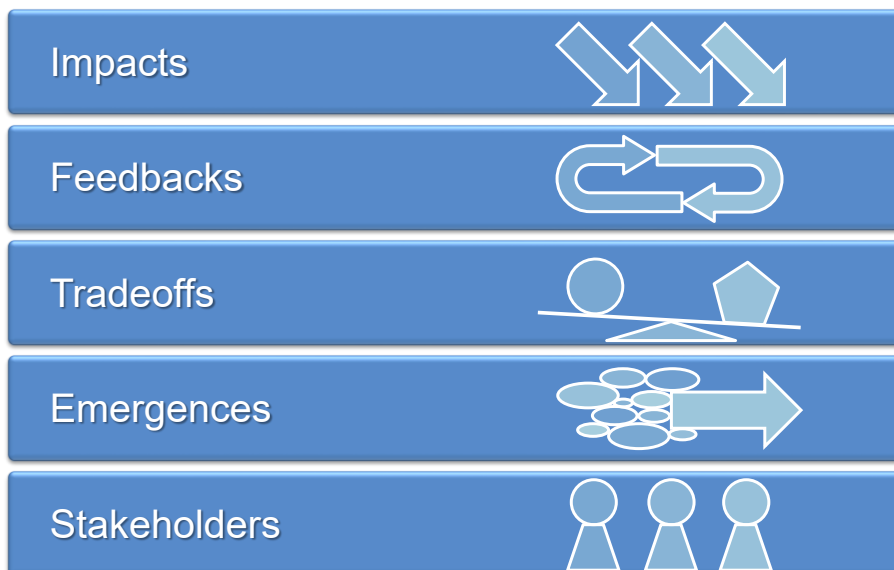
- **Practitioners.** Policymakers, public administrators, ministry officers, business leaders, diplomats, negotiators, and development-aid officials need systems thinking to arrive at more integrated solutions to many pressing policy issues. Such solutions, when devised and implemented appropriately, 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.** University, school, 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 they take such approaches into the contexts of institutional decision-making and scientific research.
- **Learners.** University 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 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 citizens interested in understanding the complex systems in which their lives unfold. 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 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 the level of knowledge the training commences

from; 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.

Systems framing

Figure 15.1. Dimensions of inclusivity important for systems framing



The key to systems thinking is a sufficiently broad and inclusive framing aware of systems dynamics. Accordingly, 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 it is widely accomplished. Systems analysis, understood in this way, keeps raising its standards.

Two recent examples illustrate this. 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 to frame a challenge in the spirit of systems thinking, many aspects need to be considered, some of which may be 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 (Figure 15.1):

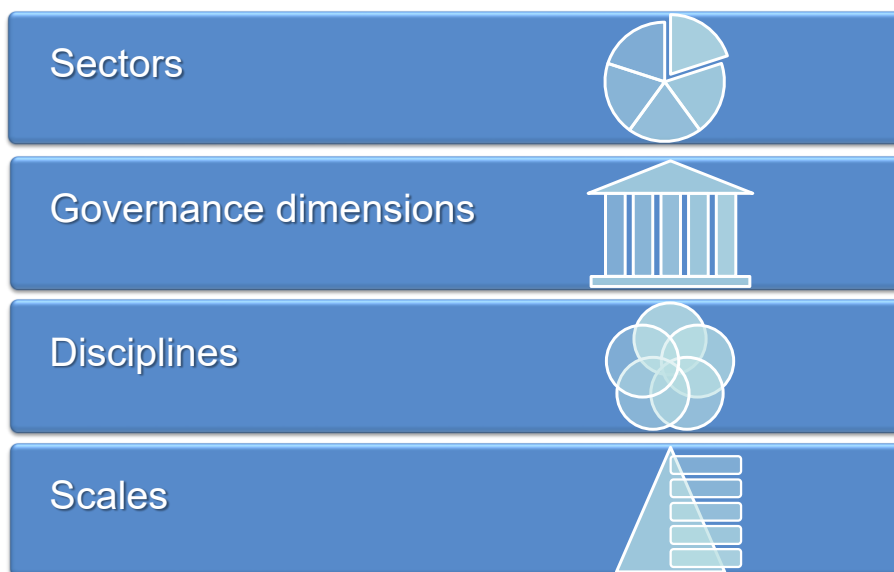
- **Impacts.** Maybe the most obvious dimension in which systems thinking requires inclusive framing concerns the impacts of the considered dynamics. This is where system boundaries feature prominently and detrimentally affect the quality of analysis when drawn too narrowly. In the latter case, important impacts are left out and cannot be accounted for as part of an integrated analysis. It is 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. Even if changes in market dynamics negatively impact those other components – be it through pollution, losses of biodiversity, overexploitation of 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 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 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 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, resulting in simplistic perspectives that increasingly reveal themselves as inadequate. 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 destabilise 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. Although any of a system's feedback loops can be critical to understanding its behaviour, overlooking positive feedbacks, with their potential for generating exponential growth or runaway collapse, can be 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. For example, many economists and corporations have traditionally viewed environmental regulations as detrimental to their performance, owing to compliance costs. However, when reframed more broadly, it has been argued that environmental regulations can lower production costs through increased resource productivity. Instead of considering the relationship between environmental health and business profits as an inevitable trade-off, this leads to a perspective in which businesses can be both environmentally friendly and economically competitive (Porter and van der Linde, 1999). As this example illustrates, 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 revolutions, the emergence of 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 profoundly affect real-world systems, the human and social dimensions of systems thinking are fundamental. Hence, including such aspects in system models can be a critical, if not sufficient, antidote against overlooking emergences. Other examples of emergent phenomena are associated with 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

Figure 15.2. Complementary perspectives facilitating systems framing



Beyond the five key dimensions of inclusivity in systems thinking outline above, four additional perspectives help avoid overly narrow framings. Each of these perspectives can be thought of as providing a mental checklist that systems analysts can use to minimise the risk of overlooking important aspects of a problem and consequently framing it too narrowly (Figure 15.2):

- **Sectors.** Good systems thinking often requires multi-sectoral approaches. Scanning through the economic sectors and governance areas that are related to a particular challenge is therefore

helpful to ensure that no important impacts, feedbacks, trade-offs, 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.

- **Governance dimensions.** Good systems thinking looks across the governance spectrum, from policy decisions to the policy institutions that shape policy development. By covering all these dimensions, systems approaches can lead to specific recommendations for changes at all of these levels, including recommendations for institutional modernisation.
- **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 risk of arriving at a too 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 and that cultural and psychological factors are properly accounted for.
- **Scales.** Good systems thinking often requires multi-scale approaches since the impacts, feedbacks, trade-offs, 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, and global stakeholders are among the benefits that are likely to accrue from an awareness of how scales are connected in the context of a particular problem. Regarding temporal scales, conflicting interests are not only central for understanding intergenerational equity, but also have a bearing on appreciating how incentives to policymakers and business leaders are affected by the durations of their terms of office.

Avoiding pitfalls

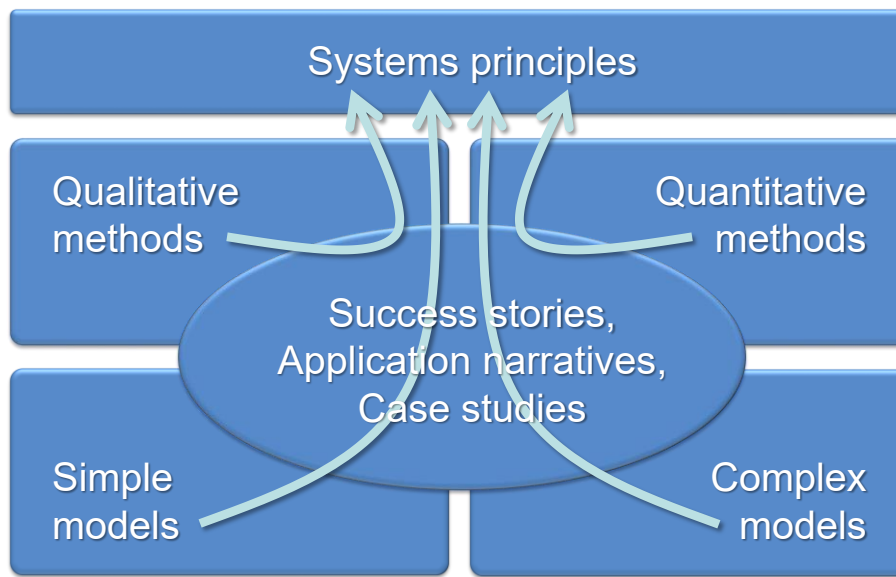
Common cognitive pitfalls can impede good systems thinking. Based on the work of several authors (Senge, 2006, Meadows, 2008, Booth Sweeney and Meadows, 2010, Benson and Marlin, 2017, Booth Sweeney, no date), we propose the following suite of mental heuristics that can aid practitioners in avoiding these pitfalls:

- **Broad perspective.** The problem should be approached from a sufficiently broad perspective, by examining its boundaries, seeking to understand the big picture, seeing the system from different angles, tolerating ambiguity, and resisting the urge to come to simple conclusions and quick fixes.
- **Structural scrutiny.** Framing the approach to a particular challenge should be undertaken with careful scrutiny of a system's structure and associated behaviour; by observing how system elements change over time; looking for connections between system elements; identifying stocks (accumulations) and flows; revealing cause-effect relationships; and anticipating unintended consequences of decisions and policies (policy resistance).
- **Nonlinearity awareness.** Nonlinearities affecting the system dynamics should receive particular attention, by identifying nonlinear interactions between system elements; accounting for loops of cause-effect relationships (feedbacks); and recognizing the impacts of time delays and cumulative processes.
- **Enlightened management.** The management of complex systems should be based on adequately modern approaches, by focusing on possible leverage actions or leverage points (Meadows, 1999); monitoring the outcomes of actions; considering iterative adjustments of actions; challenging hidden mental models (often limited by bounded rationality); and being open to deeper strategic revisions or even institutional change.

Although these mental heuristics – or examples of systems principles – may look simple in theory, they are surprisingly hard to apply in practice, as learning from evidence in complex systems can be hampered by many barriers (Sterman, 2006).

Training dimensions

Figure 15.3. Training dimensions for disseminating systems thinking



Training in systems thinking can take many forms, the best choices of which strongly depend on the intended audience. As a starting point for designing specific interventions, it may be helpful to recognise the following universally relevant training dimensions (Figure 15.3):

- **Systems principles.** Most training interventions for promoting systems thinking among non-experts will de-emphasise technicalities and instead highlight the principles characterising good systems thinking. The main aspects of these systems 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, governance dimensions, disciplines, and scales); and avoid cognitive pitfalls (by adopting a broad perspective, structural 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 additional training dimensions.
- **Qualitative methods.** Qualitative (“soft”) methods have been developed to allow non-experts to contribute to systems analysis, often in a participatory setting. In a group-learning context, such methods have been popularised, in particular, through Peter Senge’s book “The Fifth Discipline” (Senge, 2006). Qualitative methods often look very accessible at first sight, but their proper use requires expert support. For example, while using simple examples of applications of these methods during training sessions can greatly improve the tangible understanding of basic systems principles, this approach must be used with caution: its apparent simplicity can be deceptive, and the overly complicated diagrams it sometimes engenders may frustrate participants. The portfolio of qualitative methods to be covered in the teaching of systems thinking would typically include

elements of the following (Rosenhead and Mingers, 2001): qualitative scenario analysis, causal-loop analysis, cognitive mapping, and soft systems methodology.

- **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 learning of quantitative methods can raise undesirable barriers, because it requires sufficient time, depends on adequate background training, involves specialized hardware and software, and risks frustration. For such 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: quantitative scenario 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; and 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 and interpreted. 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 more comprehensible systems principles, qualitative methods, quantitative methods, and simple models.
- **Examples.** The sixth training dimension is highly important and involves success stories, application narratives, and case studies. By grounding the more general and abstract dimensions in the context of more specific and concrete challenges, approaches, and solutions, the practices of systems analysis become tangible.

For teaching systems thinking to non-experts, the approach indicated by the arrows in Figure 15.3 seems most appropriate. This approach works by illustrating qualitative and quantitative methods, as well as simple and complex models, through success stories, application narratives, and case studies, to instil in the target audience, as the primary objective of the training, a clear understanding of the principles underlying systems analysis.

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 to teachers and learners to the general public) and the training duration (ranging from minutes to years). The following list is an inventory of the broad range of possibilities:

- **For practitioners.** In typical settings, practitioners have little time to devote to learning about systems analysis and systems thinking. Training interventions for this 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, potentially using simple qualitative methods, 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. Simulation games, described in the next section, can be attractive, due to their capacity to immerse participants in relevant cases and to offer experiential learning. Some audiences, however, regard this approach as not entirely serious. In view of the relevance of systems thinking for supporting longer-term processes of institutional design and transformation, special training interventions for practitioners can be envisaged in the contexts of developmental aid and institutional management. Such interventions could be arranged over a longer 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 deemed 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 university students, school students, and adult-education students. At the next level, teaching modules can be developed that enable teachers to combine multiple modules as building blocks according to their needs. At the most concrete level, specific course materials can be offered. Teachers often need specific tools to use together with their learners. Accordingly, introducing qualitative methods and simulation games may be suitable, and even simple quantitative methods have been successfully utilised¹. 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 university students, curricula for bachelor, masters, and PhD degrees can be adjusted toward communicating the concepts and tools of systems thinking and systems analysis, potentially supported by the teaching modules and course materials mentioned above. A comprehensive approach to building societal competences in systems thinking must start with students at school or even earlier. Training elements suitable for university therefore need to be adjusted and redeveloped 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 university students, teaching should ideally be complemented by hands-on practical exercises and mentored research.

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

The various training instruments outlined above can all benefit from a 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 foundation course, such that the design of such a course can serve as a foundation for the design of more specific interventions. Ideally, the foundation course would 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 multiple alternative means of coverage that are differentially geared to the needs and capabilities of different audiences.

Simulation games

Simulation games offer an innovative, experiential 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 game² jointly developed by the Centre for Systems Solutions³ and IIASA. It combines the benefits of systems analysis and 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 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 profoundly using conventional training instruments. The simulation-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 for International Cooperation and Development of the European Commission, the European Parliament, the European External Action Service, and the OECD have successfully engaged in the “The World’s Future – A Sustainable Development Goals Game” gameplay (Figure 15.4), among 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*

Figure 15.4. Gameplay in action at the European External Action Service, Brussels (top left and right); the Directorate General for International Cooperation and Development of the European Commission, Brussels (bottom left); and at OECD, Paris (bottom right).



Key points and conclusions

- Systems thinking is increasingly recognised as a means to study and communicate about our complex and evolving world. However, disseminating systems thinking through education and training in ways that go beyond buzzwords and result in changes in understanding and actions is far from trivial.
- In this chapter, we have reviewed the mounting needs for systems approaches originating from growing interconnectedness, speed of changes, volume of data, and computing power. We have proposed an inclusive framing for systems thinking with five critical components – impacts, feedbacks, trade-offs, emergences, and stakeholders:
 - The notion of externalities results from drawing narrow boundaries around a system’s economic components, while leaving the system’s environmental and social components on the outside. It is crucial to draw system boundaries widely enough to capture the externalities as part of a sufficiently holistic accounting of impacts.
 - Crucially, the various impacts occurring throughout a system may all be part of feedback loops. Overlooking feedbacks is particularly harmful to the quality of systems analysis.
 - 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 predictions are inevitable.
 - The dynamics of complex systems often leads to emergent phenomena. In particular, since beliefs, psychology, norms, and culture profoundly affect real-world systems, often through such emergences, the human and social dimensions of systems thinking are of fundamental importance, including their repercussions for institutions and governance.
 - 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.
- Synthesising relevant literature, we have proposed systems principles that can form the basis for diverse types of education and training in systems thinking. The associated training dimensions include qualitative and quantitative methods, simple and complex models, and examples or case studies.
- These dimensions can be adapted to different audiences, and implemented, at different lengths and depths, through a variety of training instruments such as briefing materials, presentations, exercises, workshops, courses, and curricula, as well as interactive activities such as simulation games, to offer local or online opportunities for disseminating knowledge about complex systems and systems thinking to improve decisions and policies in an ever more interconnected world.

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Notes

¹ e.g. <http://web.mit.edu/sysdyn/road-maps/home.html> and <https://ccl.northwestern.edu/netlogo>

² <https://worldsfuture.socialsimulations.org>

³ <https://systemssolutions.org>

16 Outlook: Towards an OECD-IIASA Multiannual Work Programme

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Activities to extend the systems approach promoted by the OECD-IIASA Strategic Partnership and its Task Force are proposed. Issues the two organisations could collaborate on include sustainable and inclusive growth and well-being; linkages between finance, investment and climate change; concerted policies for the climate, ecosystems, energy, and water nexus; longer-term strategies for employment; 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; 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. Strengthening the systems approach within the OECD, and cooperation between the OECD, IIASA and outside partners are also discussed.

A series of scientific and analytical reports, supported by growing evidence, 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 OECD-IIASA Strategic Partnership and its Task Force - and, in a wider perspective, the challenge to OECD and IIASA - is to develop systems approaches that 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 crosscutting recommendations and briefing materials for policymakers and OECD Committees through co-ordinated 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, policymakers themselves, to understand and anticipate better the risks and opportunities of systemic challenges, and to respond effectively.

The Strategic Partnership was consolidated during 2018 and 2019, and is recognised as a credible, innovative, and useful initiative by a growing number of Ambassadors to the OECD 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 Countries. 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.

The Programme of Work is organised around seven themes that will form the basis of collaboration between the two institutions: (1) systems-based strategies to address global Issues; (2) improved analytical methods; (3) governance and institutional innovation; (4) systems leadership; (5) strengthening and extending existing joint activities; (6) initiating specific new topics for collaboration; and (7) extension and outreach.

It is expected that the programme of the Strategic Partnership will be financed mainly through voluntary contributions from governments, contributions from intergovernmental organisations, and from non-governmental sources and specific contributions to support joint projects. The government of Sweden, through the Agency for Innovation Systems, VINNOVA, committed early financial support through a contribution of €200,000 to advance the work of the Strategic Partnership. Consultations are 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 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 Priority Issues**. A number of issues will be identified for discussion with the relevant OECD Directorates and 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 the committees. This could include in particular the 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 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 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 wider 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. 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 co-ordinated presentations for policymakers, 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 the 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 use 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 policymakers and committees.

It can also encourage wide interest within OECD and its Members 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 that are so urgently required.

This initiative can help Member countries, 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.

New Approaches to Economic Challenges

Systemic Thinking for Policy Making

THE POTENTIAL OF SYSTEMS ANALYSIS FOR ADDRESSING GLOBAL POLICY CHALLENGES IN THE 21ST CENTURY

We live in a period of profound systemic change, and as in similar periods in the past, there is bound to be considerable instability and uncertainty before the new society and economy take shape. We have to identify actions that will shape change for the better, and help to build resilience to the inevitable shocks inherent in, and generated by, the complex system of systems constituted by the economy, society and the environment. These challenges require updating the way policies are devised and implemented, and developing more realistic tools and techniques to design those policies on the basis of appropriate data. In *Systemic Thinking for Policy Making* world experts from the OECD and International Institute for Applied Systems Analysis (IIASA) pool their expertise and experience to propose new approaches to analysing the interconnected trends and issues shaping today's and tomorrow's world. The authors argue that to tackle planetary emergencies linked to the environment, the economy and socio-political systems, we have to understand their systemic properties, such as tipping points, interconnectedness and resilience. They give the reader a precise introduction to the tools and techniques needed to do so, and offer hope that we can overcome the challenges the world is facing.

Consult this publication on line at <https://doi.org/10.1787/879c4f7a-en>.

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