Für Mensch und Umwelt

As of: 13. März 2024

Factsheet: Modelling methods for assessing complex and social impacts of policies

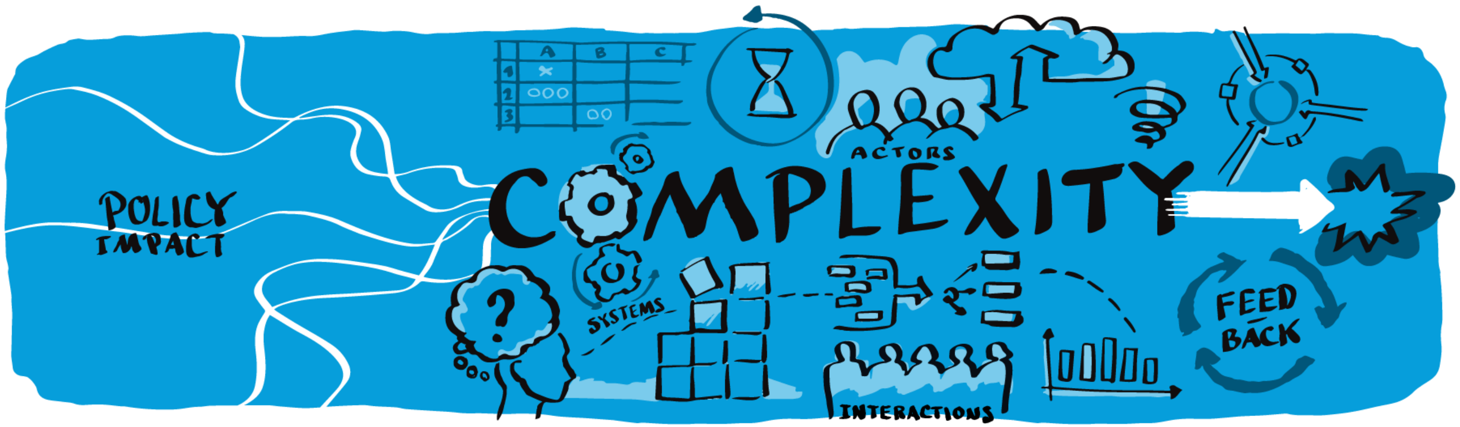
Qualitative and quantitative system modelling approaches for policy advice

The Leibniz Institute of Ecological Urban and Regional Development conducted the feasibility study titled *"Modelling Climate Adaptation Measures: Actors, Decisions, and Effectiveness – Approaches and Methods of Quantitative Policy Modelling to Assess the Effectiveness of Climate Change Adaptation Policies in Germany (FKZ 3721 48 104 0)"* on behalf of the German Environment Agency (UBA). In the final report of the project, different approaches to model complex social systems for policy impact assessment are compared. It describes the general processes, compares possible applications, and discusses the strengths and limitations of system modelling approaches. This factsheet introduces the topic and summarizes the main findings of the project.

More detailed results can be found in the final report:

Schünemann, C., Herold, H., & Reger, E. (2024). Machbarkeitsstudie: Modellierung von Anpassungsmaßnahmen: Akteure, Entscheidungen und Wirksamkeit (Climate Change). Umweltbundesamt.

Figure 1: Complex impact of policies



Source: Own illustration, IOER; Illustration: Nicolaas Bongaerts

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1 Why modelling complex and social systems?

How does a policy actually work? How do they affect different stakeholders? To what extent are they accepted or rejected and why? These questions arise for anyone developing and implementing policies. A policy is a specific measure or approach used by governments and other political institutions to tackle social challenges and achieve political goals. These policies can affect people directly, for example, through financial incentives, bans, or information campaigns. An example from climate policy would be policies that promote the expansion of urban green spaces, which can enhance cities' climate resilience. Yet policies can sometimes also ***create unintended or undesirable side effects.*** Therefore, when developing ***policies,*** it is crucial to examine their potential ***future impact*** in a foresight manner (known as ex-ante evaluations).

What are complex systems?

In complex systems the individual system components interact in a non-linear and dynamically adaptive manner. These interactions, feedback loops, linkages and dependencies generate interwoven interdependencies and non-intuitive dynamics. An example are the impacts of Climate Change.

There are various approaches available to conduct a policy impact assessment. These include expert assessments or using multi-criteria decision analysis (MCDA). However, these methods only partially consider the ***non-linear and interwoven causal consequences or side effects of policies.*** In particular, they are vague about the impact on ***social dynamics.*** Still, understanding the many possible impacts is indispensable, even more so when policies aim to tackle complex problems. Global crises or climate change are examples of such highly ***complex problems,*** which also require interdisciplinary, international, and multi-dimensional cooperation. In order to better capture the impact of policies in these complex areas, modelling approaches are suitable that originate from complexity science. By using a range of qualitative and quantitative approaches, it is possible to model complex systems in response to precise questions. ***Social factors*** can be integrated into these ***system models as complex coherences*** and linked to other topics. This allows for mapping policies and their effects in complex social systems and for uncovering hard-to-grasp, non-linear, or unaccounted-for interactions. In addition, system models facilitate virtual foresight experimentation, in which different designs of policies can be tested and refined in advance.

This factsheet presents three system modelling approaches that shed light on the complex and social impacts of policies. They are more suitable for describing real-world complexity than methods based on simplified linear causal relationships. ***Oversimplifying complexity*** is a serious drawback and ***often leads to wrong assessments,*** as certain factors or feedback loops remain unconsidered. Note that the qualitative and quantitative system models described here are exploratory approaches. They do ***not provide*** reliable ***predictions*** about the future, which is a consequence of the nature of complexity, as its potential future dynamics are inherently unpredictable.

What are complex social systems?

In such systems the complex social behaviour of actors is represented as an additional system component. Human decisions, too, are non-rational, interacting, interdependent, and thus complex relationships that change in a non-intuitive manner. Examples: Socio-technical systems, such as the diffusion of technological innovations in society.

When are qualitative or quantitative systems models suitable for evaluating the efficacy of policies?

► If conventional assessment methods only barely encompass the ***complexity*** of the system or more precisely of the policy impact in reality

► To assess the impact of the policies on the ***dynamics*** of complex interdisciplinary processes (e. g. climate change, global crises)

► If the impact of a policy on the ***behavioural change*** of individual ***actors*** or on society needs to be deeper understood

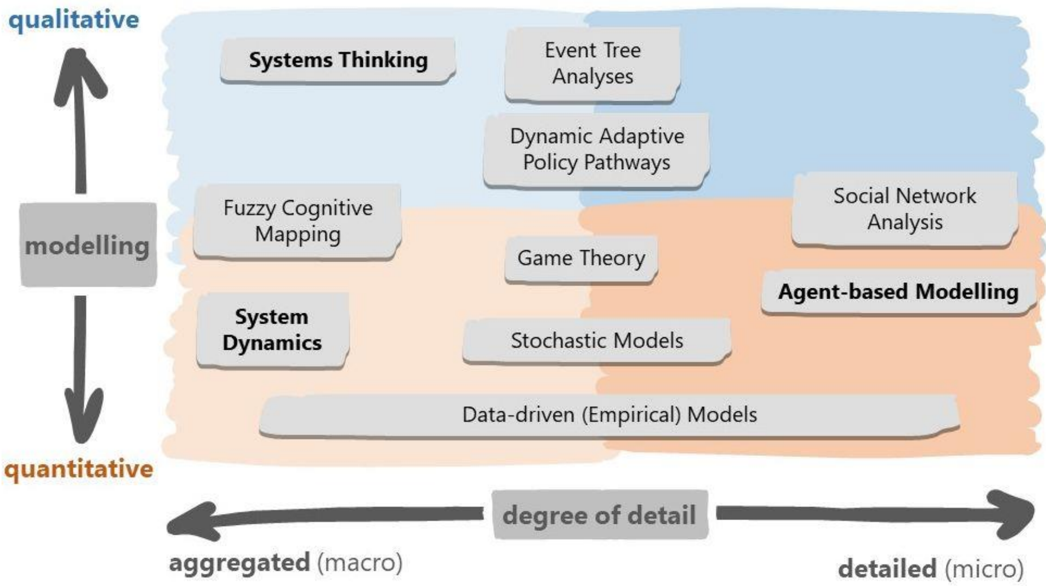
► To identify ***unintended side effects*** of policies in the complex reality in which they operate

2 Which methods are available for modelling complex systems?

System modelling methods differ primarily based on the type of data they require and the level of detail they represent. This results in four categories: ***qualitative vs. quantitative and detailed vs. aggregated system models.*** Using this classification, the following figure systematizes different modelling approaches. All of them can assess the ***complex and social effects of policies in different ways.***

More in chapter 2 of the final report.

Figure 2: Overview of different systems modelling methods for assessing the effectiveness of policies



Source: Own presentation, IOER; Illustration: Nicolaas Bongaerts

Qualitative system models rely on literature research or ***participatory*** and can also be developed in a participatory process. The latter form involves participants sharing their system knowledge and perspectives, and jointly creating the system model. Creating Causal Loop Diagrams (CLD), belonging to the ***Systems Thinking*** modelling (STM) toolbox, is an exemplary qualitative modelling approach. This type of model is ***not quantified*** and requires only qualitative data. Thus, the model output is merely descriptive. However, their major advantage is that they illustrate the behaviour of complex systems via the ***system structure,*** i. e., the complex interactions between the influences on the system. New connections, previously unnoticed interactions, or side effects can be explored. Participatory qualitative models generate ***learning effects*** among participants during the creation process. Their results are easy to visualize, and they are ***less resource-intensive*** and faster to develop than quantitative system models.

Quantitative system models use mathematical equations or decision rules. Unlike qualitative methods, they can describe the ***time-resolved dynamic behaviour of systems*** and provide ***deeper insights.*** There are two ways to do this:

- First, through ***stochastic models*** that reflect the probabilities of future events to occur.
- Second, through ***time-resolved simulation,*** which represents the dynamic time-resolved behaviour of the system and the target values in the future.

Especially for quantitative system models, the considered level of detail is crucial. Some approaches use aggregated values, such as an average of a group (e. g., ***System Dynamics*** models, SDM), while others rely on individual data to describe the behaviour of individuals, such as the dynamics resulting from the social interaction of individual agents (e. g., ***Agent-based*** models, ABM). Simulations such as ABM or SDM can provide deep insights into the potential time-resolved effects of policies. Nonetheless, obtaining and processing the necessary ***quantitative data*** can be ***challenging and resource-intensive.*** This is especially the case when studying the impact of policies on individual decisions (ABM).

3 What do examples of system models look like?

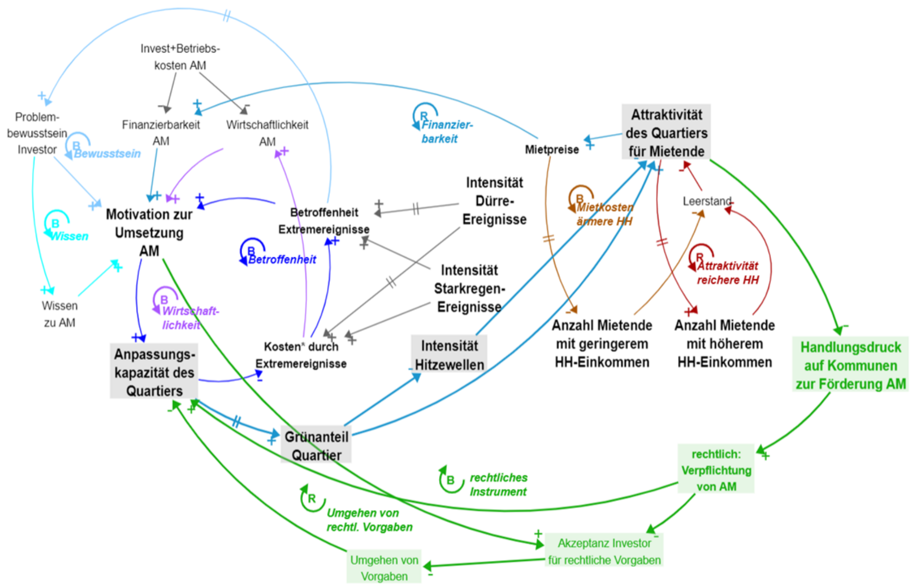
In order to point out the characteristics of the different system modelling approaches, ***three exemplary system models*** were developed within PoliMod project. One ***qualitative (CLD/STM)*** and ***two quantitative models (SDM, ABM)*** were used to analyse how ***three fictitious policies*** (informational, economic, and regulatory) could affect the systems and which aspects the different modelling approaches can illuminate. All three models describe the same hypothetical problem: the ***low implementation dynamics of Sponge-City adaptation measures*** in an urban residential area with tenants as residents and a real estate company that owns all the buildings and land in the area. We show that each modelling approach sets different priorities for evaluating the impact of policies.

More in chapter 4 of the final report.

Qualitative Causal Loop Diagram (part of STM):

The basic CLD illustrates the envisioned socio-technical system of the initial question. It depicts the system structure with its multiple interrelationships. Thus, it identifies the ***feedback loops*** that cause the non-linear, mostly non-intuitive system behaviour. In the illustrative CLD model, new reinforcing and balancing feedback loops result from ***integrating policies.*** As a consequence, this changes the structure of the system and thus alters how the system behaves. As one example, the model shows that larger green spaces increase the neighbourhood attractivity, which leads to higher rents. Eventually, ***green gentrification*** occurs as poorer tenants leave the neighbourhood and wealthier residents move in. CLDs are not quantified, so they are only descriptively dynamic. However, they can be quickly created (~a few days) and are relatively non-resource intensive.

Figure 3: Visualisation of the developed qualitative Causal Loop Diagram test model

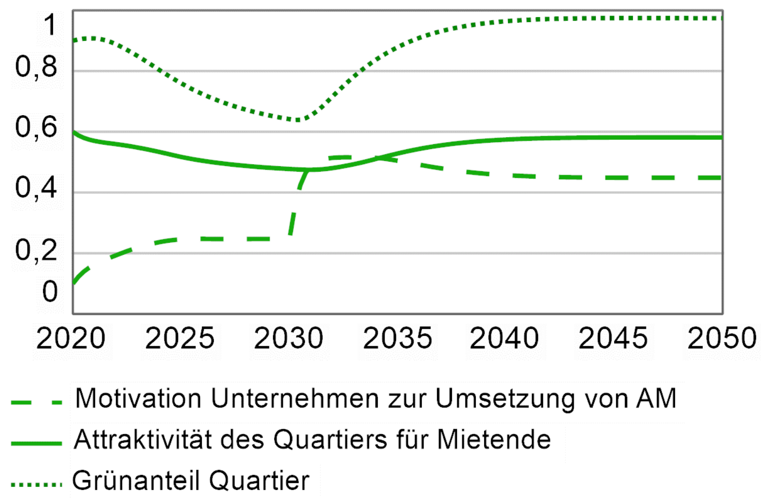


Source: Final report of the PoliMod project, IOER

System Dynamics simulations Model (SDM):

A SDM usually derives from a qualitative CLD model. However, the ***system relationships are quantified*** in the SDM. This results in a dynamic simulation model that shows how the system dynamics change over time when introducing a policy. SDM are able to represent time-dependent, non-linear system dynamics and identify dynamical tipping points in scenario analyses. In the exemplary SDM, the timing of the effects of adaptation measures on green space, neighbourhood attractiveness, and the associated migration and immigration of tenants ***are simulated and presented in graphs*** exemplarily. Because of the quantification required, the model development takes much longer than for the CLD (sometimes years) and is much more resource intensive.

Figure 4: Diagram of time-resolved dynamics obtained from the SDM test model

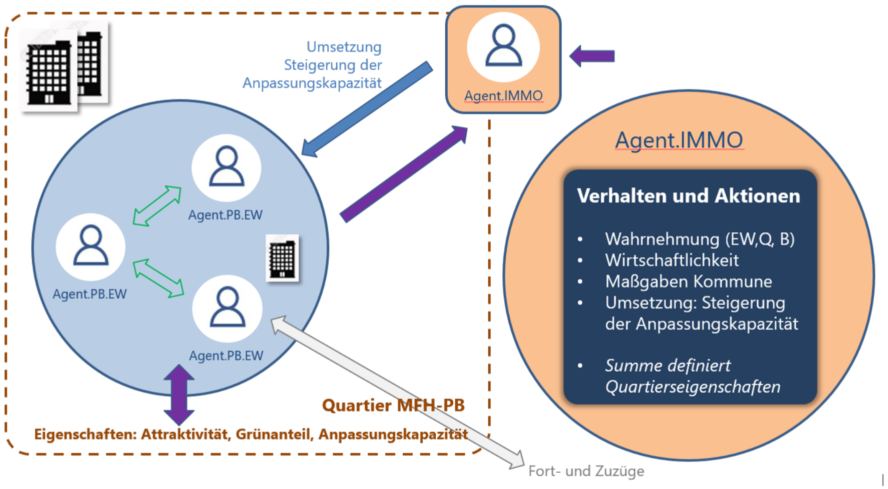


Source: Final report of the PoliMod project, IOER

Agent-based simulations Model (ABM):

Like SDM, ABM maps complex, time-resolved system dynamics. But instead of relying on averaged values (as in SDM), ABM draws on ***individual data*** that describe ***interactions and decisions by individual acteurs*** (agents). These individual decision rules are commonly difficult to obtain. However, the models can capture a very detailed and heterogeneous view of agents and the emerging system behaviour. In the developed ABM test model, tenants' decisions to move are based on neighbourhood attractiveness and rent. ABM can trace these decisions to ***different social milieus*** with corresponding behaviours. Because of the significant amount of detailed data required, ABM modelling is even more time-consuming than SDM (sometimes several years) and is therefore particularly resource-intensive.

Figure 5: Graphical scheme of the developed ABM test model



Source: Final report of the PoliMod project, IOER

4 What does the development process for system models look like?

Creating a valid system model for policy impact analysis involves several development steps. It involves close coordination between the modelling team and the client. The relevant steps are briefly outlined below.

More in chapter 3.1 of the final report.

Table 1:

Step	Title	Description
1	**Refining the problem specification and modelling objectives**	First, it is important to define the question and the aim of the model very precisely. Some helpful questions might be: Which problematic system behaviour should the policy improve and the model focus on? Where are uncertainties about the future impacts of the policy on the affected actors? Who exactly should be advised by the model outcomes?
2	**Selecting the modelling methods**	The next step is to determine which system modelling method(s) are best suited to analyse the impact of the policy or policy-mix. This question largely depends on the available resources (time, finance, personnel, expertise, data). It also involves deciding whether aggregated system analyses (focusing on interactions) are sufficient or whether it is necessary to analyse the behaviour of individual actors. For the latter, the availability of data and the effort required to obtain them are crucial.
3	**Creating the system model structures**	At this point, the model structures are created. This can be achieved by drawing on research, scientific evidence and the results of participatory processes with stakeholders.
4	**Parameterising the quantitative system models**	This step is not necessary for qualitative methods. In contrast, equations or decision rules in quantitative models must be developed and connected quantitative data. This quantification is commonly very time-consuming, especially for social data.
5	**Validating and testing the system models**	The models are validated, tested and iteratively improved. This is done through sensitivity analyses, mathematical validations, comparison of simulation results with data from the past and expert feedback.

Step	Title	Description
6	**Analysing the policy effectiveness through model scenarios**	Modelling scenarios analysis under which conditions the policy will affect system behaviour or dynamics in which manner. These include unintended side effects, tipping points, or the mutual influence of policies.
7	**Presenting the model findings**	Finally, the model outcomes are prepared to advise decision-makers developing the policy. The results must be presented in a way that is understandable and appropriate for the target audience. This is the only way to ensure that the model outcomes are actually used in consulting practice.

5 What are the benefits and limitations of system models?

The modelling approaches discussed here integrate complexity and social system influences. In particular, they can assess how policies and measures *influence the complex social behaviour of the affected actors.* Thus, the approaches support and complement policy advice, especially in the case of interdisciplinary challenges.

More in chapter 3.3 of the final report.

Table 2:

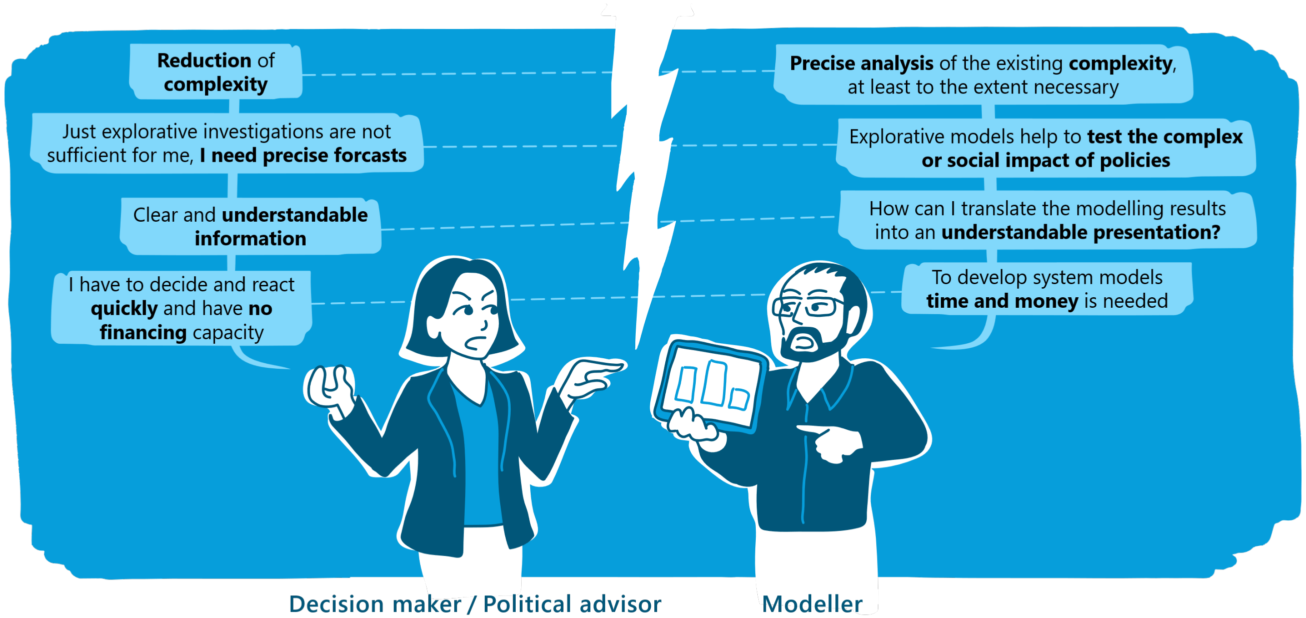
Benefits	Limitations
They allow for ex-ante experimentation with policies in a ***what-if framework. Side effects*** can be identified and considered when designing the policy.	Actually, the modelling methods are ***still little known*** in policy consulting. Consequently, the expertise to generate may be insufficient.
They consider the ***complex, non-linear effects*** of policies from the outset, whereas other methods tend to rely on linear causal logic.	Especially quantitative system modelling requires substantial ***time and financial resources.*** Hence, quantitative models are not suitable for short-term decision support.
They can depict the ***behaviour of actors*** in response to policies. They show how, when, and why their behaviour may change.	Because of the complexity and unpredictability of future conditions, system models ***cannot make future prediction.*** Instead, they help to develop and compare different scenarios for a given system.
Many models can be developed on ***a participatory and interactive basis.*** This leads to a more holistic analysis of the effectiveness of policies and strengthens the ability to reach consensus.	***Human behaviour,*** especially heterogeneous individual behaviour, is still very difficult to quantify and model.
They make it possible to effectively record the ***holistic effects of policies,*** especially in interdisciplinary areas.	System models are ***never entirely rational or objective.*** The subjectivity of those involved in the modelling process is always ingrained and can bias the results.

6 How can systems models support policy advice?

In Policymakers must continually face complex decisions, and each can be very transformative, such as introducing new policies. Among other approaches, the presented explorative system modelling methods can add great value to policy advice. They accomplish what other methods cannot in equal measure: they capture the complex effects of decisions and policies from the outset and make them intelligible. Despite their many advantages, these ***methods are rarely used*** in policy advice, which has several reasons. Decision-makers typically expect fast solutions, clear forecasts, and straightforward communication. In contrast, system modelers aim to manage and explore complexity, not dismiss it. The system models mentioned above can be used for this task. The following figure illustrates potential reasons for the diametrically ***opposed positions of decision-makers and modeller*** that can only be resolved by knowledge transfer.

More in chapters 3.4, 3.5 and 4.8 of the final report.

Figure 6: Illustration of the conflict situation between decision makers and modelers



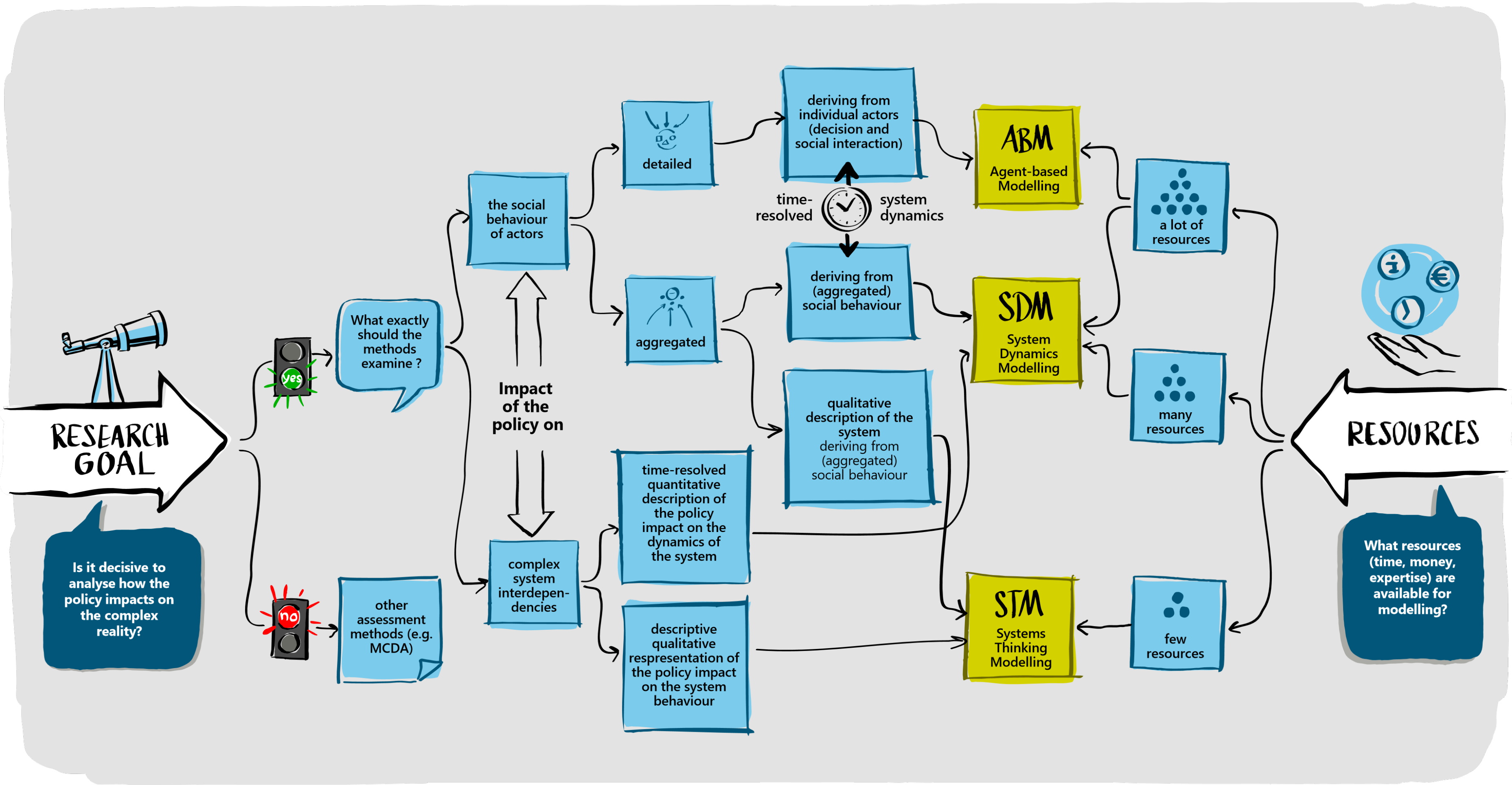
Source: Own presentation, IOER, Illustration: Nicolaas Bongaerts

Qualitative system modelling is a low threshold approach. They are fast, interactive, interdisciplinary, resource-efficient, and their results are good to visualise. In cases of disagreement among experts or uncertainty, these methods can help gain an understanding of other perspectives. As such, they are well-suited to the ***early stages of projects or policy development*** during which knowledge needs to be gathered and synthesized for a ***system overview,*** non-linear relationships uncovered, and priorities set. Qualitative system models provide rather general and descriptive statements about the impacts of policies in complex social systems.

Quantitative system modelling provides deeper insights. Although they are much more resource-intensive, they can also display the ***time-resolved complex dynamics*** that result from system interdependencies (SDM) or individual human actions (ABM). Once built, they allow for experimental tests through ***scenario analysis.*** Given sufficient resources, this approach is valuable for better assessing the impact of far-reaching and long-term policies.

The choice of the best modelling approach for estimating the impact of policies is ***not always trivial*** and depends on several factors. The following ***decision tree chart provides some guidance.*** If the complex or social impact of a policy is to be researched, the choice between the methods listed can be made either from the perspective of pragmatic resource assessment or from the perspective of the research objective. The question of resources leads to a quick answer: A large availability of resources allows all types of system modelling. Limited resources restrict the choice to STM and possibly SDM. With few resources, only qualitative STM is possible. Starting from the research objective, several aspects need to be considered. Above all, it is important whether the modelling should focus on system interrelationships or rather on the social behaviour of the actors. System interrelations and feedbacks can be described qualitatively or quantitatively, so that STM and SDM are the best methods. Actor behaviour in systems can in turn be described either in great detail or in aggregated form. In the first case, ABM is a sensible option. In the second case, either STM or SDM is suitable, depending on whether a qualitative or quantitative assessment of the policy is more expedient.

Figure 7: Illustration: Decision tree for the selection of system modelling methods



Source: Own presentation, IOER; Illustration: Nicolaas Bongaerts

Further Literature

Systems Thinking:

- Donella Meadows: Thinking in Systems (ISBN: 1603580557)
- David Peter Stroh: Systems Thinking for Social Change (ISBN: 160358580X)

System Dynamics:

- Andrew Ford: Modelling the Environment (ISBN: 1597264733)
- Donella Meadows, Jorgen Randers und Dennis Meadows: Limits to Growth – The 30-Year Update (193149858X)

Agent-based Modelling:

- Silvio Andrae und Patrick Pobuda: Agentenbasierte Modellierung: Eine interdisziplinäre Einführung (ISBN 978-3-658-34952-3)
- Claudius Wagemann, Achim Goerres und Markus Siewert: Handbuch Methoden der Politikwissenschaft (ISBN: 978-3-658-16935-0)

Online Courses

Systems Thinking: Coursera-Kurs "Systems Thinking in Public Health", *https://www.coursera.org/learn/systems-thinking*

System Dynamics: "System Dynamics Modelling and Analysis Course", University of Bergen, *https://systemdynamics.org/product/system-dynamics-modelling-analysis-bergen/*

Agentenbasierte Modellierung: Coursera course "Introduction to Agent-based Modeling with NetLogo", *https://www.coursera.org/projects/abm-netlogo*

Application Examples

Systems Thinking: Integrated Assessment Modell Sustainable Germany, *https://imodeler.info/ro?key=AZ1G5dBFBFpJygUEe_RvcvA*

System Dynamics: En-ROADS Climate Solutions Simulator, *https://en-roads.climateinteractive.org/*

Agent-based Modelling: Exemplary models in NetLogo, *http://www.netlogoweb.org/launch*

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