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The Earth4All model of human wellbeing on a finite planet towards 2100[1]

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[1] Based on a presentation with the same title to the international System Dynamics Conference in Frankfurt, Germany on July 22, 2022.

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1. Introduction: the historical and institutional context

Introduction

In the following pages, we give a short introduction to a new integrated global assessment model: *The Earth4All model of human wellbeing on a finite planet towards the year 2100*. The Earth4All (E4A) model has evolved over a fifteen-year period and represents a summary of insights we have gained during all these years (See Appendix 1 for a list of the main publications that form the foundation for the Earth4All model.) The full set of model equations are freely available (as a Vensim or Stella file) on the web[2].

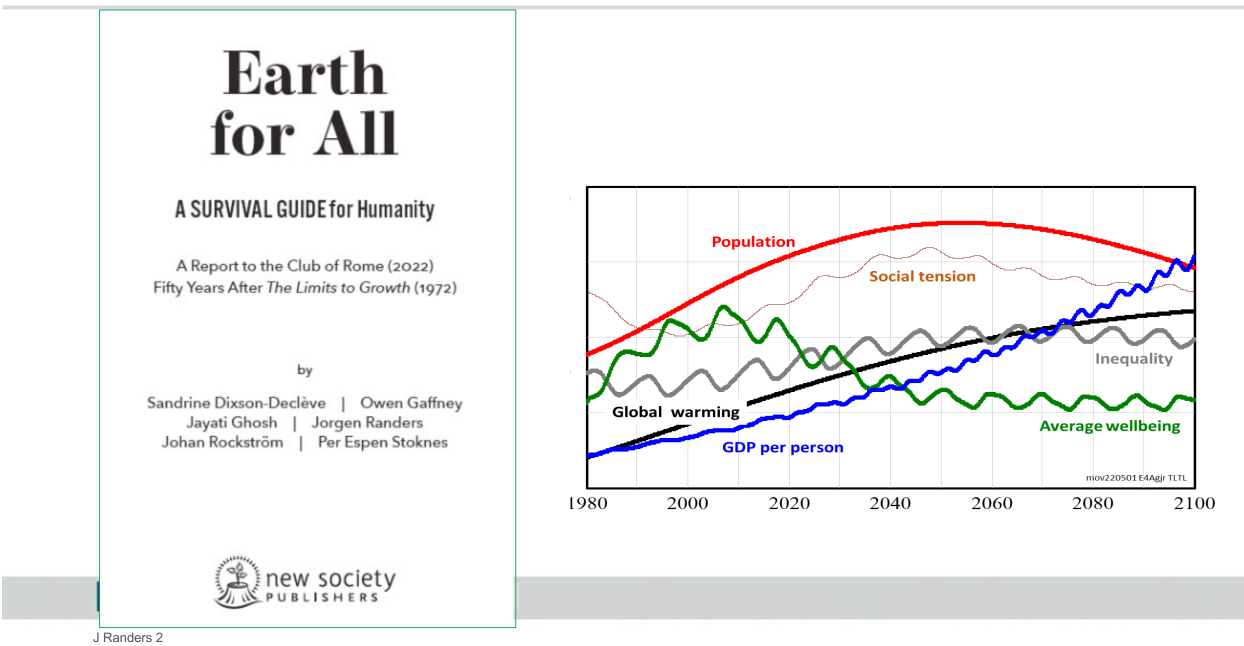

Figure 1: 50 years after The Limits to Growth: Earth for All (September 2022)

The E4A model was built as an input to a new report to the Club of Rome – *Earth for Al: A Survival Guide for Humanity*[3] which was launched in September 2022 – in connection with the celebration of the 50-year anniversary of the 1972 report *The Limits to Growth*[4], which was the first report to the Club of Rome. The *Earth for All*

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[2] A complete description of the Earth4All model is available on the web at https://www.earth4all.life/the-science in the form of the freely downloadable model equations in Vensim and Stella. At a later time, we will upload a more extensive technical report that describes the numerous sectors of the model, their structure, behavior, historical development, main assumptions and main weaknesses.

[3] Dixson-Decleve S, Gaffney O, Gosh J, Randers J, Rockstrøm J, Stoknes PE., et al. 2022. *Earth for All*. New Society Publishers: Gabriola Island, British Columbia (in press, will appear September 2022 in several languages).

[4] Meadows DH, Meadows DL, Randers J, Behrens WW. 1972. *The Limits to Growth*. Universe Books: New York. Meadows DH, Randers J, Meadows DL. 2004. *Limits to Growth - The 30 Year Update*. Chelsea Green Publishing: White River Junction, VT.

report is largely verbal. The argument is qualitative, written for the general public, and based on historical data and literature. The E4A model gives quantitative support to the *Earth for All* report.

We want to emphasize that this is work in progress. The model will be continuously updated in the coming year. This introduction, a "Technical Note" describes the version dated May 1, 2022 and includes a few small adjustments made before the first presentation to a technical audience on July 22, 2022 (Vensim file "mov220501-18 E4A-global jr").

Model purpose and scope

The E4A model explores what it will take to increase the wellbeing of humanity during the rest of this century. The ambition is to help reach a world where human wellbeing, specified as the "average wellbeing of the working majority", is better than without any extraordinary action.

The model can be described as an early example of an integrated global assessment models. It is a model that includes both the human world and the natural world, and the interactions between the two.

The E4A model is based on the system dynamics methodology[5]. Consequently, it is a causal simulation model. It is not an optimization model, where one is trying to optimize GDP or some other indicator.

It is rather a model which is capable of generating a number of internally consistent scenarios for the rest of this century. To be precise: the model is able to generate forecasts for those variables that we are interested in in the global system. It is not a model of the world. It is a model of those phenomena we are interested in and, primarily, that is the development of human wellbeing during the rest of this century.

Since the E4A model is based on general socioeconomic insights and numerical data for the forty years from 1980 to 2020, it is more reliable for the next forty years than for the final part of the 21st century.

Model perspective

The perspective is similar to that of World3, which was the system dynamics model that supported *The Limits to Growth ("LtG")* book in 1972, but with modifications to make it simpler to discuss the distinction between growth in footprint and growth in GDP ("economic growth").

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[5] Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill Higher Education.

The E4A model explores physical growth (for example in population, productive capacity, physical output, physical resource use and emissions) on a physically finite planet with several physical planetary boundaries (for example limited productive land, limited resource base for given cost, limited pollution absorption capacity for given technology). In the E4A model the boundaries (or "limits" in LtG terminology) take the form of rising costs for obtaining the same physical flow (in tons per year) of resources or pollution absorption. The harder you press against (or exceed) the limit, the more physical labor and physical capacity must be used to maintain current resource flows without degrading the environment. In economic terms this means shifting labor and capital from conventional activity into more sustainable activity ("green and fair"). This does not reduce the number of jobs but shift the jobs from providing conventional goods and services to providing a better environment (a more sustainable world). So, by shifting labor and capital from dirty to clean activity – by implementing some "forced structural change" in the economy – humanity gets slightly fewer goods and services (measured in physical units per year) in exchange for a more sustainable world.

In summary, the E4A model explores growth in the human footprint on a finite planet where it is possible to reduce the negative effect of boundaries ("increase the limits") through the use of more labor and capital. In other words, where the possibility exists to achieve a more sustainable world in exchange for a reduction in the output of goods and services (in physical units). The big question is whether this sacrifice will be big or small, and fast or slow. Or in LtG language: will there be collapse or gradual adaptation?

Technical note on growth in GDP when running into limits

In conventional macroeconomic language "running into limits" leads to (slightly) lower rates of growth in real GDP matching the (slightly) lower growth in the output of goods and services (measured in physical units) compared to a situation without limits. In other words: running into limits leads to a (slight) reduction in real labor productivity – because labor and capital is shifted into sectors with (slightly) higher costs. In the E4A model this slowing is represented as a (slight) slowing of the rate of growth in total factor productivity (TFP).

Recent history of growth and wellbeing

Fifty years after *LtG* one can conclude[6] that the world did indeed follow the main scenarios generated by World3 and described in *LtG*. Namely physical growth into physical overshoot – especially in the climate area – and with no *global* collapse – yet.

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[6] Herrington, G. (2021). Update to limits to growth: Comparing the World3 model with empirical data. *Journal of Industrial Ecology*, *25*(3), 614–626. https://doi.org/10.1111/jiec.13084;
Turner, G. (2008). A comparison of The Limits to Growth with 30 years of reality. *Global Environmental Change*, *18*(3), 397–411. https://doi.org/10.1016/j.gloenvcha.2008.05.001

This experience indicates to us that aggregate system dynamics studies of long-term global developments can provide useful insights.

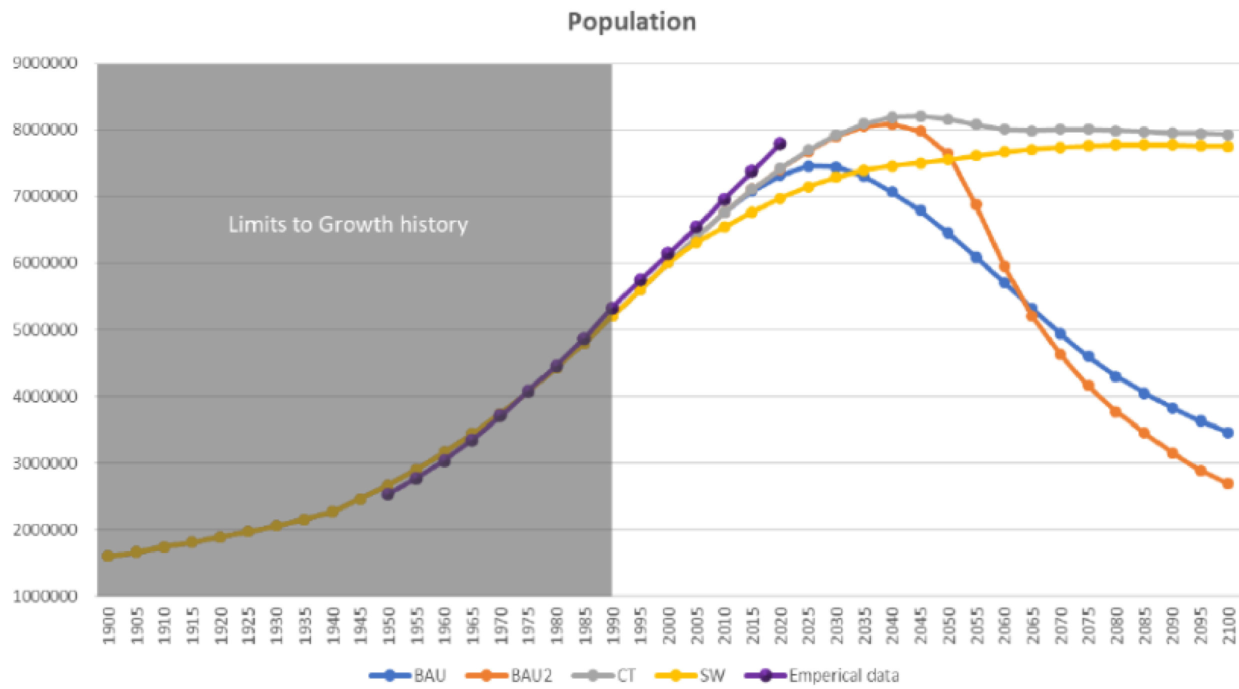

Figure 2: Population has grown, like in Limits to Growth.
Scenarios and empirical data for population (in thousands of people). Source: Herrington, G. (2021). Update to limits to growth: Comparing the World3 model with empirical data. Journal of Industrial Ecology, 25(3), 614–626. https://doi.org/10.1111/jiec.13084

Figure 2 shows the time path from 1972 to 2100 for four of the twelve scenarios in *LtG* for the size of the global population. Overlayed (in purple) is the actual development over the same period. You see that the population has grown, essentially doubled, over this period and followed the general pattern of these four scenarios from *LtG*. Importantly the real world has not yet shown population collapse – just like *LtG* did not before 2020.

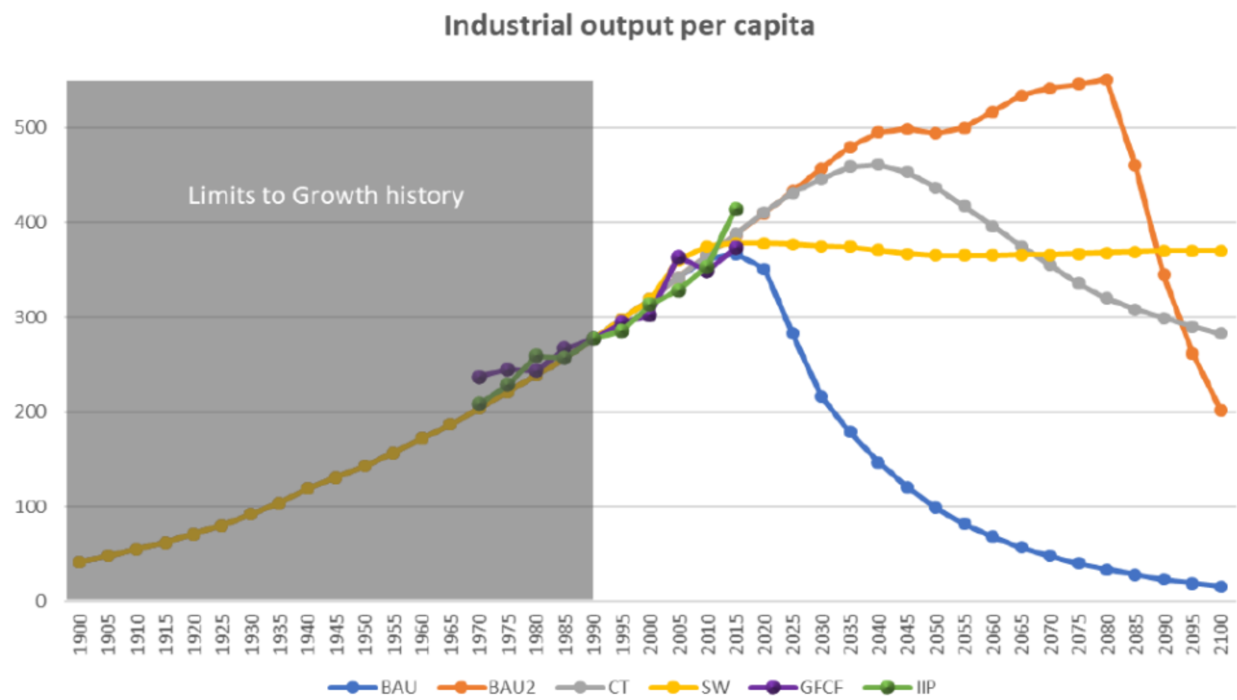

Figure 3: Industrial output has grown, like in LtG.
Scenarios and empirical data for industrial output (gross fixed capital formation and index of industrial production). Source: Herrington, G. (2021). Update to limits to growth: Comparing the World3 model with empirical data. Journal of Industrial Ecology, 25(3), 614–626. https://doi.org/10.1111/jiec.13084

In the same way (Figure 3), you see that industrial output has increased over this period, much like in *LtG*.

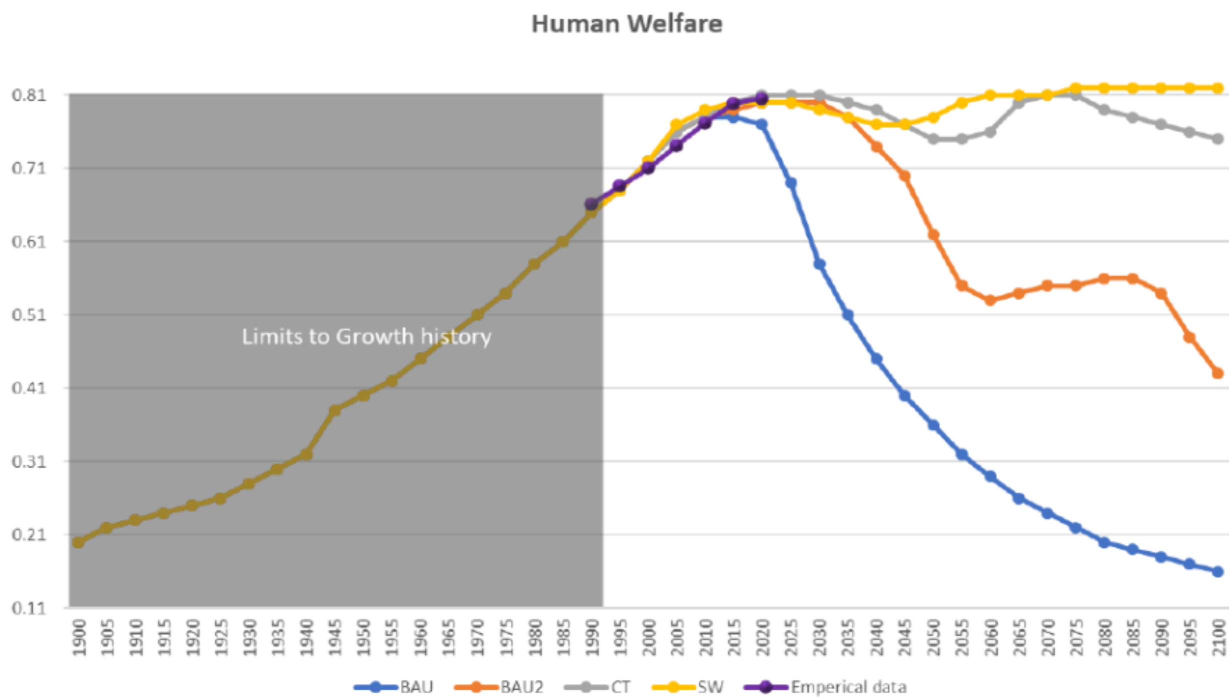

Figure 4 Wellbeing is slowing, like in LtG.
Scenarios and empirical data for welfare (UN Human Development Index). Source: Herrington, G. (2021). Update to limits to growth: Comparing the World3 model with empirical data. Journal of Industrial Ecology, 25(3), 614–626. https://doi.org/10.1111/jiec.13084

Figure 4 shows how human wellbeing has developed over the same period. But in this case it is interesting to note that the rate of growth is starting to decline: the black curve (tracking the UN Human Development Index) indicates a leveling off in average human wellbeing over the last decade or so.

2. The research question: the topic to be explored

Model question: the future of human wellbeing

The big question was: How is human wellbeing going to develop further? We have seen growth in population and output, but we have not yet seen the collapse that occurs in some of the more famous scenarios from *LtG*.

What will happen to wellbeing during the next forty years? Will stagnation lead to decline? Or will average wellbeing grow? Or possibly swing in response to societal action to improve living conditions for the majority? These are the questions we seek to analyze using our new E4A system dynamics model.

Model performance indicator: human wellbeing for the global majority

It is worth pointing out that we did *not* chose the normal success measure (or objective function) in long term studies of this type, namely the rate of growth in GDP or GDP person. Instead, we chose as our main success criterion the "average wellbeing of the working majority". We do *not* focus on the average wellbeing of the whole population. We track the wellbeing of the working majority, namely the wellbeing of that majority (>90% in most societies) who spend most of what they earn within a year. So, in E4A we have split the population into two groups: workers and owners. The workers constitute the vast majority of the population. The owners are the minority that make more in a year than what they spend and, consequently, have resources available for investment. Either profit-driven investment in the private sector, or tax-financed policy-driven investment in public goods and services (normally not profitable from an investor point of view, using conventional calculation methods).

It is worth remembering that the majority of the world's owners belong in the rich industrialized countries (which hold some 1.4 billion out of the 7.8 billion people in the world in 2020 – and controlled some 50 % of the world GDP of 130 T$/y)[7]. It is the six billion plus outside the rich industrialized world which would be the real beneficiaries of global action to improve human wellbeing – initially by removing abject poverty in the poor world through increased labor productivity.

3. Summary description of the model: a quick initial overview

Model overview

The E4A model has evolved over many years and an attempt at describing the model in detail, including argumentation for why we did not choose other formulations, runs into thousand pages or more. Much of the published work is listed in Appendix 1, and more will become available on the web, in the form of a Technical Report. The full model equations are readily available for all who can run models in Stella and in Vensim, so you can check what we have done, and modify to explore different assumptions from the ones we have made[8].

What we try to do in this introduction is to compress this vast information and give an overview and a general understanding of what we have done. This requires, sadly, omission of most of the interesting detail.

[7] Data form World Bank, International Comparison Program, World Bank | World Development Indicators database, World Bank | Eurostat-OECD PPP Programme. https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD?locations=OE-1W and United Nations Population Division. World Population Prospects: 2019 Revision. (2) Census reports and other statistical publications from national statistical offices, (3) Eurostat: Demographic Statistics, (4) United Nations Statistical Division. Population and Vital Statistics Reprot (various years), (5) U.S. Census Bureau: International Database, and (6) Secretariat of the Pacific Community: Statistics and Demography Programme. https://data.worldbank.org/indicator/SP.POP.TOTL?locations=OE-1W

[8] https://www.earth4all.life/the-science

Model main causal diagram

In order to help you maintain an overview while reading about some detail in the following pages, we start by giving you the aggregate result.

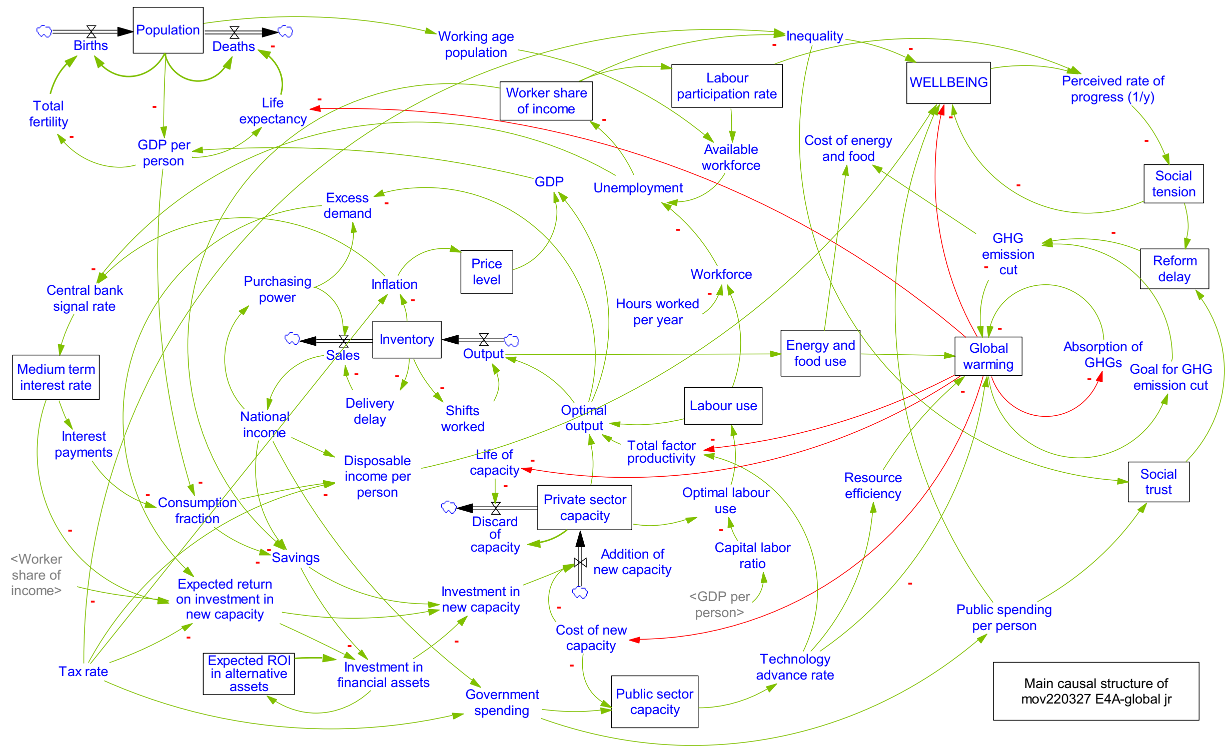

Figure 5: Causal loop diagram of Earth4All model

Figure 5 portrays a relatively high-level causal diagram of the model. Once you have read our introduction (this memo) you will know a little bit more about the main variables, and the main causal relations, their historical development, and their dynamics (behavior over time in the past and in the future).

Notice that up in the left-hand corner in Figure 5 is the population sector, in the middle the economic output sector (which in turn is split in a private and a public part – both modelled explicitly). The labor market sector is at the top: showing how owners and workers fight over the "worker share of output". To the right is the ecological footprint sector, the human use of energy and food and its impact on temperatures. In the top right-hand corner is the wellbeing sector and its effect on the capacity of society to respond to global challenges. And finally, in the bottom left-hand corner are the financial aspects of the economy which, typically, are much more short-term – time constants of 4 years and less – and will only be mentioned in passing in this introduction[9] which largely focus on the long-term dynamics of human wellbeing

[9] See Chapter 10 Model enhancement

(which are largely determined by real effects in the real economy, not by short term fluctuations in inventory, inflation, interest rates and asset values).

Model main sector summary

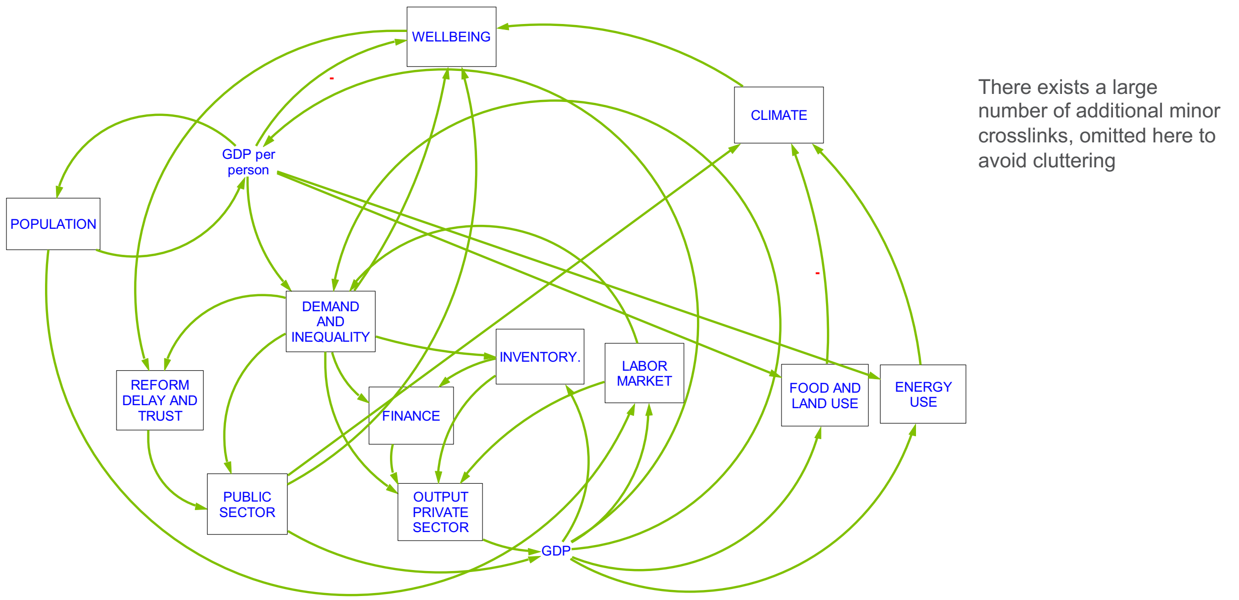

Figure 6: Model sectors and major interactions

The global model can usefully be described as consisting of the following sectors[10]. The sectors and their interactions are illustrated in Figure 6. Remember, however, that the sector perspective gives a false impression of precision. The model is not a complete description of the sectors. The model contains those elements of the sector that influence the object of study in an important way. In our case the sectors include those causal structures that influence the time development of average human wellbeing towards 2100. It is not a precise representation of all socio-economic-geo-physical-biological aspects of the sectors.

• Population sector: generates total population from fertility and mortality processes, potential workforce size, and the number of pensioners.
• Output sector: generates real GDP from real capital formation and discard, and jobs from the labor capital ratio. The economy is seen as a sum of a private sector and a public sector.
• Public sector: generates public spending from tax revenue, the net effect of debt transactions, and the distribution of the budget on governmental goods and services (including on technological advance and the five turnarounds).
• Labor market sector: generates workforce, unemployment rate, worker share of output, and the workforce participation rate.

[10] Based on text from S. Dixon-Decleve et al. *Earth for All*. New Society Publishers. (2022): 179-180

• Demand sector: generates national income, the distribution of income between owners, workers, and the public sector, the net effect of debt transactions. Also generates consumption, saving and public spending in monetary terms.
• Inventory sector: generates capacity utilization and the inflation rate.
• Finance sector: generates interest rates.
• Energy sector: generates fossil fuel-based and renewable energy production, greenhouse gas emissions from fossil fuel use, and the cost of energy.
• Food and land sector: generates crop production, environmental impacts of agriculture, and the cost of food.
• Climate sector: generates the global average surface temperature from man-made emissions, land use, and natural processes.
• Reform delay sector: generates the societal ability to react to a challenge (like climate change) as a function of social tension and trust.
• Wellbeing sector: generates global indicators measuring environmental and societal sustainability. Including the Average Wellbeing Index.

Model base run

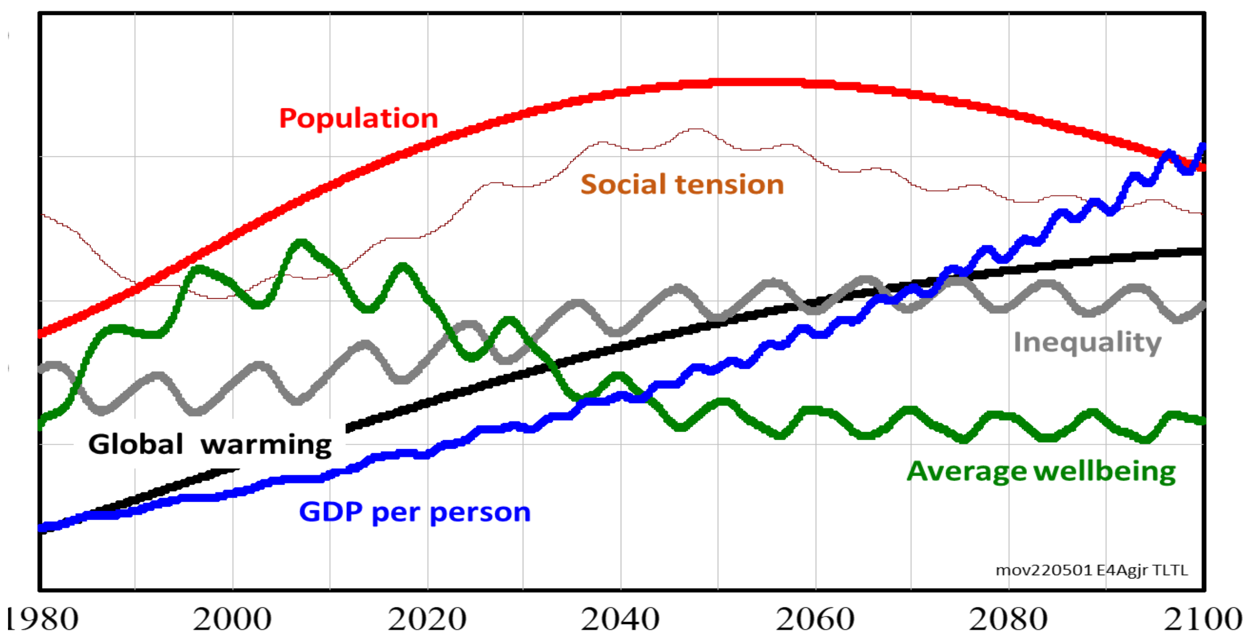

Figure 7: 6 central variables in Earth4All model Base Run – population, social tension, global warming, inequality and average wellbeing.

Figure 7 shows the base run of the E4A model. It is started in 1980, runs with few exogenous drivers except for technical advance and market liberalization, and is parameterized to match the general trends of history from 1980 to 2020. From 2020 on we assume continuation of the decision style of the last forty years. That means that there is no “truly extraordinary action” in the base run. Any truly extraordinary action beyond what we have seen over the last 40 years is explored in policy runs.

In the base run, the population (red curve) grows, peaks, and declines. The GDP per person (blue curve) continues to grow throughout the simulation. Global warming (black curve) rises as the model world is getting warmer and warmer throughout the whole period, Inequality (grey curve) first decline but then start rising – as owners gain the upper hand in the market economy. But there is a 10-year oscillation – referred to as the Juglar cycle – which reflects the undulating fight between the owners and the workers observed most easily in long-term time series for the unemployment rate and the investment fraction.

Finally, there is the average wellbeing of the majority (green curve) which grows to 2000 or so, stagnates, and then declines to 2050 or so before it levels off at a relatively low level. Again, with oscillations around the long trend, depending on the fate of the working majority in its fight for their share of the output.

The base run illustrates the problem we want to address in the E4A model: What can global society do to reverse the downwards trend in average human wellbeing over the next forty years or so?

4. The basic assumptions underlying this study of long-term global developments

Model feasibility

But first a few words about feasibility. Is it possible to make a simulation model that can say anything meaningful about human wellbeing on a forty-year horizon? Well, at least we have built a model based on generally accepted ideas and historical data, and it generates reasonable results – both covering the past and the future. So that's a first step.

The precision level is of course low, which limits (severely) what can be said with conviction about future trends. Nothing can be said about future events and exact values, but the basic mechanisms residing deep in the model structure generate believable dynamics. The E4A model passes most of the tests of model usefulness that is one of the central elements of the system dynamics method.[11]

But the main reason why we believe it is possible to say something non-trivial about the future of wellbeing is that we have found in the quantitative history of the global past that there are surprisingly stable relationships between human behavior and the GDP per person in the society that they are living in. And that's in many ways the basis for our forecasts. We assume that the human beings of the future are going to behave, when they reach different income levels, in the same way as their ancestors behaved when they reached the same income level during the last forty years.

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[11] See Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*, *12*(3), 183–210.

Global guides

The next several figures show some examples of such stable relationships, which we call "global guides".

Population birth rates

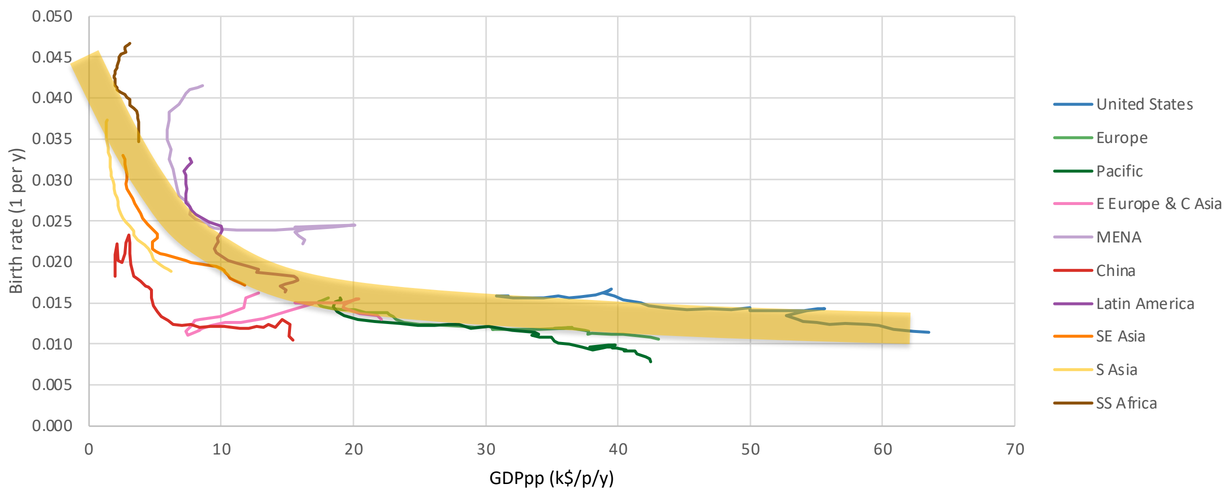


Figure 8: Birth rates decline with rising income.
Source: United Nations population statistics and Penn World Tables

In Figure 8 you see the birth rate plotted along the vertical axis (measured in 1/y, which is the fractional change per year). Along the horizontal axis is the level of income, the GDP per person (measured in PPP (purchasing power parity) 2017 dollars per person per year)[12]. The thin colored curves show the historical development from 1980 to 2020 for the 10 regions we study.

You see that the birth rate tends to decline in all regions when the region gets richer. There are of course exceptions (most easy to explain when you know the history of the region), but the very rough average shown by the broad band (orange curve) indicates the gross generalization that we use in the E4A model to represent the causal relation between income and birth rate.

The graph also illustrates the (limited) level of precision in the resulting model. The deviation between the thin regional curves and the broad band illustrates the inherent uncertainty in the relationship. Actual datapoints deviate easily by plus minus 30 % from the global guide. You see how China (red curve) deviates because of its one-child policy: being way below the global guide, while the United States maintains its high birth rate at high incomes because of the traditions and religious views of that region. These observed deviations from the global guide is a useful reminder of the

[12] It may be useful to remember that world average GDP per person in 2020 was 16.000 2017PPP$/p/y (Source: International Comparison Program, World Bank | World Development Indicators database, World Bank | Eurostat-OECD PPP Programme. https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD?locations=OE-1W)

heroic assumption we make when we use past observations to estimate what will happen to wellbeing in the future.

But on the other hand, in our view there is apparently a clear systematism: as people get richer, they choose to have fewer children.

Let us show you five other global guides that constitute in many ways the core of the predictive capacity of the E4A model.

GDP growth rate

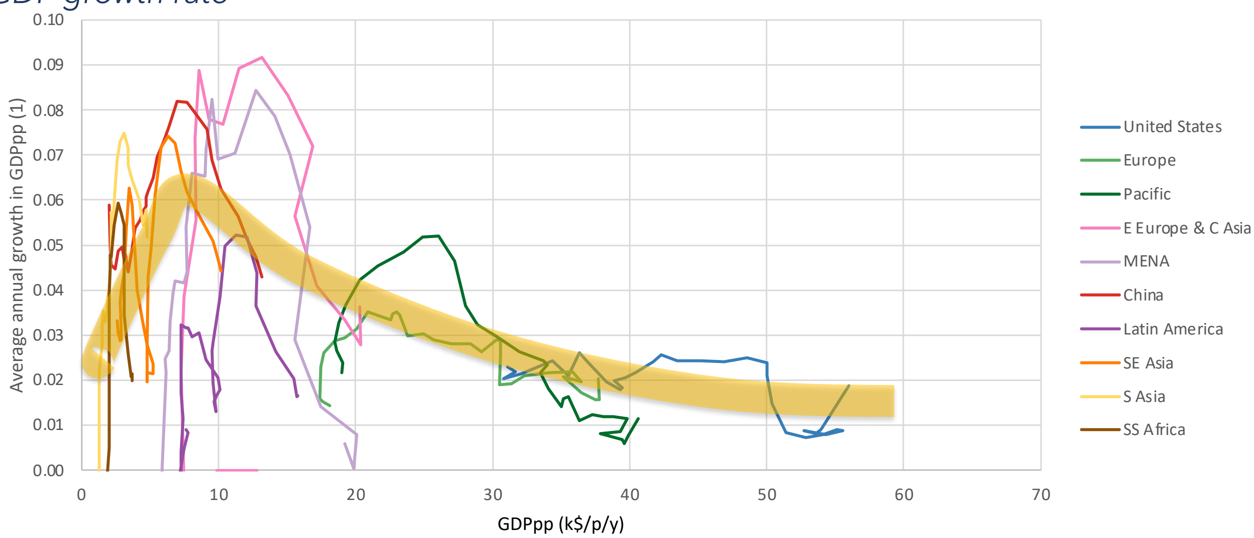


Figure 9: The economic growth rate peaks at mid income (10k$/p/y)
Source: UN Population statistics and Penn World Tables

This graph shows the rate at which the economy (measured as GDP per person) has grown in our 10 regions during the 1980 to 2020 period, plotted as a function of GDP per person. This global guide illustrates the generalization that very poor countries have low growth rates. Then, as they start industrialization, growth rates increase and finally peak at around 10.000 2017PPP$/p/y before declining as the region gets richer, seemingly leveling off at a growth rate around 1 %/y – probably determined by the normal rate of long-term technological advance.

Savings rate

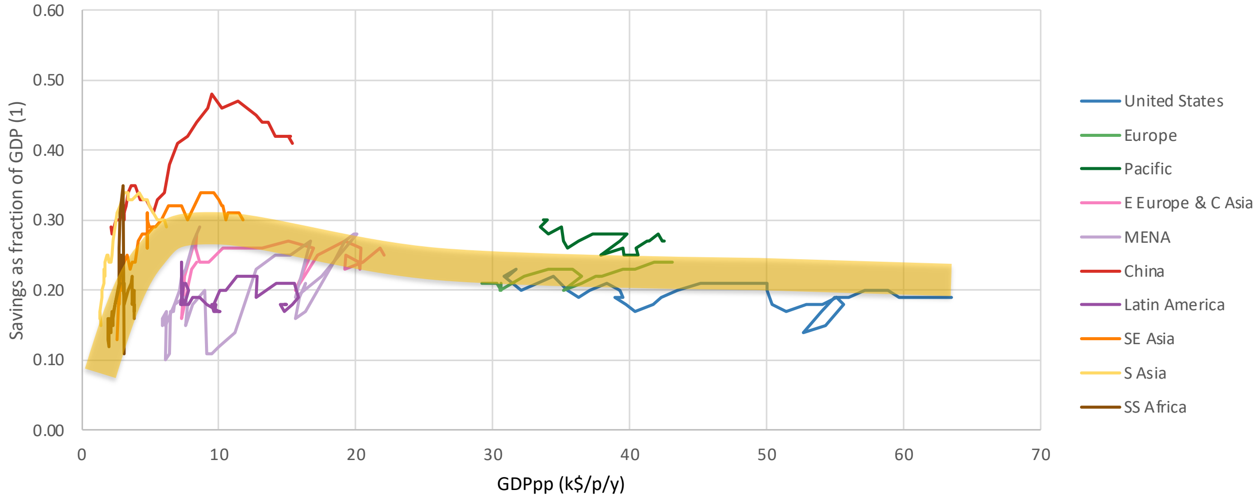


Figure 10: The savings fraction declines above mid income.
Source: UN Population statistics and Penn World Tables

Figure 10 shows the saving rate (savings divided by national income) which is important in the macroeconomic analysis. Again, you see a global guide that rises first, and then declines as the region gets richer. The decline illustrates the counterintuitive fact that nations consume more (a bigger fraction of the output) when they get very rich.

Capital-labor ratio

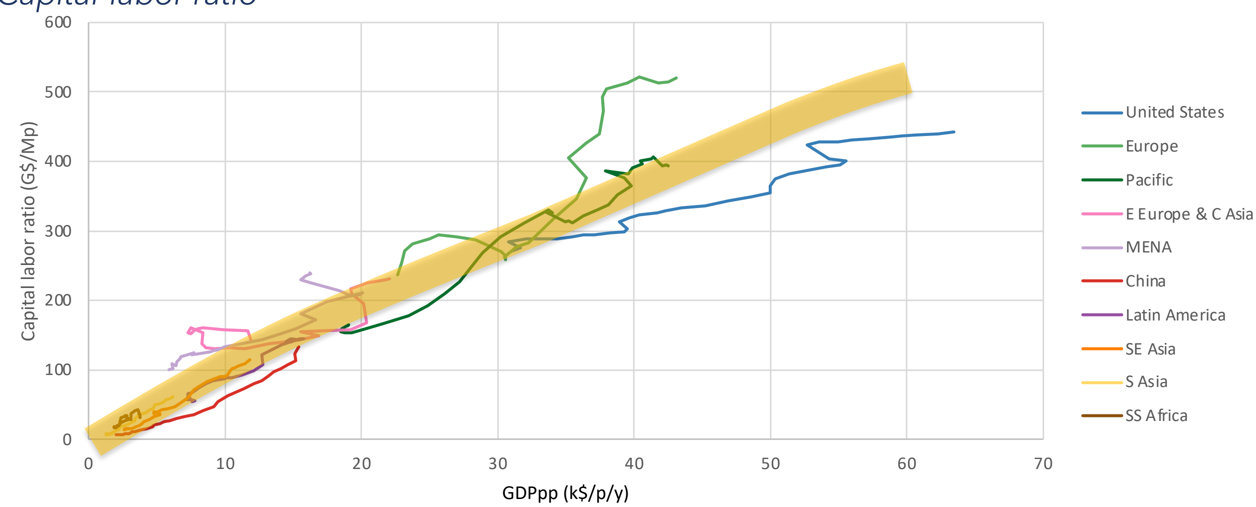


Figure 11: The capital labor ratio increases with rising income.
Source: UN Population statistics and Penn World Tables

The capital-labor ratio – the capital investment behind each worker – increases more or less linearly with income (when measured in 2017PPP$/job), Figure 11.

Government share

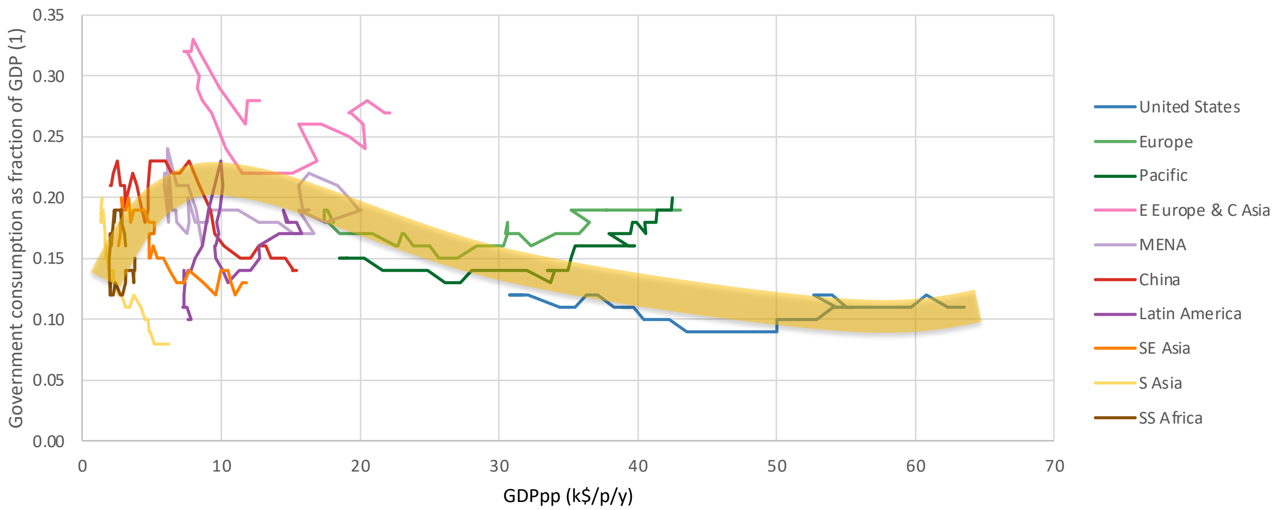


Figure 12: Government share of GDP declines with rising income.
Source: UN Population statistics and Penn World Tables

Societies decide on their government share of GDP (government spending divided by GDP – both measured in PPP2017$/y), and here tradition and political preferences gives a bigger variation among the regions than in the foregoing global guides. Still, there is a tendency that, initially, the state is small. As the region industrializes the government share increases (to a peak around 20% of GDP) before it tends to decline, Figure 12.

Clearly, if a society decided to act differently, it could well decide to have higher taxes and a bigger government and move away from the global guide (orange band). Anyhow, we use the global guide to model the surprise-free future, that is, as the assumption in the base run.

Energy use per person

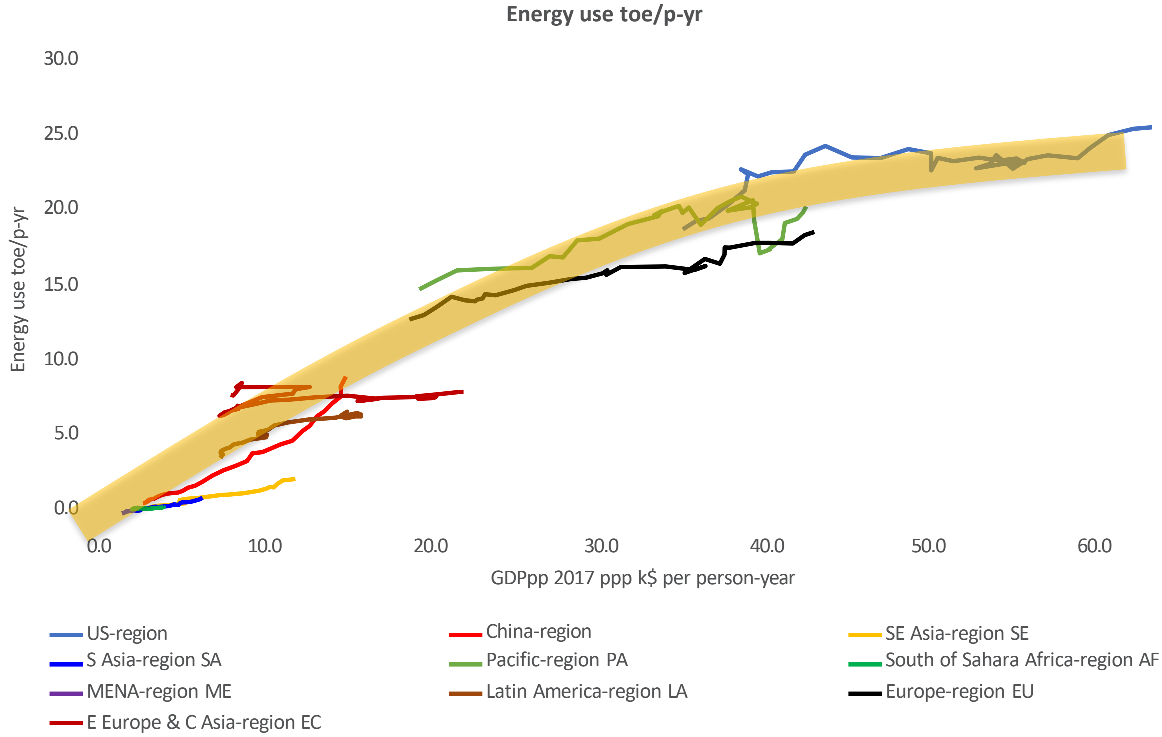


Figure 13: Energy use per person increases with rising income.
Source: UN Population statistics, Penn World Tables and BP. (2022). Statistical Review of World Energy 2022. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

The next global guide, Figure 13 , shows energy use per person (in tons of oil equivalent per person per year), which stagnates at high income levels, in contrast to the general perception of ever-rising per capita energy use. The reason for our result is that we *sum* the two major forms of energy used, namely a) electricity (measured in kWh of electricity) and b) heat for buildings, mobility and industrial purposes from fossil fuels and biomass (measured in tons of oil equivalent– after subtraction of the amount of fossil fuel used for electricity production). Next we express both in one common physical unit, namely tons of oil equivalent[13] to obtain the regional results in the graph. We derive a global guide which shows that per capita energy use rises with income at low to mid incomes, but stagnates at incomes of some 40,000 2017PPP$/p/y. If the rate of energy efficiency accelerates in the future, we may observe a Kuznets curve in real energy consumption (ie a lower per capita energy use at higher income).

[13]On average 1 Mtoe is converted to 4 TWh of electricity in a power station. The rest of the energy content in the fossil fuel (some 8 TWh of heat per Mtoe) is largely lost as waste heat.

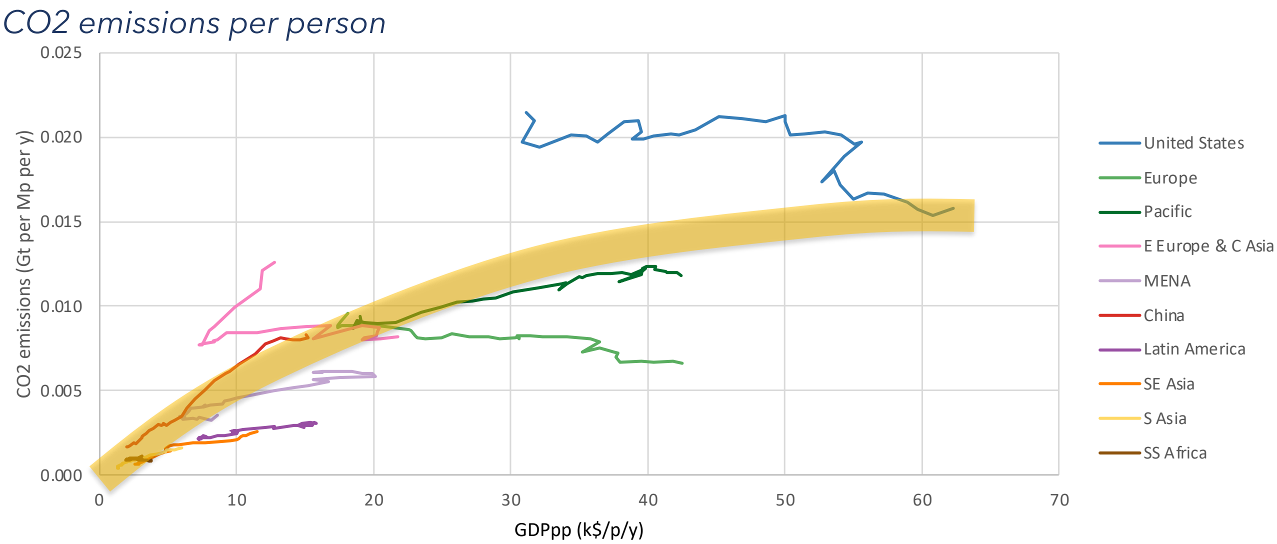


Figure 14: CO2 emissions per person increases with rising income, but is reduced by steady technical advance. Sources: Penn World Tables and EDGARv6.0_GHG website (https://edgar.jrc.ec.europa.eu/dataset_ghg60), Crippa, M., Solazzo, E., Guizzardi, D. et al. Food systems are responsible for a third of global anthropogenic GHG emissions. Nat Food 2, 198–209 (2021). https://doi.org/10.1038/s43016-021-00225-9

If you look at CO2 emissions per person once more, Figure 14, the spread is very big, but again there seems to be a tendency towards stagnation at high incomes. Notice that the regional curves tend to decline. The reason is the ongoing technological advance in the energy and climate sector, that is both in "energy use per unit of GDP" and in "CO2 emissions per unit of energy". This means that a region with income of $30,000 per person-year in 1980 had higher CO2 emissions per person than a region that reached the same income level at a later time. We could improve the match to the global guide by explicitly introducing these two forms of technological advance in the graph.

Fossil fuel use per person

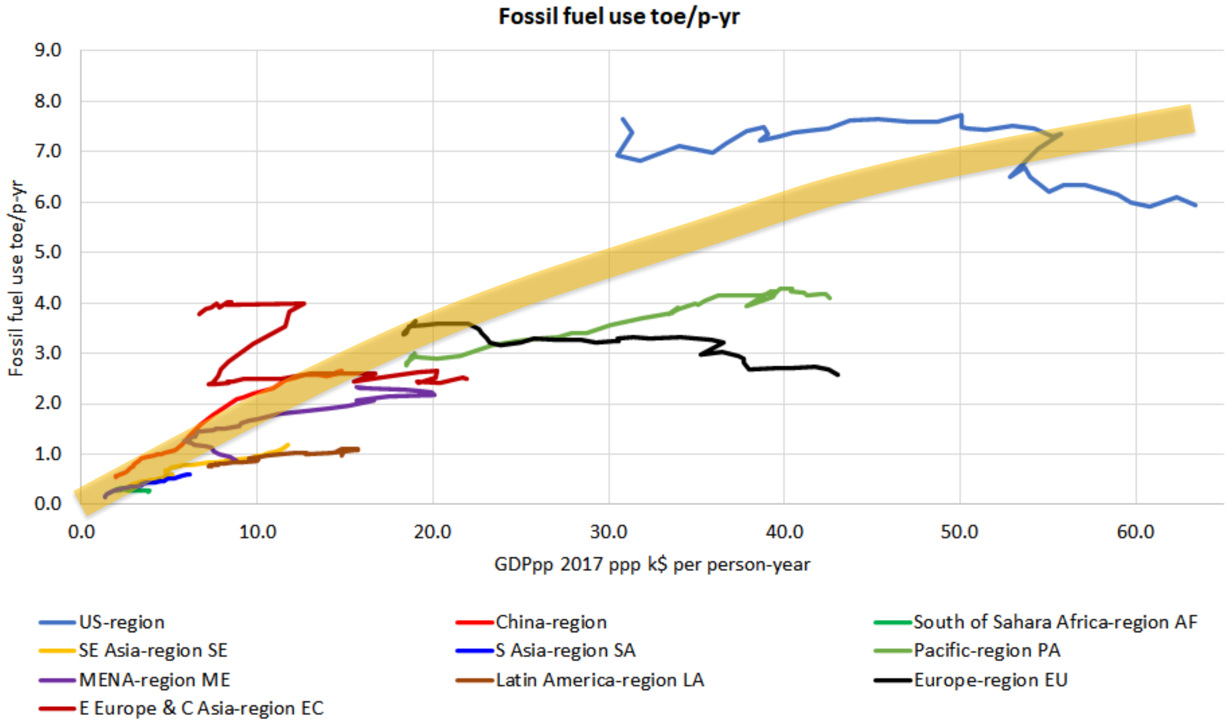


Figure 15: Fossil fuel use increases with rising income.
Source: UN Population statistics, Penn World Tables and BP. (2022). Statistical Review of World Energy 2022. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

The final graph, Figure 15, shows the per capita use of fossil fuels (for all purposes). Once more the use increases with rising income, and once more technological advance makes regions deviate from the trend. Fossil fuel use declines because energy use stagnates and because of the green shift out of fossil fuels towards non-fossil energy.

Crop use per person

Figure 16 shows how the direct consumption of crops for food rises with income, but stagnates at some 500 kg crop per person per year when incomes rise to 15.000 $/p/y. Note that the use of crop for feed (especially for chicken, pork and beef) comes in addition, Figure 17. But the sum also appears to saturate, though at a higher level (1.200 kg crop per person per year) and at higher incomes 30.000 $/p/y.

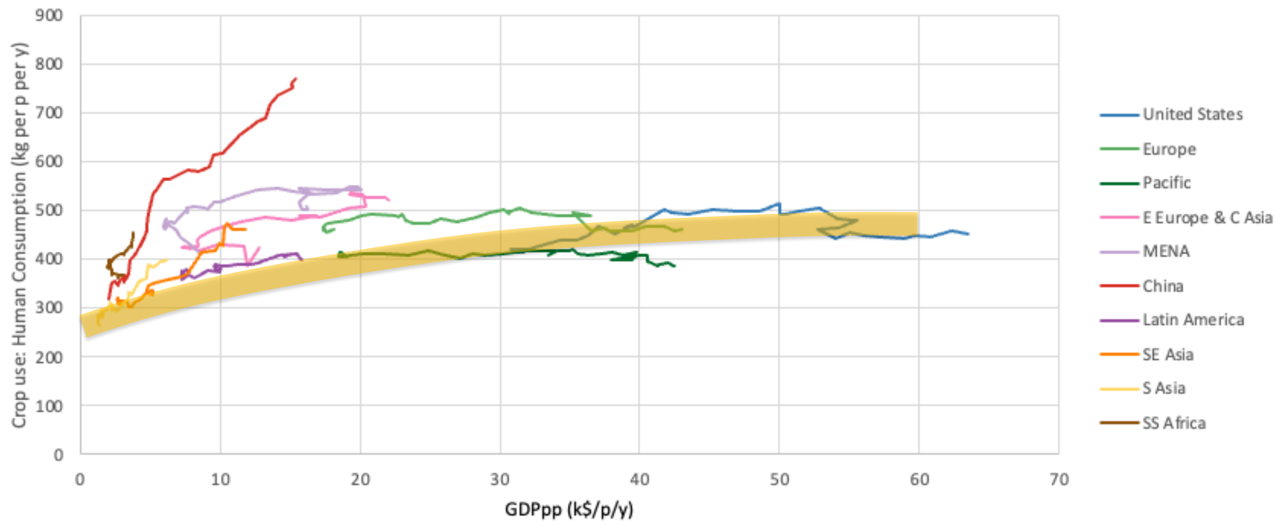


Figure 16: Food crop use grows to a max at high incomes.

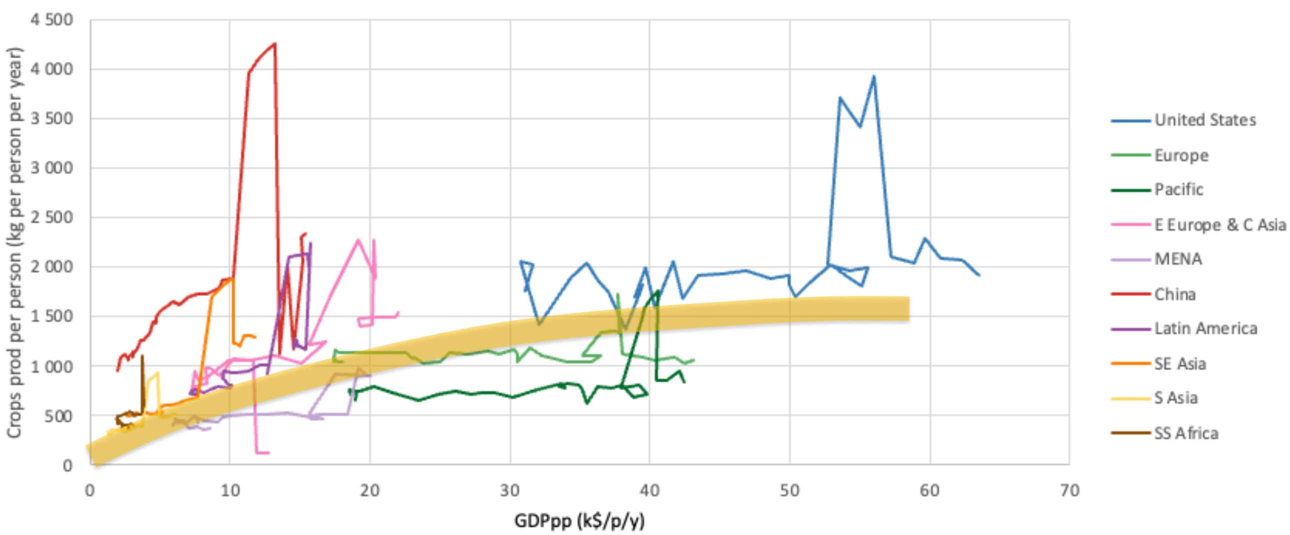


Figure 17: Total crop use (food and feed) increases with rising income.

Model reliability

At this point, you might want to ask the question: How good is the model? Our answer is that the model as good as the approximation we make when we approximate real world relationships with the global guides. This means, in our view, that the dynamics (the output curve patterns) of the model are reliable, but that the numerical values at any point in time has very little predictive power.

It is possible to increase the reliability somewhat by adapting (parametrizing) the E4A model to data for each of the 10 regions we use – and thereby getting a more detailed global model which is the sum of 10 regional models (with the same structure but different parameters). When we go down to the regional level, we replace the global guides with an approximation to and extension of the historical data for the region. We have started, but not yet completed, this work[14]. Luckily it appears that the regionalized version gives the same dynamics as the global version, that is the same development pattern within the broad uncertainty range already mentioned.

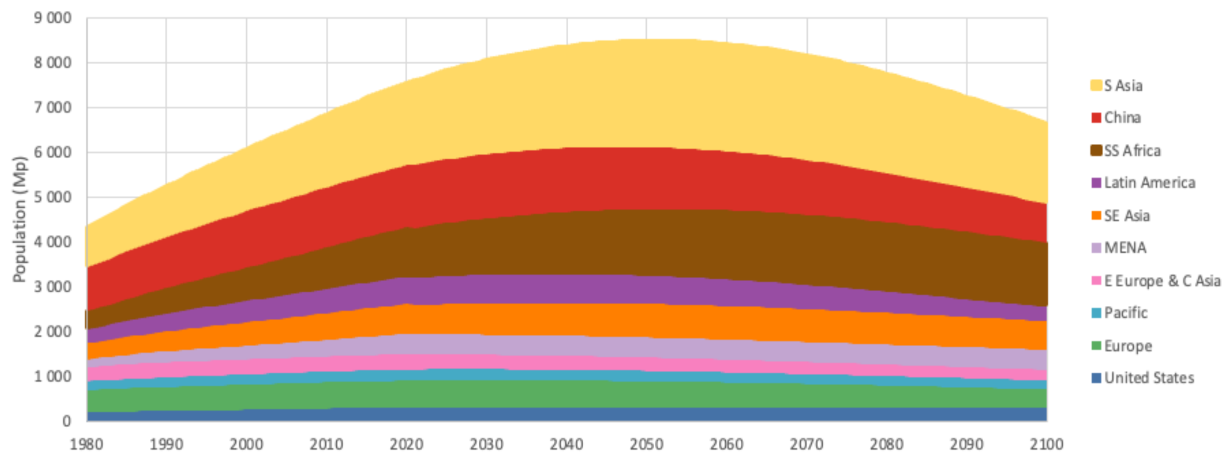


Figure 18: World population as the sum of the population in 10 regions

Figure 18 shows an example: The global population peaks in the middle of the century in the detailed model as in the aggregate model. The numerical values at any given point in time remain much less reliable, in both models, with an uncertainty range of plus minus 50%.

5. Main focus of model: average wellbeing of the global majority

Five components of the average wellbeing index

So our ambition is to forecast the dynamics of human wellbeing towards the year 2100. This requires a measurable definition of wellbeing. We have chosen to define the average wellbeing of the working majority as dependent on five components, following the guidance of the WeAll alliance: the wellbeing alliance of nations that have chosen to move away from GDP per person as the societal goal, and replace it with a wellbeing indicator[15].

[14] See Ch 10. Model enhancement
[15] https://weall.org

The E4A *Average Wellbeing Index* depends on

1. Worker disposable income per person – after tax
(in 2017 PPP $ per person per year)

2. Public spending per person
(in 2017 PPP $ per person per year)

3. The level of inequality
(Owner disposable income divided by worker disposable income)

4. Observed global warming
(Degrees Centigrade above preindustrial times)

5. Perceived progress
(The rate of increase in wellbeing during last 5 years)

Figure 19: The five components of the Earth4All wellbeing index.

We have concretized the five components of wellbeing as shown in Figure 19. The first component is worker disposable income after tax (measured in 2017PPP$ per worker per year). We assume that wellbeing increases with disposable income, but with decreasing returns.

The second component is public spending per person (measured in 2017PPP$ per citizen per year). Basically saying that the state provides more education, health, transport, infrastructure, etc, this will add to the wellbeing of people beyond their disposable income.

The third component, reasonably, is inequality. We – and WeAll – believe that an unequal society is less happy than an equal society. We measure inequality in the E4A model by an index which is equal to total owner disposable income after taxes divided by total worker disposable income after taxes. So inequality is measured as the after tax ratio of owner to worker income.

The fourth component is environmental quality, and here we use the "observed global warming" (in degrees Centigrade relative to 1850) as the indicator. We could have added many others, but for simplicity, and also because our ability to forecast global warming is much better than our ability to forecast other environmental damages, we limit ourselves to using (the inverse of) observed global warming as the fourth component.

We chose a fifth component as a proxy of what WeAll call participation, the level of popular engagement in their society. The fifth component is what we call "perceived progress". Basically, perceived progress equals the rate of increase in wellbeing during the last five years (measured as fraction per year). This assumption reflects the simple idea that if wellbeing is going up, people are happier and have higher hopes for the future than if wellbeing is stable or going down. In the latter case they are more resentful and less willing to support collective governmental action that seek to increase wellbeing in the long run.

Calculation of the average wellbeing index

The AWI is calculated as follows, relative to value in 1980

1. Worker disposable income
= (GDP * Worker share ("wso") * (1-Worker tax rate) + Transfers to workers) / Workforce (Mp)
Measured in thousand 2017PPP$/p/y
2. Public spending per person
= (National income ("NI") * Govmnt gross income as share of NI) / Population (Mp)
Measured in thousand 2017PPP$/p/y
3. Inequality
= Owner income after tax (G$/y) / Worker income after tax (G$/y)
Measured as a ratio
4. Environmental damage
= Observed global warming = a function of man-made GHG emissions from energy and food use
Measured in degrees Celsius relative to 1850
5. Perceived progress
= Rate of growth in the Average Wellbeing Index
Measured in 1/y

Figure 20: Calculating the Average Wellbeing Index (AWI)

Figure 20 shows in more detail how we calculate the value of the five components of wellbeing at any point in time. The important point is that you need to forecast a limited number of variables (those marked red) in order to be able to calculate future values of the average wellbeing index. Those variables are population, GDP, workforce, worker share of output, worker tax rate, owner tax rate, governmental transfers from the rich to the poor, national income, government gross income as share of national income, inequality index (i.e. the owner income after tax divided by the worker income after tax), observed global warming. Finally, you need to track the rate of growth in the average wellbeing index.

We combine the five components into one Average Wellbeing Index (AWI) which increases with disposable income, public spending, and perceived progress, and declines with rising inequality and higher temperatures[16].

[16] The exact weights of the combination is easily changed when running the model. Such changes do affect the absolute value of the AWI but has less effect on its dynamics (i.e. on the shape of AWI development over time).

6. More detailed description of model: the model logic

Model calculation of global time developments

In order to further clarify how the E4A model works, we now describe how relevant variables develop from 1980 to 2100 in the base run. We start by the variables that determine wellbeing. We study one variable at a time (red curve in Figure 22 through Figure 32). And compare with historical data from 1980 to 2020 (blue curve when we have data).

Each figure contains two graphs: To the left a graph showing the development of the relevant variable from 1980 to 2100 in the base run. To the right a graph showing the development of some additional variables that help explain the dynamics of the relevant variable. That is, illustrates the cause-and-effect relations that generate the time development of the relevant variable in the E4A model.

Population

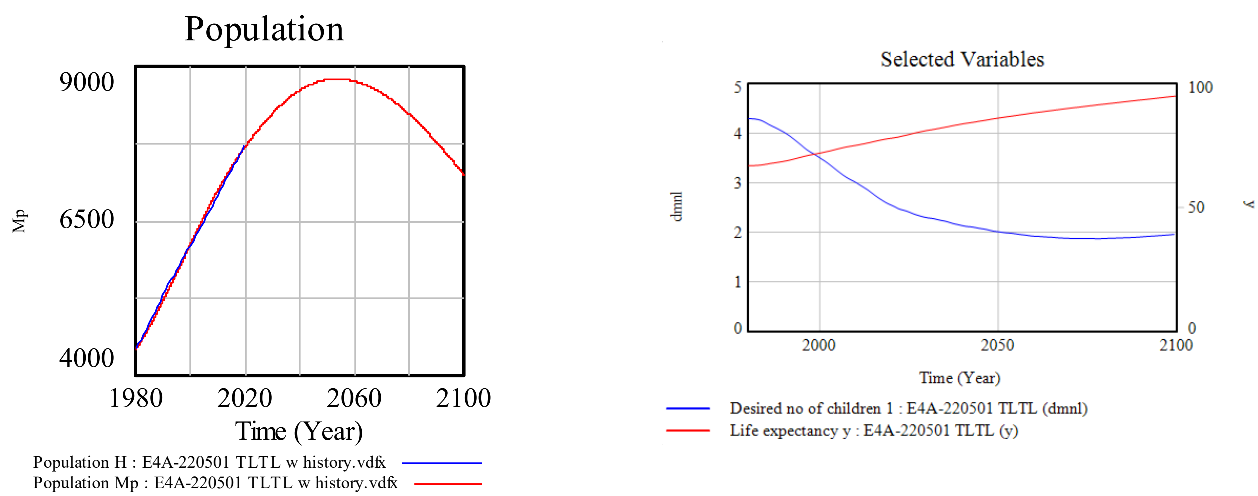


Figure 21: Population peaks when fertility falls below mortality.
Source: Earth4All model simulations and data based on UN population statistics.

Figure 21 shows the dynamics of world population to 2100 in the base run. The population grows as long as births are higher than deaths. The population peaks in the middle of the century and declines thereafter when deaths exceed births. The birth rate (the desired number of children) declines as society gets richer, because there is more public spending on education and health, more contraception and more opportunity – especially for women. But at the same time life expectancy increases reducing the death rate. But ultimately births decline below deaths, and the population starts to decline.

The fit of the model generated population (red curve) to historical data (blue curve) is very good – and indeed way better than the general precision level of the model. The good match illustrates the fact that when you have a basically correct theory for what is going on, it is simple to parameterize the theory in such a way that it fits historical data at a high level of aggregation.

GDP

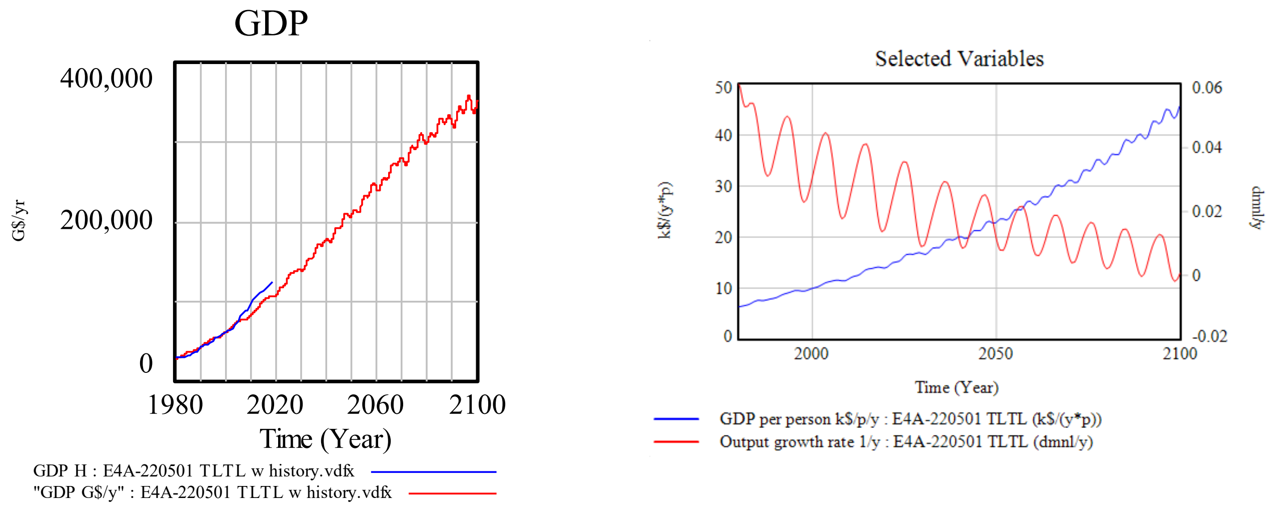


Figure 22: GDP growth slows when labor productivity rises.
Source: E4A model simulations, Penn World Tables and UN Population statistics.

Figure 22 shows the dynamics of world GDP to 2100 in the base run. It shows growth at a declining rate, reflecting the observed fact that the growth rate in an economy falls when the nations gets richer (Remember Figure 9). Notice also that GDP per person grows throughout – but not enough to compensate for the fall in wellbeing from inequality, warming and limited progress.

In addition, you can see a 10-year cycle around the long trend. The E4A model generates a superposition of long-term growth (when annual addition of capacity exceeds annual discard) and a 10-year cycle (when output fluctuates around the long-term need, causing a 10-year wave in workforce, unemployment rates, return on capacity investment, and the investment fraction). This 10-year cycle is known as the Juglar cycle[17], which we believe can help to explain the global downturns around 2000, 2008 and 2021[18].

Please notice the mismatch between GDP (red curve) and historical GDP (blue curve). This gap can easily be eliminated by adjusting one parameter in the system, namely

[17] Originally from Juglar C., 1862, Des crises commerciales en leur retour périodique en France, en Angleterre et aux États-Unis, Libraire Gillaumin.et Cie, Paris. Famously picked up by Schumpeter J.A. , 1939, Business Cycles. A Theoretical, Historical and Statistical Analysis of the Capitalist Process, New York-London. Also related to the explanations of crisis by Marx (Ayres, R. U. (2020). *On capitalism and inequality: Progress and poverty revisited*. Springer. https://doi.org/10.1007/978-3-030-39651-0). See also: A'Hearn, B., & Woitek, U. (2001). More international evidence on the historical properties of business cycles. *Journal of Monetary Economics, 47*(2), 321-346.

[18] In addition there is the 4-year inventory cycle in the model, well known to system dynamicists, and influencing the short-term dynamics of the financial variables in the model. But these are not essential in the rough calculation of long-term dynamics of human wellbeing.

the exogenous growth rate in total factor productivity. (This parameter currently is set at 1 % per year, increasing to 1.3 % per year from 2022 to reflect the generally expected acceleration of technological advance.) But fine tuning this parameter would obscure the fact that the E4A model is a very coarse approximation to the real world. By keeping some degree of mismatch serves to remind model users that the future values generated by the E4A model are unreliable. The dynamics (the curve shapes) are much more reliable.

Workforce

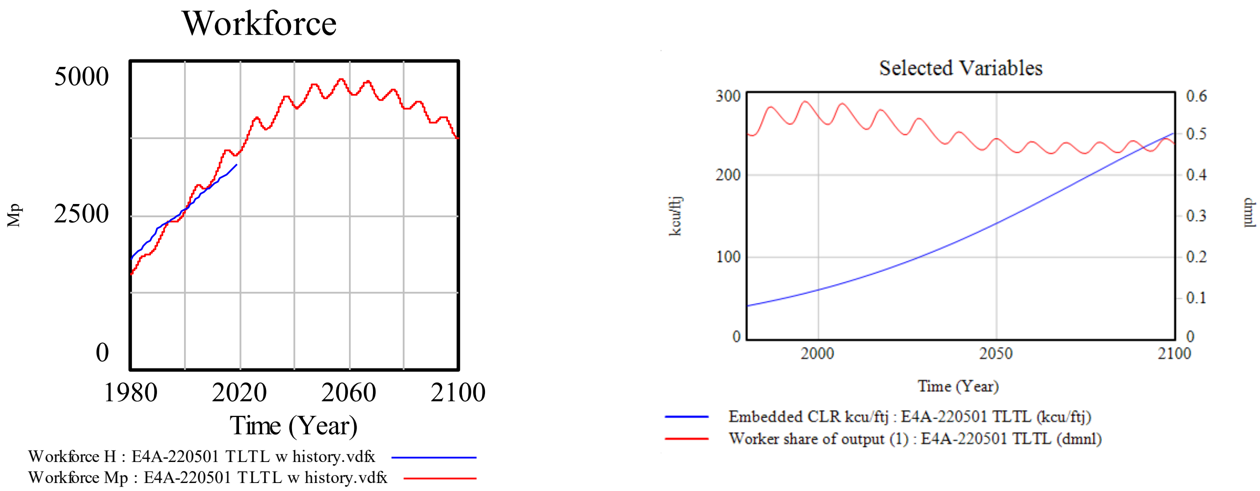


Figure 23: Workforce peaks when the capital labor ratio rises.
Source: E4A model simulations and Penn World Tables.

Figure 23 shows the work force, with a clear Juglar cycle around the long trend. The cycle involves fluctuation in the "worker share of output", which increases when labor is in short supply and owners can reduce wages. The long-term dynamics is reflected in the capital-labor ratio – defined as how many machines there are behind each worker. The capital-labor ratio grows as society gets richer (see global guide in Figure 11) reducing the number of jobs per unit of output. This is the basis for the current worry around robotization of the service sector. Robotization means very rapid increase in the capital-labor ratio of some sectors (especially office services) which leads to slower growth in the number of jobs than without robotization.

The 10-year cycle is not as visible in historical data for the workforce as it is in national data for unemployment and investment fraction.

Government share of GDP[19]

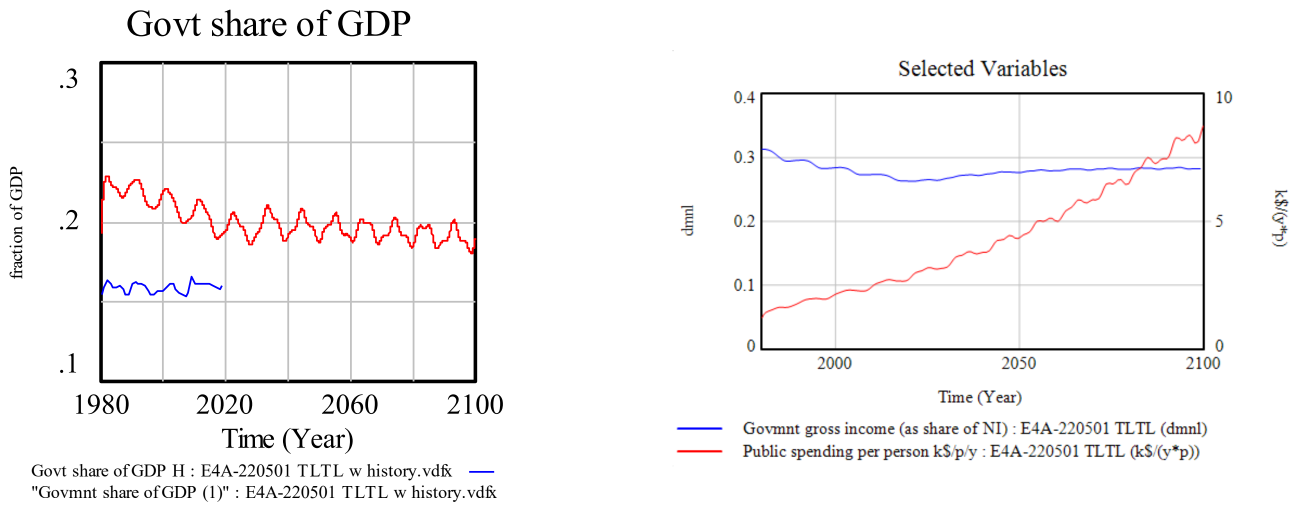


Figure 24: Government share of GDP declines slowly when nations get richer.

The government share of GDP in the E4A model (Figure 24) is mainly determined by the total tax rate (total taxes as fraction of total national income). The tax rate first rises and then declines as a region gets richer (see global guide in Figure 12). In E4A model taxes are around 22 % of GDP, which is some 30% lower than the observed historical average for the world at 17%.[20] The taxes funds rising public spending per person which is one of the real drivers of human wellbeing in this coming century.

Inequality

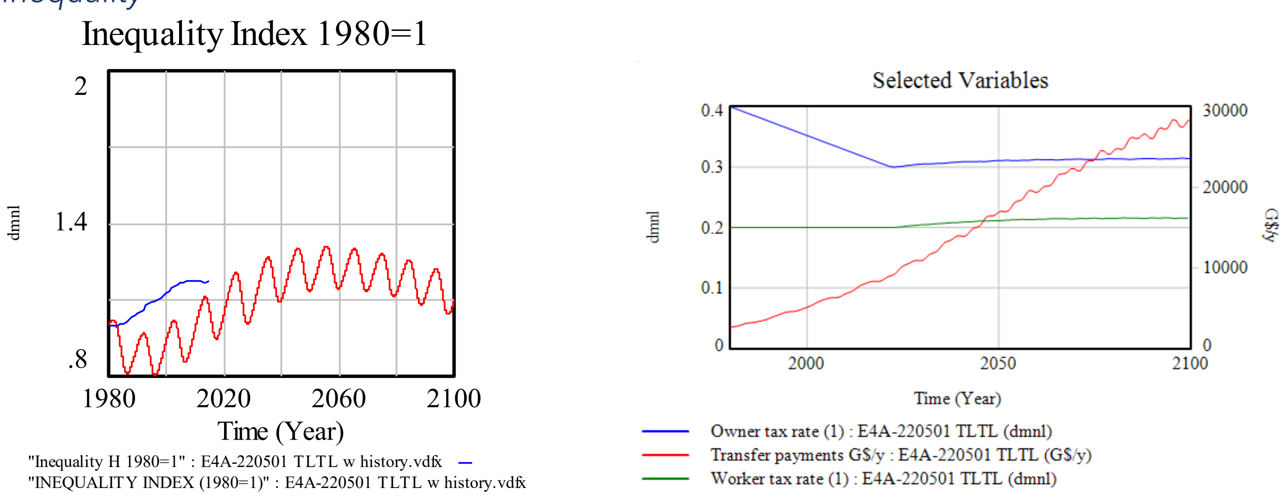


Figure 25: Inequality rises when tax rates are cut.

The dynamics of our Inequality Index is shown in Figure 25. The inequality index (the ratio of owner to worker income) rises in the E4A model in the base run, because

[19] It would be conceptually better to use the government share of national income (NI), not GDP. We choose to use GDP because most analyses use this denominator.

[20] In the next version of the E4A model we will improve this match.

owners are gaining the upper hand in the fight over income. The Juglar cycle is clearly visible – showing the fluctuation in the struggle between labor and capital.
Since we do not have data for our Inequality Index, we compare with historical development of the Gini index[21] that is commonly used as a measure of inequality. Both show the same upwards trend. And the common reason for both declines, we believe, is declining tax rates over the last 40 years of increased liberalization. In the E4A model we make the contestable assumption that tax rates will not continue to decline, that they will stabilize at current levels and finance governmental action which is not eroded year by year. We know that this is a truly heroic assumption, and stress that it can easily be changed in model simulations.

Energy use

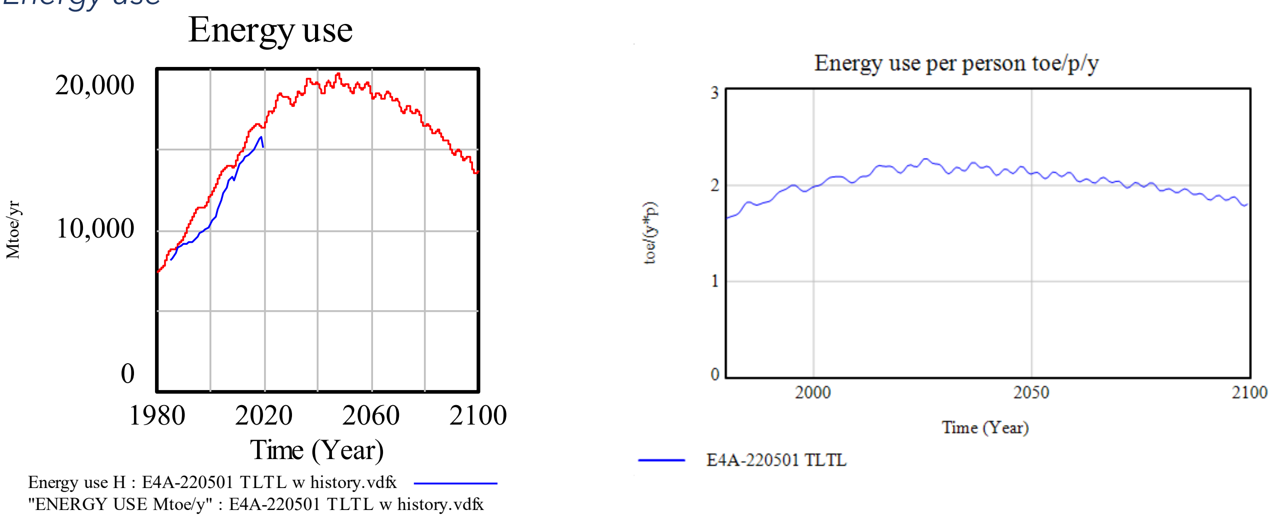


Figure 26: Energy use peaks when GDP growth is trumped by efficiency.

Figure 25 shows the dynamics of total energy use in the base run. Energy use grows to a flat peak in the middle of century – when we define total energy use as the sum of electricity and heat measured in the proper manner to avoid double counting. (See discussion of the global guide for energy use in Figure 13.) Energy use reaches a peak because the global population peaks, because the per capita use of energy plateaus at higher incomes, and because continuing increase in energy efficiency finally drives total consumption down.

The expected peak in total energy use is a somewhat surprising result, but the historical data gives hints in the same direction. Very roughly, over the last forty years global energy use has grown by 140 % while the global population has grown by some 70%. Thus per capita energy use has only grown by 40 % (since 2.4/1.7 = 1.4) in 40 years. That is much less than 1 % per year in forty years, and due to technological advance in energy production and use. When populations stagnate in this century,

[21] The value of the GINI index multiplied by 2 is numerically approximately equal to the fraction of national income accrues to the richest one half of the population. See chapter 9 for a discussion of three different measures of inequality: GINI, the Palma ratio, and our Inequality Index.

total energy use will not grow much, because of the great potential in energy efficiency (both normal and in electrification).

Electricity use

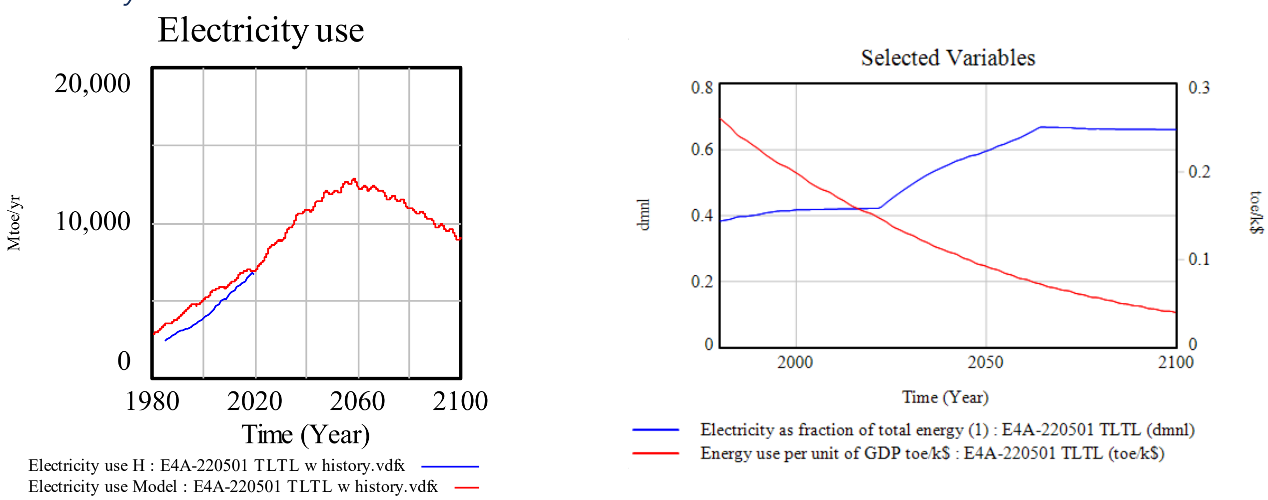
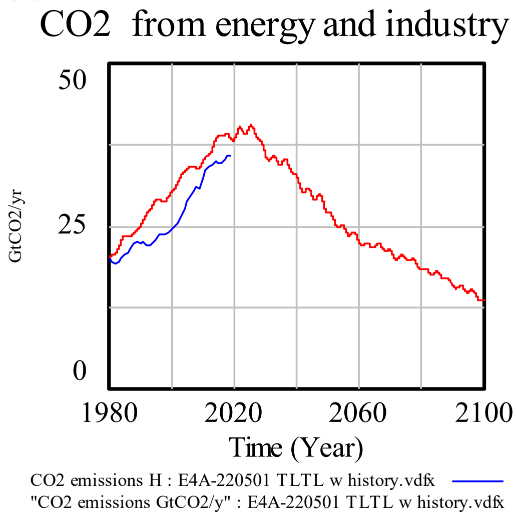


Figure 27: Electricity use peaks as efficiency rises.

Figure 27 shows the dynamics of global use of electricity in the base run. Total electricity use grows to a peak in 2060 (at twice the use in 2020) before it declines – much like total energy use. But in the long run – towards 2100 – the global use of electricity is higher than today, while the total use of energy is lower. This is the combined effect of continued increases in energy efficiency, and the ongoing process of electrification - the shift from obtaining heat, transportation and manufacturing from the burning of fossil fuels, to obtaining the same services through modern electric infrastructure (electric vehicles, heat pumps, etc).

This shift is illustrated by the rise in fraction of electricity in the energy mix.

CO2 emissions



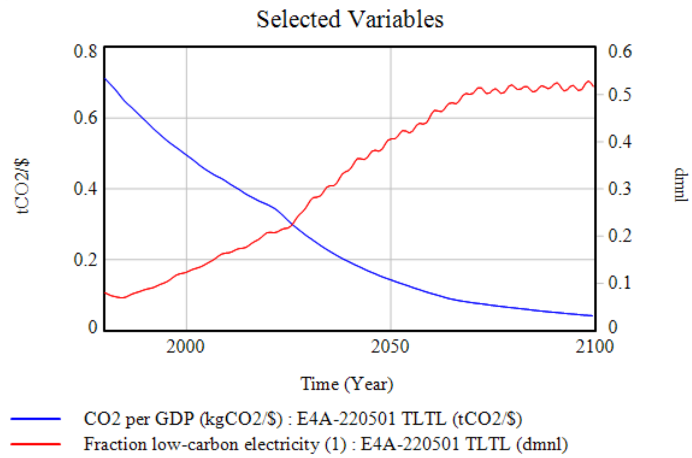


Figure 28: Emissions peak as low-carbon electricity replaces fossil fuels.

Figure 28 shows the resulting emissions of CO2 from energy and industry – that is from the remaining use of fossil fuels. You see emissions rising from the roughly 15 GtCO2/y in 1980 and to roughly 32 in 2020 – more than doubling (occurring while global society has discussed the "urgent need to cut climate gas emissions").

In the E4A model base run CO2 emissions peak relatively soon (before 2025) and then decline gradually by two thirds during the rest of the century. This forecast is determined by the totality of model developments: including the peak in population and energy use, continuing GDP growth and so on.

It is interesting to note the steady decline in "CO2 per GDP" (blue curve to the right) which measures the true climate efficiency of the economy. This indicator has come down dramatically since 1980 - from 0.65 kilogram per dollar of GDP then to 0.38 now. We expect this decline to accelerate a little in the future base run[22].

Another indicator of interest is the "fraction of low-carbon electricity" - the amount of sun, wind, hydro, biomass and nuclear as a fraction of total electricity. In the base run this fraction grows from some 30% in 2020 to 60% in 2060. Thus, unless there is truly extraordinary action, by 2050 half of the world's electricity will still come from low-carbon sources and one half from fossil fuels, in spite of the much repeated much higher political ambitions.

[22] Which means that in this particular case we believe there will be a limited positive deviation from the "traditional decision-making style".

Global warming

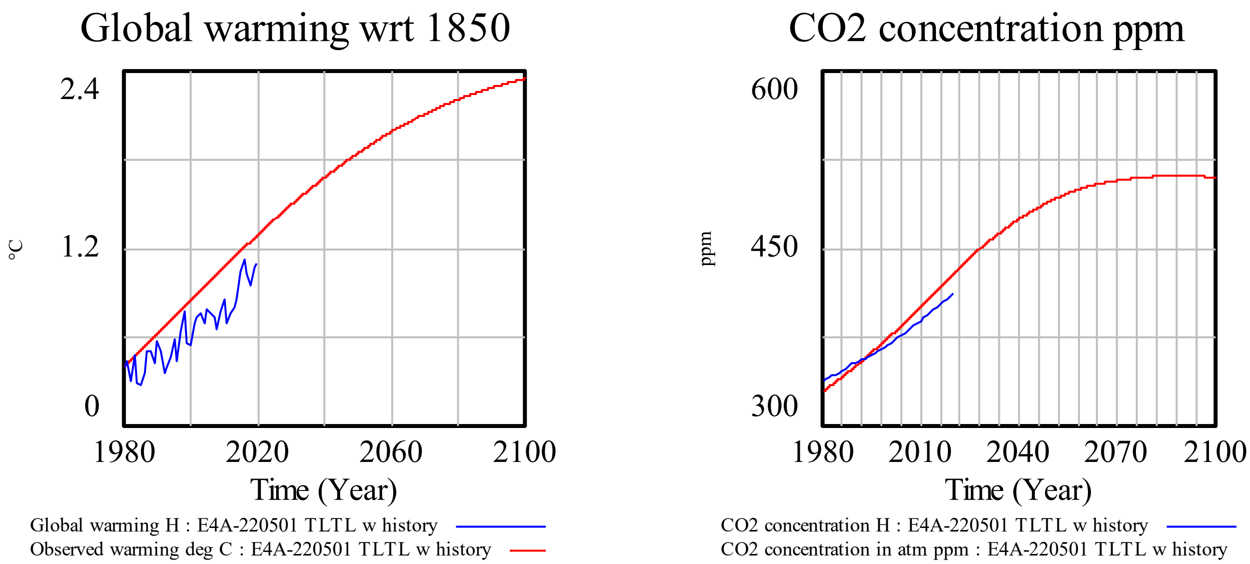


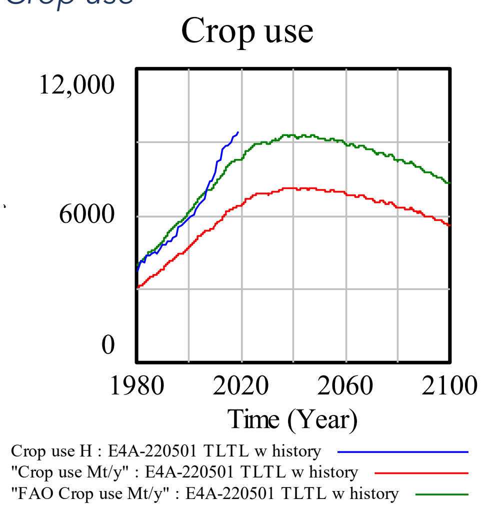
Figure 29: Temperature rises with concentration of CO2 in atmosphere.

Figure 29 shows the result for the rise in the global average surface temperature (GAST) in the base run. The temperatures continue to rise throughout the century, but at a declining rate. The warming occurs in the E4A model because of rising concentrations in the atmosphere of CO2 and other greenhouse gases – like in the real world. Continued warming at the pace foreseen in the base run would imply ever more scary and ever more extreme weather as the decades pass – draughts, floods, forest fires, snow cover melt, sea level rise, acidification, dieback of forests and coral reefs, and so on.

The red curve is model output, the blue curve is what actually happened over the last forty years. We plan to adjust the E4A model to obtain a better match between the two[23]

[23] This means to adjust the climate sector in the E4A model so it better mimics the output from our detailed climate model ESMICON. This will be part of the next update. Randers J, Goluke U, Wenstøp F, Wenstøp S. 2016. ”A user-friendly earth system model of low complexity: the ESCIMO system dynamics model of global warming towards 2100”. *Earth System Dynamics* Vol 7, pp 831–850 https://doi.org/10.5194/esd-7-831-2016

Crop use



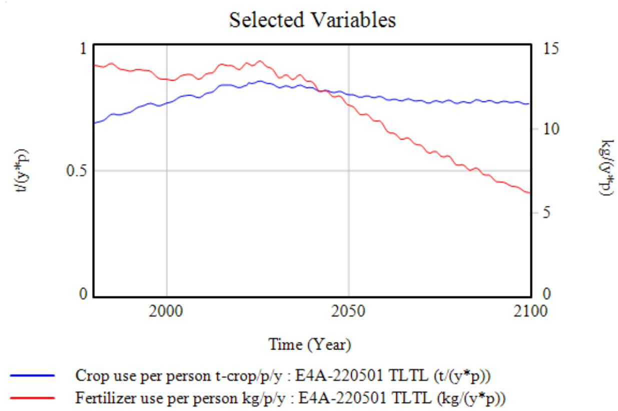


Figure 30: Crop use determined by demand and input use.
Source: FAO data and UN Populations statistics

Figure 30 shows the total use of crops – both for food and feed. In the E4A model the demand for food equals the number of people times crop demand per person – which is a function of income and peaks around 20.000 2017PPP$/p/y. Demand is also influenced by societal decisions to reduce waste, to reduce the use of red meat, and continuing rise in agricultural productivity.
The crop supply is driven by demand and comes from the use of cropland (with high yields determined by fertilizer use), plus feed from grazing land (with low yields determined by nature). If there is not enough food in the E4A model, society seeks to expand croplands and intensify land use, which gets increasingly difficult as the world approaches full use of its agricultural resources.

In the based run, annual crop use (red curve) rises to a peak some 30% above current use. This results because the population peaks, because per capita use stagnates (around 1 ton of crop per person per year) when people get rich, and because there is a steady shift towards more efficient agriculture. The historical data (blue curve) comes from FAO data and deviates from model output because FAO defines "a ton of crop" in a different manner than we do. If we multiply our definition of "a ton of crop" with the constant factor 1.4, we get the "FAO use of crops" (green curve) which matches history somewhat better[24].

To the right in Figure 30 you see two other aspects of crop use in the base run - crop use per person (stagnating as income rises) and fertilizer use per person (declining as fertilizer use per crop is reduced as regenerative agricultural practices gain ground).

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[24] We include this discussion statistical problems in order to highlight the point that the FAO agricultural time series data, which is the best there is, is plagued with internally inconsistencies that he makes them very difficult to use as a quality check when you are trying to build a causal model which is consistent over time.

Cropland

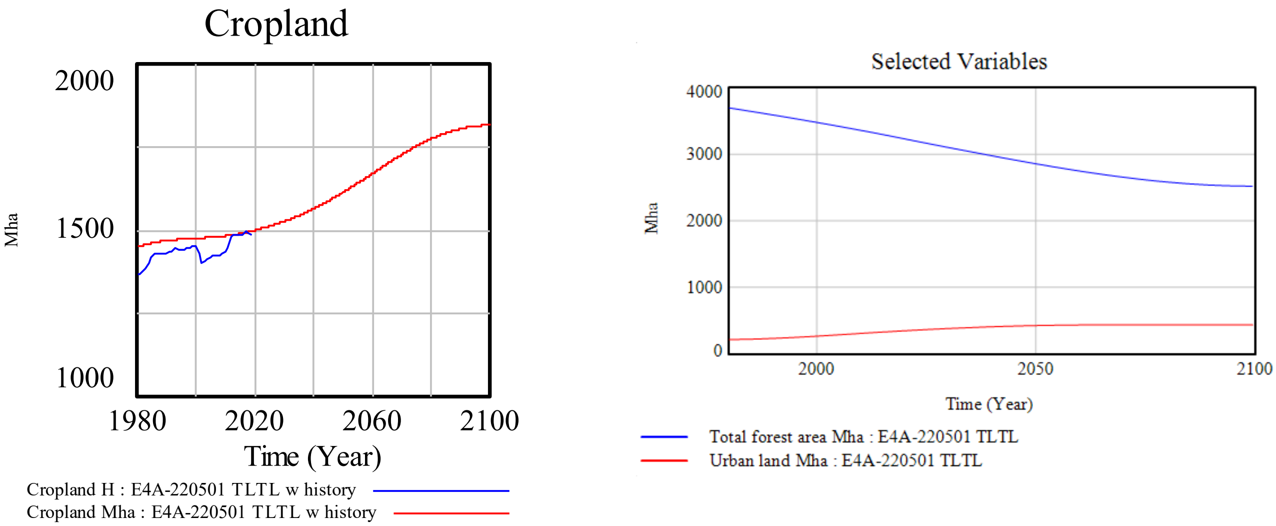

Figure 31: Rising use of land for crops and cities reduces forest land.
Source: E4A model simulations, FAO data and UN Populations statistics

Figure 31 shows the amount of cropland used in the E4A model (red curve) compared to historical data (blue curve). Over the last forty years the area of cropland has been relatively stable around 1300 - 1500 million hectares (Mha), but during the same time food production has more than doubled. This is mainly because of increased use of fertilizer.

Going forward in the base run there is need for more cropland because we have reached saturation in the use of our fertilizer in parts of the world. More cropland in E4A means the need to cut more forest. If you look to the right in Figure 31 you see remaining forest area (blue curve) declining – indicating a decline in remaining biodiversity – while the urban land and waste land (not plotted), are increasing. In sum, the base run shows a global shift from undisturbed forest to destroyed land.

Wellbeing

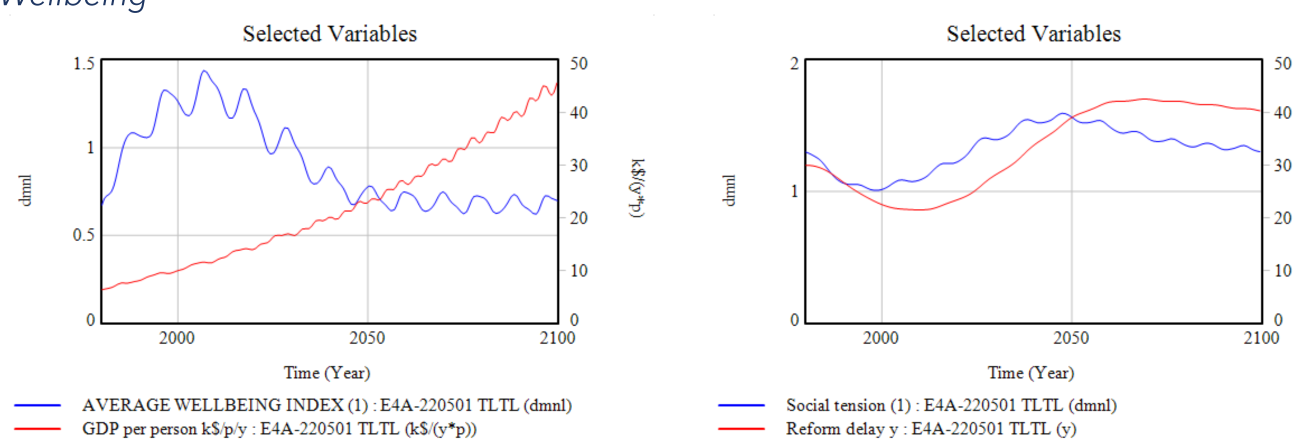

Figure 32: Wellbeing declines even though income rise.

And then, finally, we can calculate the sum of it all, our chosen performance indicator, which is the average wellbeing index (red curve to the left). You see that the average wellbeing index rises from 1980 to 2010, then plateaus before it declines towards 2050 and remains at a low level. This is because worker benefits - both disposable income and public services per person - are increasing and improving the situation. But as the decades pass, the negative influences become more intensive: more warming and more inequality. Ultimately, the two negative effects overwhelms the two positive effects, and wellbeing declines.

The graph to the left shows what happens to GDP per person (blue curve) in the E4A model in the base run during the next 30 years. Notice first that GDP per person continues to grow, because the economy expands and physical labor productivity rises. But at the same time, wellbeing – our new and wider welfare measure – is going down. This indicates how difficult it is to use GDP per person is as your only indicator when your goal is to increase human wellbeing.

To the right, you see another important indicator: the social tension indicator (blue curve). In the E4A model social tension is modelled as the derivative (the rate of change in % per year) of wellbeing – with a minus in front. So, when wellbeing is rising from 1980 to 2010, you see social tension going down. And when wellbeing is declining from 2020 to 2050, you see social tension rise. When wellbeing levels off, so does social tension.
In all the wellbeing and social tension graphs you see the 10-year Juglar cycle on top of the long trends.

7. Model base run: assuming decision-making as usual

The base run (aka: Too Little Too Late scenario)

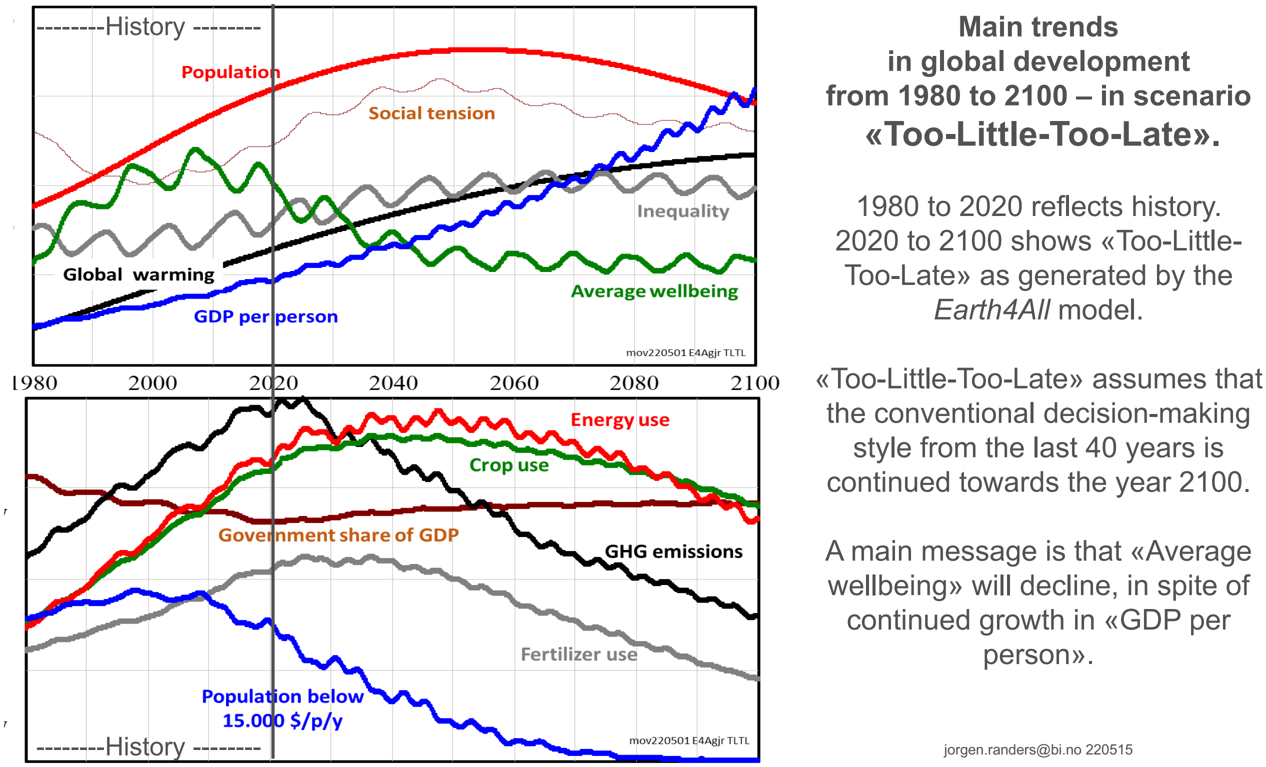

Figure 33: Output from the model run.

The last figures have provided a glimpse into the detailed working of the E4A model. The presentation illustrates how much more time we would need to go through all model variables (some 200 important ones). And more important illustrates the need for an overview. We will give you two: The overall dynamics of the base run, and (at the end of the paper) the high-level causal structure that captures the essence of the E4A model.

First, the overall dynamics of the base run. Figure 33 (top panel) repeats the six main variables shown initially: the peaking population, the growing GDP, the rising global average temperature, the rising inequality, and the resulting average wellbeing which goes up and then down – in opposite pace to social tension. Hopefully you now understand more about how we calculate those variables.

In the bottom panel we show the path of six other model variables. The blue curve at the bottom is the one that interests most people outside the West. This is the number of people that are below $15,000 in GDP per person per year. 15,000 2017PPP$/p/y is (approximately) the income necessary in order to satisfy human wellbeing as defined in the UN Sustainable Development Goals[25]. Societies that exceed $15,000 typically satisfies most of the Sustainable Development Goals. $15,000 is interestingly the current GDP per person in China. And, furthermore, also the current world average! To compare Europe is around $40,000, United States is at $60,000 and Norway is even beyond this. South Asia and Africa South to Sahara are down around $4,000-6,000 per person. Needless to say, there is huge regional variation.

The graph shows that the number of people below 15,000 2017PPP$/p/y has come down a little bit during the last forty years and will - in the base run - decline to zero during the next forty years or so. This is how fast global poverty will disappear if there is no truly extraordinary action.

The graph furthermore shows how energy use peaks (red curve), how crop use peaks (green curve), how the government share of GDP (brown curve) rises a little bit (because even in the base run, after the end of the liberalization wave nations start to spend tax money on what is needed cut emissions and inequality). The fertilizer use (grey curve) declines because nations reduce waste, to make the transition to red meat and to introduce regenerative agriculture at the speed which is profitable. The speed is not impressive, but helpful.

Finally, the greenhouse gas emissions (black curve) follow what we see as the surprise-free path – that is the path without any truly extraordinary action. In the base run, emissions peak in this decade, are cut by 25% by 2050, and then by another 30-40% by the year 2100. This is way below current ambitions recommended by IPCC. In other words, we fear that continuation of past decision-making styles will not keep global warming below the levels recommended by the Paris agreement.

[25] Collste, D., Cornell, S. E., Randers, J., Rockström, J., & Stoknes, P. E. (2021). Human wellbeing in the Anthropocene: Limits to growth. *Global Sustainability*, 1–17. https://doi.org/10.1017/sus.2021.26

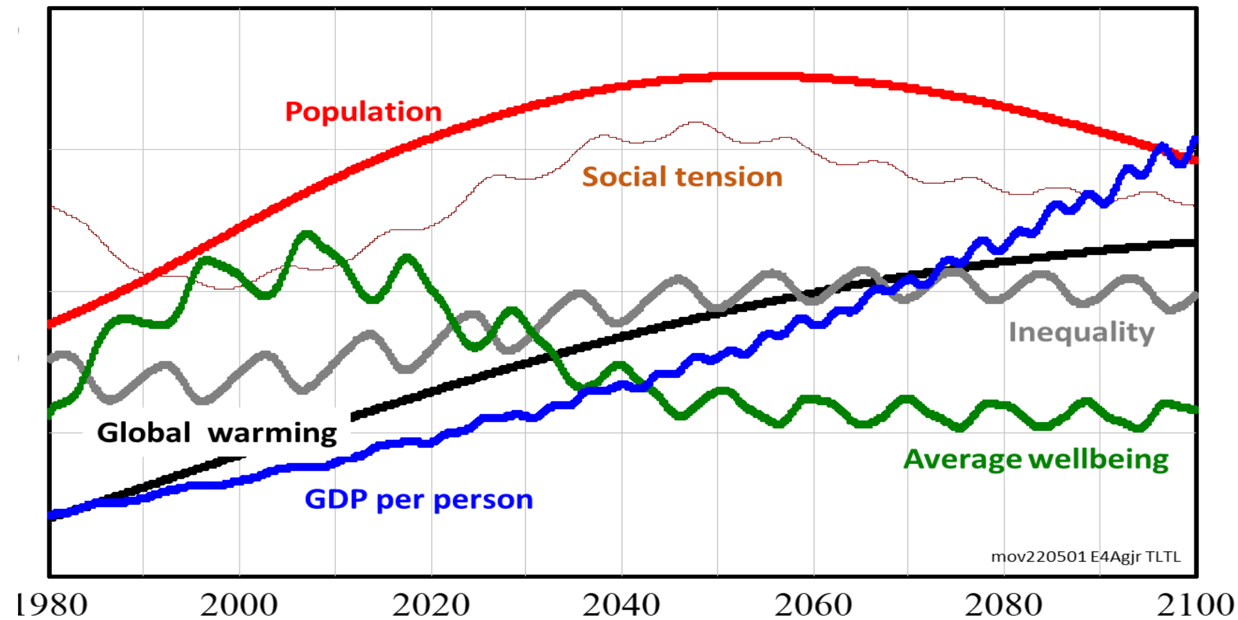

Figure 34: Main trends in global development – Too-Little-Too-Late

Figure 34 is included to simplify presentation of the first scenario of the *Earth for All* study.

8. Model solution run: testing policy for higher wellbeing

Ideas for improved wellbeing

So, we have the E4A model – an approximate, model of long-term trends in human wellbeing – which indicates a downwards trend in wellbeing over the next forty years or so. It is tempting to use the model to explore possible ways to reverse this downwards trend, which will differ in detail among regions, but appear likely both in the rich and the poor world.

1. Eliminate global poverty (Use new growth models: more plan less market)
2. Stop climate change (Replace fossils with wind and sun, efficiency, and CCS)
3. Halt biodiversity decline (Introduce regenerative agriculture to protect remaining forests)
4. Stop population growth (=reduce consumption pressure) (More education, health, contraception and opportunity to women)
5. Reduce inequality (Make the rich pay for higher wellbeing for the working majority)

Figure 35: Five ideas for improved wellbeing in the long run.

In light of the dynamics in the base run of the E4A model and their causes, it appears reasonable to explore a number of (oft-repeated) policy ideas[26]: 1. Eliminate global poverty, 2. Stop climate change, 3. Halt biodiversity decline, 4. Stop population growth, 5. Reduce inequality (Figure 35).

Poverty alleviation

The first idea is to eliminate global poverty, which primarily amounts to reducing the number of poor people (defined as the number living with a GDP per person below 15,000 2017PPP$/p/y). This has been attempted for decades through conventional development theory and assistance, without much success. It appears necessary to explore new growth models, involving more plan and less market. Moving away from traditional market-based strategies, and following the lead of China, Costa Rica, or Norway between 1945 and 1965 which all built the nation according to plan, instead be dominated by free market thinking.

Stopping climate change

The second idea is to stop climate change, which primarily amounts to stopping emissions from the burning of fossil fuels (coal, oil and gas). This means to replace fossil electricity with renewable electricity (primarily from sun, wind, hydro and biomass) and fossil heat with renewable heat (from biomass, from green hydrogen, and blue hydrogen (from fossil gas using CCS to sequester the carbon). The task is made simpler by continuing focus on efficiency.

Preserving biodiversity

The third idea is to halt biodiversity decline, which primarily amounts to preserving the world's remaining old growth forests (and coral reefs). This means to manage within existing cropland area and existing fertilizer use, and rather reduce waste and red meat consumption. Plus accelerate through subsidies and education, "regenerative agriculture" (defined as sustainable intensification practices).

Stopping population growth

The fourth idea is to stop population growth, in order to make sure long-term consumption demand will not exceed planetary boundaries. This amounts to supplying education, health, contraception and opportunity to all women of the world. In order to make families feel safe when they choose to have much fewer children (to support them at old age). The last forty years have shown that this approach to population control works very well: average fertility has fallen from 5.5 to 2.5 children per woman as a world average.

Reducing inequality

The fifth idea – to reduce economic inequality – is as simple in principle as it difficult in the real world of conflicting interests between workers and owner. It means to take

[26] All of these ideas are discussed in our earlier studies of the global future (see Appendix 1)

from the rich and give to the poor. Or more acceptably put: Make the rich pay for higher wellbeing of the working majority.

This far it has proven impossible to gather broad support for such unconventional and unpopular action, and agreement to pay the cost.

The 5 Turnarounds

One ambition of the current Earth for All project was to promote a (political) program that is intended to improve the wellbeing of the working majority on a finite planet during the next 50 years. The end result of the discussion about what policies to include in the program was a focus on "5 Turnarounds" - five transformational changes that would create a better world than if the current decision-making style is continued. The five are the Poverty turnaround, the Inequality turnaround, the Empowerment turnaround, the Food turnaround, and the Energy turnaround. They are described in detail in the *Earth for All* book. In sum they constitute a "transformation of the modern economy" also described as "a full upgrade".

A solution run (aka Giant Leap scenario)

The 5 Turnarounds in the Earth for All study

Poverty Turnaround:
Accelerate GDP growth in countries with less than 15 k$/p/y using modern technology –debt cancellation, new development models, more industrial policy and infant industry protection
Inequality Turnaround:
Take from the few rich and give to the many poor – higher taxes on owners used to improve the wellbeing of the working majority
Empowerment Turnaround:
Improve the quality of life for women so they prefer to have few children – more education, health, contraception, and opportunity
Food Turnaround:
Reduce the annual crop needed to feed everyone the diet they demand – more efficiency, less waste, less red meat, more regenerative agriculture
Energy Turnaround:
Reduce the GHG emissions from the energy production that is needed to give everyone the energy supply they demand – more efficiency, more electrification, more renewables, more CCS.

Figure 36: The five turnarounds.

Figure 36 describes the content of the 5 Turnarounds and in Appendix 2 we show the parameter changes we made in the E4A model to move from the base run (Too Little Too late) to a solutions run (Giant Leap).

In the following 9 figures we show the effect in the E4A model of the change from Too Little Too Late policies (blue curves) to Giant Leap (GL) policies (red curves).

Poverty reduction

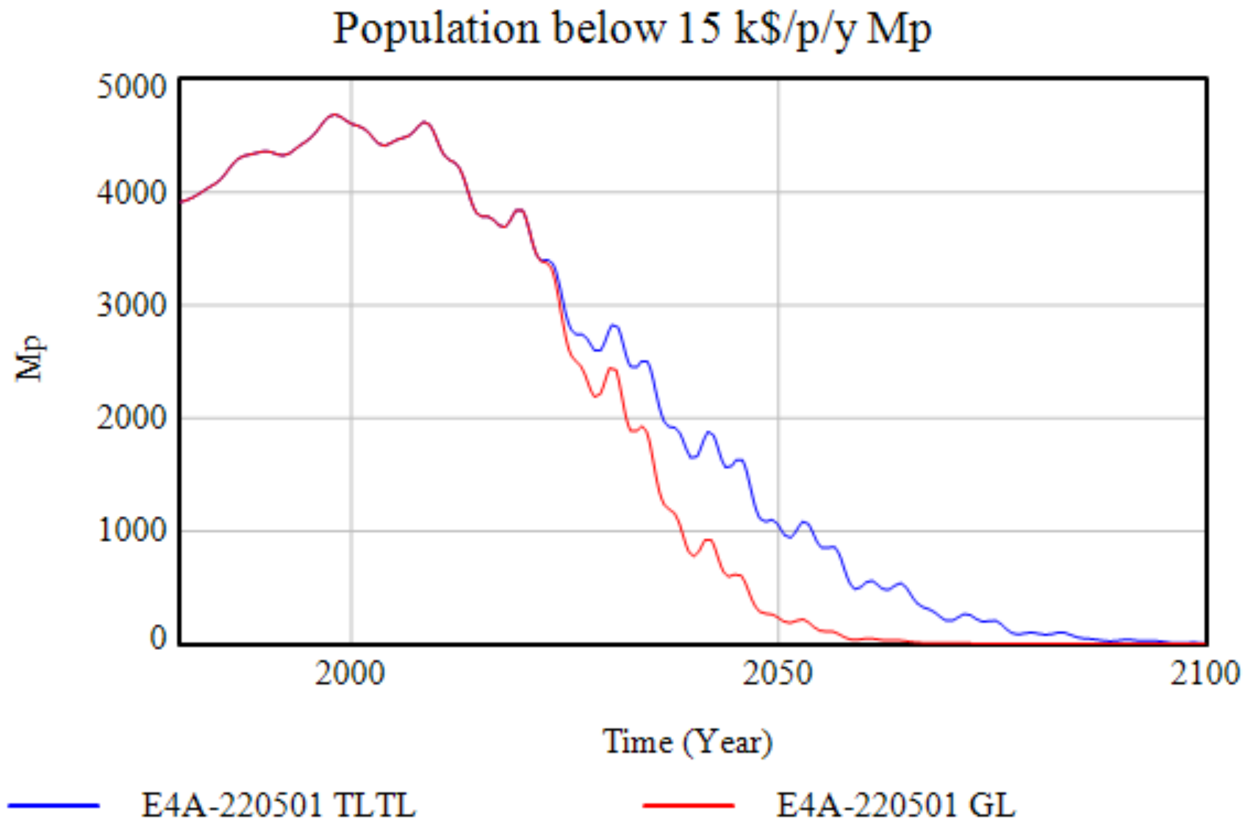

Figure 37: Poverty reduction in Giant Leap relative to TLTL.

The Giant Leap policies eliminate global poverty by 2050, which is 30 years earlier than in TLTL, and largely due to the use of new development models with more planning and state action (Figure 37).

Inequality reduction

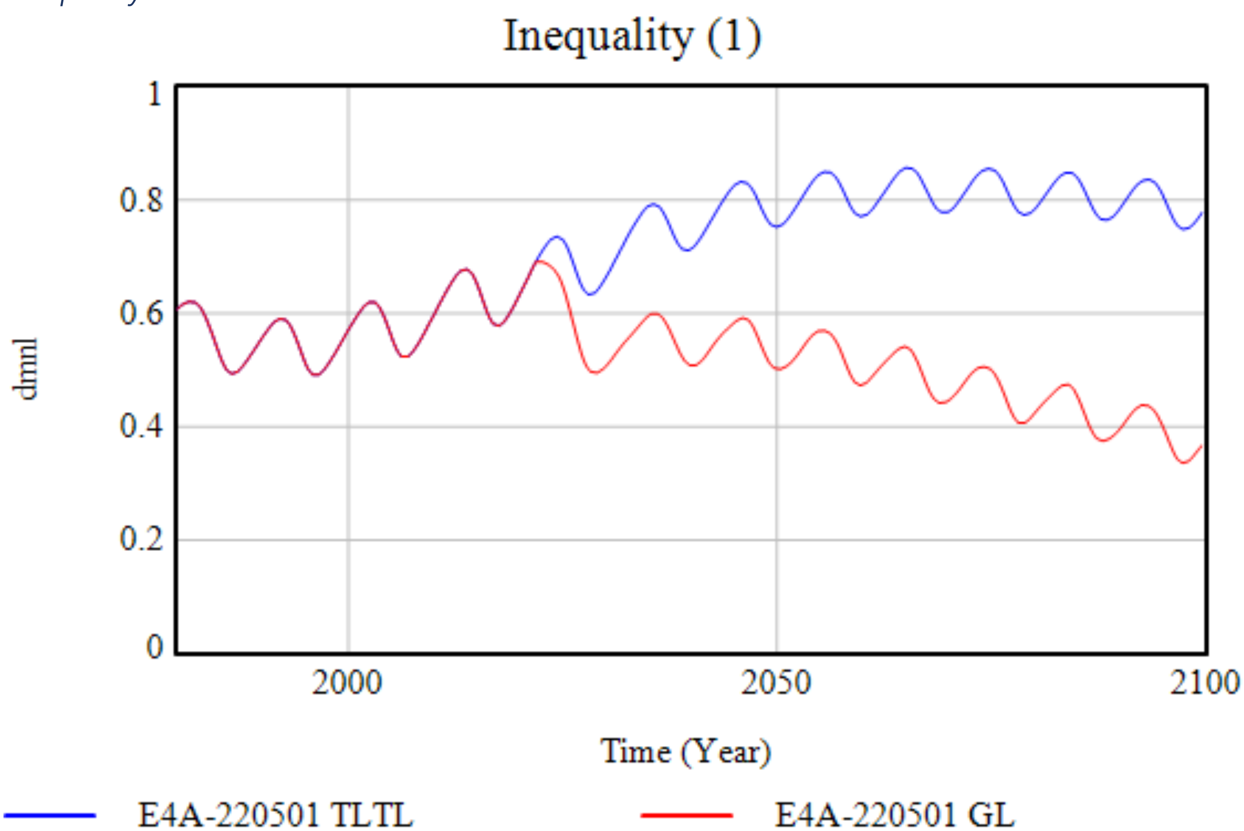

Figure 38: Inequality reduction in Giant Leap relative to TLTL

Inequality is reduced because of the shifts in taxation and strengthening of labor, Figure 38.

Desired number of children

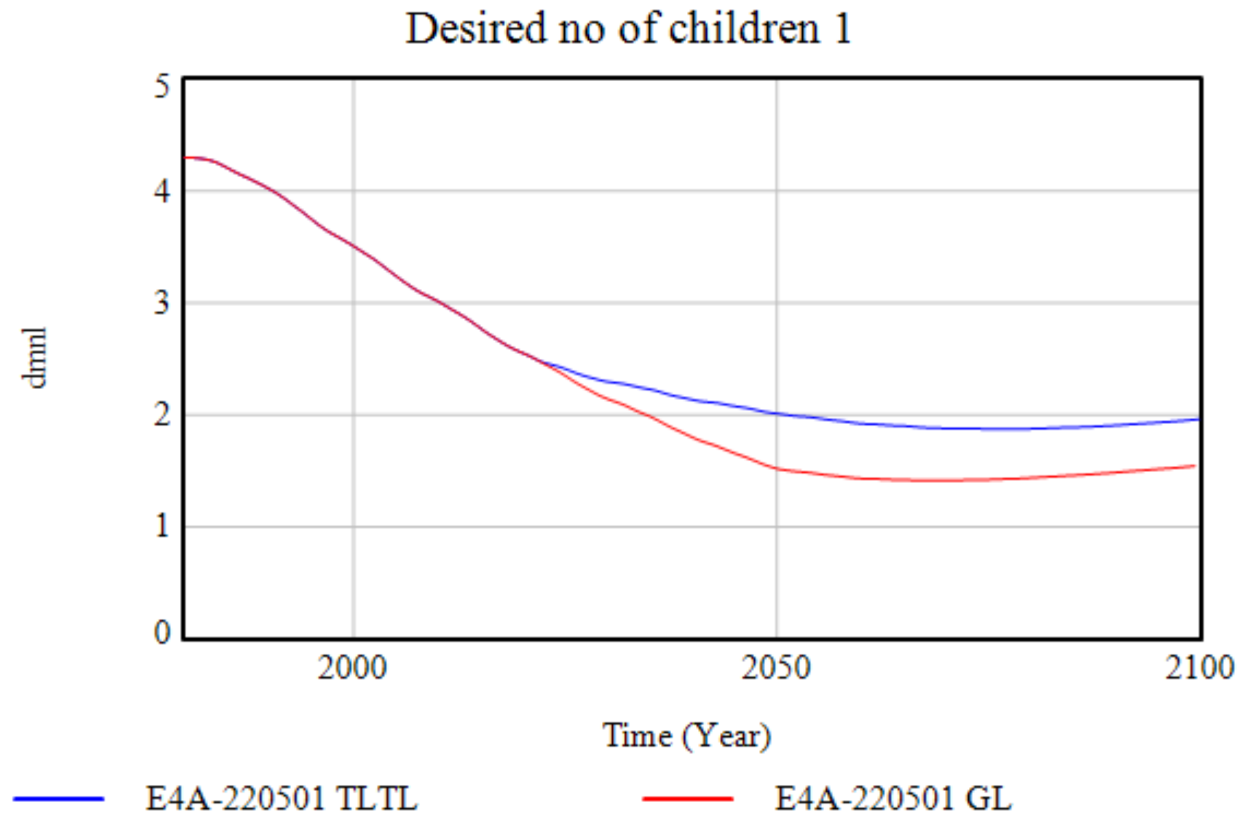

Figure 39: Fertility reduction in Giant Leap relative to TLTL.

Figure 39 presents the effect of introducing more health and education. Instead of ending up around two children per woman during her reproductive life, the world average declines to one and a half. This causes the population to decline somewhat faster in the second half of the 21st century.

Total forest land

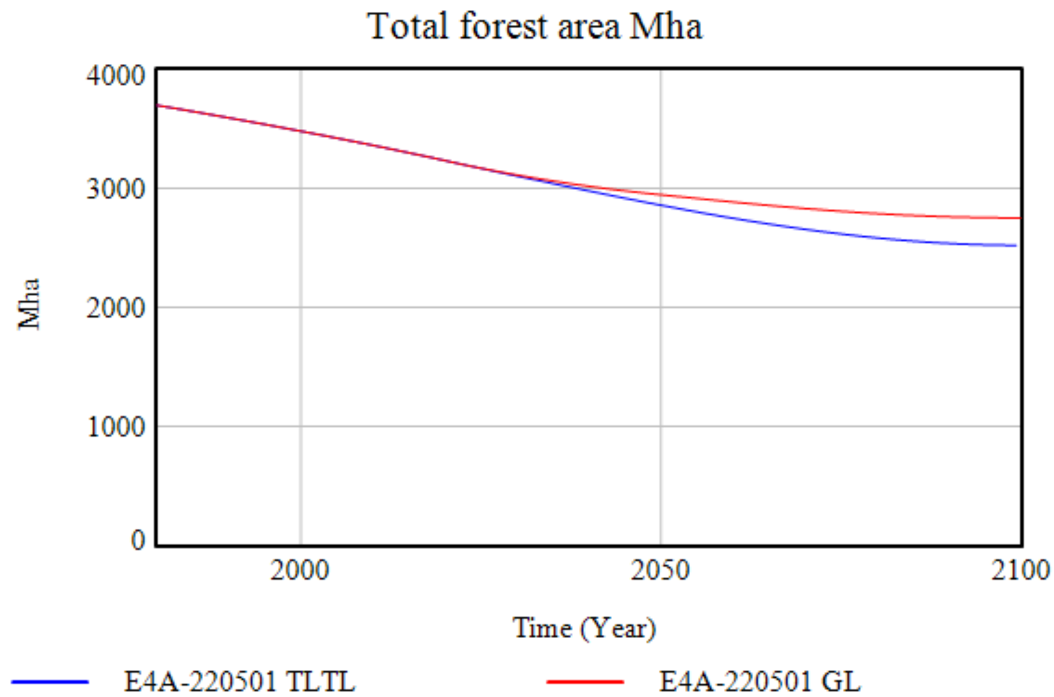

Figure 40: Forest land increase in Giant Leap relative to TLTL.

The Giant Leap contributes towards stopping the loss of old growth forests, and hence the loss of biodiversity, Figure 40.

Greenhouse gas emissions

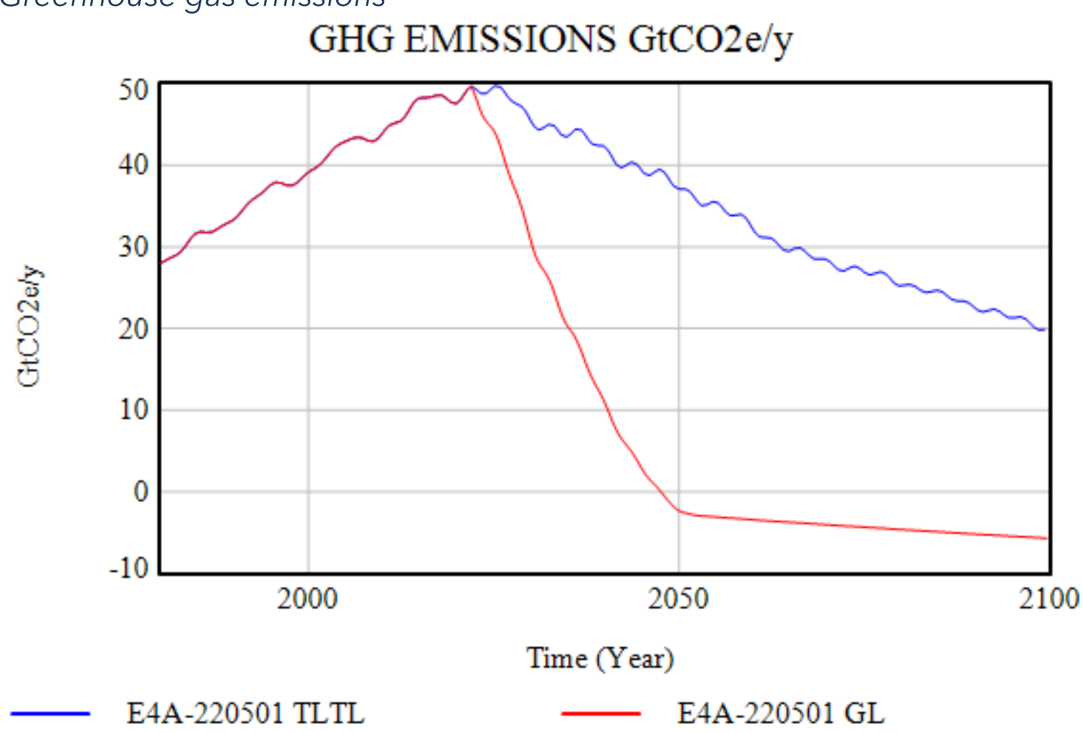

Figure 41: GHG emissions reduction in Giant Leap relative to TLTL.

Figure 41 shows the spectacular decline in emissions that can be achieved by acceleration of the investments in renewable energy, electrification, and energy efficiency. wind and sun. Greenhouse gas emissions are cut by some 90% by 2050. But please notice that in order to achieve this result in the E4A model, we needed to assume large-scale, carbon capture and storage on most direct use of fossil fuels from 2050, and also significant direct air capture of CO2 from the atmosphere. Without such (unrealistic?) action the E4A model gives a much higher temperature at the end of the century.

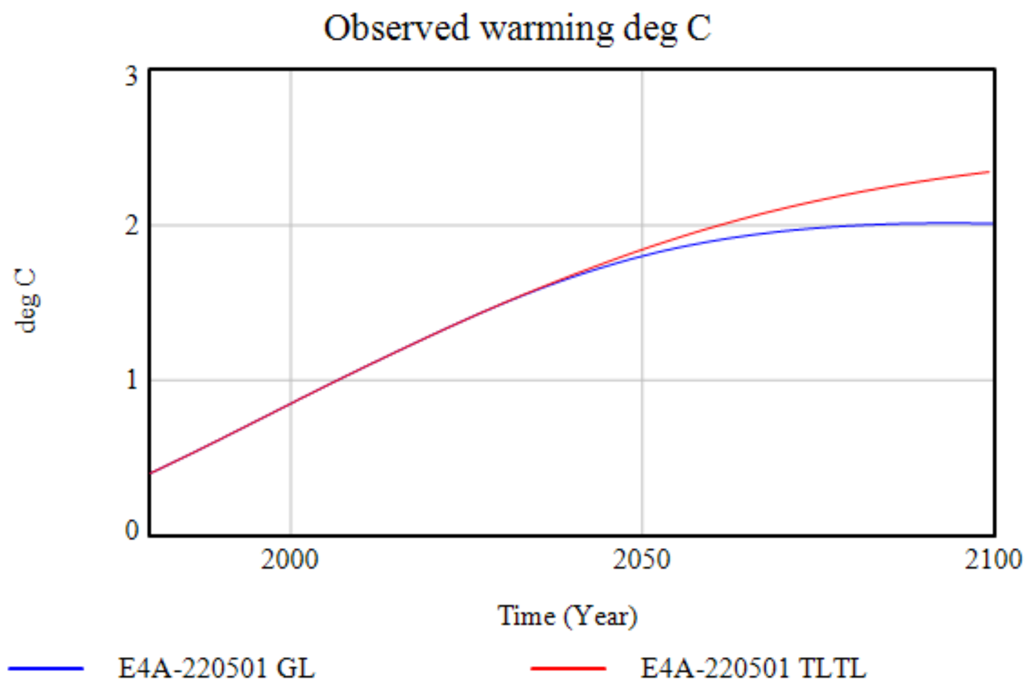

Figure 42: Global warming I Giant Leap relative to TLTL. Please note that in this figure, the colors are switched. TLTL should be blue, GL should be red.

Figure 42 shows that the extraordinary action in the Giant Leap scenario is sufficient (in the E4A model) to lower the rate of increase in the global average surface temperature, and make it stabilize before the end of the century.

The average wellbeing index

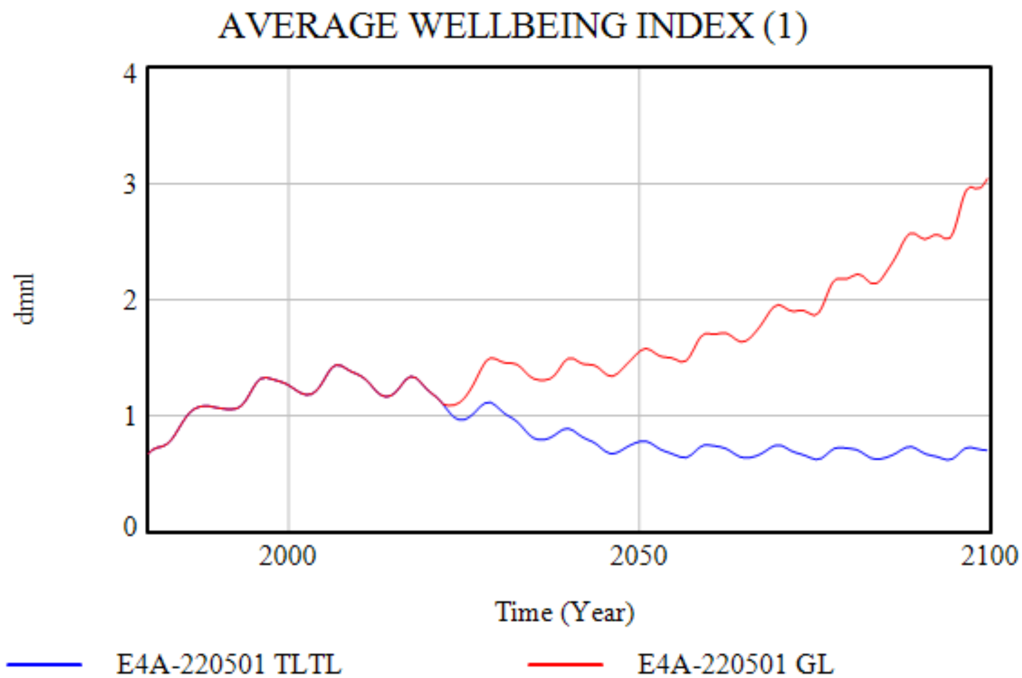

Figure 43: Wellbeing increase in Giant Leap relative to TLTL.

The total effect of the implementation of the 5 Turnarounds in the E4A model is to stabilize the level of wellbeing during the next 30 years, and then make it rise in the second half of the century because of the removal of poverty, lower warming and less inequality, Figure 43.

Reduced social tension

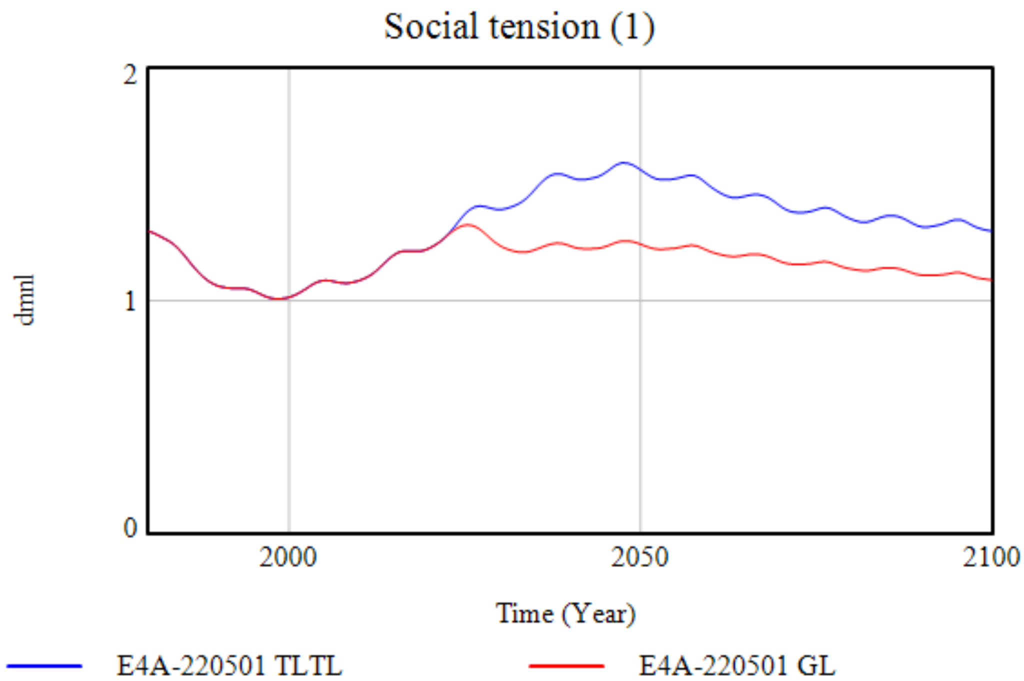

Figure 44: Reduced social tension in Giant Leap relative to TLTL.

Social tension is reduced as a consequence of growth in wellbeing, thereby facilitating the implementation of further government action to improve the situation for the working majority, Figure 44.

The Giant Leap Scenario: summary graph

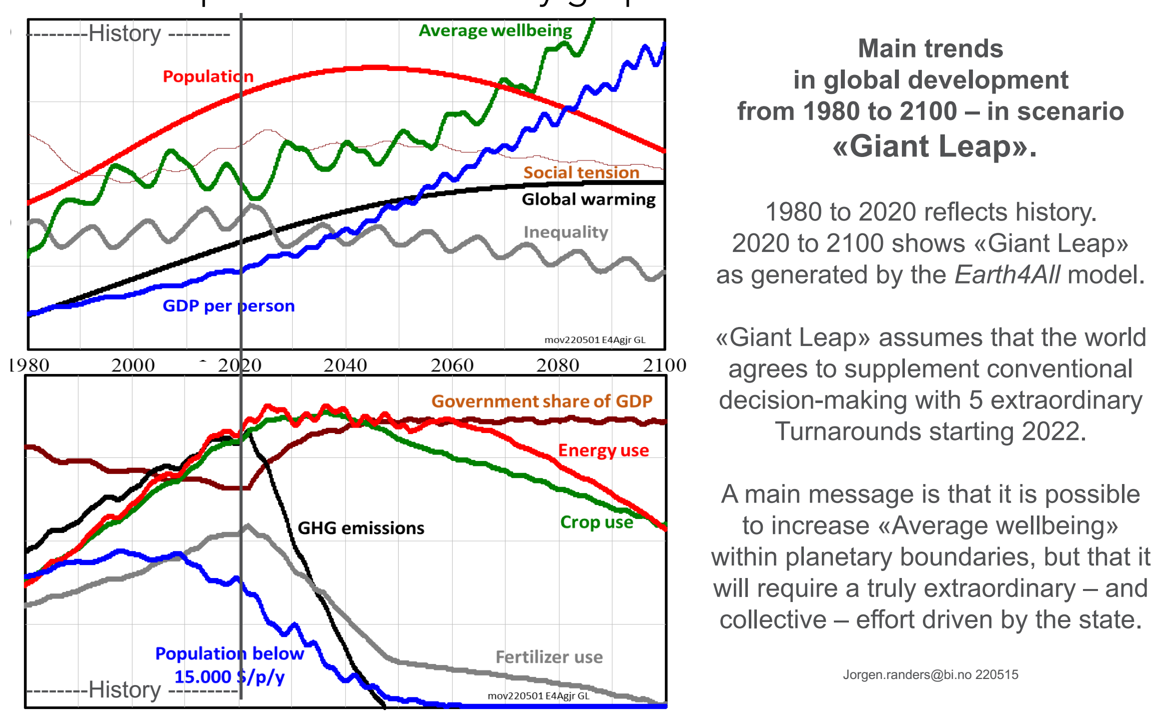

Figure 45: Main trends in global development based on the Giant Leap scenario.

Figure 46 summarizes the Giant Leap scenario.

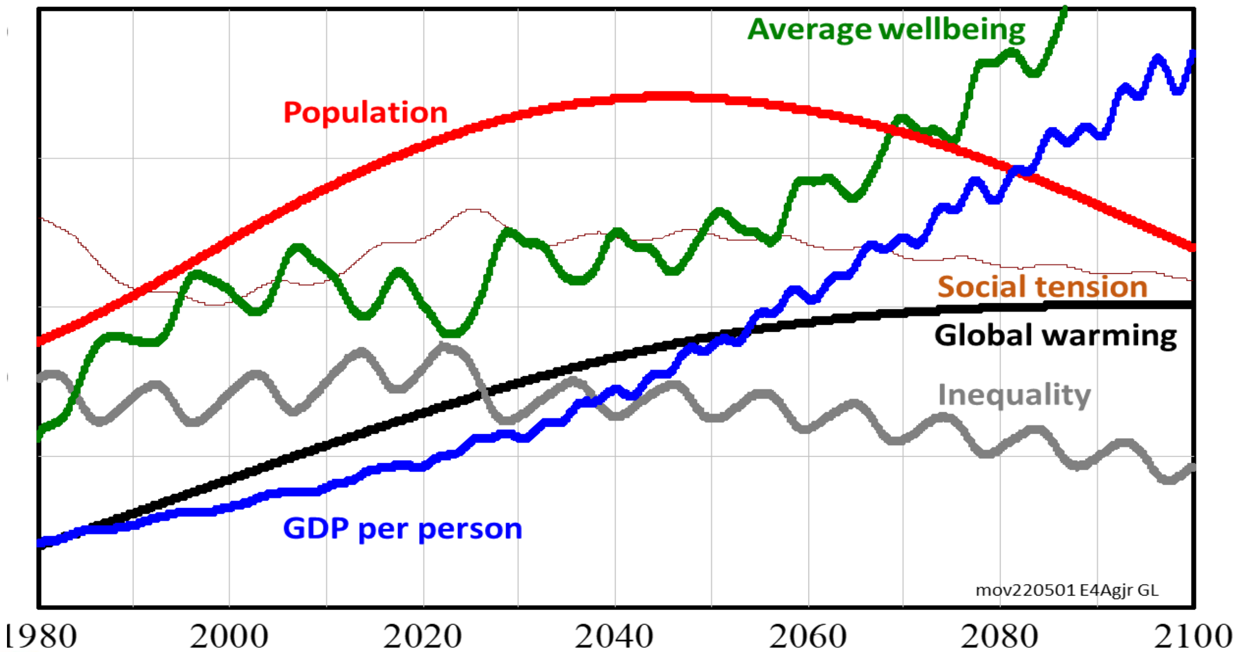

Figure 46: Main trends in global development – Giant Leap

We try to convey the message that in the E4A model system, it is possible to turn the declining trend in wellbeing by acting on the five fronts of poverty, inequality, empowerment, food, and energy.

Whether this is possible in the real world, is an open question. All we can tell from a model builder's perspective is that the turnarounds work in the E4A model, and that the resulting dynamics appear plausible. However, the individual numerical values at specific points in time are not reliable and should be given less emphasis. The model is shared in order to promote its use and enable changing its underlying assumptions and ask "what-if" questions.

Implementing the five turnarounds would amount to a true transformation of the world societies. If implemented with speed and strength we believe they could remove global poverty, halt global warming, and slow global biodiversity loss within forty years.

We believe the main challenge in the decade ahead will be to obtain the necessary public funds to pay for the transformation. We present various solutions (including higher taxes on the rich, more government debt, printing money earmarked for green activity, innovative ways of redistributing existing income and wealth – see Appendix B). The real hurdle in the real world of politics may be to gather a voter majority for one or more of these solutions. And in the very long run, truly unconventional solutions - like printing of money earmarked for green purposes – may win forth simply because they push the cost onto the rich minority and shield the majority.

9. Discussion: insights gained from model use

In the following sections we discuss insights we have gained from building and using the E4A model. The topics are extensive and require more space than available in the current introduction to the E4A model. Most of the following insights will be further developed over the years ahead.

Cost: Assessing the cost of policy change

The cost of implementing the five ideas discussed above – which basically equals the cost of achieving global sustainability – has been discussed for decades[27]. The cost has two components – a monetary cost and the cost of forced behavior change – and depends on the time horizon used in the calculation. We believe the most useful way to describe this cost is to say that achieving sustainability will require a shift of 2 – 4 % of global labor and capital from conventional activity to green activity (eg from building fossil capacity to building sun and wind, from cultivating the soil in industrial ways to regenerative ways)[28]. The cost equals the cost of shifting labor and capital from what is profitable to what is needed to create higher wellbeing in the long run.

There is a monetary cost involved in this shift because the green jobs typically have lower labor productivity (output per person hour) in the short run. Because of this cost barrier, it will require subsidies and bans ("collective action") to make the green shift happen at speed and scale in a market economy.[29]

Other current sources, like the IPCC and IEA, support the view that the cost of the energy and emissions transformation is of the order of some percentage points of global GDP.[30]

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[27] Vorisek and Yu (2020) present some of the estimates in relation to achieving development goals including the SDGs. Vorisek, D., & Yu, S. (2020). *Understanding the Cost of Achieving the Sustainable Development Goals*. World Bank, Washington, DC. https://doi.org/10.1596/1813-9450-9164

[28] In more detail: The green shift involves moving labor and capital from current activities to greener and more equitable ("sustainable") activities that have lower labor productivity than current activities. The result is slightly lower consumption growth in return for a more sustainable (greener and more equitable) world economy.

[29] Since this green shift is not seen by investors as profitable or cost efficient using current calculation methods

[30] According to the 2019 IPCC Special report, "pathways limiting global warming to 1.5°C are projected to involve the annual average investment needs in the energy system of around 2.4 trillion USD2010 between 2016 and 2035, representing about 2.5% of the world GDP (*medium confidence*)".
IPCC. (2019). Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. https://www.ipcc.ch/sr15/download/.

The International Energy Agency (IEA) estimates that the total annual capital investment in energy in order to reach net zero emissions by 2030 needs to increase from 2.5% of global GDP in recent years to 4.5% in 2030, before falling back to 2.5% by 2050. IEA. (2021). *Net Zero by 2050* (p. 224). https://www.iea.org/reports/net-zero-by-2050

Since the world's 10% richest people control 50 % of global income[31], the total cost of 2 – 4 % can be covered by an extra tax of 4 – 8 % on the 10% richest of the world. Such a tax increase will of course be fiercely resisted and, we believe, is unlikely to be adopted. Still, it is important to know that it is possible for an informed majority to pass legislation that would create higher wellbeing for the majority in the long run, without any direct cost to themselves.

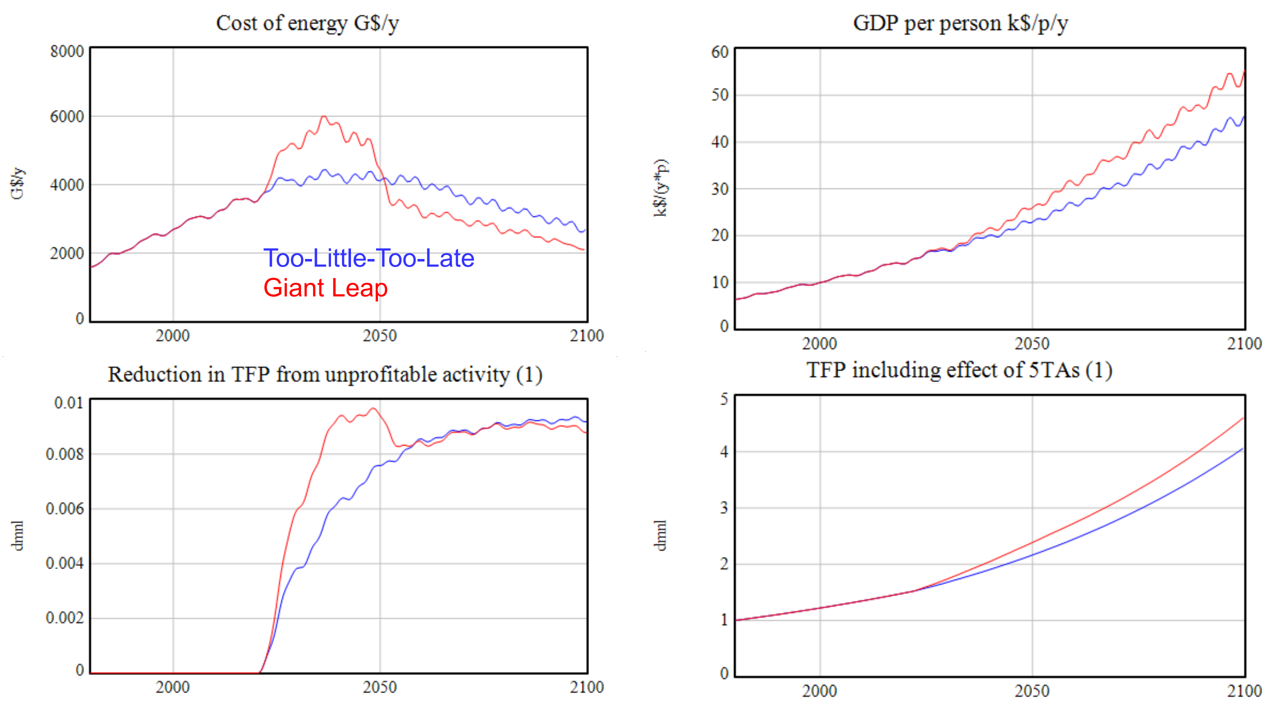

Figure 47: What will it cost? A shift of L&K to less productive sectors.

Figure 47 shows the time profile the some of the costs involved. The time profile is more significant than the absolute values indicated, more reliable and more interesting.

The blue curve (top left panel) shows that in the Too Little Too Late scenario the cost of energy stays around $4 trillion per year over the next thirty years, before declining towards the end of the century. In the Giant Leap, with its strongly accelerated introduction of renewable energy, CCS and air capture, the cost of energy rises, adding roughly $2 trillion per year (around 2% of the world GDP). But it only takes some thirty years before the operating costs of the new low-carbon energy system is much lower than the fossil alternatives. In other words a situation where the current generation carries the cost of transforming the energy system, while the next generation gets the benefit of a much smaller energy bill. This time profile is politically

[31] Chancel, L., Piketty, T., Saez, E., Zucman, G. et al. World Inequality Report 2022, World Inequality Lab.

important, because it means we have to make sacrifices today which leads to benefits thirty years in the future.

Many are worried that GDP - the level of economic activity – will decline if the world decides to face the sustainability challenge. Figure 47 (top right panel) shows that this is not the situation in the E4A model. The Giant Leap policies lead to an increase in the total GDP – that is to higher economic growth rates – than Too Little Too Late. Very roughly speaking, this is because the Giant Leap involves higher investment growth at the cost of some reduction in consumption growth.

Figure 47 (two bottom panels) illustrates what happens in conventional economic terms. What we're doing when we use labor and capital to solve problems that are not profitable is actually to deliberately lower productivity, lower labor productivity. Moving people from high productivity to lower productivity activity. In macroeconomic terms, this amounts to a reduction in is the "total factor productivity". But the reduction in the short term only lasts for some twenty years before it is overwhelmed by productivity rise from learning.

Inequality: Comparing different measures

There exist several commonly used measures of inequality. Our measure, the Inequality Index defined as owner income after tax divided by worker income after tax, has a relatively straightforward relation to the GINI index and to the Palma Index. All three increase when national income is concentrated in the hands of the richest part of the population. During the liberalization period since 1980, inequality has risen in many parts of the world because the worker share of income has decreased, social security has ceased and because taxes on the rich have been lowered.

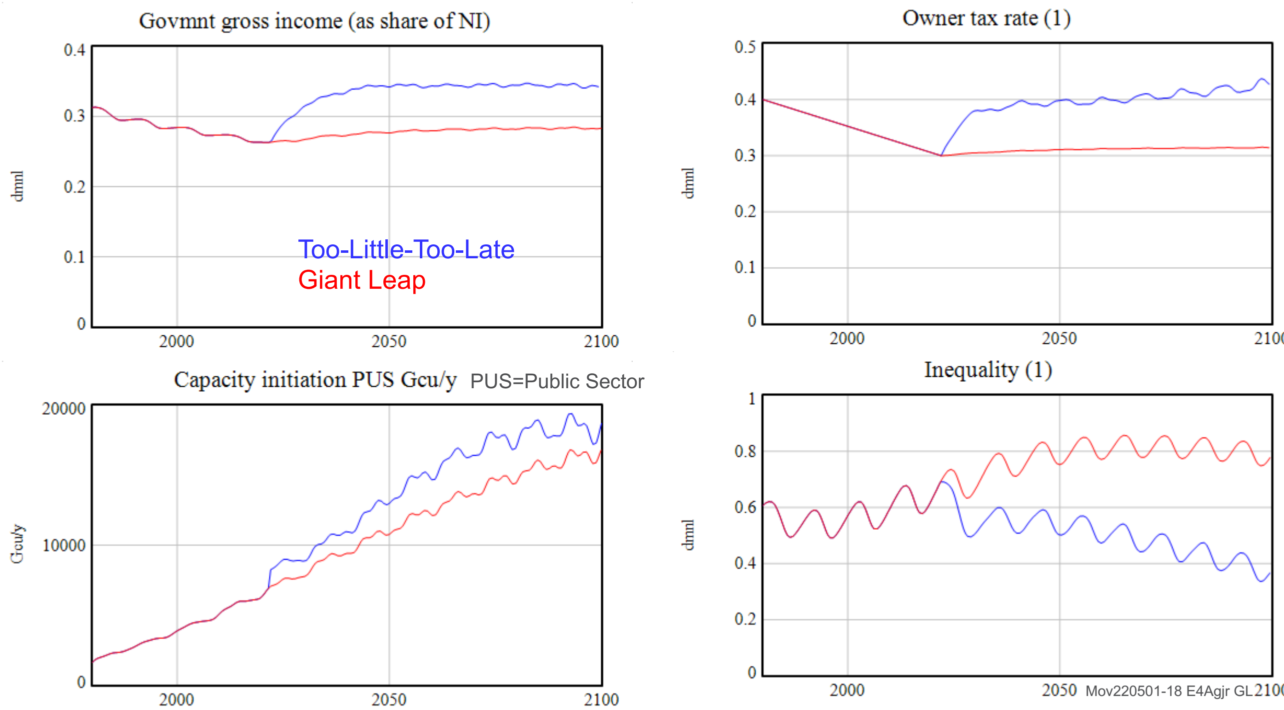

Figure 48: What will it take? More collective action paid by the rich.

Figure 48 illustrates the main effect on inequality in the Giant Leap. It shows a strong rise in collective action – paid for by the rich through increased taxation.

Collapse: Local dynamics of trust erosion

There exist in the model system the possibility of a negative spiral (a vicious cycle) where the nation's failure in providing rising wellbeing to its citizens lead to lower social trust and less support for the long-term effort needed to solve the problems of climate change and inequality. If the vicious cycle is allowed to spin out of control, the result can be social breakdown (aka regional social collapse). Figure 49 shows the underlying causal structure.

Model dynamics: The important assumptions

The dynamics generated by the E4A model is a result of the assumptions made. It is useful to list what we believe are the most important assumptions made, to help identify what are the core assumptions and what are the ones with less effect on insights gained.

1.We are seeking to build one generic model that can then be applied to 10 regions.
2. We accept that the precision level will be low. Only dynamics will be reliable, not absolute values and especially in the future.
3. We split the population in two groups: workers (who spend most of their income) and owners (who have enough to save/invest).
4. We divide the economy in a private sector and a public sector.

5. We maintain a dual perspective on the economy, there is the real economy in the model (expressed in physical units), and the financial economy (expressed in value terms). They are separate, which is very important when we get into that detail.
6. We see energy as the sum of electricity and heat. Heat is the direct use of fuels, with or without carbon capture and storage (CCS).
7. Crops are split in food and feed
8. Land is split in forest land, grazing land, crop land, urban land and wasteland.
9. Finally, and important since we have not discussed this before, we split investment in a) investment in productive capacity and b) investment in financial assets (like gold, shares, and paper, real estate being a border case).

This is important because in rich nations, like the United States, a large fraction of the current investment flow goes into financial assets – and hence do not lead to increased capacity in the short term, only to an increase in the dollar value of financial assets. This is a bubble that will break, sooner or later, leading to collapse in financial values and reducing the share of investments that goes into financial assets. But after some years of normal valuations, the phenomenon will start again, and replay. In our view the tendency to invest in financial assets accentuates the Juglar cycle, adding to it a periodic Minsky instability every 10 years or so[32]. These short term financial dynamics are not yet included in the E4A model because they do not dominate the long trends in human wellbeing

Planetary boundaries: may be underestimated

It should be emphasized that the total effect of transgressing planetary boundaries may be underestimated.

Other conclusions of interest

We want to supplement our summary with a few high-level generalizations that we believe are valid in light of our work with the model:
1. Global warming and biodiversity loss will continue
Temperatures (GAST) will continue to rise, and nature (volume and diversity) will continue to decline, but somewhat less if there is strong collective action for example on the 5 Turnarounds. There is disagreement within the modeling team whether the world is likely to experience global collapse for environmental reasons before 2100.
2. The risk of local social collapse will increase

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[32] We see the current (2022) downturn as the decline/collapse from the recent peak in financial investments, cause by the bubble breaking.

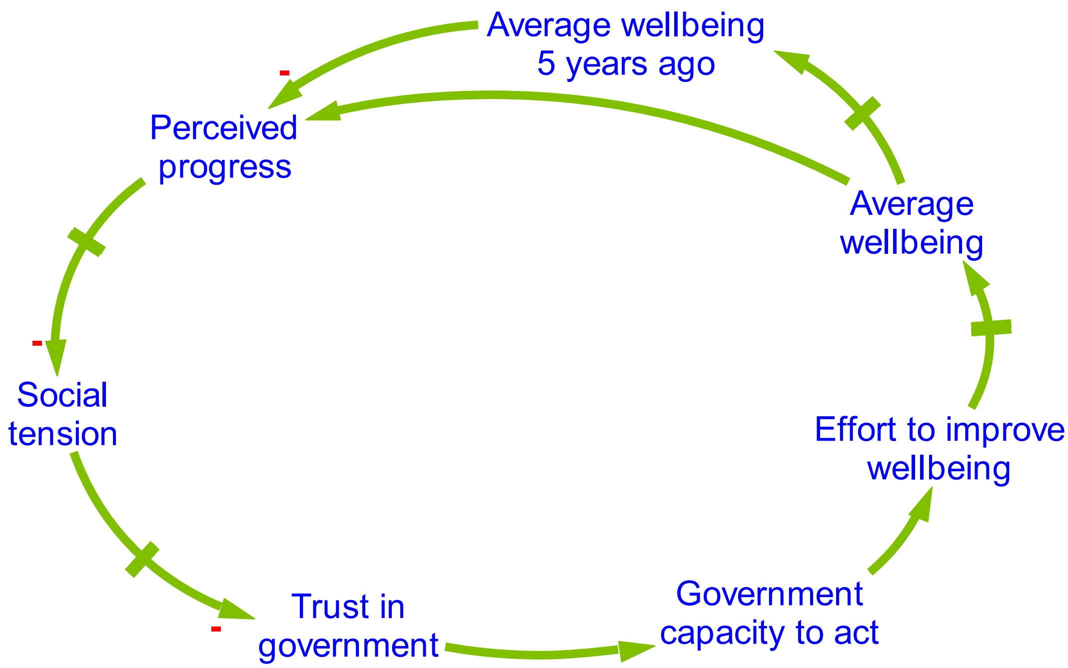

Figure 49: Declining trust cycle may cause social collapse.

Social trust and the ability of government to act will decline when people experience continuing decline in wellbeing. Lack of action will further reduce wellbeing and trust. This is a potentially self-reinforcing cycle that can lead to regional social collapse.

3. Higher wellbeing requires collective action on unprofitable activity

It will not be enough with voluntary and individual response, given that what is needed is not profitable from the investor point of view.

4. Very strong action is needed to achieve significant results within forty years

It took a hundred years to increase the concentration of CO2 in the atmosphere (through tens of thousands of power plants and hundreds of millions of vehicles), it is very hard to undo the damage in less time.

5. Planetary boundaries manifest themselves as increasing costs

Running into planetary boundaries manifest themselves as increase in the labor and capital cost of achieving the same physical output/service as before. In other words, a forced reduction of labor productivity in certain sectors (energy, agriculture, mining, pollution control) in order to obtain a sustainable flow of materials and environmental services.

6. Higher wellbeing requires both public and private investment

Useful to conceptualize the human effort to improve the future wellbeing for the majority as the sum of profit-driven investment by private investors and policy-driven investment by governments. Only the former yields a profit, but both create jobs and worker income.

10. Model enhancement: improving scope and detail

The current version of the E4A model should be seen as work in progress. The model is operational and can be used as is, but the model can be improved in numerous ways. Both in order to increase its reliability, but also in order to improve the richness of the description of wellbeing dynamics. In Appendix 4 Main weaknesses of the current model we provide a list of the main weaknesses in our judgement. Below section we describe some areas where there has already been some progress.

Adding the financial perspective

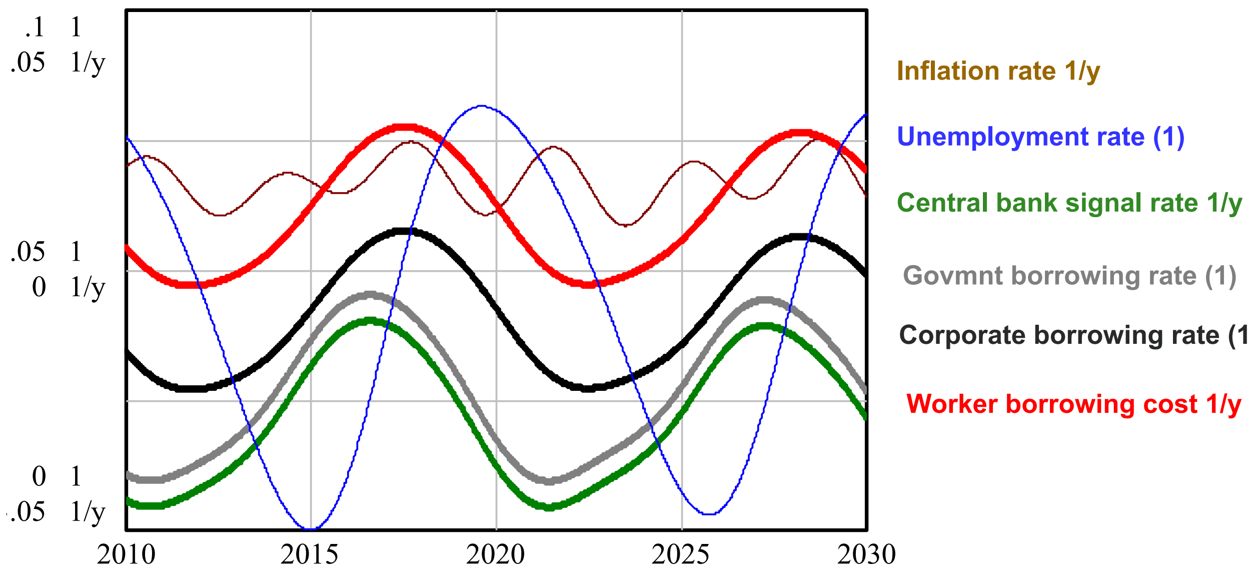

Figure 50: In the background – short-term financial dynamics

There is one important part of the model that we have not yet covered, namely the fact that the model also includes a description of the financial world – the world as it appears when observed and measured in dollar terms. Much of that description is rather conventional and takes the form of conventional national accounts and aggregate private sector accounts. The novel parts involve our representation of the way in which interest rates are formed in modern economies.

The main effect of the financial sector is to determine interest rates, which in turn impacts net debt transactions. Figure 50 shows the financial sector so the inflation rate is brown, the unemployment rate is blue, the Central Bank reacts to the inflation rate and to the employment rate and gives the Central Bank signal rate, which is the green one. The government borrowing rate is slightly higher than the green one and the corporate borrowing rate is slightly higher than this again and the worker borrowing rate is higher again. The only thing which is important here is that the financial sector accentuates the 10-year wave in the struggle between owners and workers by doing exactly the opposite of what they ought to do. The current system is set up in order to lower the inflation and lower unemployment, but it works in the model system exactly the other way around. It just helps making the 10-year fluctuation in the economy much sharper.

This is easily observed, we are now in the middle of one of these financial downturns. 10 years ago there was the financial crisis, and 10 years before there was the dot com bubble. Notice here that the time is now this product is down to 20 years. So these are the short term inventory imbalance type of activities.

Adding more age groups

We have made a version of the model with 100 age groups instead of the current 4 and shown that this further increases model match to historical data. But the increased complexity does not add much to our understanding of the overall dynamics of human wellbeing.

Adding more regions

We are also building a model with 10 regions instead of 1. This model is able to illustrate the differences between the regional dynamics that result from them being at very different levels of economic development, and also having different resource endowments. Finally, the regional model is necessary if we are to add trade and migration flows in the model. This far we do not, because the trade and migration flows are relatively small in percent of the total GDP and Population in the regions that we use.

Adding materials use

The current model is treating materials flows in the food and energy sectors. But we want to add a sector describing other uses of material – to reflect the decline in minerals reserves, the concomitant increase in costs, the effects of technological advance in resources, and finally the lowering of cost through learning. We do not believe this will change the main dynamics of wellbeing, but still want to add a Materials sector to demonstrate the point.

11. Summary: understanding the dynamics of global wellbeing

A high-level conceptual model

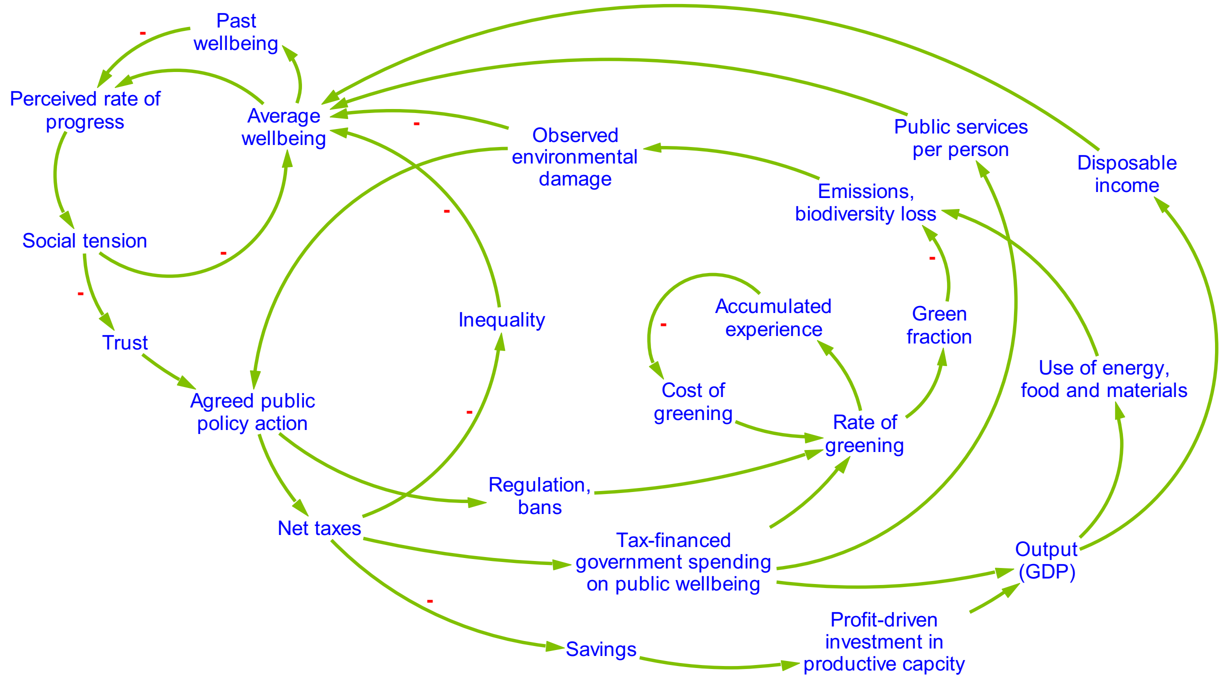

Figure 51: High-level summary of the E4A model

This high-level causal diagram illustrates how we think you should remember the E4A model. It shows a useful way of thinking about human wellbeing on a finite planet. It represents an alternative high-level perspective on economic development, and simple way to summarize the large amount of detail in the E4A model. It can be described as a conceptual model for practical use in verbal discussion.

In this conceptual model we see global socio-economic development as the result of two drivers that affect human wellbeing: First, "Profit-driven investment in productive capacity", and second, "Tax-financed government spending on public wellbeing". Both lead to higher economic activity, that is more "Output" of goods and services. Profit-driven ("private") investment leads to more of what is profitable from the investor point of view. Tax-financed ("public") investment leads to more of what improves wellbeing, but without necessarily being profitable from the investor point of view. In sum the two drivers cause higher wellbeing – in the form of higher "Disposable income" and higher "Public services", but also to a higher human footprint (that is an increase in the "Use of energy and food"), with a certain degree of environmental damage ("Emissions, biodiversity loss").

There are positive effects on "Average wellbeing" (top left-hand corner) from "Disposable income" and "Public services per person". And there are negative effects from "Observed environmental damage".[33] So when output increases, we get a

[33] In order to visualize the variable "inequality" one can think of it as a green attribute that reduces the environmental damage from the human footprint.

positive effect because of rising output (GDP) and a negative effect because of the rise in the footprint associated with the rising output. The net effect is first positive (rising wellbeing from 1980 to 2010), leading to a higher "Perceived rate of progress", which in turn leads to more societal "Trust", more support for "Public policy action" in order to further improve wellbeing. This in turn leads to acceptance of higher "Net taxes" and more "Regulation and subsidies", which in turn accelerates the "Rate of greening". The cost of the greening falls as society accumulates experience with a green solution and moves down the learning curve.

In other words, the conceptual model reflects our belief that society ultimately responds to observed threats – in this case the rising threat to wellbeing from climate change and inequality, observed by voters as slow "Perceived rate of (social) progress" – by agreeing on public policy that seeks to accelerate the shift of societal resources from profit-driven to policy-driven investment (in order to solve problems that cannot be solved by the un-aided market).

Two important behavior modes

Two important dynamics reside in this simple conceptual model.

First, a positive spiral (a self-reinforcing loop) where a nation's success in providing rising wellbeing to its citizens lead to higher social trust and more support for the long-term effort needed to solve the problems of climate change and inequality.

Second, a negative spiral (a vicious cycle) where the nation's failure in providing rising wellbeing to its citizens lead to lower social trust and less support for the long-term effort needed to solve the problems of climate change and inequality. If the vicious cycle is allowed to spin out of control, the result is social breakdown (aka regional social collapse).

As we see it, the current world – seen as a whole – is at a point where a significant increase in tax-financed public spending is necessary to boost an observable increase in the wellbeing of the majority. It needs to happen fast, to avoid us getting stuck in the vicious cycle.

12. APPENDICES

Appendix 1: Documentation underpinning the Earth4All model

Below is the list of our papers and books that discuss and defend various aspects of the current version of the Earth4All-model

Books

Randers J, Rockstrøm J, Stoknes PE, Goluke U, Collste D, Cornell S. 2018. **Transformation is feasible!** Stockholm Resilience Center: Stockholm, 60 pages
https://www.clubofrome.org/publication/transformation-is-feasible/

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Appendix 2: Parameter values for two scenarios in the Earth4All model

Earth4All turnaround levers with variables		Updated by JR 220501	
Policy description in report	Policy handles in Earth4All model	Parameter values in two scenarios	
Poverty		Too Little Too Late	Giant Leap
Expand policy space	Fraction of govmnt debt cancelled in 2022 1/y	0	0,1
Trade reregionalisation	Unconventional stimulus in PIS from 2022 (share of GDP)	0	0,01
New growth models	Unconventional stimulus in PUS from 2022 (share of GDP)	0	0,01
	Max imported ROTA from 2022 1/y	0	0,005
Inequality			
Progressive taxation	Extra general tax rate from 2022 (1)	0	0,01
	Fraction of extra taxes paid by owners (1)	0,5	0,8
Strengthen unions	Extra transfer of govmnt budget to workers (1)	0	0,2
Universal Basic Dividend	Goal for extra income from commons (share of NI)	0	0,02
Empowerment			
Education to all	Goal for extra fertility reduction (1)	0	0,2
female leaderships	Extra empowerment tax from 2022 (share of NI)	0	0,02
Pensions to all	Extra pension tax from 2022 (share of NI)	0	0,02
Food			
Food-system efficiency	ROC in food sector productivity from 2022 1/y	0,002	0,002
	Goal for crop waste reduction (1)	0,05	0,2
New farming techniques	Goal for fraction regenerative agriculture (1)	0,1	0,5
Change diets	Goal for fraction new red meat (1)	0,1	0,5
Energy			
Energy-system efficiency	Extra ROC in energy productivity after 2022 1/y	0,002	0,004
Electrify everything	Goal for fraction new electrification (1)	0,5	1
Abundant renewables	Goal for renewable el fraction (1)	0,5	1
	Goal for fraction of CO2-sources with CCS (1)	0,2	0,9
	Direct air capture of CO2 in 2100 GtCO2/y	0	8
Other			
	Extra rate of decline in CH4 pr kg fertilizer 1/y	0	0,01
	Extra rate of decline in N2O pr kg fertilizer 1/y	0	0,01
	Crop yield in reg ag t-crop/ha/y	5	5
	Time to implement new taxes y	5	5
	Natural N2O emissions GtNO2/y	Reduced from 0.009 in 2022 to 0 in 2100	Reduced from 0.009 in 2022 to 0 in 2101

Appendix 3: Novelties in the Earth4All model[34]

Why make a new model when there are so many others out there already? What unique attributes does the Earth4All model offer? Here we list eight novelties that address some of the shortcomings in the global systems modeling field:

1. Inequality: We investigate the distributional effects in terms of owner and worker share of output from both private investment and public sector activities, confirming the preliminary evidence that distributional patterns are relevant to sustainable policymaking.[35]

2. Ecology: We include the wider effect of the human economy on the main planetary boundaries (climate, nutrients, forests, biodiversity), the impact of natural boundaries on economic development, and their complex feedback effects.[36]

3. Public sector: We model an active public sector with public infrastructure capacity, welfare policies, and climate-change mitigation policy stance.[37]

4. Finance: We include the effects from debt and money supply, central bank interest rates,
and corporate capital costs, addressing the call for further integration of financial mechanisms within integrated assessment models (IAMs), used to test the feasibility of climate goals.[38]

5. Labor: We are able to simulate a recurrent ten-year unemployment cycle, and its macroeconomic consequences, a global first.[39]

6. Population: In contrast to the UN's statistical approach, the Earth4All model has endogenous population dynamics affected by investment levels in public spending, education, and income levels, improving on existing IAMs with demographic sectors.[40]

7. Wellbeing: We integrate an Average Wellbeing Index (as a function

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[34] Based on text from S. Dixon-Decleve et al. *Earth for All*. New Society Publishers. (2022): 179-180

[35] Narasimha D. Rao, Bas J. van Ruijven, Keywan Riahi, and Valentina Bosetti, "Improving Poverty and Inequality Modelling in Climate Research," *Nature Climate Change* 7, no. 12 (2017): 857–62.

[36] Michael Harfoot et al., "Integrated Assessment Models for Ecologists: The Present and the Future," *Global Ecology and Biogeography* 23, no. 2 (2014): 124–43.

[37] Mariana Mazzucato, "Financing the Green New Deal," *Nature Sustainability* (2021): 1–2.

[38] Stefano Battiston, Irene Monasterolo, Keywan Riahi, and Bas J. van Ruijven, "Accounting for Finance Is Key for Climate Mitigation Pathways," *Science* 372, no. 6545 (2021): 918–20.

[39] Tommaso Ciarli and Maria Savona, "Modelling the Evolution of Economic Structure and Climate Change: A review," *Ecological Economics* 158 (2019): 51–64.

[40] Victor Court and Florent McIsaac, "A Representation of the World Population Dynamics for Integrated Assessment Models," *Environmental Modeling & Assessment* 25, no. 5 (2020): 611–32.

of disposable income, income inequality, government services, the climate crisis, and perceived progress), illustrating the connection between environmental sustainability and social trust, and linking declining trust to public decision-making delays in an integrated assessment model for the first time.[41]

8. Social tension: We integrate a Social Tension Index (as a function of perceived progress, defined as the rate of change in the Average Wellbeing Index) that influences the speed and strength at which societies react to an emerging challenge. That is, as the Social Tension
Index rises, we interpret this as driving greater polarization in societies, making it more challenging to agree on solutions to societal challenges like the climate emergency.

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[41] Efrat Eizenberg and Yosef Jabareen, "Social Sustainability: A New Conceptual Framework," *Sustainability* 9, no. 1 (2017): 68

Appendix 4: Planned improvements of the current version of the Earth4All model

The following is a list of work that we plan to undertake to reduce the weaknesses that we see as most important in the current version of the E4A model. The list will be updated as the model is being improved:

- Fine-tune the climate sector, the energy sector, and the food sector
  - Cleaner conceptualization, better fit to historical data
- Clarify the issue of cost
- Clarify the concept of inequality
- Complete the finance sector
  - Handle: corporate debt, Minsky instability, investments in financial assets, capital labor ratio, etc.
- Add materials sector
  - Handle: Non-energy and non-food resource scarcity, technological advance, learning curves.
- Improve fit to 10 regions
- Clarify linkage to conventional macroeconomic terms.