# A Simple Sustainability Model

Simulating growth with just joules of energy and bits of data

Anton W. Trijssenaar
tryser@mac.com

## Abstract

*The paper intends to help entangle the narrative about sustainability and growth. It seeks to describe the evolution of growth with the most minimalistic model possible. To this end, successive energy diagrams are made of the earth's most basic stocks & flows of energy, including the stock of greenhouse energy. A simulation model is then presented in which the energy dynamics are governed by the creation, storage and destruction of data in the DNA of living organisms, and by the ever increasing 'bits of data' created by humans. An example is given where the iPad based model can enable ad-hoc, one-on-one discussions about assumed trends and scenarios.*

## Systemic Choices

Viewed from space, earth can be seen as a closed system: closed to matter, but open to the inflow and outflow of energy. Much of that inflow doesn't stay long in the system before being emitted to space. Yet there are parts saved and reinvested in local 'open' systems: open to the inflow and outflow of energy and matter, keeping them in a state of self-organisation far from thermodynamic equilibrium. The dynamics of those systems are inherently complex and uncertain (Prigogine 1978). This makes the study of open systems extremely challenging in sustainability analyses.

Sustainability analyses are compelled to deal with open systems. Yet, their complexity makes it virtually impossible to analyse an open system without some form of simplification. A prime example is the basic model of the world economy, where monetary flows represent the 'real' economy. The result is a fit-to-analyse simplification of the physical world, with the monetary value of goods and services as a common denominator (Nordhaus 2007).

Agreeing on analysing methods is especially difficult in discussions about economics and the environment. One way to simplify the sustainability analysis is to use the thermodynamical 'closed' nature of earth as the least complex tip of the system's complexity pyramid. The paper aims to remain as high as possible at this level of aggregation.

In a truly closed system, the energy that is trapped within the system can only be measured as the missing part from the input output equation. The diagrams below are a subjective attempt to map the most basic stocks and flows of energy within that missing part. It only shows the structure; the plumbing, of where the different amounts of energy could be envisioned. It models the conversion of a combined energy input into just two energy qualities: (1) ambient energy (greenhouse energy) that is in transit to being emitted to space, and (2) stocks and flows of retained energy, capable of performing work.

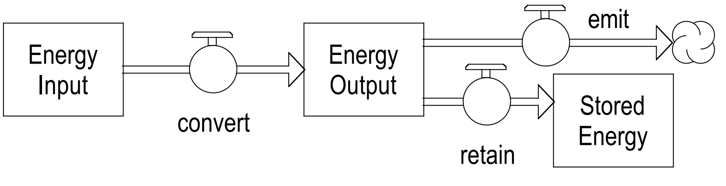

*Figure 1. Basic structure of the model.*

Of note here is that Energy Input is where the split in energy quantities takes place. Both it and Energy Output are stocks, used as distributing nodes to combine or split a flow. They should give the same visual anchors as ‘Households’ and ‘Firms’ do in the economic model Macro-Lab (Wheat 2007). In this way it builds on well-established tools in system dynamics (Richmond, Peterson et al. 1987), (Richmond 1994).

### Diagrams

By making a series of diagrams it is possible to project at least the contours of an evolutionary path (Trijssenaar 2006). In the simulation model, that follows after the diagrams, there are two quantities added that govern the energy dynamics: the accumulation of data in the DNA of living species, and the accumulation of data created by man.

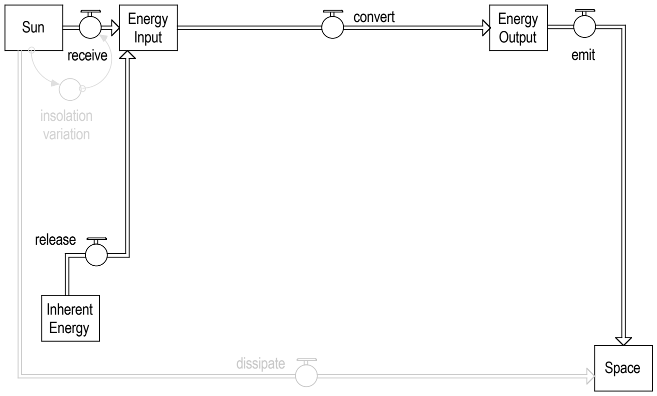

Figure 2. The energy basics of the moon.

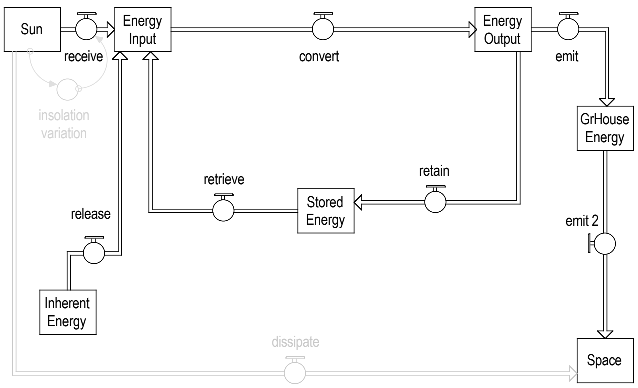

Figure 3. Earth with only oceans to store energy

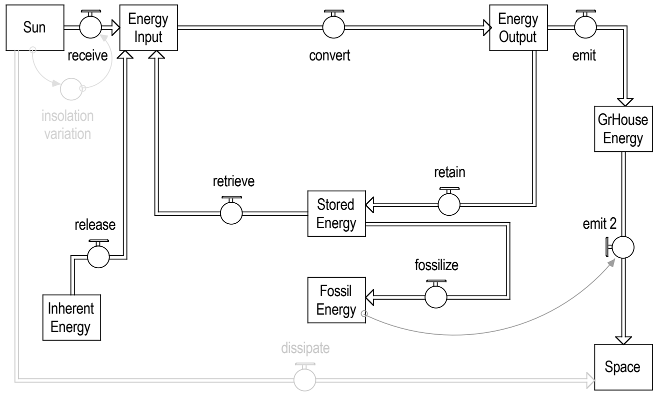

Figure 4. Storage of energy from micro organisms and plants

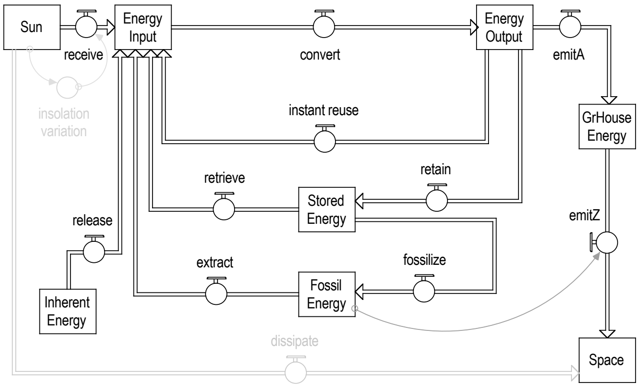

Figure 5. Retrieval, extraction, and instant reuse

The earth’s energy evolution is pictured here in four consecutive snapshot diagrams. Figure 2 is a reference diagram of the moon, showing that all of the received solar energy is almost immediately emitted to space, and that non of the energy is retained and stored. Figure 3 shows the basic elements that started on earth about 4 billion years ago. Here the oceans’ mass of water levelled off to a temperature in which the organic evolution could start. All subsequent methods to retain and retrieve energy are based on the existence of water. The stored energy in oceans and air can partly be regarded as dispersed ambient energy, or ‘Greenhouse Energy’. Figure 4 symbolises the world of autotrophs. A world of plants and algae that created layers of different niches, all resulting in more solar joules being retained as reusable energy within the system. This accumulation is represented as ‘Stored Energy’ in the diagram. In time, some retained energy became unretrievable by any life form, and ended up as 'Fossil Energy’. Figure 5 represents the net retrieval and extraction by hetrotrophs.

Net retrieval results from the biologic activities, based on previously stored energy. The 'extraction' in the diagram is of course due to the abilities of man since the industrial revolution. With it comes an increase in the amount of Greenhouse Energy. The flow of 'instant reuse' represents man's recent abilities to convert sunlight directly into work, as is often the case with electricity from photovoltaics. The different methods to retain, store, and retrieve energy are path-dependent, as each method builds on the existence of previously developed evolutions. All instructions to retain and retrieve energy are embedded in the DNA in nearly every cell of a living species. Each evolution in DNA is path-dependent and is built upon previous developments and shared among close to 100% of a specific species.

### Simulation Model

Information about DNA only became known in the nineteen fifties. The vastly expanding exploration of DNA makes it more and more possible to estimate the total amount of bytes of data that is contained in the DNA of all the cells of different species. These amounts refer to the bytes of (raw) data irrespective of the information quality of the data. Hence, bytes of data are used in the model as a common, quantitative unit of accounting, regardless of its information quality. It seems plausible to take the mass of living species as an indication of the amount of DNA data. A 'guesstimated' graph is used in the model to mimic the growth rate of the mass of biological species as a proxy for the amount of bits of DNA data. This has been done to simplify the communication with experts in the field about the DNA growth, and to keep the model as simple and uncluttered as possible.

The simulation model runs on an iPad, which enables ad-hoc, one-on-one discussions about assumed trends and scenarios. In fact, one of the aims of the model is to use it as a means to collect expert opinions about the assumed equations and quantities in the model. The simple structure of the model makes it easy to challenge and adjust the assumptions. (The iPad helps to perform a kind of 'elevator pitch' in questioning experts and interested parties.)

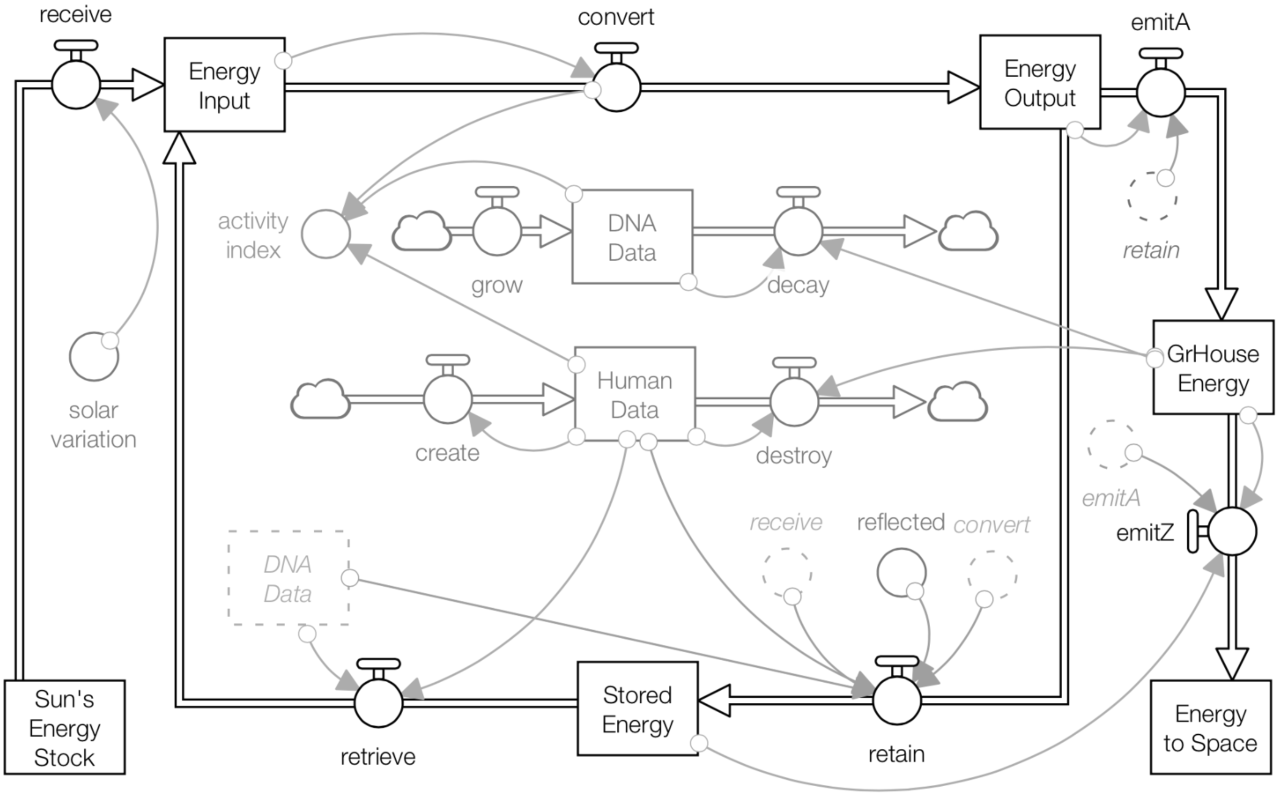

*Figure 6. Screenshot of the simulation model running on an iPad with STELLA software*

In the model, ’convert’, shown in figure 6, leads from one combined energy input into two different thermo-dynamic qualities: to ‘retain’, the flow of energy, capable of performing work, and to ‘emitA’ that goes through a trap of 'Greenhouse Energy' before being emitted to space via ‘emitZ’. The reflected sunlight to space (technically unconverted) is subtracted in the ‘retain’ equation from the ‘receive’ flow. This will enable the simulation of reflection spikes due to extended snow cover, or volcanic clouds.

The ‘activity index’ is a mix of the ‘convert’ flow, and the net addition of data. This throughput indicator could, perhaps, give a quantitative indication of the activities at system earth over extended periods of time. Given the simplicity of the model, the index looks, of course, only at about the highest possible level of aggregation.

’Stored Energy’ represents the amount of joules of all retained energy. Further specifics are, that for simplicity reasons: insolation variation is kept constant, and gravitational force from the moon is not taken into account, nor are incursions from space. Geothermal and nuclear energy (part of Inherent Energy) can be viewed as the heritage that is part of the (retrievable) Stored Energy. The results from volcanic eruptions can be simulated trough ‘reflected’ spikes.

The energy stocks are presumed to be governed by two data flows: the growth of DNA-data, and the creation of human data on various media. Below is the reference mode of a base run with only the (exa)bits of human data on a quasi logarithmic time scale.

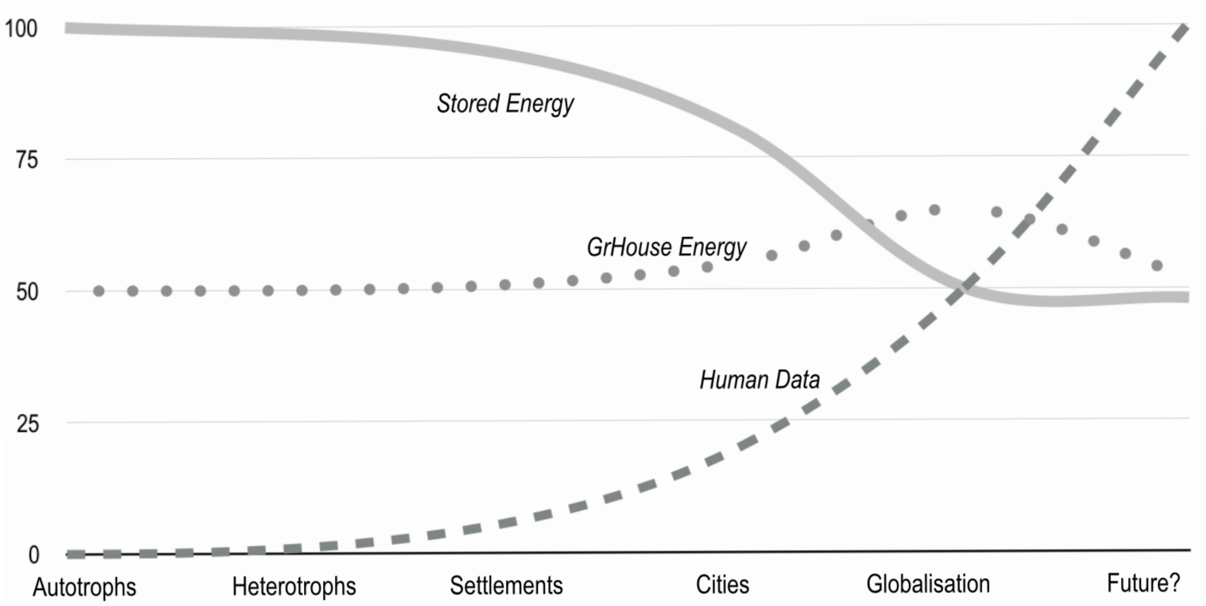

*Figure 7. Indicative graph of the model’s accumulations of data, energy, and greenhouse energy on a quasi logarithmic time scale from 3.5 billion ago to 20 years into the future*

### Presumed activity trends & limits to growth

It is assumed, that an evolution of sustained growth of activities has been possible due to:

- moderate ambient temperature levels (guesstimated as greenhouse energy in the model),
- the availability of stored energy able to perform work,
- an ever increasing accumulation of data,

- data that contain (ever increasing) instructions for path-dependent methods of retaining, storing, and retrieving of energy.

The model distinguishes two modes of growth. Both are presumed to be governed by accumulated data, but differ in the retention and retrieval of energy. They are:

- The autotroph mode: with plants, algae, and some bacteria that convert sunlight into hydrocarbons through photosynthesis. By doing so they're retaining parts of the received solar energy and hence contribute more to the Stored Energy than they retrieve.
- The hetrotroph mode: with all life forms that can only grow by retrieving previously stored energy. They are by nature unable to be net contributors to the Stored Energy.

The model's limits to the first mode of growth are excess Stored Energy followed by a loss of Greenhouse Energy and a subsequent loss of DNA-data. This would enable a simulation of the autotrophs' oxygen crisis (before hetrotrophs came to inhale oxygen, and exhale $CO_2$).
The second mode of growth solves the oxygen problem and the excess growth of Stored Energy. The limits to this mode of growth are programmed in such a way that an excess retrieval of Stored Energy leads to increases in Greenhouse Energy and, ultimately, a loss of DNA-data and Human Data. The energy retrieval is assumed to be governed by different levels in the accumulation of DNA Data & Human Data.

### Human data

In the real world, human knowledge and information (and thus data) has enabled the use of wood and fossil fuels. This kind of energy use is most probably leading to the present onset of climate change (IPCC 2013). It is therefor understandable that science is drawing attention to the consequences of the continued retrieval of energy 'capital' by man. What is assumed in the model is that the retrieved energy act as an 'investment' that leads to a continuous growth in the creation of human data.
The last decades saw quantum leaps in the rate of data creation and storage. A study from 2011 finds that, between 1986 and 2007, the compound growth rate was 23% per year, reaching $2.4*10^{21}$ (optimally compressed) bits stored by humanity in all of its technological devices in 2007 (Hilbert and Lopez 2011). To put it in perspective: this is, according to the study, approaching the order of magnitude of the roughly $10^{23}$ bits stored in the DNA of one human adult.

Proposals to reduce the world's $CO_2$ emissions are based on projections of decades into the future. Predictions about data and information technology, on the other hand, don't often go beyond one or two years. Yet, even the knowledge about climate change is dependent on the accumulation of data and the information technology behind it. The model can be used to question experts and interested parties about the development of human data over the same period as in the climate change discussions. Some obvious questions about the ever growing accumulation of data are:

(1) how the data can actively lead to less retrieval of stored fossil energy by more energy efficiency (Koomey, Berard et al. 2011);
(2) when and how will it overtake (dominate) the energy conversion activities in the energy/data mix of the world economies;
(3) in what way could it speed up the retention of solar energy, something that, eventually, could bring system earth back to the first mode of growth, in which more is contributed to the Stored Energy than is retrieved.

These are questions that do not necessarily need a simulation model. Yet a simple, iPad based model enables ad-hoc, one-on-one discussions about assumed trends and scenarios and about the effect of one answer on all other factors of the model.

### Ad-hoc Debate

An early result of this approach is a discussion that evolved at a short course about climate change; a course, organised by HOVO (higher education for older people) at VU University Amsterdam, and given by professor Pier Vellinga in February/March 2014.

After several one-on-one discussions, and encouraged by prof. Vellinga, the assumptions of the model made their way to a group discussion on the last college day of the five day course. To make it relevant for a climate debate, a scenario was presented in which man is going to stop burning fossil fuel altogether in order to avoid an accelerating climate change (Vellinga 2011). The implication is an energy curve that has to decline as depicted in figure 8. The curve of the creation of human data in figure 8 is based on the preliminary assumptions in the model, and is stacked on top of the energy curve. This ‘scenario’ suggests that the creation of data would mean a continued increase of human activities that would more than offset the decline in fossil fuel content of the activity mix.

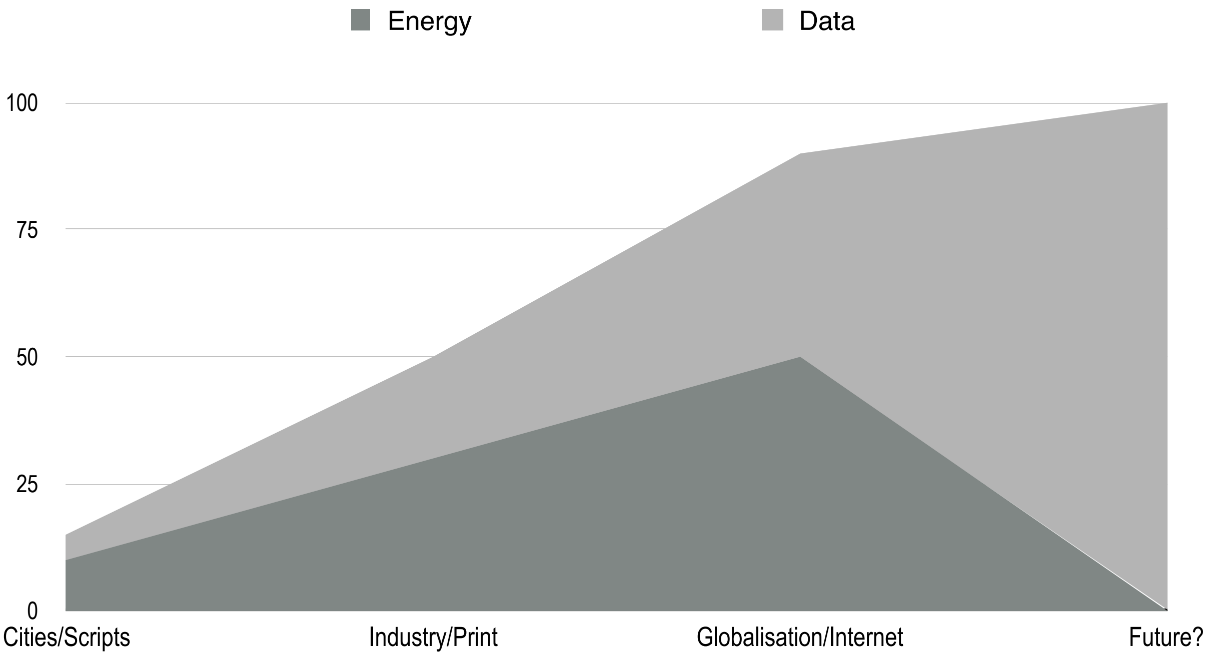

*Figure 8. An index of human activity: creation of human data stacked on top of wood and fossil energy use*

The creation of information and knowledge has recently been advanced in the Netherlands as a benchmarks to measure economic growth (WRR 2014). Yet, the group’s discussion quickly focused on the shortcomings of data creation as a measure of economic growth, particularly in light of the present jobless growth, and the emerging replacement of jobs by computerisation (Frey and Osborne 2013). The discussion itself proofed, that the model could help facilitate an ad-hoc debate about some basic, and often overlooked aspects of sustainable growth.

### Big History

The still somewhat unconventional view of earth as a system has been stimulated by the *‘Operating Manual For Spaceship Earth’* (Fuller 1968). Before that, Odum (1963) modelled the *Ecosystem Ecology*, putting the world of the contemporary ecology in focus. Whereas, later on, the *World Model* of Forrester’s System Dynamics Group (Meadows, Meadows et al. 1972) described the consequences on resources of the present and future behaviour of the world population. This, like many ‘world’ models, is a simplified subsystem in space and time of system earth, as exemplified with the amount of solar energy that earth receives, which is only represented in the model by an endogenous stock of conservation technologies.

A relatively new academic discipline is ‘Big History’ (Christian 2011, Dowd 2012, Quaedackers 2014). The new, interdisciplinary field places the growing complexity at system earth in a continued evolution from the Big Bang onwards. The ‘free energy rate density’, or ‘power density’ that transforms energy through matter is seen as a measure that governs the evolving levels of complexity of the earth’s systems, or ‘adaptive regimes’ (Spier 2011). As stated by Fred Spier it was Erich Jantsch who first developed a systematic model for big history with his *‘The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution’* (Jantsch 1980). The book is dedicated to Illia Prigigine, which Jantsch called: “Catalyst of the self-organisation paradigm”. According to this paradigm, life on earth exists in a system far from thermodynamic equilibrium for which the theory of self-organisation in non-equilibrium systems applies (Prigogine 1978).

The first iteration of the present paper’s sustainability model was used in the early nineteen eighties as a reference for a model of the province of North Holland (Engelen and Allen 1986). The basics of that model are described in *‘The Self-Organizing Universe’* (Jantsch 1980, p. 71-72). In the planning stage of the N-Holland project, in 1983, it was stated that: “The new concept emerging from the discovery of ‘dissipative structures’ by Prigogine in the physical science, offers us a new basis on which to understand complex systems, a basis capable of describing evolutionary change”. Yet in the end, the *inherent* uncertainty in predicting self-organisation made the model as dependent on extrapolating the past as any other model, be it in a more sophisticated way. From this experience followed the present, unconventional development of a simplest possible model that covers the whole earth, both in space and in time. The unconventionality of this approach will no doubt disappear with the advancement of Big History and the many similar academic disciplines. The resemblance between big history and this paper’s model is, that earth is seen as a system that evolved over a period of billions of years. The difference concerns the aggregation levels. Big history looks at power densities and intelligence, which can be seen as an interplay between two very complex qualities of energy and data. The present model doesn’t go deeper than the relation between two simple quantities: the amount of joules of energy, and the amount of bytes of data. The model explores the correlation between creating data, and retaining/retrieving energy. It does so by simulating the correlations at different time scales, all the way back to billions of years up to a time scale of one hour divided in one time-step per second (see technical annex).

### Sustainable Growth

In the model, the rates at which the system retains and retrieves energy are governed by the stocks of DNA Data and Human Data. The flows into those stocks have no direct feedback from the energy stocks & flows that they give instructions to. They are, technically, exogenous variables. Their equations, however, are assumed to incorporate estimates from experts, and/or dedicated sub-models.

The other ends of the data stocks do have endogenous energy feedbacks in their outflow. They cause a decay and destruction of data as a result of the levels of Greenhouse Energy. This has in effect been the case on earth more than once. The mass of living species (and thus the amount of DNA) has seen several instances of decay as a result of greenhouse energy levels coming too low or too high. The underlying hypothesis in the model is, that system earth managed to sustain those instances first and foremost because of the size of its pool of data. Testing this hypothesis should be done by going into the “great oxidation event” about 2.3 billion years ago, at a time when free oxygen started to accumulated dramatically in the earth’s atmosphere. This oxygen, produced (as waste) by cyanobacteria via photosynthesis, was the first biological contributor to an ice age: the Huronian glaciation (Canfield 2014). Simulating those early energy/data developments during and after this glaciation would give a bench mark for sustainability exercises with the model. However, life, and its production of free oxygen, were mutually dependent on profoundly changing geological developments. Incorporating the early developments of geology and oxygen would make the model too complex at this stage. Yet, by changing the fixed reflection rate in the 'retain' equation, it is possible to simulate a spike in the reflection of solar energy caused by snow cover, or volcanic dust.

The hypothesis is that the total mass of living species can be equated with its total amount of bytes of DNA, and that more bytes of DNA data leads to more chances for sustainable developments. Coupled to that is the assumption that the data, created and stored by humans can be compared with the stored DNA data in living species. Along this line, a growth pattern could be discerned of more bytes of data corresponding to more energy that the system is able to retain and/or reuse. The resulting growth in retaining and/or retrieving energy enlarges the pool of data from where sustainable solutions can be drawn.

This pattern of sustained growth now seems to have turned into an over-investment of retained (fossil) energy, managed by an exploding creation of human data. But, although huge in human terms, the total amount of human data is still a small fraction of the bytes of data in the DNA of all living species. And, of the human data, still only a relatively small number of the human population have access to a significant part of it. What sustainable growth seems to imply is the need to create data on how ‘nature’ managed to gain orders of magnitude higher energy productivity levels, while at the same time creating access to that data to the whole population of every species. A priority for further research is to substantiate the underlying assumptions with more references in the literature.

## Bibliography

Canfield, D. E. (2014). Oxygen: A Four Billion Year History, Princeton University Press.

Christian, D. (2011). Maps of Time: An Introduction to Big History, University of California Press.

Dowd, M. (2012). Big History Hits the Big Time. Huffington Post.

Engelen and Allen (1986). "Modelling the spatial distribution of energy demand for the Province of Noord Holland: towards an integrated approach." Sistemi Urbani(2/3): 241-261.

Frey, C. B. and M. A. Osborne (2013). "The Future of Employment: How susceptible are jobs to computerisation?".

Fuller, B. (1968). Operating Manual for Spaceship Earth.

Hilbert, M. and P. Lopez (2011). "The World's Technological Capacity to Store, Communicate, and Compute Information." Science 332(6025), 60–65. doi:10.1126/science.1200970.

IPCC (2013). "Climate Change 2013 - The Physical Science Basis."

Jantsch, E. (1980). The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution, Pergamon Press.

Koomey, J., S. Berard, M. Sanchez and H. Wong (2011). "Implications of Historical Trends in the Electrical Efficiency of Computing." Stanford University, Annals of the History of Computing, IEEE 33(3): 46-54.

Meadows, D. H., D. L. Meadows, J. Randers, W. W. Behrens, Jørgen and W. W. III (1972). The Limits to growth; a report for the Club of Rome's project on the predicament of mankind. New York, Universe Books.

Nordhaus, W. (2007). The Challenge of Global Warming: Economic Models and Environmental Policy. New Haven, Connecticut USA, Yale University.

Odum, P. O. (1963). Ecology: The Link Between the Natural and the Social Sciences, Holt Rinehart and Winston.

Prigogine, I. (1978). "Time, Structure and Fluctuations. (Nobel lecture)." Science Vol. 201(No. 4358).

Quaedackers, E. (2014). Big history - Van de Oerknal tot nu. Cursusaanbod najaar 2014, HOVO / VU Amsterdam.

Richmond, B. (1994). "Systems thinking / system dynamics: let's just get on with it." System Dynamics Review 10(2-3 Summer-Fall): 135-157.

Richmond, B., S. Peterson, P. Vescuso and N. Maville (1987). An Academic User's Guide to Stella Software. Lebanon, NH, USA, High Performance Systems/ISEE.

Spier, F. (2011). Big History and the Future of Humanity, Wiley-Blackwell.

Trijssenaar, A. W. (2006). Jeu-de-Joule: a conceptual earthly energy model. 27th International System Dynamics Conference. Nijmegen University, System Dynamics Society.

Vellinga, P. (2011). "Hoezo klimaatverandering: Feiten, fabels en open vragen."

Wheat, D. (2007). The Feedback Method. A System Dynamics Approach to Teaching Macroeconomics Doctoral thesis, The University of Bergen.

WRR (2014). "WRR-report 90: The Netherland's earning capacity."