Saving the World with Models?

System Dynamics Models on and across Global, Regional, and Country Scales.

Dr. Erik Pruyt & Dr. Tushith Islam

PEAS.Center

Center for Policy Exploration Analysis and Simulation

PEAS Center BV, The Hague, The Netherlands. www.peas.center

Abstract

Many grand challenges and complex policy issues require urgent action. However, before action, one should test policies and plans of action – not just for one potential future, but across many plausible futures. System Dynamics (SD) is a systems modelling and simulation approach that is useful for dealing with truly grand challenges. In fact, it has been used for such purposes ever since the first Limits to Growth study. Lately, supplementary and complementary approaches, including Agent-Based Modelling and AI, have been suggested to be needed for dealing with grand challenges. While methodological diversity is enriching and should be welcomed, we believe SD should be used for doing so. This requires dealing with some shortcomings. This paper builds on recent SD modelling for dealing with such grand challenges and discusses solutions to some of the shortcomings. We argue that - for dealing with grand challenges - SD modelling among else needs to embrace modelling with building blocks, data-rich modelling, multi-scale modelling, simulation under deep uncertainty, and needs to work on getting the message across. Finally, we call the System Dynamics community to redirect their attention towards grand challenges – to do daring studies that matter and share our associated research agenda.

NOTE THAT…

This proceedings paper is a short version of the reviewed conference paper, leaving out many of the lessons learned that will first and foremost make AI smarter, but will not make the world a better place.

The full conference paper is available for interested readers upon request. Most of the contents of the longer conference paper will also soon be published in a chapter on *System Dynamics Modelling and Simulation in Practice* in an *Advanced System Dynamics Modelling and Simulation* book scheduled for release in 2027 (Pruyt and Islam, 2027 forthcoming) and in a soon-to-be finished book on *Intermediate System Dynamics Modelling and Simulation* (Pruyt, 2027 forthcoming).

The intermediate book and advanced book will complement many of the books we developed for students and practitioners of systems modelling and simulation, including the second edition of the *Small SD Models for Big Issues* book (Pruyt, 2026), and the books in the *Systems Modelling and Simulation for Everyone* series. The books in this series target specific domains and domain experts and are used to teach workshops offered by the PEAS Center, Center for SYSTEMS, and Policy Academy & ReThink Institute. Many of the books/domains in the *Systems Modelling and Simulation for Everyone* series deal with grand challenges and major problems, but on an introductory level. Domains / topics dealt with in the *Systems Modelling and Simulation for Everyone* series include:

- Sustainability, Circularity, and Transitions
- Climate Change, Mitigation, and Adaptation
- Nature, Nature-based Solutions, Ecosystems, Ecosystem Services, and Biodiversity
- Contamination, Environmental Risk Assessment, Environmental Remediation
- Agriculture, Biobased Economy, Land Use, and Land Use Change
- Epidemiology, Population Health
- Migration, Displacement, Asylum
- Safety, Security, Public Order
- Economics, Capitals, Wealth, Welfare, Wellbeing
- Economics, Productivity, Labour, Education, Innovation, Markets
- Infrastructure and Dynamic Asset Resource Management

The *Advanced System Dynamics Modelling & Simulation* book deals with: Multi-Scale SD Modelling / Entity-Based Modelling; Multi-Dimensional Data Data-Rich Systems Modelling (with Python Scripting); Developing Digital Twins and Building Blocks for Digital Twins; Advanced Analysis to Do More with SD Models; Deep Uncertainty and Robust Decision Making; Advanced Systems Modelling in Practice.

The *Intermediate System Dynamics Modelling & Simulation* book provides in depth discussions of and learning of Data-Rich SD Modelling (without Python scripting); Operational versus Non-Operational Modelling; Modelling Complex Structures and Mechanisms; Policy Testing in Practice: Levers and Leverage; Serious SD Gaming and Lego Game Prototyping; System Dynamics in Practice.

1. Introduction

Agent Based modelling (ABM) and Artificial Intelligence (AI) have over the past years been proposed as *the* tools that will save us by solving the grand challenges of our times.

The Guardian reported on Doyne Farmer's pursuit to build a super simulator of the global economy, in which every company is individually represented, to forecast the economy with "unprecedented clarity" and enable "politicians and business leaders to far more confidently forecast the impact of their decisions" (Carrington 2026). Farmer's team is currently developing a model of the energy sector. Their goal is to develop a model of the global economy within 5 to 10 years from now.

Eric Schmidt, former CEO of Google, has for many years advocated for massive AI investment to accelerate the further development of AI to revolutionize scientific discovery and tackle the world's grand challenges – the world's hard problems such as population growth, climate change, development and education.

Although we completely understand both men's fascination with solving grand challenges and their desire to do so with computer models and data, there are serious problems with the approaches they propose. Detailed ABM models and AI models require a large amount of energy to develop and run, and the answers provided by ABMs and AI are not likely to be better than answers that can be provided with other means – for example data-rich SD models or common sense. This is not to say that AI and ABM are not useful. To the contrary. AI may surely become instrumental in solving many scientific problems. However, having developed models for dealing with several global grand challenges, we do not believe these attempts will make *the* difference. To the contrary, while we can be sure that AI and ABM models developed specifically to solve these grand challenges will use many resources (funding, brain power, time, and energy), we do not believe they will solve these grand challenges any better or more transparently than solid Integrated Assessment models (IAMs).

Many IAMs are in fact SD models. Although they may not refer explicitly to the SD method and may not have been implemented in typical SD software, in essence many of these IAMs or their core models are SD models. Examples include Barry Hughes' International Futures model (Hughes, 2019), a simulation model to study long-term national, regional, and global issues, and the IMAGE model (Stehfest et al., 2014), a simulation model to explore the long-term dynamics and impacts of global changes that result from socio-economic and environmental factors. The World Models used for the Club of Rome Limits to Growth studies of course clear examples of SD models, as are the many models that are further elaborations or specifications of the initial world model (e.g., WORLD7, Earth for All). Apart from world models, many integrated assessment models have been developed to help policy-making on the country level (see for instance the work of the Millennium Institute). Other good SD examples are the models underlying the Climate Interactive simulators.

Instead of spending enormous resources on ABM and AI models to "save the world", yet by doing so spend enormous resources and move the world further from that goal, we believe good SD models could and should be at the forefront of advising about grand challenges, big issues, major problems. For those who want to join us in this endeavour, we discuss in this paper lessons we learned while trying to do exactly that and actions we think should be taken, by individuals and by the community.

2. Grand Challenges & Dealing with Grand Challenges

Grand challenges are crucially important issues that require urgent yet long-term action on many scales and across many (sub)systems. Most grand challenges are complex, deeply uncertain, multi-dimensional, play out across multiple geo-spatial areas/scales and policy scales, and are caused by and require the involvement of many stakeholders. There are grand challenges in almost any policy domain (e.g., health, development); There are grand challenges that span multiple policy domains (e.g., energy-climate); The grandest challenges span all policy domains (e.g., biodiversity).

Examples of grand challenges include the long-term liveability of our planet, human-induced climate change and urgently needed energy transitions all over the world to mitigate further human-induced climate change, sustainable development (both in the developed and in the developing world – be it along very different lines), increasing fresh water scarcity and material scarcity, plastics and other forms of pollution, migration, et cetera. Grand challenges are "grand" because of their massive scale and importance. They are "challenges" because of the exceptional transformation they require.

Trying to deal with grand challenges is challenging. Grand challenges are caused by complex and uncertain systems and require solutions all over the world and on many different scales, are often characterized by lack of data or conflicting data and ambiguous information, require the understanding and involvement of many (if not all) humans, and require well aligned high-level policies and specific actionable measures on lower scales, and action by everyone.

System Dynamics models/studies already address many grand challenges. Why then are they not as prominently in the news as the calls for funding for ABM and AI approaches? Why are the insights and policies suggested by them not followed? What is needed for them to be taken more seriously?

We believe models / modelling studies should be useful on multiple decision levels as well as trustworthy. Models need to capture the entire system and processes at the overall systems level as well as operational mechanisms at lower levels of aggregation. Models need to be evidence-based:

they need to correspond to data and function as the system seems to function. Yet, they need to be sufficiently explorative to explore effects of all sorts of trends terms and policies/measures. In other words, they need to be agile and interactive – which also means fast, both in terms of development and in terms of providing answers to questions. We believe SD models have not had the impact they deserve because of their level of aggregation and their development time. Both can be dealt with.

We believe the SD field should do so and do more daring work on grand challenges. Doing so would be in line with Forrester's (2007) call for daring important studies. We are not starting from scratch. To the contrary. Most of what is needed, already exists or requires relatively small modifications.

3. Methodology

Although SD is sometimes referred to as "Data Poor" modelling, this does not mean that data is not used, nor does it mean that data should not be used. To the contrary: good SD requires as much good information ***AND DATA*** as one can possibly obtain – preferably multi-dimensional data. What it really means is that SD is an information/theory rich modelling approach, which can be used in both data rich and data poor contexts. But if data may be available, then there is just no excuse not to look for it and use it. However, our experience shows that data-rich SD modelling requires an additional step in the SD modelling process, namely explicit "data modelling". Data modelling refers to modelling to make sense of data in databases instead of developing models based purely on mental models of participants or experts.

Grand challenges often have an explicit geo-spatial aspect. Data is often geo-spatial to, albeit often on higher scales than desirable. Although SD is mostly applied on an aggregated scale, it is possible to apply SD on a disaggregated scale, geo-spatially. Examples of early geo-spatial SD work include Ruth and Pieper (1994), Vries et al. (1999) and Struben (2005). One difference with early geo-spatial SD work is that, today, much geo-spatial data is available. Another difference is that it is much easier today to link geo-spatial data across different scales. The label "multi-scale system dynamics modelling" refers to models that comprise multiple levels or scales – for example multiple geo-spatial scales (Municipalities > Provinces > Nations > Continents > the World) or organizational scales (operational tactical > strategic) – with feedback within and between these levels or scales.

Traditionally, SD models are highly aggregated and flat (all at one level of aggregation). Stocks (i.e., integral equations) are used to group homogenous items/people/etc. Today, we are witnessing the shift from aggregated flat models towards multi-scale model-of-models, disaggregated database-driven model instantiation, and multi-resolution modelling. That is, several modelling approaches have recently been or are currently being developed that enable one to represent systems at a lower level of aggregation while, overall, preserving the same broad systemic boundaries and system-wide feedback and accumulation effects. That is, the aggregation assumption can be relaxed in several ways without throwing away the big picture systems perspective.

Let us illustrate this using the example of world modelling. The first world models (exemplified by World3 and its predecessors (Forrester 1971, Meadows et al., 1972, 2004)) were at the world level only and for the entire world (see (a) in Figure 1). Later, vector ranges…

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4. Dealing with Grand Challenges Using SD: Two Recent Examples

We have recently been involved in several multi-scale studies, for several clients and some for the public at large (i.e., for the sake of the grand challenge itself). Two of these modelling jobs, one on the global energy system and one on the global agriculture and food production system are used here as examples. We worked on many of these grand challenges though, including…

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The way in which we use SD for grand challenges could be labelled data-rich multi-scale geo-spatial modelling and simulation under deep uncertainty. To identify policy leverage, we use machine learning techniques. We use python scripting to pull data from databases and structure them for use in simulation models, automatically multi-scale model structure generation and cleaning and importing of data, sample across large uncertainty spaces and instructing SD packages to simulate runs, store time series outputs and terminal outputs in convenient data structures, use machine learning techniques to analyse data and simulation results, keep track of everything we do from sampling to simulation and analysis, prepare results for visualization and visualize/animate results.

4.1 The Global Energy System / Global Energy Transition Model

In 2018, we developed our global energy system model, comprising the world, 7 regions, 217 countries for all IEA energy sectors and flows. Modelling worldwide energy systems and energy system transitions requires the inclusion of distinct (groups of) countries and/or regions and their characteristics, as well as the (global) interactions between them.

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4.2 Food and Agriculture.

In 2022-2023, we developed an integrated assessment model that allows for in-depth system-wide what-if investigations of the Agri-Food system and related systems like the energy system and the transportation system.

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5. Discussion: Lessons Learned, Filling the Gaps, Getting to Action

In the previous section, we described two of several recent modelling and simulation projects related to grand challenges. The main goal of presenting these projects/models was (1) to show that grand challenges can be dealt with SD (albeit after some modifications/extensions), and (2) that modifications to traditional SD had to be made to deal with these grand challenges.

Without these modifications, these projects would not have been as meaningful to them as they are now. Especially the ability to provide multi-scale / multi-resolution simulation runs under uncertainty was perceived to be useful.

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With these additional changes, SD is better suited to deal with grand challenges. But even without them, we should get involved in solving grand challenges, with models or with real action. It takes more than a model to solve a grand challenge.

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CONTACT

For questions or requests related to Systems Modelling and Simulation, please contact Erik at PEAS dddddot center.
For questions or requests related to advanced Data Science, Data handing for SD, Scripting, contact Tushith at PEAS ddddddot center.

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