Industry note: Seeing through the SDG maze – the iSDG model, a simulation-based tool to aid SDG planners

Steven Arquitt

Millennium Institute,
2200 Pennsylvania Ave, NW,
4th Floor East Tower, Washington DC, 20037, USA
Email: sa@millennium-institute.org

Biographical notes: Steven Arquitt is a Senior Research Analyst and Asia Lead at the Millennium Institute. His work currently focuses on developing system dynamics models to guide policies for the sustainable development goals.

1 Introduction

The Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda are the world community's roadmap to a sustainable and equitable future, free of hunger and extreme poverty. The SDGs have been adopted by some 193 nations, however progress on the SDGs has been mixed and only ten years remain under the 2030 Agenda mandate. Achieving the SDGs has proven to be an extraordinarily difficult challenge and a daunting expense.

The SDGs are characterised by a web of complex causal linkages and feedback loops with extensive time lags between cause and effect. Such systems present an extremely difficult learning environment for policy makers (Sterman, 2000). Also learning through experimentation is essentially impossible due to expense and lengthy time lags. In this complex SDG system it is likely that some policies for SDG attainment in one sector may cause perverse outcomes in other sectors. Conversely, some SDG policies may bolster performance for other SDGs. Clearly policy makers need special tools to see through the SDG maze and chart pathways to effective SDG policies. Addressing this need, the Millennium Institute has developed the Integrated Sustainable Development Goal (iSDG) model. The iSDG model is an integrated system dynamics model designed to help policy-makers and planners find efficient pathways to the SDGs. The iSDG model generally is applied at national or regional scale with relatively course detail and is not intended as a replacement for more detailed sector-focused models. The purpose is to help policy-makers and planners make sense of the dynamic complexity they face in their policy environment, and to help them design integrated policies for the SDGs.

The remainder of this paper will present a description of the iSDG model structure and method, give an example analysis of policy for SDG2 from Malawi, and conclude with a brief discussion.

2 The iSDG model – essentials

2.1 iSDG background

The iSDG model is grounded in System Dynamics, a theory and methodology for understanding and taking effective action in complex systems. The core elements of System Dynamics are feedback, stocks-and-flows, information delays, and nonlinear relationships (Forrester, 1961), and is therefore highly appropriate for analysing SDG policy. System dynamics emphasises the need for computer simulation of complex feedback systems, as human cognition cannot accurately intuit the implications and behaviours of such systems (Forrester, 1961; Sterman, 2000). The iSDG is developed from the Millennium Institute's Threshold-21 (T21) modelling framework. T21 models, designed for integrated sustainable development planning primarily at national scale, have been under continuous development and evolution for 35 years and have been implemented in over 40 countries across the world.

2.2 iSDG structure

The iSDG model is organised into 30 sub-sectors falling within the three dimensions of environment, economics, and society. The model is fully integrated with causal linkages and feedback loops running across dimensions, sectors and within sectors. Table 1 gives a list of the core sectors within the principal dimensions of the model.

Table 1 Core sectors of iSDG model

Environment	*Society*	*Economy*
Land	Population	Finance
Water demand	Mortality	Agriculture
Water supply	Health	Investment
Emissions and waste	Education	Services
Soil	Vehicles	Households
Biodiversity	Infrastructure	Balance of payments
Material consumption	Employment	Industry
Electricity generation	Income distribution	Governance
Energy supply	Poverty	Aggregate production
Energy consumption	Fertility	Government

The iSDG model captures all 17 SDGs and makes use of approximately 80 SDG indicators. For detailed descriptions of the sector structure, and key assumptions and equations of iSDG refer to the Millennium Institute website (https://www.millennium-institute.org). Also detailed descriptions of iSDG can be found in Pedercini et al. (2018, 2019). The most recent versions of iSDG are implemented in the Stella Architect software (https://www.iseesystems.com). The iSDG models are customised for individual countries or regions. The models are developed and implemented in cooperation with in-country modelling teams. Capacity development and training of modelling teams is a very high priority in iSDG projects to insure local ownership and participation and to allow model users to expand and revise their iSDG model after project completion. The iSDG models are grounded in the best available data from international and local sources.

3 An example of policy for SDG-2 from Malawi

Through simulations with the iSDG we anticipate the effects of policy interventions within specific sectors and across other linked sectors. We attempt to identify feedback processes that link multiple objectives and that create synergetic effects over time. The iSDG model demonstrates how policies have effects, both favourable and not favourable, across sectors and across SDGs. In Malawi an iSDG model was developed to aid the National Planning Council to incorporate the SDGs into the Malawi national plan. Here we demonstrate the use of the model with an example from Malawi, investment in water efficient irrigation to promote SDG-2.

Figure 1 shows simulation results for cereal production, crop production per unit of labour, prevalence of undernourishment, population below poverty line, agricultural GDP, and water vulnerability index (an aggregated measure of water stress) when government expenditure for water efficient irrigation is increased by 1.0% of GDP for each year between 2017 and 2030. These performance variables were selected because of their importance as SDG indicators and because of important cross-sector impacts of the efficient irrigation policy. Investment in irrigation is selected because it is a high priority in the current Malawi national agriculture plan. The blue curves in the charts are the simulations under the water efficient irrigation policy. The red curves are the business as usual case (no new policies in place).

Crop production [Figure 1(a), and 1(e)] and productivity increase as would be expected. Also, there is some improvement in the prevalence of undernourishment [Figure 1(b)]. The water vulnerability index has however increased dramatically [Figure 1(f)].

Figure 2 is a causal loop diagram that helps explain the behaviour of the variables in terms the causal linkages and feedback loops within the model. The unidirectional arrows indicate causal linkages. The direction of causality is indicated by the polarities (positive and negative signs) at the arrow tips. A positive causal linkage means that a change in the variable at the base of the arrow will tend to cause change in the *same direction* in the variable at the tip of the arrow. A negative causal linkage means that a change in the variable at the base of the arrow will tend to cause change in the *opposite direction* in the variable at the tip of the arrow. For additional clarity the positive linkages are shown in blue, the negative linkages are shown in red. In Figure 2 feedback loops are indicated by ‘R’ which stands for *reinforcing feedback loop*. Reinforcing feedback loops in isolation cause runaway growth or collapse.

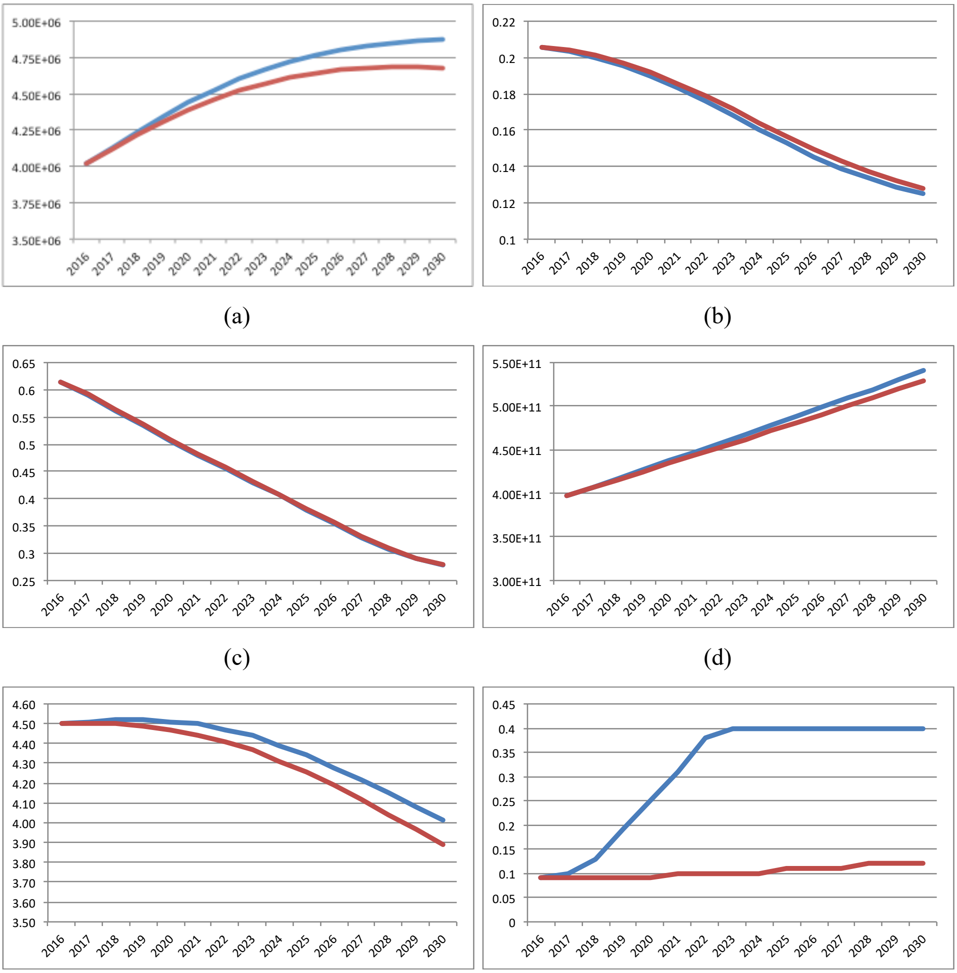
When the percent of GDP for efficient irrigation is increased by 1.0% of GDP (see lower left of Figure 2) the absolute expenditure for efficient irrigation increases. This leads to

1 conversion of existing irrigation to water efficient technology

2 expansion of efficient irrigation into land not previously irrigated, this includes land under rain-fed agriculture and land not under any form of cropping.

As the total area under irrigation (including irrigated lands existing before implementation of the water efficient irrigation policy) increases, cropping intensity will increase (the possibility of growing more than one crop per year on irrigated land) and the total land area under crops will increase (because a portion of the expanded irrigation will allow crop production on land not previously farmed).

Figure 1 Simulated behaviours of key SDG indicators under policy for expansion of water efficient irrigation (a) crop production (metric tons cereal crops per year) (SDG 2) (b) prevalence of undernourishment (proportion)(SDG 2) (c) proportion of population below poverty line (percentage) (SDG 1) (d) agricultural GDP (total agricultural value added) (real currency/year) (e) agriculture production per labour unit (metric tons per year per person) (SDG 2) (f) water vulnerability index (dimensionless, water used/water supply) (SDG 6) (see online version for colours)



(a) (b)

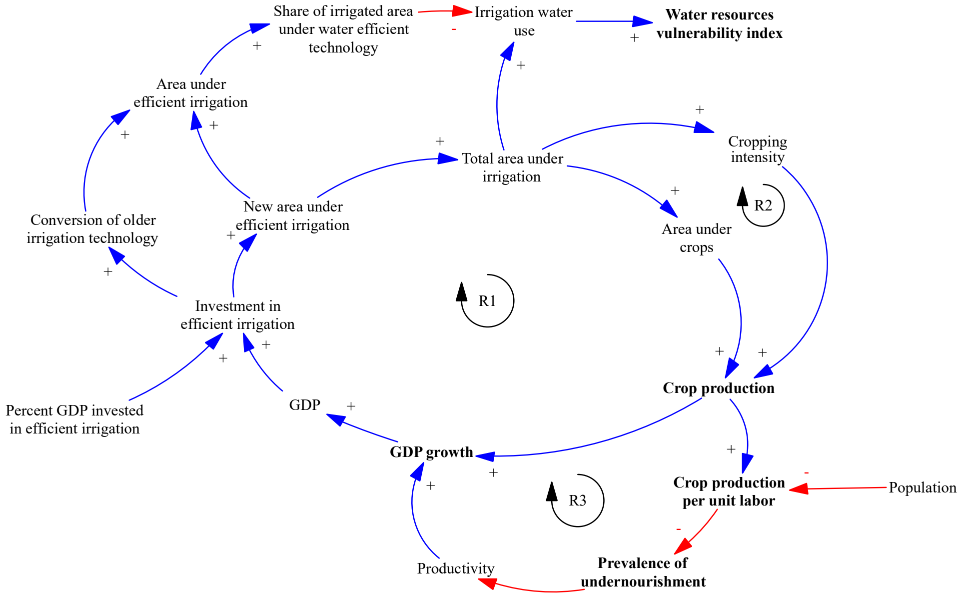
(c) (d)

(e) (f)

Notes: Red curves represent business as usual (BAU), i.e., no new policy in place. Blue curves represent simulated behaviour under a policy of expansion of efficient irrigation (1.0 % of GDP invested each year between the first year of SDG implementation and 2030). The x-axis shows the years of the SDG time horizon. The dimensions of the y-axes are given in the titles of the graphs.

The assumption is made that all new irrigation is water efficient. As the area of efficient irrigation increases, the ratio of efficient irrigation to total irrigation increases, this indicates a decrease in water used by agriculture. However, because the total irrigated area increases, the overall amount of water consumed by irrigation also increases over time. This causes the increase in the water vulnerability index as shown in Figure 1F. The abrupt levelling out of the curve in Figure 1(f) is due to the irrigated area reaching the limit of land area suitable for irrigation.

Figure 2 Feedback loops and causal linkages underlying behaviours associated with the simulated water efficient irrigation policy (see online version for colours)

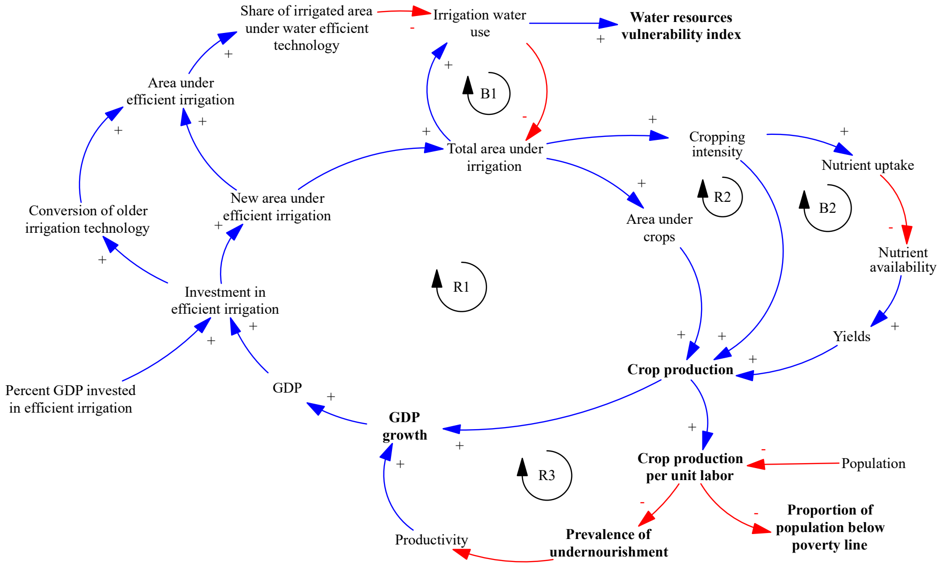


Greater cropping intensity and crop area lead to increased crop production [Figure 1(a)], and consequently GDP growth [Figure 1(d)] and GDP, putting in place the reinforcing feedback loops R1 and R2. Since GDP is increased, expenditure for more irrigation is increased (assuming the percent of GDP for efficient irrigation remains constant over the policy horizon). Increased crop production causes crop production per unit of labour to increase initially, however population growth ultimately causes crop production per unit of labour to decrease over time; this constrains improvements in poverty [Figure 1(c)] and in the prevalence of undernourishment [Figure 1(b)].

There are numerous feedback loops related to the irrigation policy. Two balancing feedback loops are added in Figure 3. Balancing feedback loops resist change in the variables within the feedback loop. ‘B’ indicates a balancing feedback loop.

As the total area under irrigation increases, driving up water consumed by irrigation, water availability imposes a resource limitation constraint on further irrigation development (balancing feedback loop B1). As average cropping intensity increases with expansion of irrigation, nutrient uptake by crops is also increased. This lowers nutrient availability and puts downward pressure on yields and crop production (balancing feedback loop B2). Without complimentary policy, irrigation expansion has the potential to accelerate depletion of soil nutrients and increase reliance on chemical fertilisers. Figure 3 demonstrates that policies such as expansion of irrigation can have unintended consequences that can compromise or even defeat the policy. These effects, however, may become apparent only after significant time lags, highlighting the value of simulation modelling in policy design.

Figure 3 Expanded feedback loops associated with water efficient irrigation policy (see online version for colours)



4 Discussion

Simulating single policies with the iSDG as in the above example is useful for understanding cross-sector impacts of policies both favorable and unfavorable. However, the real strength of the iSDG model is running policy mixes concurrently. The model makes it possible to run numerous policies in all sectors and then assess the impacts on all 17 SGD. Figure 4 shows part of the models user interface that gives a quick view of SDG attainment at years 2030 when a policy mix is simulated. Policies include investments in sustainable agriculture capacity building, efficient irrigation, education, heal, family planning, gender equity, sustainable energy, climate change mitigation and more. The Appendix gives a lit of the policies simulated in the iSDG-Malawi. The policy inputs can vary for each year of the SDG period and so affords a huge variety of policy combinations. In Figure 4 a total SDP expenditure of 12% of GDP was invested in SDG policies. The red (upper) bar under each SDG icon represents SDG attainment at year 2030 under the business as usual assumption. The blue (lower) bar shows attainment under the policy mix.

The results shown above are from but one policy mixture test. Iterative policy tests run by stakeholder groups informed by single policy simulations can help identify effective policy mixes in terms of both performance and cost. Simulations can help identify policy combinations that produce synergetic effects in which a set of policies implemented together produce better results than the sum of the same policies when implemented individually (Pedercini et al., 2019). Such an experimental approach can provide a foundation of evidence for policy makers and planners attempting to maximise their SDG attainment.

Figure 4 Simulation of SDG attainment at year 2030 (see online version for colours)

Note: Red (upper) bars indicate business as usual. Blue (lower) bars represent attainment under a policy mix.

Acknowledgements

For the section on SDG-2 in Malawi I would like to acknowledge the support of the United Nations Development Programme and the National Planning Commission of Malawi.

References

Forrester, J.W. (1961) *Industrial Dynamics*, Productivity Press, Cambridge, MA.

Pedercini, M., Zuellich, G., Dianati, K. and Arquitt, S. (2018) 'Towards achieving the SDGs in Ivory Coast – simulating pathways to sustainable development', *Sustainable Development*. Vol. 26, No. 6, pp.588–595.

Pedercini, M., Arquitt, S., Collste, D. and Herren, H. (2019) 'Harvesting synergy from sustainable development goal interactions', *Proceedings of the National Academy of Sciences*, Vol. 116, No. 46, pp.23021–23028.

Sterman, J. (2000) *Business Dynamics: Systems Thinking and Modeling for a Complex World*, Irwin/McGraw-Hill, Boston.

Appendix

SDG	*Policies simulated*
1	• Subsidies and transfers
	• Distribution by income percentile
2	• Capacity development in sustainable agriculture
	• Water efficient irrigation
	• Fertiliser subsidies
3	• Access to basic heal care
	• Family planning
4	• Investment in education, primary, secondary, tertiary levels
5	• Gender equity in education
	• Gender equity in career
6	• Investment in access to clean drinking water
	• Investment in sanitation
7	• Investment in solar energy
	• Investment in small-scale hydro power
8	• Investment in energy efficient households
	• Investment in energy efficient industry
9	• Investment in paved road infrastructure
	• Investment in rail
10	• Fiscal pressure distribution
11	• Waste management
	• Vehicles energy efficiency
	• Maximum age of imported vehicles
12	• Large scale hydropower
	• Large scale solar power
13	• Investment in climate adaptive infrastructure
14	• Investment in marine protected areas, sustainable fisheries
15	• Investment in terrestrial protected areas
	• Re-forestation
16	• Promotion of good governance, six different indicators
17	• International grants
	• Income tax
	• Tax on international trade