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Complexity Science in the Context of Policymaking

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Key takeaways

- In order to understand the complexity of many real-world phenomena such as resilience, emergent properties, collective decision-making, evolutionary change and many others, it is necessary to change the perspective from the parts of the system to the connections between the parts and to the system as a whole, i.e., from reductionism to holism.
- Reductionism and holism are complementary.
- Effective policymaking benefits from appreciating this complementarity.



Introduction: Why Is Complexity Science Relevant?

In economics and policymaking, many concepts and models talk about equilibrium, masses and centres of gravity (EU, 2019a; EU, 2013). They talk about linear cause and effect chains, prediction and precision. One consequence of this worldview is that many policymakers assume that having more details and more precise figures help them to make better policies.

Many organisations amongst them the OECD, the European Commission's Joint Research Centre, think tanks and academic institutions have recognised that this reductionist worldview concentrating on the parts of a system is no longer sufficient in accounting for the complexity encountered in the economy, society and the environment.



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In fact, many real-world systems show nonlinear interactions and are rarely in equilibrium. They show phenomena such as adaptation (e.g., markets, innovation), the formation of hierarchies (e.g., public and private organisations, discussions), self-organisation (e.g., collective decisions, public opinion formation), robustness and fault tolerance (e.g., many biological systems), resilience (e.g., ecosystems, some technological 'ecosystems'), lack of central control (e.g., collective decisions in social insects, bird flocks, fish swarms, task allocation in computer systems) and other features well known from complexity science (CS). None of these properties can be understood on the basis of the properties of the parts of the system alone. Instead, the relations and interactions between the parts are relevant and need to be studied.

Complex system behaviour also relates to the issue of reflexivity covering phenomena, e.g., the reflexive questioning of values, background assumptions and normative orientations, as well as the role of conscious reflection guiding individuals' behaviour and potentially making collective large-scale behaviour unpredictable.

Sound and fit-for-purpose scientific approaches are a necessary and minimal condition for effective and successful policymaking. The human nature and condition with its values, beliefs, drivers, emotions and other factors also need to be taken into account, and they are a source of complexity, too; hence, the issue of complexity relates also to the Enlightenment 2.0 discussion (EC, 2019b; Heath, 2014).

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Reductionist approaches are useful for understanding the parts of a system, i.e., parts of the economy, the environment and society. Yet, when it comes to understanding the complex dynamics resulting from the interaction of these parts, it is necessary for both, scientists and policymakers, to shift the perspective from the parts to the system and to the interactions between the parts of the system. This is the realm of CS.

What Is Complexity Science?

Defining complex systems is a challenge, and there are different ways in which people have defined complex systems. As an example, complex systems (or CS) is defined by OECD (2009) as follows:



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A complex system is composed of many parts that interact with and adapt to each other and, in so doing, affect their own individual environments and, hence, their own futures. The combined system-level behaviour arises from the interactions of parts that are, in turn, influenced by the overall state of the system. Global patterns emerge from the autonomous but interdependent mutual adjustments of the components.

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Complex systems exist in many domains of science, and many attempts have been made to grapple with them from within each domain (e.g., biology of ants and birds; computation with cellular automata; etc.). CS straddles many science fields, see [Fig. 1](#).

Since CS deals with the relations between the parts of the system, it represents a holistic counterpart to reductionism.

Neither reductionism nor holism presents the full picture, instead they are complementary.

Complex systems research is also characterised by a change in the mathematical tools involved. This resulted in shifting from a focus on figures and the quantitative (in reductionism) to a focus on geometry and the qualitative (in holism), (see, e.g., several examples in [Capra \(1996\)](#)). This means that while it may be possible to predict the qualitative features of a system, quantitative predictions are rarely possible. A key output of CS methods is what one might refer to as complexity reduction. Often, the observed complex behaviour of a system may be related to one or a small number of equations or behavioural rules or a mathematical principle. The complexity is still there, but knowing what – simple – mechanisms are causing it, one appreciates and embraces the complexity – which is a great step forward towards a better understanding of a complex system. Some may want to say that CS provides methods for sense making.

The complex world around us is governed by many different forces, rules and boundary conditions, requiring different approaches for understanding them and for coping with them. The mathematician Lee Segel once said that it might be well imaginable that we need more than one theory for explaining complex systems such as the immune system. This may also be the case for the even more complex real world of human society. One may view these theories as models, grammars or even worldviews, depending on how encompassing they are. The crucial thing is one approach only focuses on some aspects of reality, whereas other phenomena remain disregarded, and these different approaches are needed for appreciating and coping with this complexity. The sciences of complexity and related methods based on discourse, inclusion, communication and others can contribute to this objective.

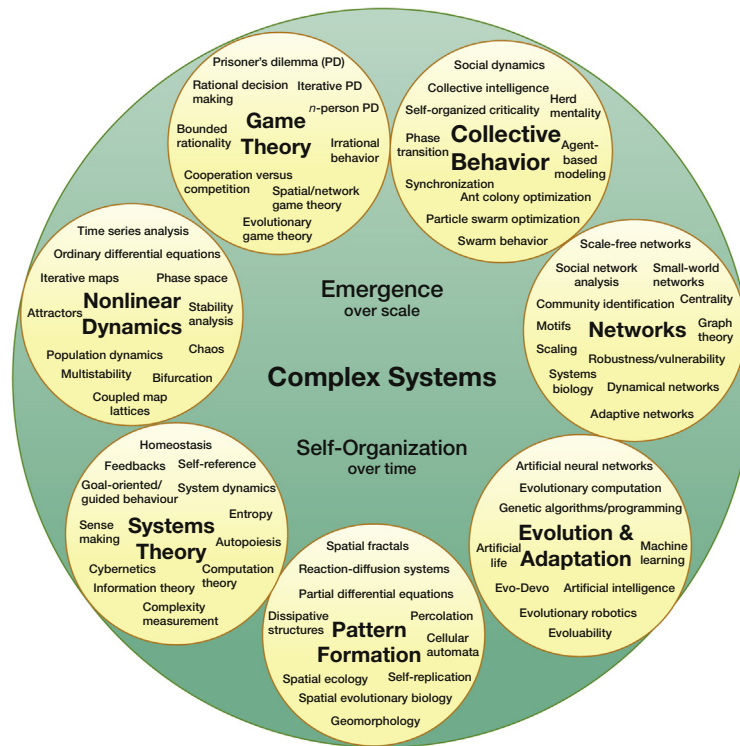


FIGURE 1 An organisational map of complex systems broken into seven subgroups. (Fig. 1: Created by Hiroki Sayama, D.Sc., *Collective Dynamics of Complex Systems (CoCo)*, 2010, taken from https://en.wikipedia.org/wiki/Complex_system.)

What Are the Challenges that CS can Help to Tackle?

Communication

Policymakers are increasingly faced with the challenge of communicating about both, the complexity of reality and the policies addressing the issues arising from this complexity. CS methods provide powerful tools for addressing this challenge:

1. Since CS methods often involve a shift from a quantitative to a qualitative description, i.e., a shift from figures to geometry, visual concepts such as phase space, attractors, fitness landscapes and maps, they have the potential of being very powerful tools for understanding, describing and communicating complex issues – even to laypersons. For example, discussions on the transition from a fossil fuel-based energy system to a decarbonised one focus much on the technologies, markets, cost-benefits considerations and many other important aspects. Yet, for understanding lock-in phenomena such as technological and institutional, it helps to shift to CS methods. A fitness landscape perspective



allows understanding new aspects of these phenomena and thereby helps to focus the debate. In essence, it makes visible the trade-offs of, e.g., investing into marginal efficiency gains of combustion engines on the one hand or instead investing the same resources into renewable technologies on the other. The shift away from the quantitative to the qualitative is also illustrated by the use of the Economic Complexity Index (ECI) going beyond GDP. The ECI was developed by [Hidalgo and Hausmann \(2009\)](#) as a predictive tool for economic growth and income equality. The index is a ‘holistic’ measure of the productive capabilities of large economic systems, e.g., countries or regions. It aims to capture the knowledge accumulated in a population and which is expressed in the economic activities. The ECI covers information on the diversity of countries and the ubiquity of products. This information is used to produce a measure of economic complexity, containing information about both, the diversity of a country’s export and their sophistication. Hence, highly developed countries with high ECIs and highly diversified economies export many goods of low ubiquity, whereas countries of a lower development degree with lower ECI and lower diversified economies export only a few products, which are of relatively high ubiquity ([Cristelli et al., 2013, 2015](#); [Hausmann et al., 2013](#)).

2. CS methods also deliver powerful communication metaphors such as ‘fitness landscapes’, ‘tipping points’, ‘critical points’, ‘point of no return’, ‘emergent properties’, ‘order on the edge of chaos’, ‘self-organised criticality’ and ‘multistationarity’ to mention just a few. Due to the visual messages they bear, they lend themselves to be used as tools in communication between experts and nonexperts. For example, the notion of emergent property is related to hierarchical ontologies (i.e., system properties built up from the bottom to the top) as opposed to historical ontologies (i.e., properties result as a consequence of linear, consecutive steps). First, it is crucial to acknowledge such bottom-up processes. Second, awareness of emergent properties gives policymakers new levers for action. Examples of emergent properties include the appearance of resilience (in ecosystems ([Peterson, 2000](#); [Gunderson, 2000](#)) and human society ([Faulkner et al., 2018](#)), collective decision-making, such as in public opinion formation ([Weidlich and Haag, 1983](#)), and the selection of technologies ([Arthur, 1994](#))).
3. CS methods such as bifurcation theory, agent-based modelling and leverage point analysis (see more detail in [Coping With Complexity](#) section) as well as concepts such as fitness landscapes can help reducing complexity – in the sense described in [What Is Complexity Science?](#) section – and overcome mental lock-ins, thereby enabling powerful communication.

Coping With Complexity

CS methods can help to go beyond communication and allow coping with complexity. The following case distinction may illustrate this:

1. **Complexity reduction I:** Very often, complex behaviour can arise from very simple mechanisms or rules at the level of the interacting parts of the system ([May, 1976](#)). Whenever this is the case, developing models, followed by performing, e.g., *stability* and *bifurcation analysis* and an *analysis of the boundary conditions*, can help to reveal the simplicity underlying complexity. This way, policymakers find powerful places to intervene



in a complex system. This is used, e.g., for analysing technology lock-in (e.g., nonlinear Polya processes, i.e., a stochastic mechanism used for describing consumer choice in the case of increasing returns (Arthur, ditto)). [Grandmont \(1985\)](#) has shown how endogenous mechanisms can cause complex economic cycles. In ecological contexts, complex population dynamics, e.g., of insects can often be reduced to the logistic equation ([Murray, 2008](#)), and in fisheries, the Lotka–Volterra model is an important reference (Murray, ditto). Negative experiences like overfishing have been linked to using concepts such as ‘maximal sustainable yield’, possibly involving too simplistic and unrealistic assumptions regarding age structures of fish population ([Walters and Maguire, 1996](#)). The pattern of increasing fish catches followed by a sharp decline has been linked to phase transition behaviour ([Pauly et al., 1998](#)).

2. **Complexity reduction II:** Even if complex behaviour cannot be reduced to simple interactions at the level of the interacting subparts of the system, the method of *leverage point analysis* can provide a qualitative analysis of the relative importance of the system’s parameters, feedback loops and boundary conditions, as well as about the assumptions made about the system, thereby delivering places for policymakers to intervene in a complex system ([Meadows, 2008](#)). Leverage point analysis facilitates identification of necessary and sufficient conditions with respect to the larger context. This way, important challenges such as reconciling micro- and macroeconomic objectives can be addressed, which is relevant in the sustainable development debate.
3. **Network analysis:** Not all complexity can be reduced and simplified as described before. There are cases, where the mere number of different interacting subcomponents of a system is entangled in such a way that the key to coping with a complex system lies in trying to figure out how strong and in which way parts are coupled to each other, using *network theoretical methods*. The behaviour of power grids, communication networks such as the Internet (a so-called ‘small-world’ net), as well as network-based infrastructures in general, the emergence of public opinion and many other phenomena can thus be analysed, possibly leading to increased understanding of such systems allowing analysis of stability and eventually coping with the system (see e.g., Garas and Lapatinas, 2017).
4. **Participatory approaches:** If none of the previous methods work, the minimum one would like to obtain is a description of the relevant factors of the complex system. Participatory approaches, such as *Living Labs* and *Maker Spaces*, are examples of participatory approaches where scientific and citizen knowledge is brought together to jointly account for the complexity of a system. The larger the amount of information added, the greater the knowledge. This way, parts, domains and rules of the system as well as parameters and boundary conditions become transparent through looking at and interacting with the system, thereby revealing powerful information for policymakers. Participatory approaches aiming at capturing a system understanding are also at play in *foresight* practice and the Joint Research Centre’s *Policy Lab*. Participatory approaches are helpful to elaborate the scope of a complex situation. Modelling, which may follow in a next step to better understand a complex phenomenon, often focuses only on small parts of the entire scope. So, participatory approaches can help to appreciate what we know not.



Participatory approaches do not necessarily lead to one ‘model’ of a complex system. At best, one can obtain relevant ‘models’ that are jointly needed to describe the complex system. In the worst case, revealing ever more information about the complexity does not lead to actionable complexity reduction (see next point).

5. **Wicked problems:** There are systems in which nearly everything is connected to everything and where revealing more information does not lead to any complexity reduction. The complex behaviour of such systems is referred to as wicked problems ([Rittel and Webber, 1973](#)) – as opposed to tame systems, which may be tackled using reductionist methods. Such wicked systems are often encountered in social, urban and regional planning contexts (the domains in which the term was coined).

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One very powerful approach for analysing such systems is to establish scaling laws. For example, the energy consumption of a town as a function of the number of inhabitants typically scales as a power law. Establishing such power laws does not reveal much about the underlying mechanisms as such – hence, more detailed models are needed – but it allows categorising towns and regions, thereby opening spaces for coping with complexity (see [West \(2018\)](#) for numerous examples). Scaling laws also help in other contexts, e.g., for categorising networks, such as (economic) issues related to internet traffic (e.g., [Willinger et al., 2002](#)).

6. **Sociological analysis:** There are questions, which can hardly be answered by any of the approaches above. For example, do modern societies create complexity by their very actions – and policies? Sociological analysis, i.e., stepping out of the system and taking a remote perspective, may propose answers to issues such as resilience of infrastructures, the occurrence of power blackouts, technology transitions like the shift to a decarbonised energy system, the shift towards a circular economy, the security of the internet and more generally (see, e.g., [Labanca, 2017](#)).

From a certain level of complexity onwards, it is very difficult to see effects, phenomena or even structures. Here, new modelling and quantification methods come into play. They can help to reveal structures in big data. Reductionist in essence, they make possible further analysis from a holistic perspective at a later stage. Hence, such methods help connecting the reductionist and holistic perspectives.

In essence, such new modelling and quantification methods contribute to bringing in new actors’ perspectives in modelling (e.g., agent-based modelling ([Bonabeau, 2002](#))) for tapping into new sources of (big) data or using modelling methods coming from the natural sciences for strengthening the economic modelling capacity.

Complex system methods span a wide range of scientific disciplines starting from the molecular level over the cellular to the societal level. It has been shown that similar phenomena and similar mechanisms apply to specific cases located at different levels and in different



fields (Mikhailov and Calenbuhr, 2002). Hence, since many if not most policy issues are of an across-disciplinary nature, complex systems methods have great potential in supporting policymakers.

What Are the Implications for Policymakers?

Traditional equilibrium and linear cause and effect thinking and related models based on a reductionist mind set can neither cope with nor help managing complexity, since they do not address the interactions of system components.

Widening the concepts and tools including methods from CS will enable policymakers to deal with complex issues more appropriately. Yet, using CS methods will require from policymakers to widen their mind set, to be ready to give up concepts and expectations such as predictability, precision and control and replace them with thinking in terms of scenarios, fitness landscapes, connectivities, probabilities, etc.

The benefit of this can bring a critical support to policy coherence as focussing on the whole system will raise the profile of the interplay between policies, the possible synergies and trade-offs.

Complexity Science Initiatives at the JRC

Appreciating the fact that many complex system phenomena are of an across-disciplinary nature, the European Commission's Joint Research Centre is launching a series of projects addressing societal challenges. One project addresses the transition from a linear to a circular economy using the ECI, network theory and agent-based modelling. Another project analyses the social innovation dynamics emerging in the context of the transition towards a decarbonised energy system. Finally, dynamic aspects of hybrid threats are studied using game theory and learning algorithms. In order to overcome a too strong focus on mathematical methods, all projects contain four building blocks, i.e., a citizen engagement component for scoping the issue; a series of mutually supporting mathematical analysis and computer simulations to focus on specific constellations; sociological analysis to build on the citizen engagement and analytic results, and to put them into a wider picture, and finally advanced visualisation methods to support communication including with laypersons.

Conclusion

Complex systems methods have been applied in many domains, which are relevant for policymakers. In a next step, such methods could complement traditional reductionist approaches of scientific policy support.

In a wider context, there are also several discussion fora and initiatives with associated conferences addressing the question if and to what degree CS can be used in the policy context.



Amongst supportive opinions, there are also critical voices. One of the main criticisms expressed addresses the difficulty of defining a societal system in such a way that it can be analysed using a CS method. This is a justified criticism, and it also applies to all reductionist economic models currently used. After all, a model is only a reflection of reality and as such an idealisation.

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