To: Paul Shrivastava and Sandrine Dixson-Declève
Co-presidents of the CoR

From: Vala Ragnarsdóttir
January 11, 2024; Revised March 25, 2024

Re: Earth4All system dynamics model (E4A) and Earth for All book (EarthforAll) – preliminary review

Introduction
This review text is written in collaboration with Harald Sverdrup, Hördur Haraldsson and Birgit Kopainsky – in order to outline the flaws that we have found in the E4A model and claims in the EarthForAll book. I have asked them to keep their findings between us, and they understand the seriousness for the reputation of the Club of Rome – and are therefore helping me to put forward the case presented here.

Who are we:
- Kristin Vala Ragnarsdottir, Professor of Earth Sciences, University of Iceland, Reykjavik, Iceland. Full Member of the International Club of Rome
- Harald Sverdrup, Professor of System Dynamics, Inland Norway University of Applied Sciences, Hamar, Norway. He and members of his system dynamics research group have inspected the E4A model.
- Dr. Hördur Haraldsson, Future Analyst, European Environment Agency (EEA), Copenhagen, Denmark (Seconded National Expert from Sweden), from the Swedish Environmental Protection Agency (SEPA), Östersund, Sweden. *(Disclaimer: This review constitutes Haraldsson´s individual opinion, and does not represent the official view or position of neither the EEA nor SEPA).*
- Birgit Kopainsky, Professor of System Dynamics, University of Bergen, Norway. She and members of her system dynamics research group have inspected the E4A model.

We have downloaded the E4A model from the Earth4All website. We looked at both the Vensim model version and the Vensim version opened in STELLA. Numerous test runs show that they give the same outcomes.

Suggested further reviewers:
- John Sterman, Professor, System Dynamics Group, MIT
- Dr Tom Fiddaman, Ventana Systems
- Drew Jones, Climate Interactive
- Sibel Eker, assistant professor, IIASA and Radboud University in the Netherlands
- Salim Belyazid, Associate Professor, Physical Geography, Stockholm University, Sweden. salim.belyazid@natgeo.su.se
- Dr. Deniz Koca, Senior Scientist, Environmental, Climate and Ecology Center, Ecology Institute, Lund University, Sweden. deniz.koca@cec.lu.se
- Dr Anna Hulda Ólafsdóttir, Climate Change Office, Icelandic Met Office, Reykjavik, Iceland. annaol@vedur.is
- Dr Beth Sawin, Multisolving Institute, Vermont, USA
- Michael Obersteiner, Professor and Director Oxford Environmental Change Institute, Oxford, UK; Formerly at IIASA, Vienna, Austria

A scientific review of the Earth4All model, presented to the Club of Rome

K. Vala Ragnarsdottir, Harald U. Sverdrup, Hördur V. Haraldsson, Birgit Kopainsky

Executive summary

The E4A model has a pervasive set of forcing functions and commands that give a number of pre-set outcomes as desired by the authors of the code. The E4A outcomes are hence exogenously driven. The E4A construct has been wrapped in a software used for system dynamics modelling, to give it the outward appearance of a legitimate dynamic model. It is neither a model driven by internal dynamic functions, nor is it a system dynamics model.

The E4A model is neither mass balance nor energy balance consistent. It is dominated by preset values and forcing functions and lacks all of the most necessary and required stocks in a World System model. Several of the stocks present in the E4A model have been short-circuited. model.Both the GL and the TLTL (BAU) scenarios wreck the world after 2100 because the forcing functions are only set until 2100 and lose control of model output after that.

Many aspects of the model are partly discussed in papers that are not peer reviewed, but available on-line and in the EarthForAll book. Several aspects discussed in the book are not included the E4A model. We observe that:

1. The 5 transitions and policy outcomes described in the book are not supported by the E4A model. The 5 transitions have no representation in the E4A model!
2. E4A is not a proper dynamic model based on causal connections, feedbacks and mass balances, but rather a set of command- and control functions, forcing a preset output as a response to an assumed policy.
3. The population module in E4A has some serious flaws and fails to make realistic scenarios.
4. The food and agricultural module in E4A lacks basic components such as food supply and does not constitute a valid agricultural model.
5. There is no economic model. The labor-market module yields more employed people than the working age population and is not mass balance consistent with the population module.
6. There are no natural resources in E4A of any kind.

Many aspect descriptions are lacking contact with data or with relevant scientific research in the field.

Regarding the 5 turnarounds described in the EarthForAll book and how they are handled in the model - **Poverty** is solved by handouts and printing money without limit, **Inequality** is done by forcing functions towards a commanded end result, **Empowerment** of women is not in the E4A model, indeed there are no women in the model. **Food** is done with an invalid model of agriculture in the E4A model, and it is not mass balance consistent. **Climate change** is done by linear scaling and forcing functions, there is no carbon balance. There is no valid climate change model in E4A. **Energy** is done by creating renewable energy without any metal/material limits. There are no energy balances anywhere in the E4A model.

The model lacks mass- and energy balances, and all conclusions made based on the model are not supported. Despite all its good intentions, nothing in the EarthForAll project and book is supported by the E4A model. An operational representation of the mechanisms and causalities of the Earth System has been replaced with commanding forcing functions.

One might ask - what does a **forcing function** mean? It means that a variable that has a set value for 1980 will be forced to get a pre-set value in 2100 by command and smoothing functions to make the commended change appear as reasonable. The implication is that the output value is reached in the model because the model builders dictated the output value. This is equivalent to "it has that value of X because I say so!" No reason is given why, commands that are used are not substantiated. Inspection of the code shows that far too many outcomes (nearly all) are controlled like this in the E4A model.

Removing many of the most obvious forcing assumptions makes the E4A model go out of control and derail at once. This is caused by the interlinked attempt at keeping the outputs within the desired range, creating internal conflicts and loss of output control. If changes in basic input variables make the model go out of control, then this illustrates that the E4A model is not a stable construct, and that it is unfit for use in any policy assessment.

To us it looks like the E4A model cannot be salvaged by any patch-up operations or upgrades. The very fundamental structure is flawed as outlined above. In its present state, the Earth4All model is a huge liability for the Club of Rome.

Recommendation to the Club of Rome:

- Remove the E4A model software from the Club of Rome and Earth4All websites immediately.[1] If we, the reviewers here, can find the flaws, others can find out also. If it comes out in the media or is discovered by governmental bodies how flawed the E4A model is, the Club of Rome will see its reputation severely compromised.

- Withdraw all papers based on the model or claimed to be based on the model and remove them from the Club of Rome website and from the Stockholm Resilience Centre repository. Most claims in the unpublished texts on the Club of Rome website and the EarthForAll book are not supported by the model.

- If an integrated dynamic global systems model for the Earth4All project is desired, it is necessary to start from new with mapping the system, using state-of-the art system analysis, causal loop mapping and match them with fully consistent mass and energy balances drawn up as flow charts. It is also crucial to ground the model in extensive and up to date global time series data. When the construction drawing has been agreed on and is internally consistent, it is necessary to find people competent in system dynamics to implement this in the actual simulating software.

- There are very serious fundamental flaws in the E4A model, and it is doubtful if any of the sub-modules can be salvaged. Most probably, the E4A model is beyond any rescue.

- The E4A model can neither be used for global policy development, nor for **regional** development. Making regional models that do not add up to the global one is a sign that something at the fundamental level is wrong.

- The Club of Rome has been using its credibility and weight to give serious policy advice in Europe, UN, EU Commission, based on using this flawed E4A model. This could lead to

[1] https://earth4all.life/

serious adverse outcomes for the Earth´s and Europe's future. More than just the reputation of The Club of Rome stand to be compromised.

The E4A model gives the field of system dynamics a bad name by claiming to be a system dynamics model. It is definitely no such thing, it merely uses system dynamics software – and it is the reason why we have spent some time in summarising the underlying fundamental problems.

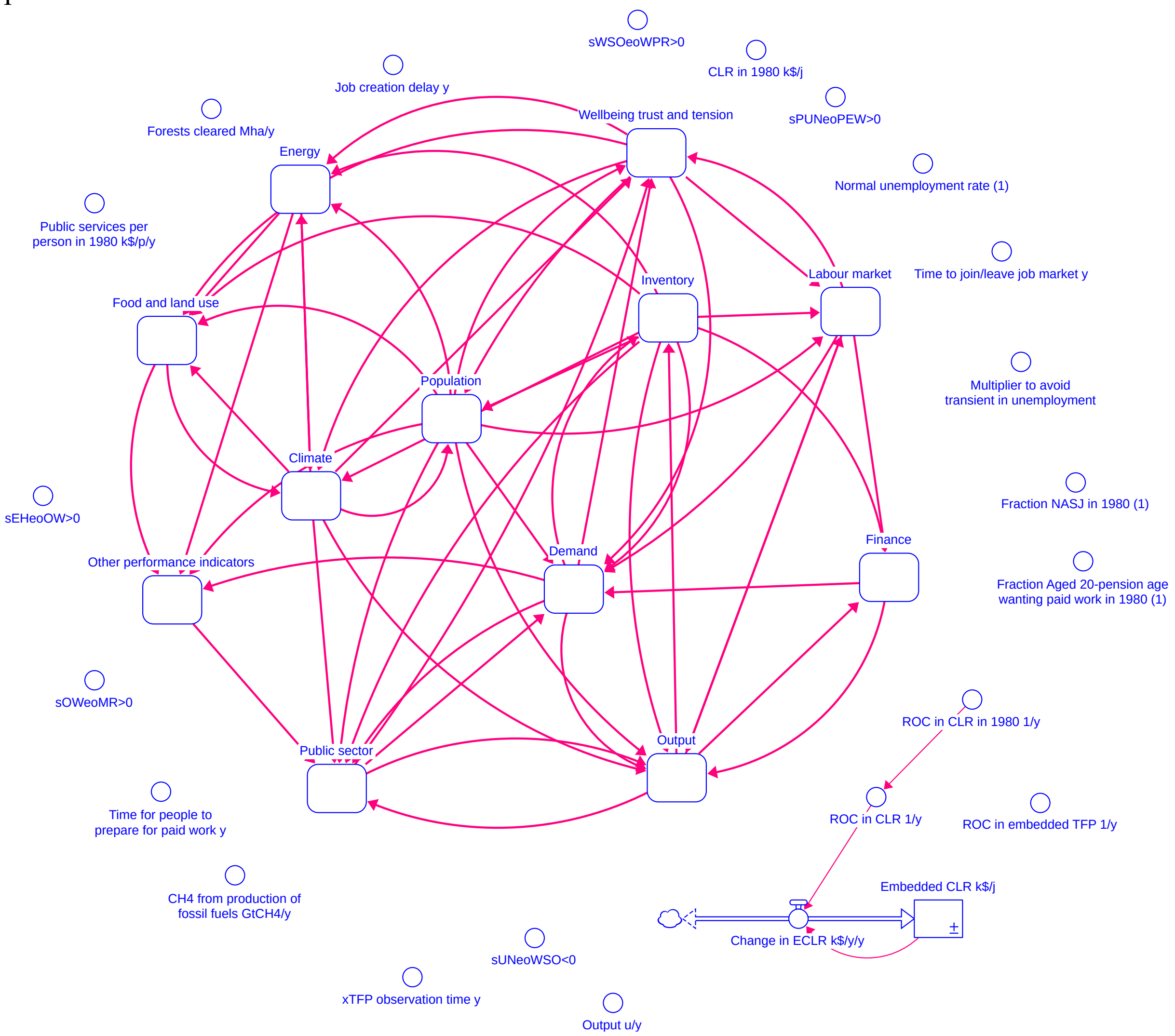


Figure 1. Overview of the E4A model modules as they appear when the Vensim version is opened with STELLA.

The Earth4All model, a review

The key questions to address
The model was reviewed against a set of criteria used to assess whether the E4A meets the standards of what is required for an assessment model (Forrester 1958, 1961, 1968, 1969, 1973a,b, Senge 1990, 1994, Martinez and Richardson 2001, Cavana and Mares 2004, Sterman 2000, Sverdrup et al., 2022). These criteria are in many ways self-explanatory and obvious, but still need to be stated (Forrester 1971a, 1989):

1. Content and relevance
   a. Does it have the required and necessary parts of the system represented in the model?
   b. Does the model have a causal feedback structure representative of the system it is meant to represent?
   c. Are the key policies and the systems they involve represented in the model?
2. Internal consistency
   a. Is this clearly shown in causal loop diagrams and flow charts in the background documentation?
   b. Is the model mass balance and energy balance consistent? (Eddington 1928, Hougen and Watson 1948, Hougen et al., 1949, any model that violates the basic principles of thermodynamics, is invalid and beyond any rescue).
3. Validity
   a. Has the model performance been tested on observed independent data for the past, and that that data was not used in the calibration?
   b. Is the model consistent with earlier research in the field?

We will try the E4A model against each of these criteria, and return to them in our conclusions.

In general about E4A model
The E4A model is lacking a number of real-life stocks that cause delay in the physical Earth System (Figure 1 shows the outline of E4A model, we have checked inside every box in detail for the actual code). There are no supply chains in the model, and delays are set by command, not by system processes - this refers to delays in supply chains and turn-over times for system stocks. This is compensated for by using preset forced delays and smoothing functions to cover over discontinuities coming from the lack of mass balances and jumps between forced input and output values. The E4A model is neither mass balance consistent in any of its modules, nor is E4A energy balance consistent. The economy and finances are neither book-keeping balanced, nor mass and energy consistent (see for example Sverdrup et al. 2021). This is a fatal flaw at the fundamental level, and the E4A model is beyond any doubt not a valid model for the Earth System and interactions between human civilization and the physical planet (Eddington 1928, Hougen and Watson 1948, Hougen et al., 1949). The way the E4A model has been set up, leads to that it crashes after the set forcing functions are no longer in operation after 2100 (using functions like shown in Figure 3).

Nothing in the Earth4All model is tested against quantitative goals for sustainability. The model does not connect to any of the Sustainability Development Goals or in any way to any planetary boundaries. There seems to be a lack of understanding that the UN sustainability goals are intentions but have quantitative measures. This is also a weakness in the EarthforAll project where sustainability is not quantitative.

Checking for sustainability depends on the ability to express sustainability boundaries quantitatively, and to be able to quantify the gap between the present system state in quantitative terms and the sustainability boundary. Making a system more sustainable is to close the gap.

There are no boundaries quantified in the E4A model, nor is sustainability quantified in any way. All statements about what is sustainable or not are untested claims.

Based on the absence of causal loop and stock and flow diagrams, it appears that the systems analysis phase of the development for the E4A model is missing. It is apparent that the E4A model is exogenously driven and formulated to push towards desired outcomes.

The E4A model is not a *high-level simple model for overview assessment*, rather it is a set of commanding functions securing the appearance of pre-determined outputs (Figures 2 and 3). The model does not have any of the feedback functions or dynamics independent of the preset output commands. It is thus, not a system dynamics model.

What does "forcing function" mean?

Forcing functions are used in models when the mechanism or process is unknown or ignored, and it is used to give a command to write out a certain outcome, regardless of what happens inside the model (Figure 4). When smoothed step changes are not used, "if-then" statements have been used to command outcomes.

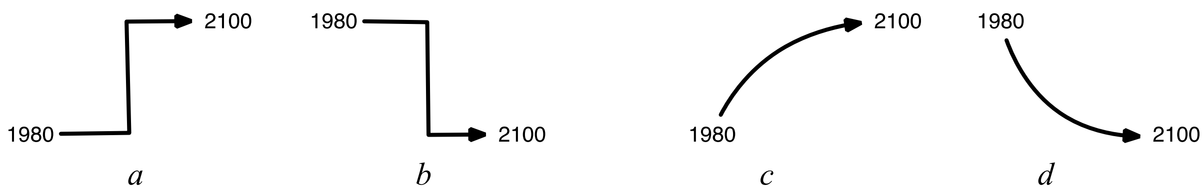


Figure 2. The model is based on pre-set values, defining the output and the change rate from the start in 1980 to 2100. First the values are set for 1980 and 2100 (a, b), then a delay time is set. The step change is avoided by using smoothing functions, and the final forcing function will be continuous.

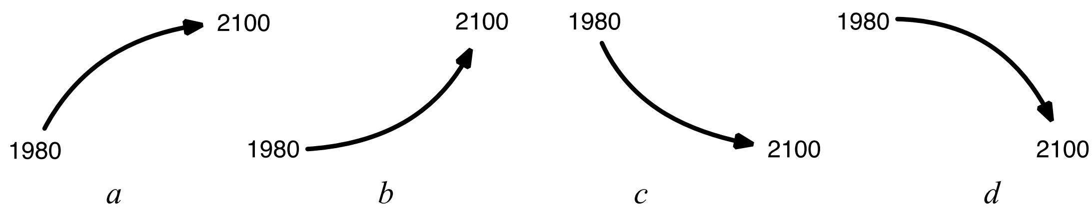


Figure 3. Four types of forcing functions have been used. The forcing functions were calibrated to give the desired output in 2100, with no regard for what happens later.

The command and control methodology of E4A

The E4A methodology is illustrated in Figures 2-4. Figure 1 shows how the E4A model is based on pre-set model output values, defining the output and the change rate from the start in 1980 to 2100. First the values are set up for 1980 and 2100 (Figure 2a, b), then a delay time is set. The step change is avoided by using smoothing functions (Figure 2c, d), and the final forcing function becomes continuous, avoiding step-changes in the output that would reveal the use of a forcing function. Four types of forcing functions have been used in the E4A model (Figure 3). The forcing functions were calibrated to give the desired output in 2100, with no regard for what happens later. Especially the type of functions like 3b and 3d cause the model to derail after 2100. In a system of pre-set forcing functions, the outputs will be redundant to the inputs.

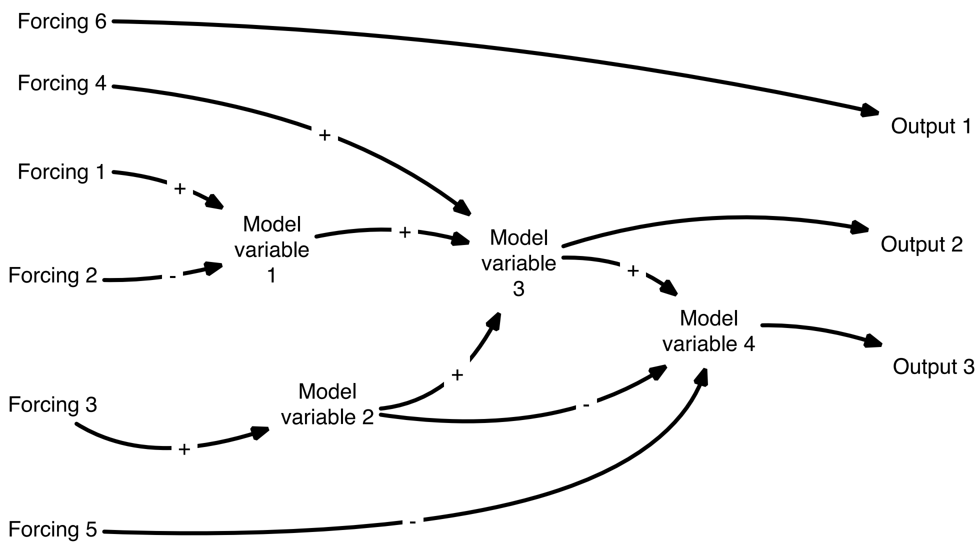


Figure 4. A system of pre-set forcing functions, make the outputs redundant to the inputs.

Figure 5 shows how by assembling the forcing functions, commands of outputs, smoothing functions and if-then statements (Figure 4 and Figure 5a) into sub-modules, the appearance of a dynamic model is created. The whole E4A model is a nest of these forcing functions, mostly arranged in a forward linear way.

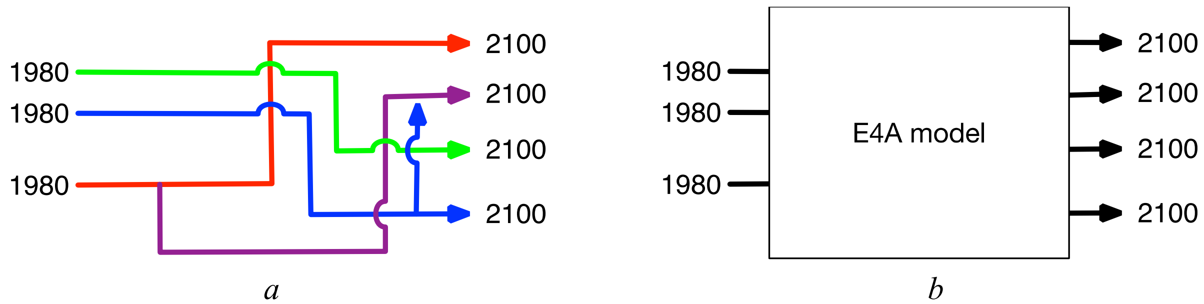


Figure 5. By assembling the forcing functions, commands of outputs, smoothing functions and if-then statements (a) into sub-modules, the appearance of a dynamic model is created (b).

The use of bi-flows to move material out or into stocks instead of uni-flows in all of the E4A model has some consequences for the model. This is especially visible for the population module, where it creates a situation where the population cohort can go into negative value, which conceptually should not be possible..

It should be understood that using a bi-flow function in STELLA or VENSIM software is to combine two actions into one. This can be done when it is clear that the principles behind the act of adding to a stock is identically symmetrical to subtracting from the same stock. For a global population stock, adding to it is done by the change from one younger cohort to an older cohort at a graduation age. The removal of persons from a global population age cohort is done by the process of aging out of it (leave and go to the next cohort) and into the next older cohort and by additional and the independent process of death, which is driven by different dynamics. And in population models there is no such thing as going from an older cohort to a younger.

The population module inside E4A model has no death rate other than flowing out of the last cohort and then the death rate is depended upon exponential functions with feedback from wellbeing and climate (amongst other with very little model impact). Other causes of death than high age are ignored (see e.g. Newman et al. 2014 or Sverdrup et al., 2022). This is too restricted for the model as whole, due to the fact the E4A model is population driven and it shows in the output.

Exponential functions are widely used for representing behaviour of exogenous variables inputs in the E4A model. This creates oscillating behaviour that is falsely explained in a manuscript by Collste et al. (no year) as something special (Jugular cycle of the economy module). Are they originating as stocks induced behaviour or are they induced by oscillation of the linked exponential functions redressed by smoothing functions in the model variables?.

There is a lack of environmental health (pollution and impact on human health) in the E4A model. This was prominent in **World3** (Meadows et al., 1972, 1974), but was ignored in the E4A model. The E4A model claims to include CO_2 emissions, but there is not a climate model in E4A. There is no mass balance for CO_2 and no connection to other mass balances, for the simple reasons that there are no other mass balances in the model.

Review of E4A submodules

Population module

The population module is shown in Figure 6. It is arranged as four stocks in a row. We discovered when testing the model that the stocks can take negative values, and do so during simulations. There is no mortality for the models´ cohort´s, except the last one. The cohorts of children, young adults, or elderly adults are all immortal.

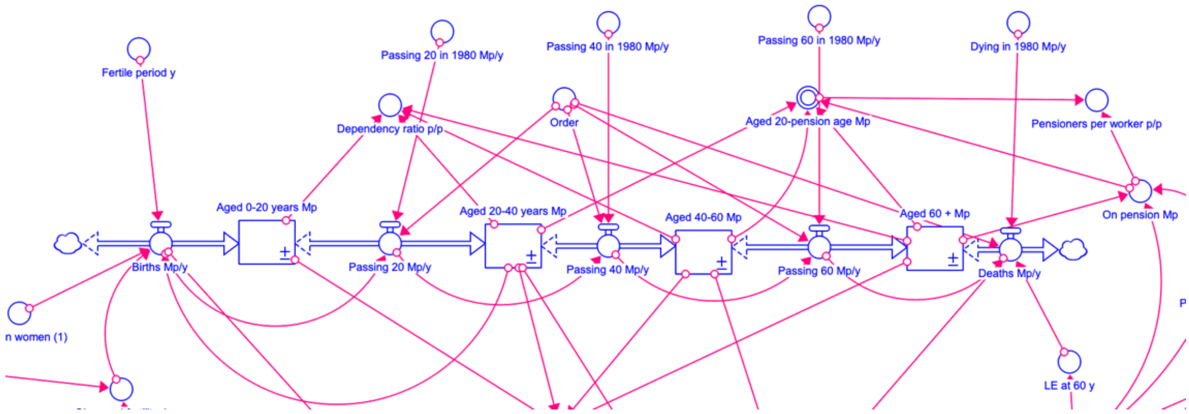
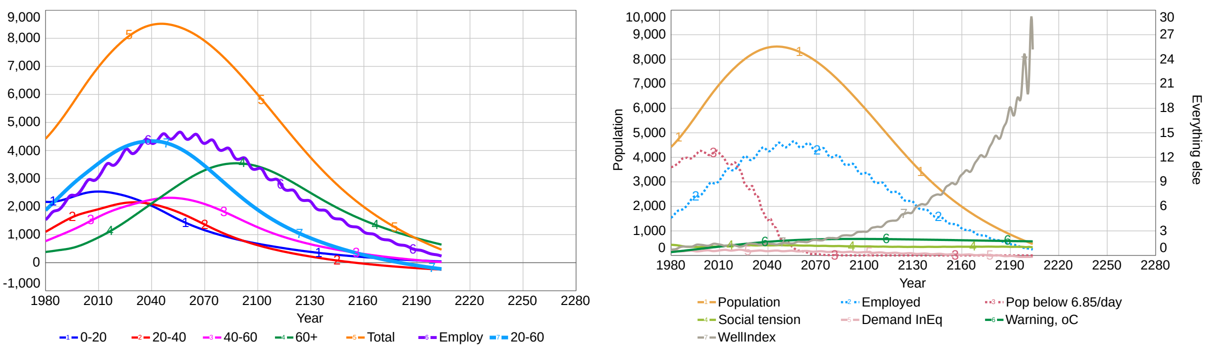


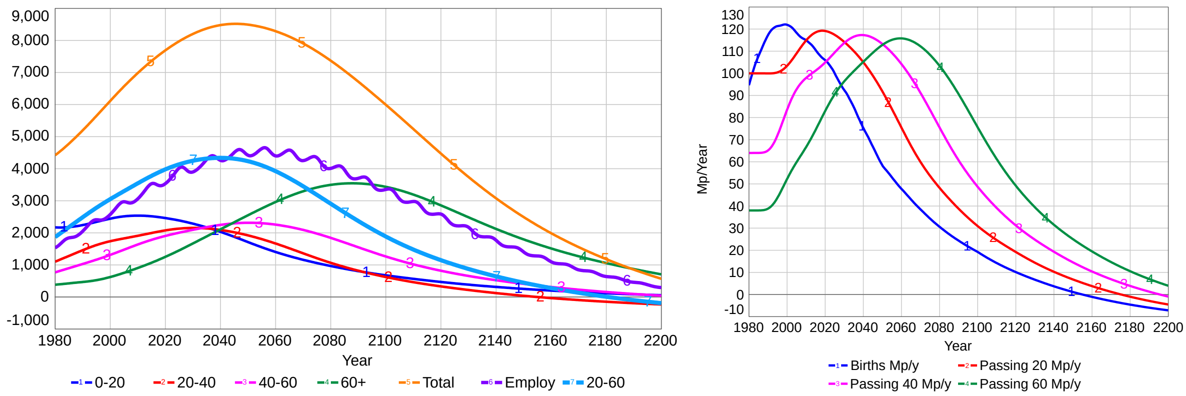
Figure 6. The population module in E4A model.



a b

Figure 7. The model stops in 2203 because of exponential forcing functions (Wellbeing) running out of control. (GL and TLTL versions). In 2203 the global population crashes in the model.

The population only passes from age group to age group with no loss (i.e. death), only dying out of the last cohort (after 60 years of age) at the life expectancy age. In a simulation to 2202, the 20-40 age cohort goes negative by several hundred million (see Figure 7). This leads in the model to negative birth rate, causing negative population. By 2200, the global population has crashed and dies out. This happens in both the GL and TLTL scenarios. One may say that the model was not designed for any longer than 2100, but this is a very poor excuse for covering over – i.e. that is when the commands to set the output ends and the whole model unravels. model. The stocks can be set to be of a non-zero type, and then cohort 20-40 age goes to zero. The implication is the collapse of the global population when that happens (Newman et al., 2014). This shows that the population module has obvious flaws once the forcing function is not operational anymore.



a *b*

Figure 8. (a) Population outputs from the model. (b) Population flow between cohorts. Take note that the cohorts 0-20 years, 20-40 years, 40-60 years have zero mortality.

Figure 8a shows outputs from the model; Figure 8b shows the population flow between cohorts. Take note that the cohorts 0-20 years, 20-40 years, and 40-60 years age cohorts have zero mortality at all times. The population model severe issues that include: Assumption 1 and 2: Age group 0-20 years has no mortality, and the 0-20 years stock can have negative value. Assumption 3-4: age group 20-40 years has no mortality, and the 20-40 years stock can have negative value. Assumption 5-6: age group 40-60 years have no mortality, and the 40-60 years stock can have negative value. Fertility is driven by a number of forcing functions, mostly by a dependence on GDP. The movement between the cohorts is done using the transfer in 1980 and commanding functions and delays that are pre-set. The use of forcing functions instead of feedbacks and population dynamics is surprising, and reminiscent of how things are done when moving things in an excel spread sheet.

How the E4A model is moving people between the cohorts in the population submodule is illustrated in Figure 9. The passing of people out of a cohort is done by using what goes into the stock and letting the same amount out after a delay and it is independent of how many people are actually in the stock. The movement between the cohorts is done using the transfer in 1980 and commanding functions and delays that are preset. The use of forcing functions instead of feedbacks and population dynamics is surprising, and reminiscent of the use of excel spreadsheets. The transfer equation taken from the code is:

`DELAYN("Births_Mp/y",20,Order,"Passing_20_in_1980_Mp/y")` where order= 10 and passing 20 in 1980 is 100.

The "order" is a parameter in the smoothing function, to hide the step function from the input to the commanded output.

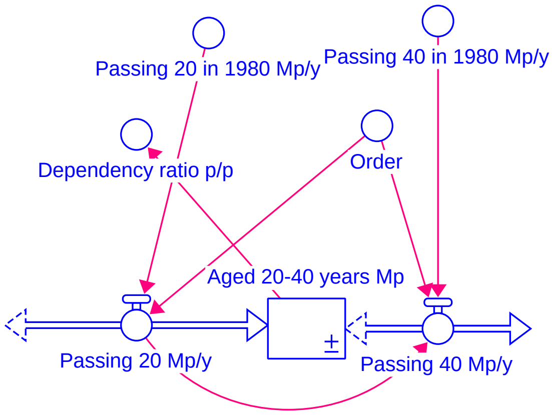
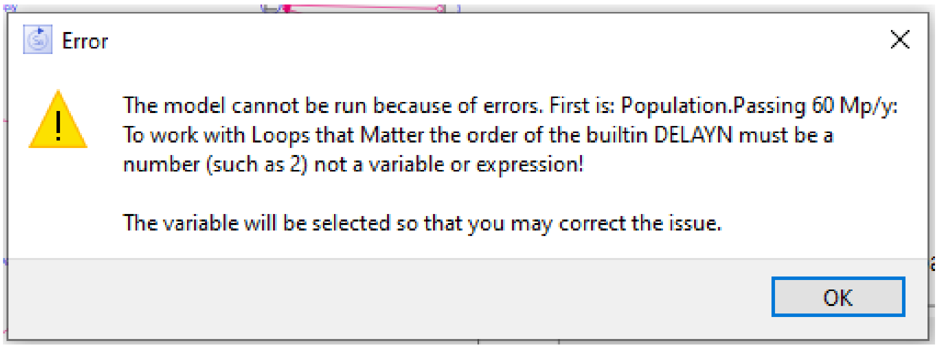


Figure 9. The passing of people out of a cohort is done by using what goes into the stock and letting it out by a delay and it is independent of how many are actually in the stock.

The question arises, of why the population module from World3 (and also the remainder of the model) was not used? Or any other basic population model?

The delay in the E4A population module prevents analysis of loops that matter in the model. Stella (in Vensim they do not check for loop dominance) has this function for a reason, in order to track shifts in loop dominance over time. When the population model is ridded of the delays and a simple population module is replaced, it is possible to perform a loop dominance analysis. Here we can see that only two variables are mainly responsible for deathrate (effective GDP and life expectancy). The model lacks deaths on the age cohorts (see above), and the workforce population is especially important in this sense. Having deaths related to environmental health would have much greater effect on the dynamicity of the outputs. See Figure 10a and b. The text box shows what happens when the model as is, is tried for finding the dominant loops.

Changing some of the inputs to the population module show the flaws very well. Changing the years of fertility, yields a very strange result. Shorter years of fertility gives a larger population, longer years of fertility a smaller population. The fertility and mortality seem to have no connection to food availability. Causal links are missing and have been replaced with forcing functions.



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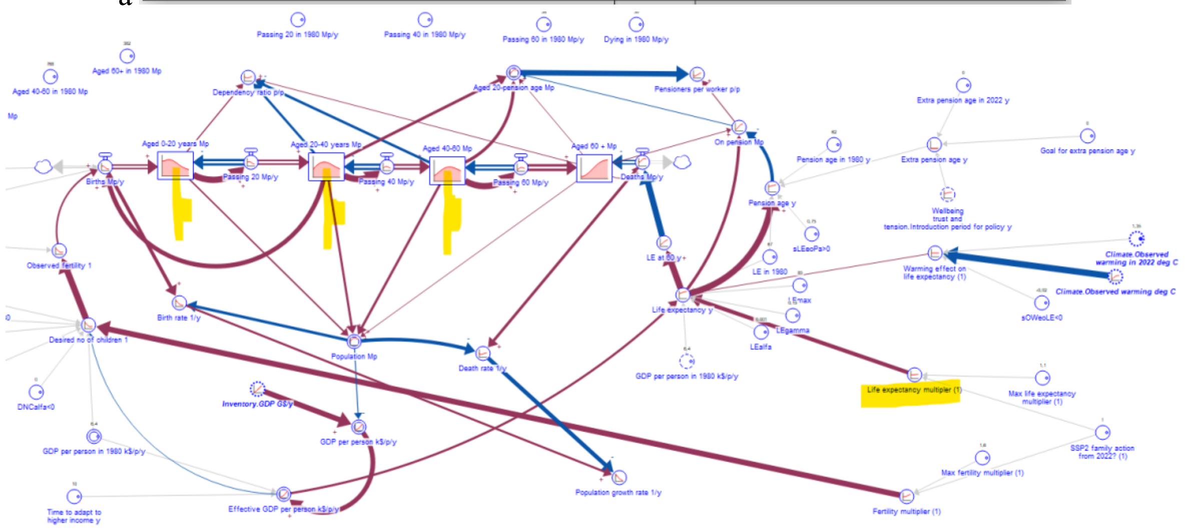


b

Figure 10: (a) shows what happens when the model as is, is tried for finding the dominant loops. (b) The STELLA software can be used to investigate where the dominant loops in the system are. To do this, the original E4A model had to be changed by taking away some of the built-in assumptions. Fertility and life expectancy commands dominate.

Energy

There are only two stocks in the energy module. Fossil electricity capacity and renewable electricity capacity. There are no stocks of fossil fuels. There are no limitations to renewable energy needed metals/materials, they are simply made limitless. Therefore, there are no limits to any technology that can be made. The model is a push-through model driven by forcing functions. The renewables are nearly equal to fossil fuel electricity in 2023, which is not the case. The increased rates of renewables are far faster than any equipment production rate that can be achieved in the real world. The final renewable electricity capacity is massively above anything that can be supported by the available material resources (Sverdrup et al., 2024, Van Allen et al., 2024).

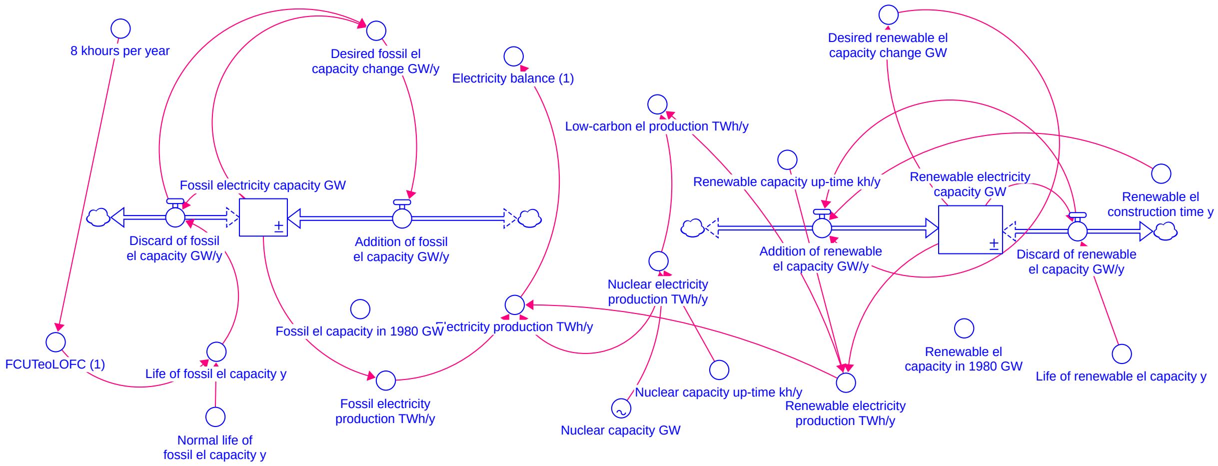


Figure 11. The energy module. There are only two stocks, fossil electricity capacity and renewable electricity capacity. Nothing else, no fossil fuels, no energy balances, no material limits. Note that nuclear power is done as constant input, with no feedback and no changes. It adds into fossil electricity production and remains in operation even when the model outputs for fossil electricity are manipulated down to zero.

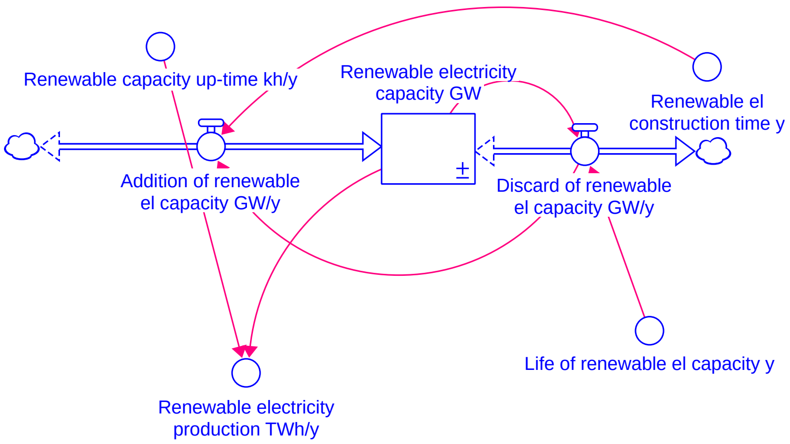


Figure 12. The renewable energy module. Again, outgoing renewable power is the entering amount, forced out after a set delay, but not dependent of how much capacity is actually in the stock.

Figure 11 shows the renewable energy module. Outgoing renewable power is the entering amount, the same amount is forced out after a set delay, but not dependent of how much capacity is available in the stock. Again, this is more like how things are moved in an excel spreadsheet.

See Figure 12 for the renewable energy module and Figure 13 for an output plot for installed renewable energy capacity. There outgoing renewable power is same as the entering amount, with forced delay. The assumptions of the model imply that there is no maintenance of the renewable energy production equipment, it is given a lifetime of 40 years. That is true for solar photovoltaics and hydropower, but not for all else. There are no limits to stocks of metals/materials for renewable energy production.

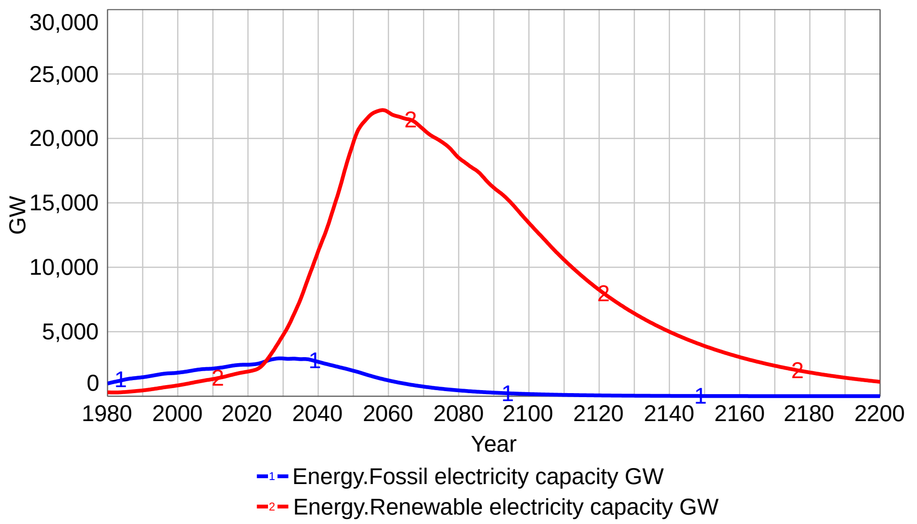


Figure 13. Outputs from the two energy stocks in the model. The graph shows that renewables can have electricity generating capacity of 10 times all present fossil capacity.

The graph in Figure 13 shows that renewables can have electricity generating capacity of 10 times all present fossil capacity. Other studies (e.g. the EU project LOCOMOTION and a number of other studies) show how this rapid solar power technology instalment rate is not feasible, and that material limitations cap it at about 2,500 GW installed effect (Ole van Allen et al., 2024 to be published, Sverdrup et al., 2023). Current knowledge based on mass balances suggest that the real number is somewhere between 20-30%. This discrepancy is caused by lack of including technology metals in the E4A model which limit how much new technology can be made. The rate of renewables increases as shown in Figure 13 is way above what is industrially possible to build and supply (see Sverdrup and Ragnasdottir (2014), and later Sverdrup et al. (2024)). Note that nuclear energy feeds into the fossil electricity capacity (see Figure 13).

Industry

There is no industrial activity in the model, but there is a technology development index driven by a forcing function and there are no supply chains (Figure 14). The inventory is not driven by supply and demand and the residence time is months. Furthermore, there is no market in the E4A model. Things are pushed around with commands. The partial business module (Inventory module) is not in tune with the fundamental structures of industrial dynamics (Forrester 1958, 1961, 1968, 1969, 1971a, 1971b, Sterman 2000, Sverdrup et al. 2021).

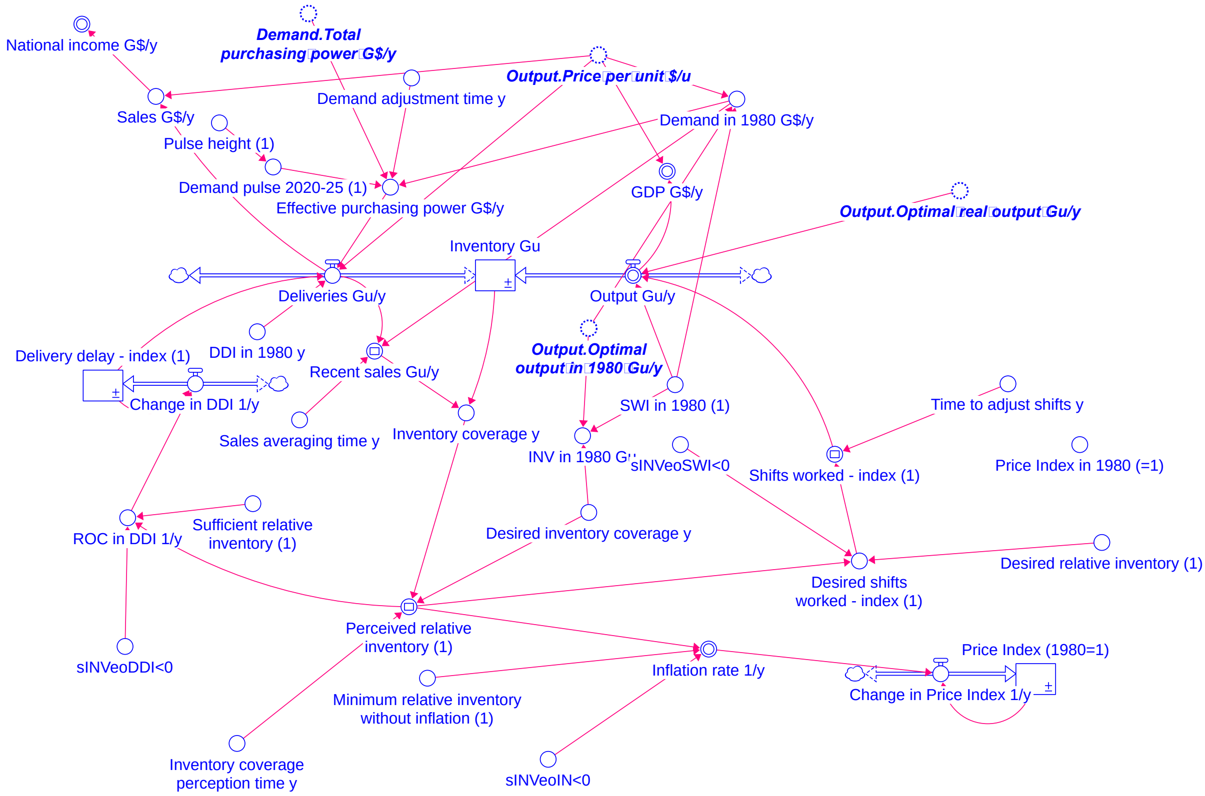


Figure 14. The partial industrial module.

Material resources

There are no materials resources in the model. No stocks of materials, no metals, no phosphorus. This is in contrast to the Limits to Growth study (Meadows et al., 1972, 1974) and the literature on resources scarcity (Meadows et al., 1974, Bardi 2013, Sverdrup and Ragnarsdottir 2014, Acemoglu et al., 2012, Acemoglu and Robinson 2013).

Demand Private persons debts and governmental debt are in the demand module. There are no corporate debts in the model. There is no banking system. There is governmental tax income, a basic income payout, but no money stock and no bookkeeping with money in this module either. Demand is driven by disposable income for "workers" and forcing functions.

Finances and money

There are no money balances anywhere in the model. There is mechanism for value creation. In the E4A model money is printed. There is no bookkeeping in the model. Inventory is the total stock of consumables in one stock, being pushed through using forcing functions and population numbers.

Poverty eradication is "solved" by cash handouts and printing the money needed. This method is well known from Germany in the 1920'ies, but also from countries like Argentina, Venezuela, Soviet Union or other hyperinflation countries that regularly destroy their currencies and create debts and poverty in the process. Poverty is eradicated by using an exponential function, operating by commanding statements. This does not reflect the root causes of poverty in society and where it comes from (e.g., Bhattacharyya 2016, Acemoglu and Robinson 2013, Landes 1998)

The policy for printing money to "solve" poverty, based on advice from the Earth4All project, risk being damaging to the poor of the World and probably do not lead to solving any of the root causes of poverty. The advice is in no way supported by the E4A model as it consists of pre-set commands, and lack of an economic model. Money given from printing money have in all instances in the past caused inflation and larger economic divides in society (Rothstein 2004, Diamond 2012, Acemoglu and Robinson 2002, Stiglitz and Regmi 2023, Bhattacharyya 2011, 2016).

Cash handouts - from Collste et al. (this paper is not peer reviewed; it is on the Club of Rome website) comments on their "finding":

"....representing the Juglar cycle, reflecting the undulating co-development of workers', and owners' income shares, and related unemployment dynamics. This can be most easily observed in the long-term time series of employment and investments....."

This part of the E4A model is, however, driven by forcing functions and smoothing, and thus done by control and command. The oscillations are a result of poorly matched forcing functions.

GDP is driven up by a forcing function that follows population and printing money. It is pushed by Rate of Technology Advance (ROTA), which is driven by an exponential function. It is hidden behind a chain of manipulations going back to forcing functions. It has been made to look as if it is created from production of "inventory," but goes back to forcing functions. It is not related to any material or energy stocks.

Wellbeing and trust

The trust and wellbeing module is shown in Figure 15. Wellbeing comes from disposable income and state spending in the E4A model. This definition does not tally well with the scientific literature on wellbeing. See for example references like Gillett-Swan and Sargeant (2015), Costanza et al. (2016), Fioramonti et al. (2017; 2022), Hough-Stewart et al. (2019), Coburn and Gormally (2020), Janoo et al. (2021) and Ragnarsdottir and Parker (2022) for examples. Other variables remain rather constant in the model. Progress and inequality are set by forcing functions, magnified and added to wellbeing. No causal loop diagram appears to have been made for the wellbeing module. There are no loss terms and corruption in different variants are totally absent.

The **Social trust** part uses relationships quite differently from the current scientific literature on trust and trust creation and destruction (Tilly 2005, 2006, 2007, Rothstein 2004, 2005, Fukuyama 2004, Missimer et al., 2010, 2017a, b).

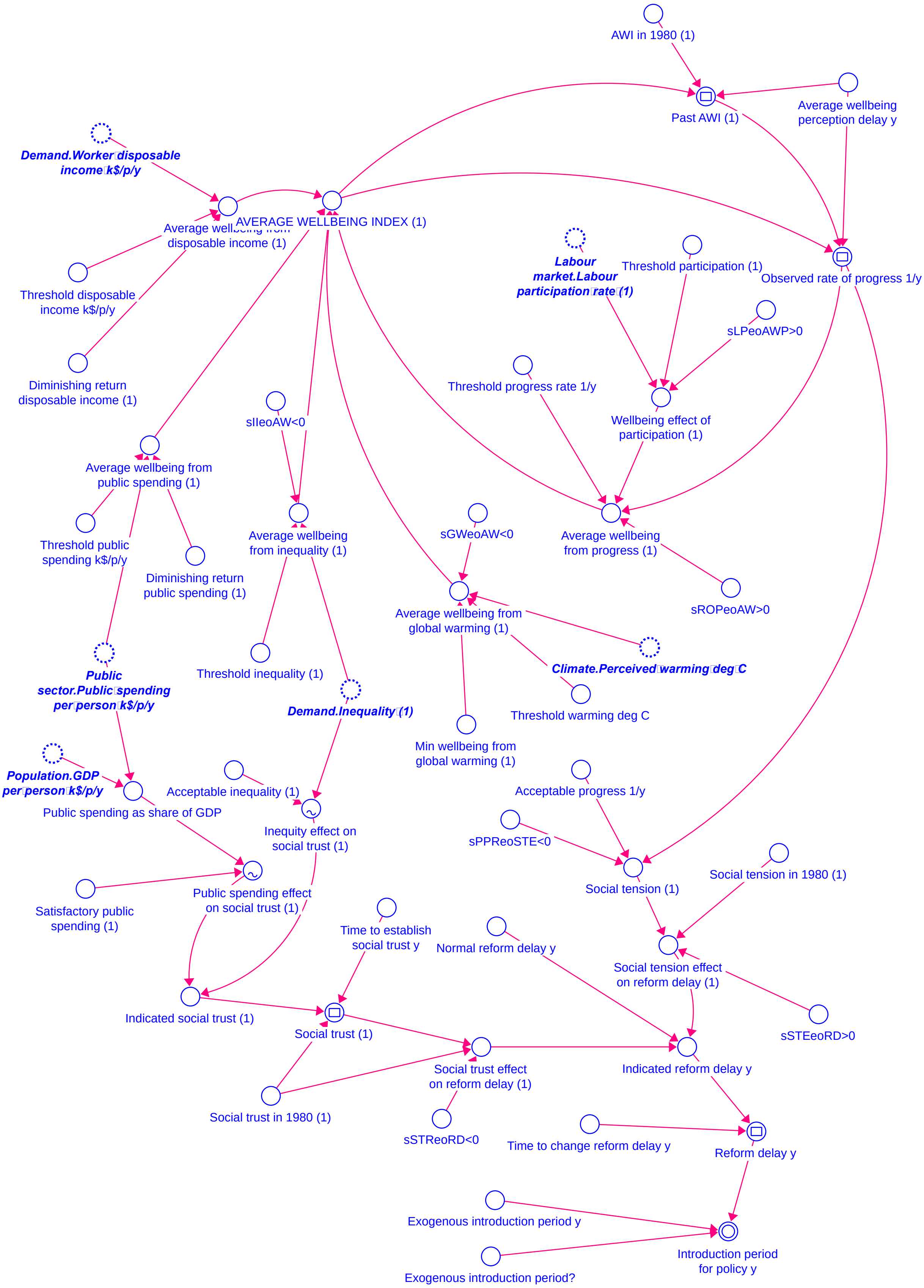
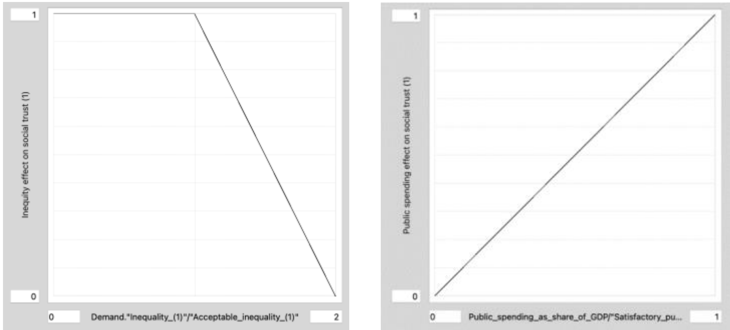


Figure 15. The trust and wellbeing module. The module has no stock of trust of any kind.



a *b*

Figure 16. Two graphical functions determine social trust in the model. Where do they come from? These are examples of crude forcing functions used in the E4A model.

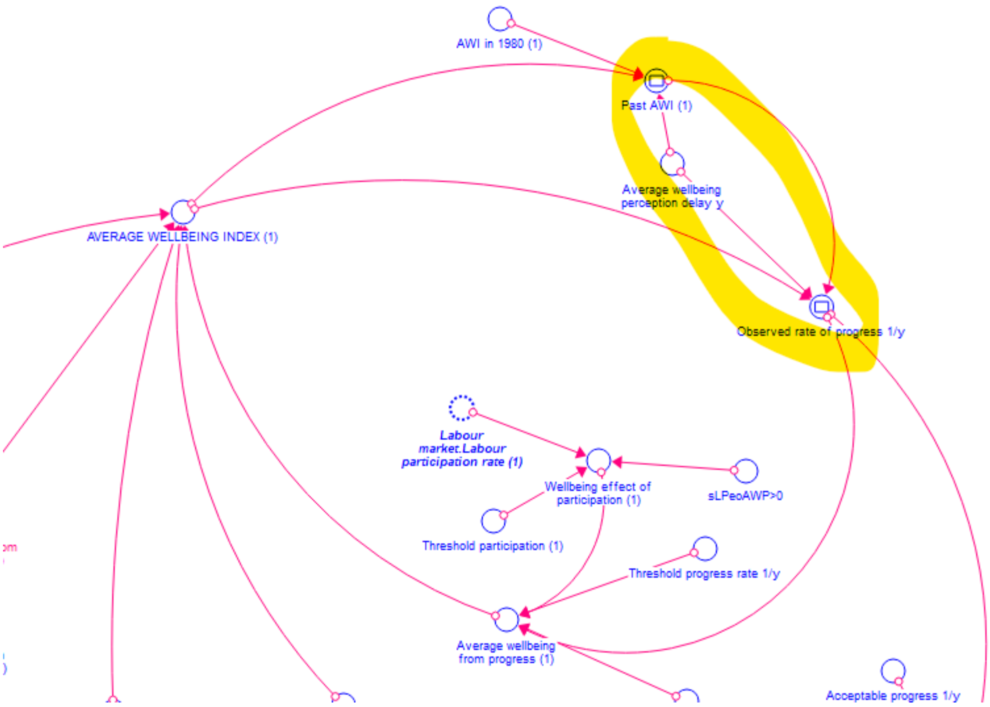


Figure 17. Cut-out from the wellbeing module. The piece marked in yellow illustrates the circumvention of a missing stock

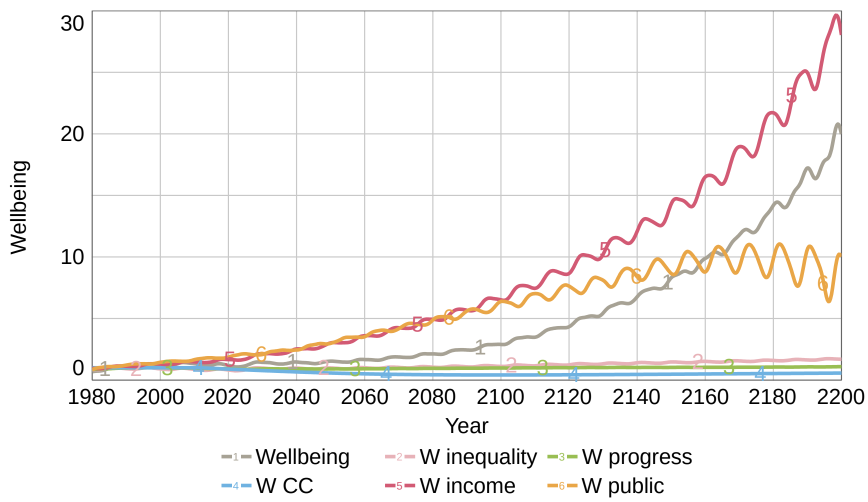


Figure 18. Outputs from the wellbeing module. Wellbeing is dominated by disposable income in the model (GL).

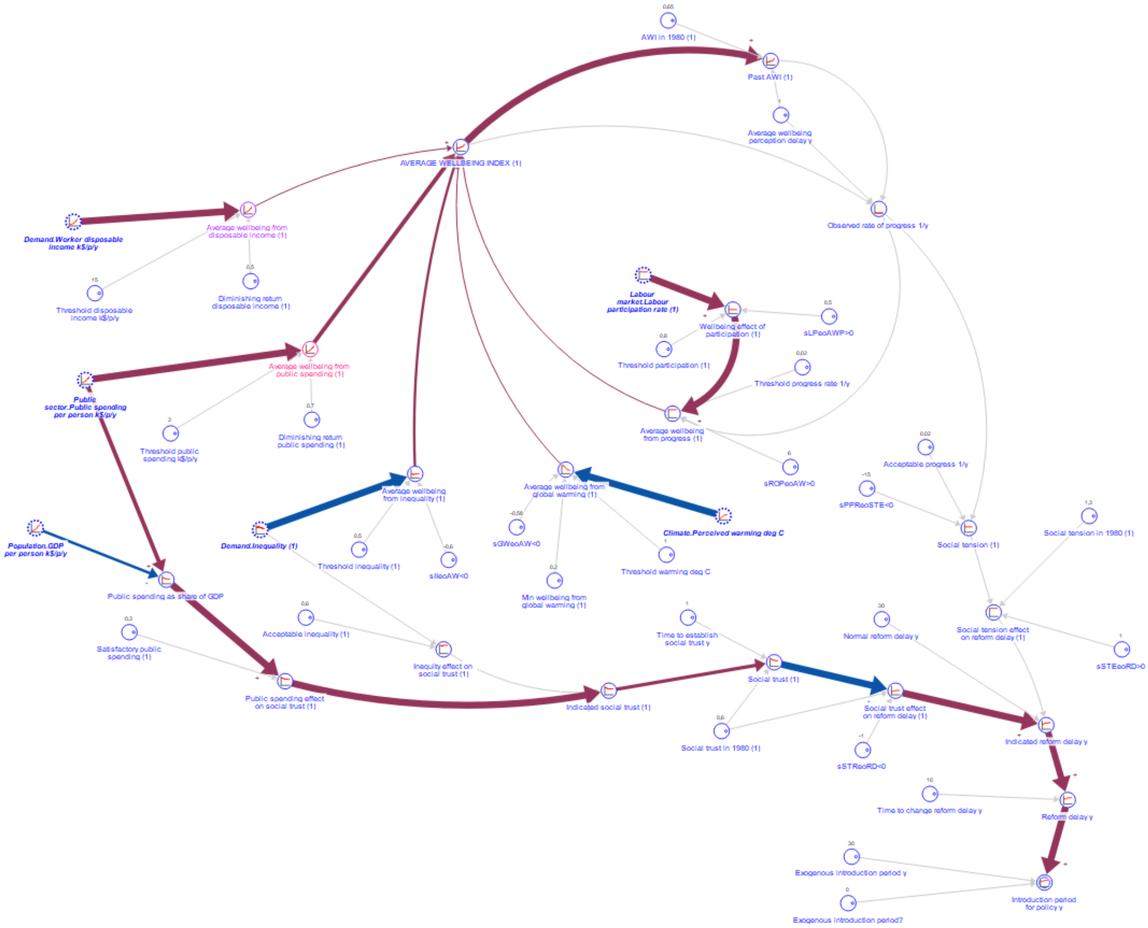


Figure 18: Lack of feedback loop behaviour from Wellbeing module shows the need of stocks to create the feedback. The test shows a simple push-thru of pre-set values and a chain of commands.

There are no stocks of trust in the E4A model, there is no trust generation in the E4A model and no trust consumption in the E4A model (see Figures 15-18).

The main problem with the wellbeing module is that it lacks a stock to represent the feedback loop of the connected converters. The missing stock is circumvented by using a smoothing function with a delay between *"Past AWI"* (Average Wellbeing Index) and *"Observed rate of progress,"* which without smoothing creates a circular connection (Figures 15 and 18). The converters are also difficult to follow since the indices "stack upon each other," mimicking the work what a stock would do. The wellbeing index is also driven by an Exponential function which affects the overall behaviour of the model as "pusher." A stock representing "Wellbeing" would create a proper "book-keeping" of what goes in and out and what the contribution of the different drivers are on the model as a whole. The "Average wellbeing perception delay" is already representing how long the "Wellbeing points" should reside in the stock. Please note the lack of feedback and causal connections to factors that drive wellbeing in the real world.

Agriculture and food

The agronomy-module has cost forcing functions, but no market and no price. When price is mentioned, this is done as a cost with an addition. Thus, demand has no effect on price, and price has no effect on price. Neither has scarcity. The E4A model has no food market, no supply chain, no loss terms.

The model has an area balance-consistent model for land use. Food is depending only on agricultural area, with no considerations on nutrient balances as related to food production.

"Regenerative agriculture" appears as by magic to have 20 kg/ha/yr of nitrogen available regardless, also when industrial nitrogen nutrient inputs are removed. No mass balances for nitrogen are made. No mass balance for any other nutrient is made, such as phosphorus, potassium or magnesium. It is assumed that there will always be enough of all other nutrients. Crop size is driven by forcing functions, preset and smoothing values between them over time. Animal manure or compost does not appear anywhere in the model. Grazing animals or steered grazing are not included for what is traditionally referred to as "regenerative agriculture." It is called “regenerative” through a forcing function.

Red meat appears in the model, but there are no animals in the model. No cows, no pigs, no sheep, no horses... No poultry either. Food just appears. All red meat is assumed to arise in something called feedlots but there are no real feedlots in the model.

There is no mass balance for carbon in the agricultural model. No mass balance involving animals and fodder. There is no food market in the model, no food stocks, no back-ups and there are no supply chains.

There is no dynamics between food production, food supply, food demand and food price. There is no checking of potential for food scarcity. The "agricultural module" fails to capture agriculture as a food production system based in physical realities and does not constitute a valid model that captures the main functions of integrated agriculture of any kind. Nothing in the agricultural module appears to be tested for sustainability.

Climate change

There is no carbon mass balance in E4A nor is soil in the model. There is no global carbon balance and no climate model in E4A. N_2O emissions from agricultural soil are driven by forcing functions for claimed difference between "conventional" and "regenerative" agriculture. The applied difference is not substantiated by existing research.

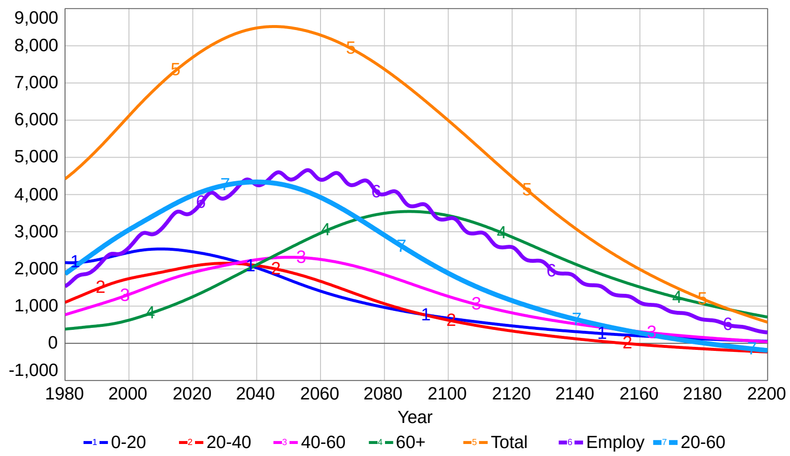


Figure 19. Workforce and people in working age. There is a visible mismatch that is rather serious (see text) (GL).

Labour market

There are more people employed after 2040, than there are people in working age (see figure 19). The workforce in the E4A model is a stock that can take on negative values. Wage is modelled as a stock.

Empowering women

There are no women in the model. Women are assumed to be 50% at all times, and they are not distinguished in the work market nor in employment, nor in disposable income. Gender equality is assumed to be proportional to GDP, which many women would object to. Gender equality in the EarthForAll book is not supported by a corresponding structure in the E4A model. Gender inequality is a social system dynamics output, and not something that is solved by command and control.

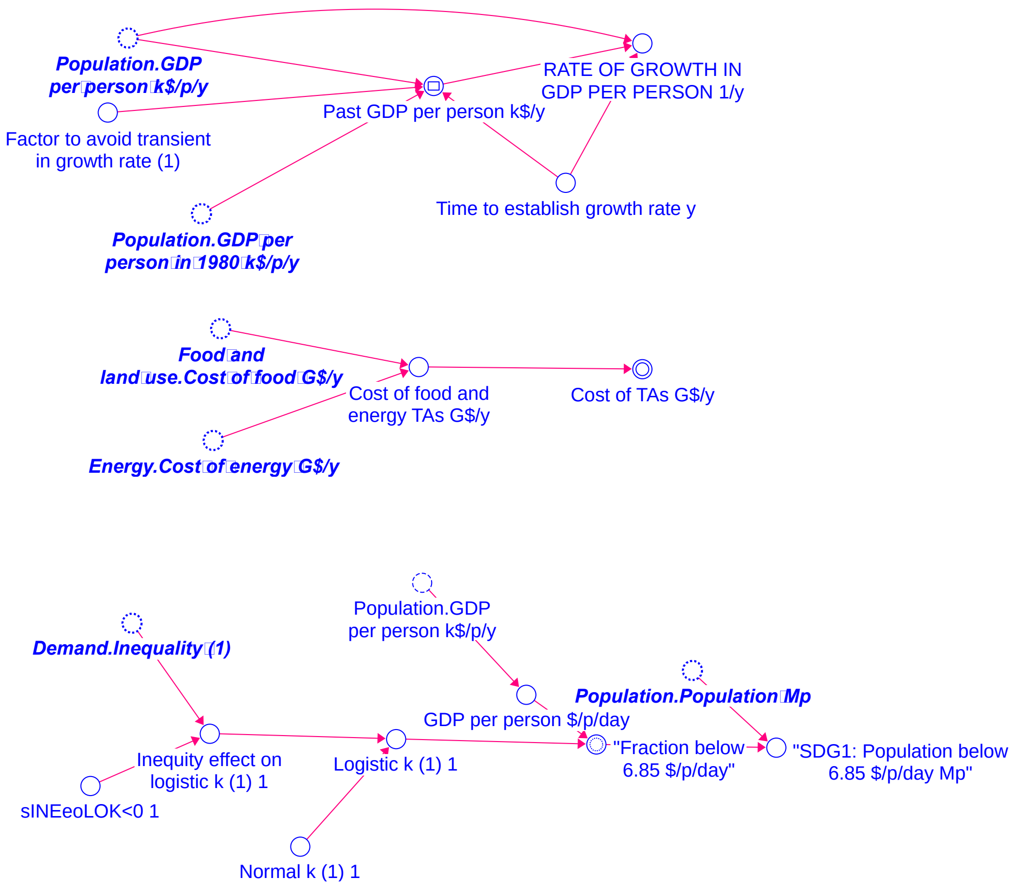


Figure 20. Where equality is done in the model. A simple push-through of forcing functions. No dynamics. Exogenously driven.

Equality

Equality is derived by cutting a certain portion from a normal distribution of income driven up by printing money. Thus, equality is driven by forcing functions. There is no causality in the E4A model beyond printing money. See Figure 20. This part is not substantiated by the literature concerning inequality (Acemoglu et al. 2002, Acemoglu and Robinson 2013).

Education

There is **no education** of any type in the E4A model. Text about education in the EarthForAll book is not supported by a corresponding structure in the E4A model

Exponential functions:

In the E4A model exponential functions are widely used. That raises the question whether that is the correct function for some of the variables and flows. Exponential functions can indicate that the underlying behaviour from the variable is reinforcing only, implying that there are no balancing feedback loops and no brakes in the system. Is that expected in all the variables or could some of them assume saturation behaviour? This exogenous reinforcing behaviour creates large oscillations that when the model is stress tested will run e.g. wellbeing out of control. See Figure 21.

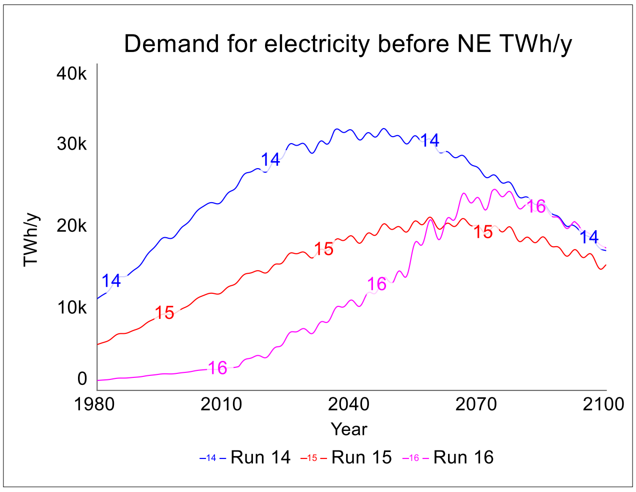


Figure 21: Demand on energy before NE TWh/y and use of different graphical stock functions, i.e. used in model, linear (software stock), S-shape (software stock). The choice of forcing function fully controls the response in the output.

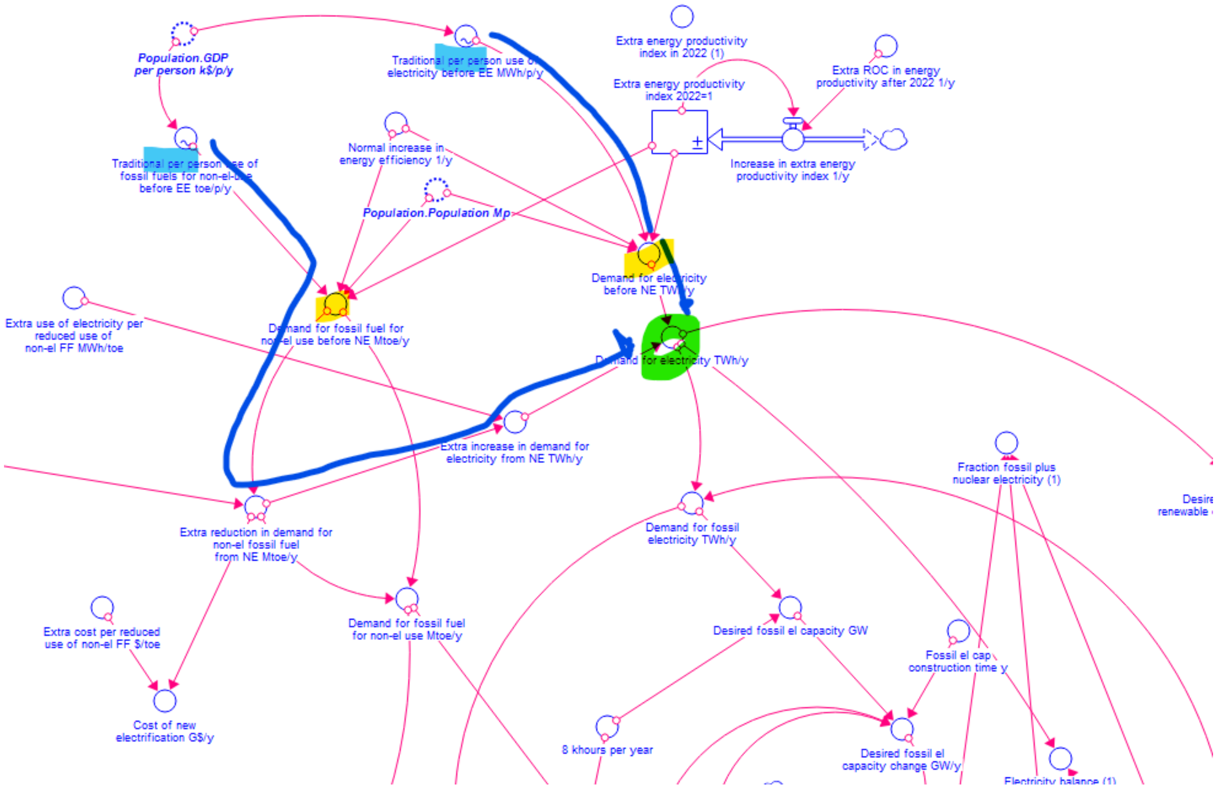


Figure 22. Exponential problems in the Energy module, marked in yellow illustrates the source of circumvention of the" missing stock."

Consequences of using exponential functions

Just to illustrate the problem with over-use of exponential functions on sensitivity, Figure 22 from the "Energy" module shows the connection of two graphical functions *"Traditional per person use of fossil fuels for non-el-use before EE toe/p/y"* and *"Traditional per person use of electricity before EE MWh/p/y (coloured blue) into variables"* to *"Demand for fossil fuel…"*

and *"Demand for electricity…"*, respectively (coloured yellow), and ultimately to *"Demand of "Electricity TWh/y."* In this case the slight alteration of the graphical function *"Traditional per person use of fossil fuels for non-el-use before EE toe/p/y"* results in a large impact on results on *"Demand of "Electricity TWh/y"* (coloured green). This is illustrated in the results graph in Figure 21. Ultimately, it has a large impact on the model output-parameters as a whole.

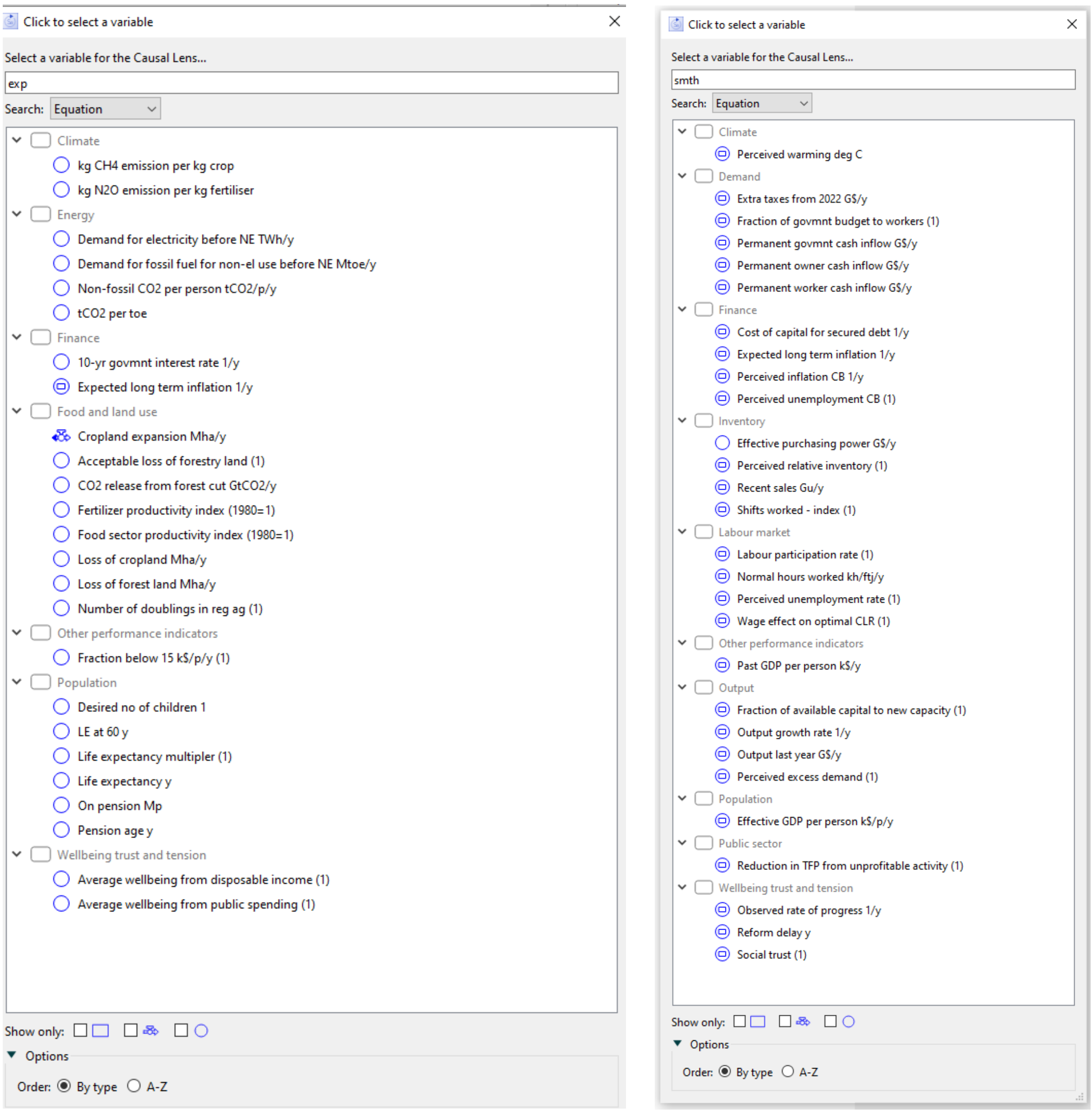


Figure 23: (a) The model uses a total of 25 exponential functions. Are these functions correctly capturing the exogenous and endogenous behaviours in the E4A model? (b) Use of Smoothing functions in the model.

Smoothing functions:

E4A uses excessive numbers of smoothing functions in the model. In the "Wellbeing trust and tension" module, smoothing together with delay is used to enable circular connection of the variable (which would otherwise not be allowed in the software). Without them, the model does not run. See Figure 23 for how many.

System dynamics

The use of system dynamics software alone does not make a system dynamics project (Cavana and Mares, 2006, Sterman 2000, Martinez and Richardson 2001, Sverdrup et al., 2022). The reviewers strongly reject that the E4A model can be referred to as a System Dynamics model. The team being responsible for the work put into E4A model cannot be allowed to taint the reputation of system dynamics as powerful modelling method through this work. The model and all claims based on it, jeopardizes not only the Club of Rome but also the system dynamics modelling method and the academic field of systems thinking. Talking about system thinking is not equivalent to actually do system thinking.

Assessment of model criteria

We return to the initial evaluation criteria to make the final assessment for the E4A model. Our results of the model review are as follows:

1. Model content and relevance
    - **a.** Does it have the required and necessary parts of the system represented in the model?
        - **i. NO, a significant part of necessary and required parts are totally absent from the E4A model.**
    - **b.** Does the model have a causal feedback structure representative of the system it is meant to represent?
        - **i. NO, it is controlled by forcing the outputs, and a causal feedback structure is largely missing. Much of what is there is faulty or outright wrong.**
    - **c.** Are the key policies and the systems they involve represented in the model?
        - **i. NO, they are missing in their entirety.**
2. Model internal consistency
    - **a.** Is this clearly shown in causal loop diagrams and flow charts in the background documentation?
        - **i. The diagrams that are found in the draft publications are after-constructions and not a truthful representation of what is in the E4A model. This is deceptive.**
    - **b.** Is the model mass balance and energy balance consistent?
        - **i. NO**
3. Model validity
    - a. Has the model performance been tested on observed independent data for the past, and that that data was not used in the calibration?
        - i. **NO**
    - b. Is the model consistent with earlier research in the field?
        - i. **NO**
    - c. Does the model utilize earlier insights and results from earlier Club of Rome modelling like World3?
        - i. **NO**

Conclusions

We can confidently conclude that the E4A model does not constitute a valid model for its purpose. The E4A model cannot be used for any future projections and is invalid as a policy support or assessment tool. Using the model for policy advice has a large risk of leading to harmful policies.

For the 5 turnarounds described in the EarthForAll book and how they are handled in the E4A model - **Poverty** is solved by handouts and printing money without limit, **Inequality** is done by forcing functions towards a commanded end result, **Empowerment** of women is not in the E4A model, indeed there are no women in the model. **Food** and **Agriculture** are done with an invalid model of agriculture in E4A model, a lack of food supply chain and loss terms on the way, and it is not mass balance consistent. There is no valid food and agriculture module in E4A. **Climate change** is done by linear scaling and forcing functions, there is no carbon balance. There is no valid climate change model in E4A. **Energy** is done by creating renewable energy without any metal/material limits. There are no energy balances anywhere in the E4A model.

We conclude that there is no "fix" or "repair" that can be done to the E4A model to rescue the effort. We observe that:

1. The 5 transitions and policy outcomes described in the book are not supported by the E4A model. The 5 transitions have no representation in the E4A model!
2. E4A is not a proper dynamic model based on causal connections, feedbacks and mass balances, but rather a set of command- and control functions, forcing a preset output as a response to an assumed policy.
3. The population module in E4A has some serious flaws and fails to make realistic scenarios.
4. The food and agricultural module in E4A lacks basic components such as food supply and does not constitute a valid agricultural model.
5. There is no economic model. The labor-market module yields more employed people than the working age population and is not mass balance consistent with the population module.
6. There are no natural resources in E4A of any kind.

Many aspect descriptions are lacking contact with data or with relevant scientific research in the field.

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