Climate Crisis and Gaia Theory

A systems perspective

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The man-made climate crisis is the most significant threat, not only to mankind, but to the entire planet. Yet many people still believe that this statement is untrue: some deny that climate change is happening at all, and that any recent increases in global temperature are simply statistical fluctuations or the result of temporary solar activity; some deny that man-made greenhouse gases - especially carbon dioxide - have any temperature effect at all.

The purpose of this document is to demonstrate, using the systems perspective, how man's activities, and the consequent production of greenhouse gases, interact with the self-organising global feedback systems of Gaia to drive climate change.

This document further illustrates that, if left unchecked, a possible consequence of climate change is to bring about a feedback loop which stabilises the Earth's temperature by eliminating the fundamental problem - namely, man.

And finally, this document shows that by far the wisest intervention to avoid this catastrophe is not to restrict emissions, but rather to develop large scale technologies - 'geoengineering' - to extract greenhouse gases directly from the atmosphere.

"But it is increasingly clearer that reducing emissions is not enough - we must also actively remove greenhouse gases from the atmosphere."

page 7

https://royalsociety.org/-/media/policy/projects/greenhouse-gas-removal/royal-society-greenhouse-gas-removal-report-2018.pdf

This document has been prepared by Dennis Sherwood of *Silver Bullet* to explore how the 'systems perspective' can vividly demonstrate a truly holistic understanding of a truly holistic problem, that of the climate crisis.

Why is this helpful? Or rather, essential?

For two reasons:

- **Firstly, to provide a platform for building a genuinely shared understanding of the holistic mechanisms underpinning the climate crisis - a shared understanding is an absolute pre-requisite for concerted action.**
- **Secondly, to help identify the wisest policies for intervention, so that the actions taken really work.**

If the 'systems perspective' is unfamiliar, pages 4 to 7 provide a brief introduction; pages 9 to 41 then show how the systems perspective can tame the complexity of the most important problem facing mankind today.

Finally, pages 43 to 56 show the results of some simulation models.

The systems perspective

The ‘systems perspective’ facilitates our exploration of complex systems, both as regards enriching our understanding of existing systems, as well as informing our ability to design effective new ones.

The central feature of the systems perspective is the willingness - or rather the obligation - to take a ‘whole system view’, to examine the entire system regardless of organisational, geographical or temporal boundaries. For only by examining systems holistically can we successfully anticipate, and so avoid:

- ‘quick fixes that backfire’
- ‘unintended consequences’
- designing a system that merely shifts the problem from ‘here’ to ‘there’.

Furthermore, the systems perspective enables us to describe the structure of a system with great clarity, so helping us to communicate the essence of the system to others. This can be of enormous value in helping others to see how the system works, how they can work within it, and how best to intervene in the system wisely - three essential components in building their willingness to accept reality, and to agree on policies and actions for change.

The language of systems

Pages 5, 6 and 7 are for those unfamiliar with the tools and techniques associated with the systems perspective. Very briefly…

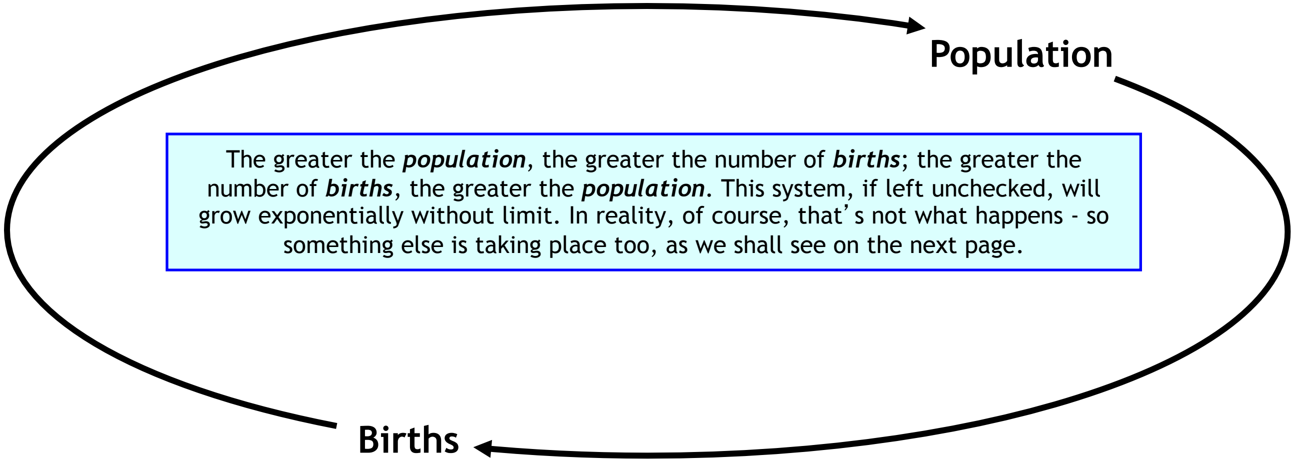
- **A 'system' is a 'community of connected entities'**, where the emphasis is on the connectedness between the entities, rather than on the entities themselves.
- **Systems show 'emergent behaviour'** - properties that exist at the level of the system, rather than at the level of the individual entities from which the system is composed. An example is the system "I went to the bank", in which the 'entities' are words in the English language, connected together to form the 'system' of a sentence. The meaning of the sentence is a property of the sentence as a whole - a meaning which cannot be inferred however hard we study any individual entity, such as the single word 'went'. The existence of emergent properties implies that systems must be studied as a whole.
- A powerful way of describing the structure of a system is by means of **'causal loop diagrams'** or 'influence diagrams'. These diagrams show 'chains of causality', which capture our belief that a given 'cause' drives a given 'effect'. This causal relationship is shown by connecting the 'cause' to the 'effect' with a link, represented by an arrow.
- If an *increase* in a 'cause' drives an *increase* in the corresponding 'effect', the link is known as a **direct link**, as indicated by a solid arrow (some sources associate the head of the arrow with a + sign, or the letter ***S***, representing 'same', since the variables at the head and the tail of the link move in the same direction).

- If an *increase* in a 'cause' drives a *decrease* in the corresponding 'effect', the link is known as an **inverse link**, as indicated by a dashed arrow (some sources associate the head of the arrow with a – sign, or the letter ***O***, representing 'opposite', since the variables at the head and the tail of the link move in opposite directions).

- Chains of causality usually form closed loops known as *feedback loops*; 'open-loop systems', chains of causality that do not form closed loops, are very rare, and are usually indicative of the likelihood that the description of the system under study is as yet incomplete. **Feedback loops are of two, and only two, fundamental types: reinforcing loops (see page 6) and balancing loops (see page 7).** Dynamically, a reinforcing loop exhibits either exponential growth or decline; a balancing loop either oscillates, stabilises on a target, or modifies the dynamic behaviour of an associated, linked loop - for example, by slowing the growth of a linked reinforcing loop.
- **Real systems are (often complex) networks of interconnecting reinforcing and balancing loops** (see, for example, page 35). Despite this complexity, great insight into the behaviour of a system as a whole can be deduced from the structure of its reinforcing and balancing components.

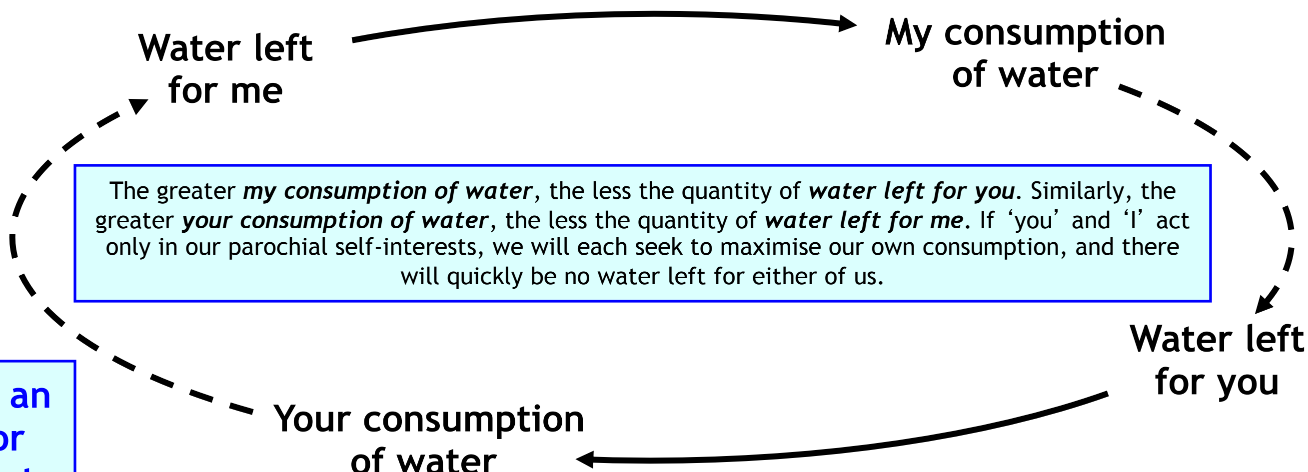
Reinforcing loops

Reinforcing loops are closed loops that contain an even number of inverse links (zero is an even number)…



The greater the ***population***, the greater the number of ***births***; the greater the number of ***births***, the greater the ***population***. This system, if left unchecked, will grow exponentially without limit. In reality, of course, that's not what happens - so something else is taking place too, as we shall see on the next page.

…and exhibit two forms of behaviour - either exponential growth…

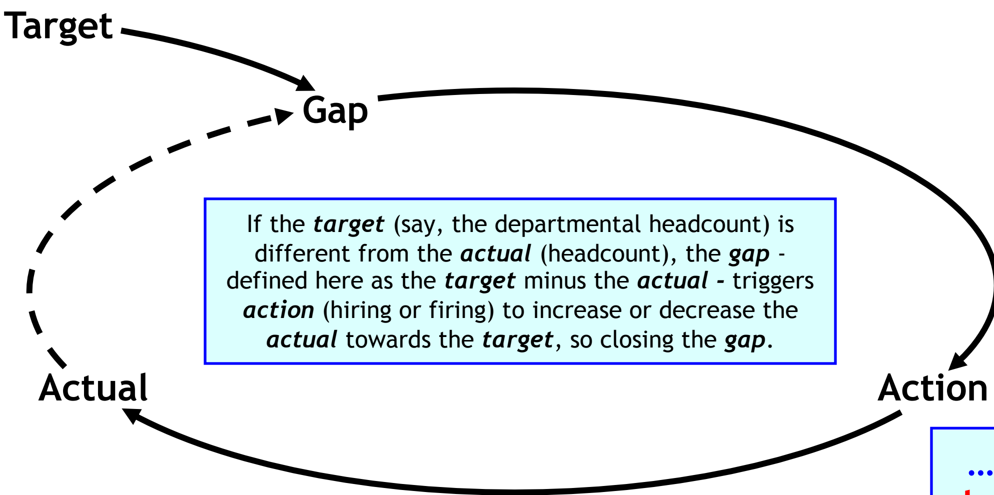


The greater ***my consumption of water***, the less the quantity of ***water left for you***. Similarly, the greater ***your consumption of water***, the less the quantity of ***water left for me***. If 'you' and 'I' act only in our parochial self-interests, we will each seek to maximise our own consumption, and there will quickly be no water left for either of us.

…or exponential decline.

This form of feedback, in which an initial signal of either growth or decline is progressively amplified, is known as positive feedback.

Balancing loops

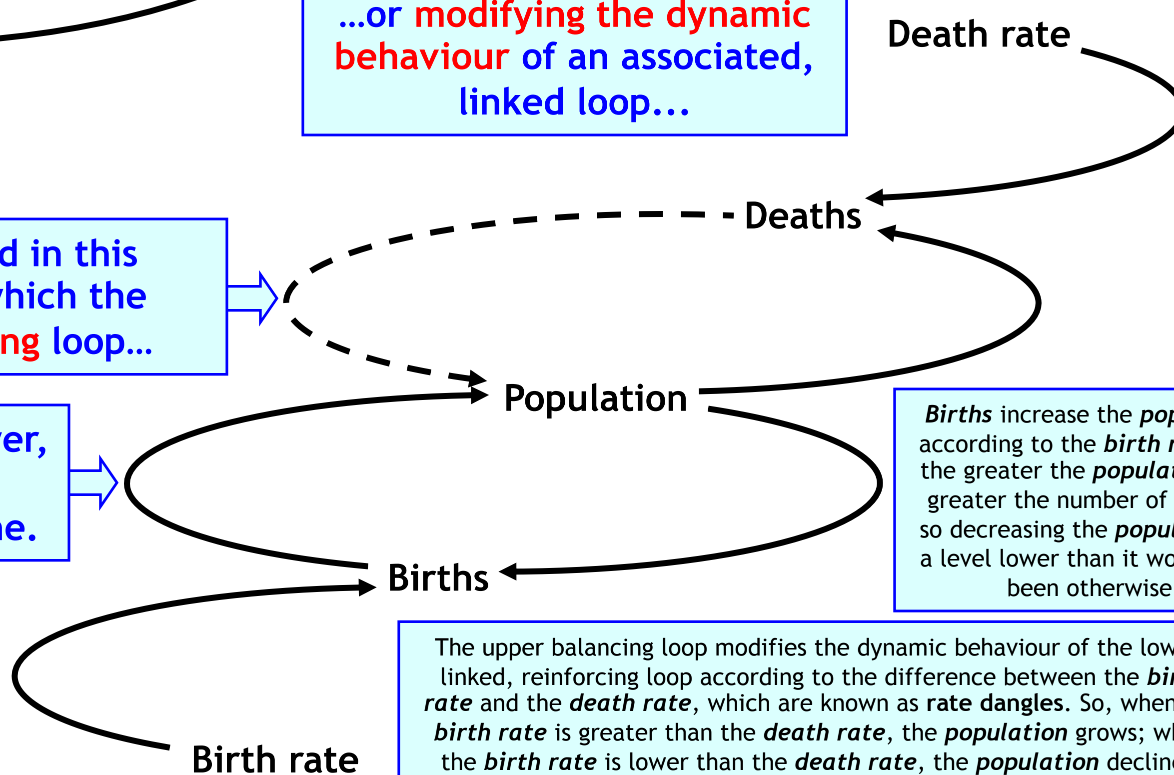


If the ***target*** (say, the departmental headcount) is different from the ***actual*** (headcount), the ***gap*** - defined here as the ***target*** minus the ***actual*** - triggers ***action*** (hiring or firing) to increase or decrease the ***actual*** towards the ***target***, so closing the ***gap***.

Balancing loops are closed loops that contain an odd number of indirect links, and most commonly exhibit two forms of behaviour…

…either converging, and ultimately stabilising, on a target, as determined by a target dangle…

…or modifying the dynamic behaviour of an associated, linked loop…



…as illustrated in this example, in which the upper, balancing loop…

…slows the rate of growth of the lower, linked, reinforcing loop…
…and might even drive it into decline.

Births increase the ***population*** according to the ***birth rate***. But the greater the ***population***, the greater the number of ***deaths***, so decreasing the ***population*** to a level lower than it would have been otherwise.

The upper balancing loop modifies the dynamic behaviour of the lower, linked, reinforcing loop according to the difference between the ***birth rate*** and the ***death rate***, which are known as **rate dangles**. So, when the ***birth rate*** is greater than the ***death rate***, the ***population*** grows; when the ***birth rate*** is lower than the ***death rate***, the ***population*** declines; when the ***birth rate*** equals the ***death rate***, the ***population*** is stable.

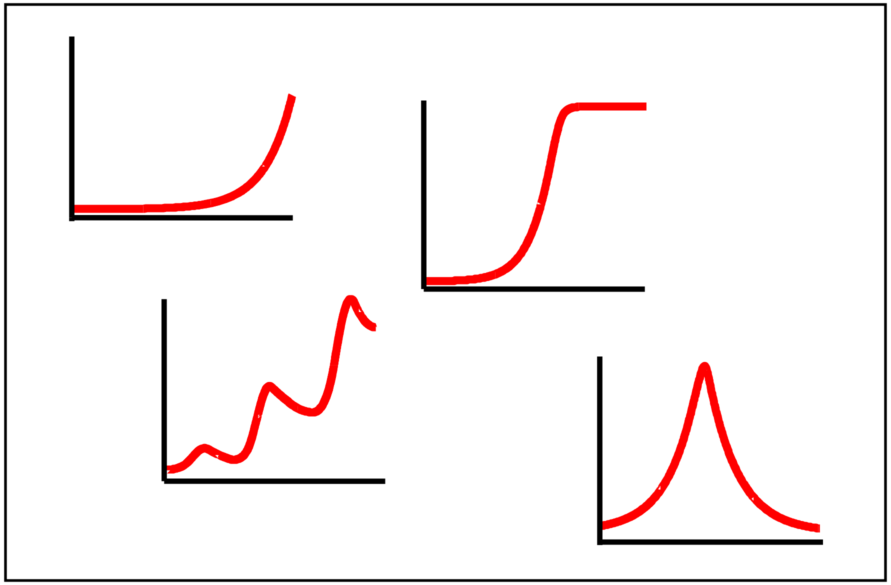
This form of feedback, which acts to stabilise or to limit, is known as negative feedback.

Handprints in the Cueva de las Manos, Argentina,
***c*. 10,000 years old**

The story of man over the last three thousand years on half a page

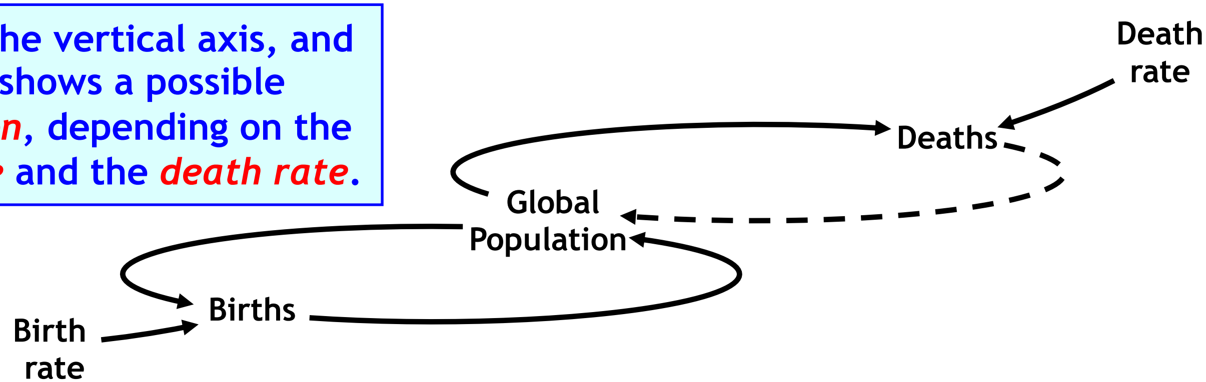
Population is the key driver…

The reinforcing loop of *births* seeks to grow exponentially, as determined by the *birth rate*. But at the same time, the *global population* is being depleted by *deaths*, as determined by the *death rate*.



The dynamic behaviour of this system - a reinforcing loop seeking to grow exponentially, constrained by a balancing loop - can be very complex, and depends on the instantaneous behaviour of the *birth rate* and the *death rate*. If, at any time, the *birth rate* exceeds the *death rate*, the *population* grows; if the *death rate* exceeds the *birth rate*, the *population* declines; if the *birth rate* equals the *death rate*, the *population* is stable.

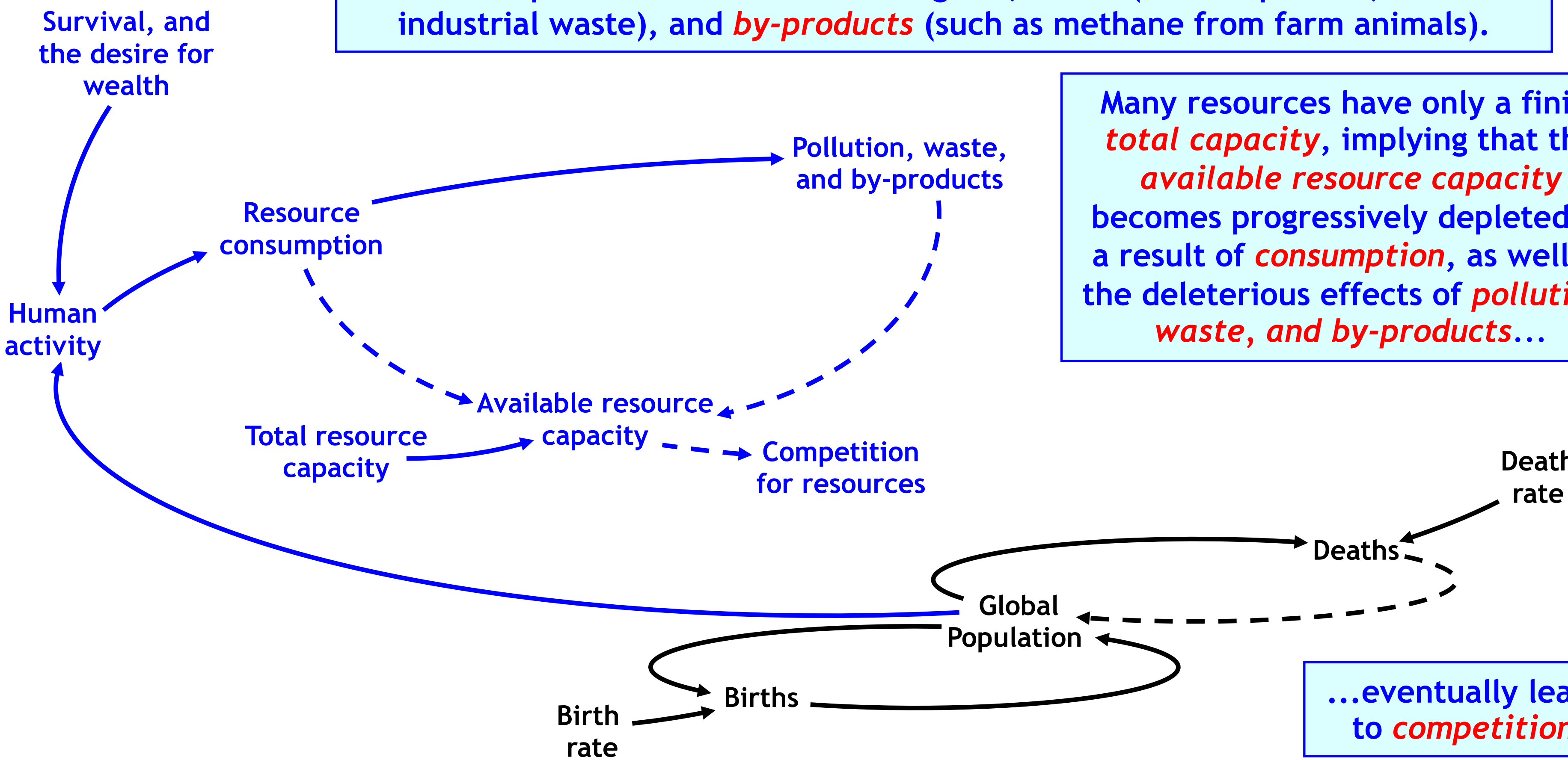
These graphs all have *population* as the vertical axis, and time as the horizontal axis. Each shows a possible behaviour over time of the *population*, depending on the instantaneous values of the *birth rate* and the *death rate*.



…and drives human activity…

Driven by the needs for *survival and the desire for wealth*, a *population* will engage in *human activity*, such as farming, building, manufacturing and trading. All these activities *consume resources* such as land and water, minerals and gases, coal and oil...

...resulting in *pollution* (such as carbon dioxide from fossil fuels, and nitrogen oxides and particulates from diesel engines, *waste* (such as plastics, CFCs and industrial waste), and *by-products* (such as methane from farm animals).



Many resources have only a finite *total capacity*, implying that the *available resource capacity* becomes progressively depleted as a result of *consumption*, as well as the deleterious effects of *pollution*, *waste*, *and by-products*...

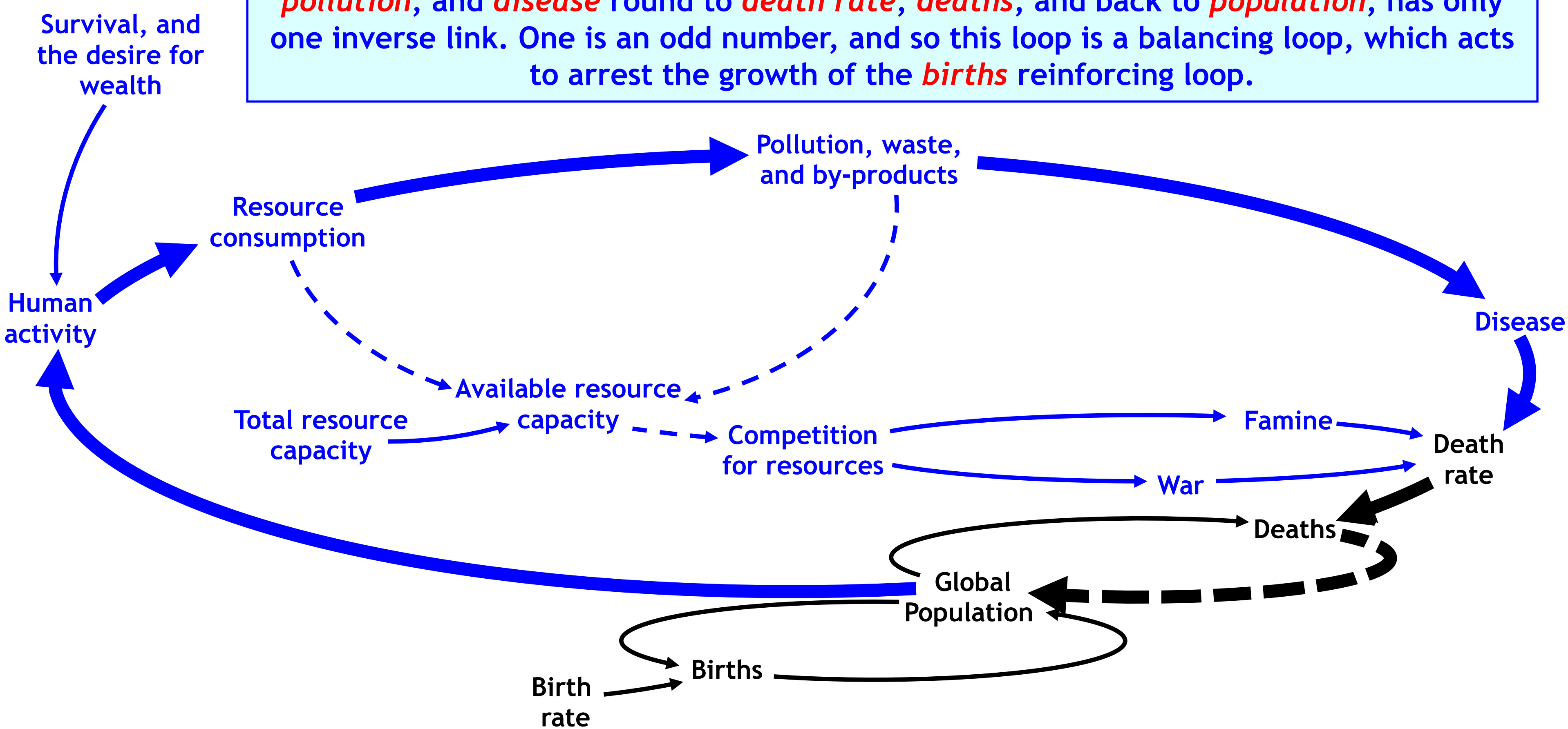
...eventually leading to *competition*...

…leading to war, famine and disease…

Pollution, waste, and by-products **create the conditions in which *disease* flourishes, and *competition for resources* can result in *war* and *famine*.**

***War*, *famine* and *disease* all increase the *death rate* beyond that attributable to natural processes such as ageing.**

The closed loop from *population* through *human activity*, *resource consumption*, *pollution*, and *disease* round to *death rate*, *deaths*, and back to *population*, has only one inverse link. One is an odd number, and so this loop is a balancing loop, which acts to arrest the growth of the *births* reinforcing loop.



This is just one of five balancing loops, all of which act simultaneously to limit the *births* reinforcing loop.

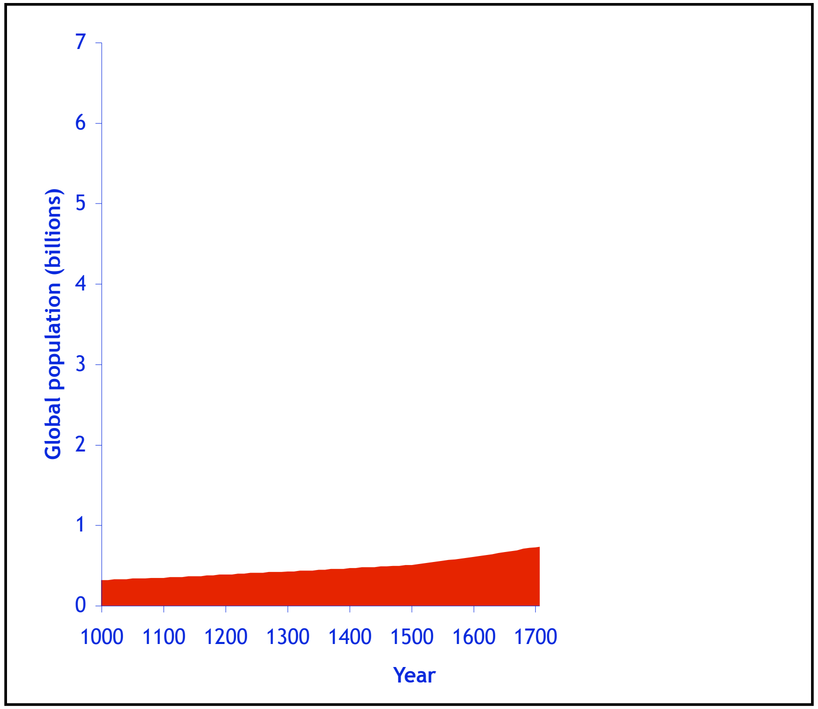
The Four Horsemen

The diagram on page 12 shows a single reinforcing loop seeking to grow exponentially, being limited by five simultaneous balancing loops, all resulting in *deaths* - either from natural causes, or resulting from *disease*, *famine* and *war*.

The Four Horsemen are real…

The Four Horsemen of the Apocalypse, woodcut by Albrecht Dürer, 1498.

…and for many hundreds, if not thousands, of years, held the global human population in check, with very slow growth…



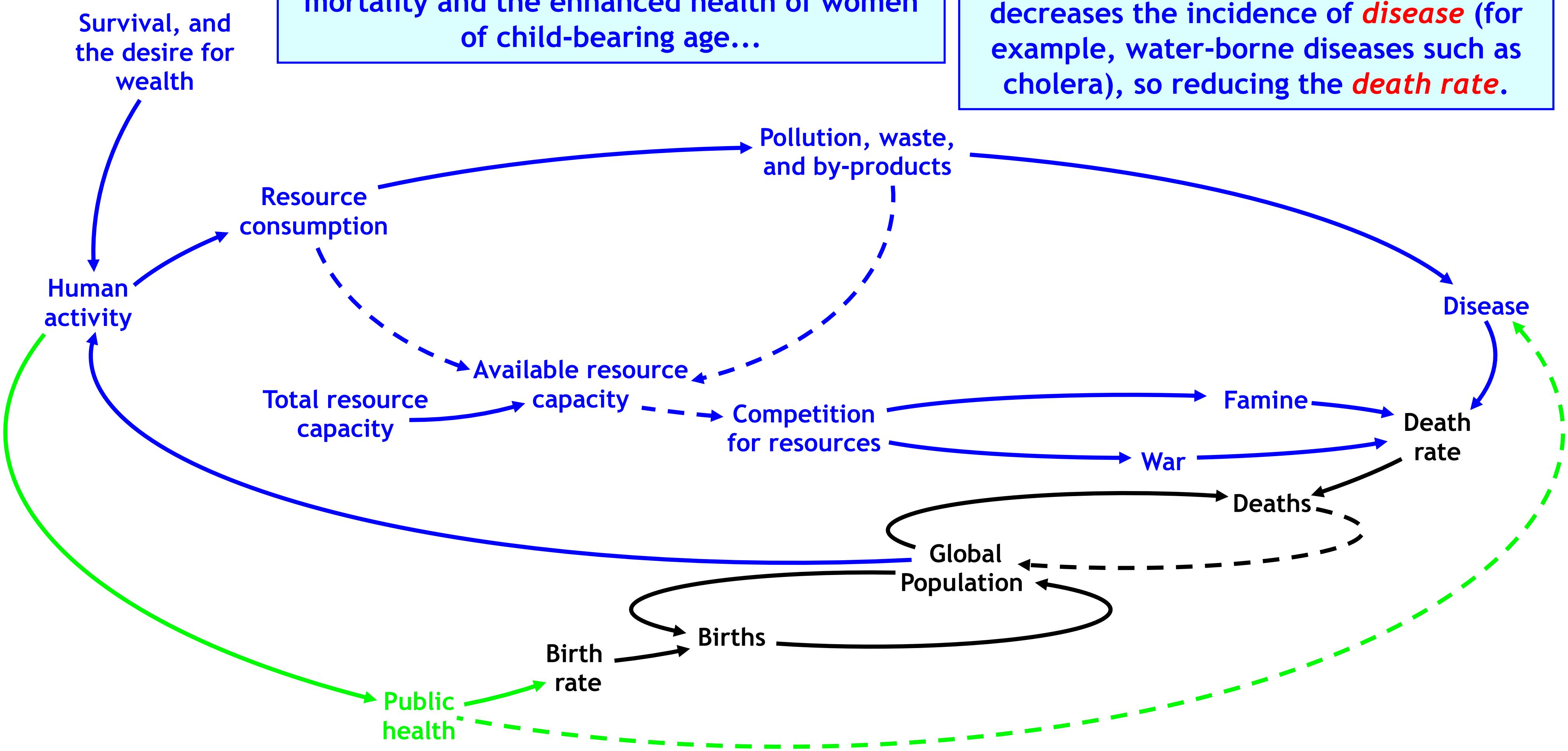
Source: The United Nations Population Division, Department of Economic and Social Affairs

The benefits of public health

As economies became more developed, and our understanding of disease became more scientific, some *human activity* was devoted to *public health*, especially the provision of clean water, and the treatment of sewage, in cities. This has two, simultaneous effects...

...firstly, improved *public health* increases the *birth rate*, due to both a reduction in infant mortality and the enhanced health of women of child-bearing age...

...secondly, improved *public health* decreases the incidence of *disease* (for example, water-borne diseases such as cholera), so reducing the *death rate*.

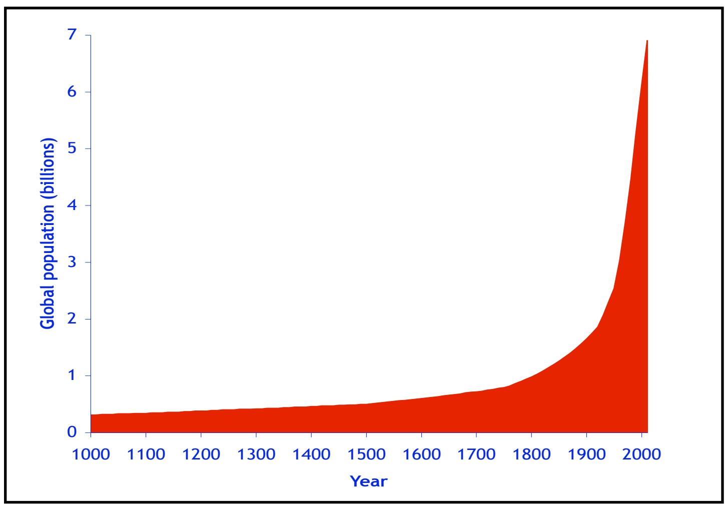


The population explosion

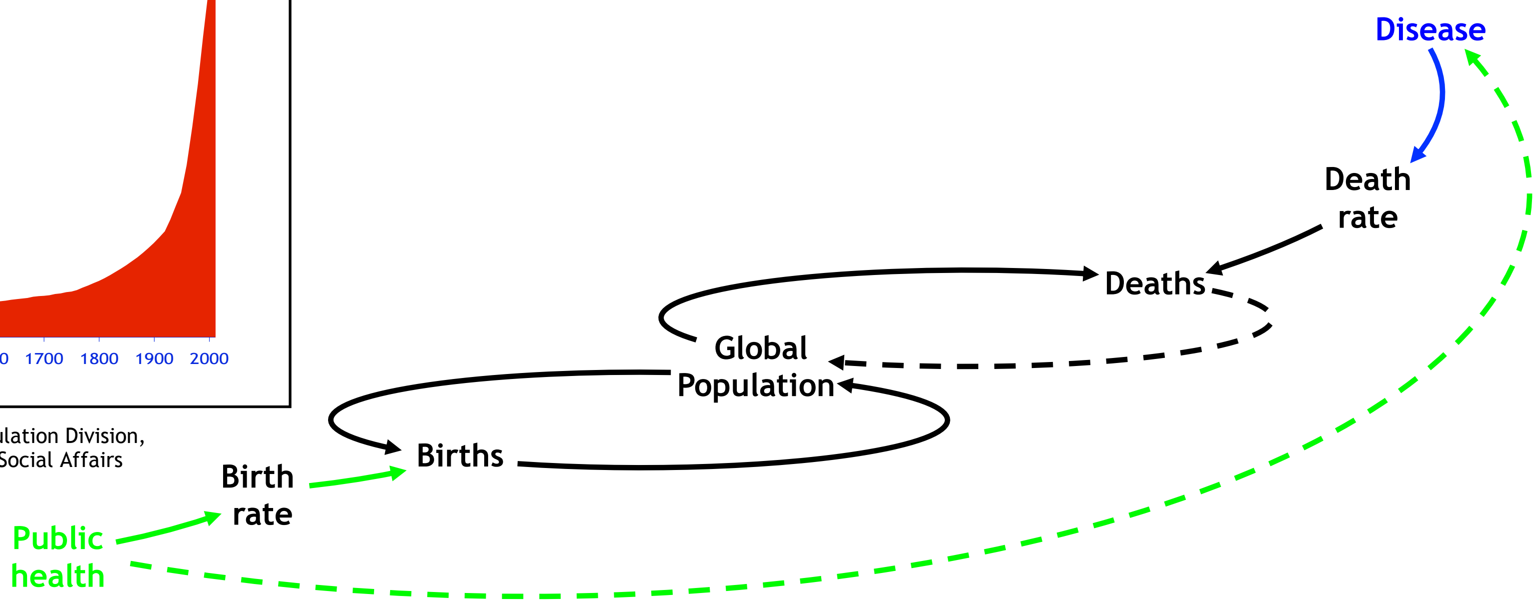
As we have already seen, the rate of growth of the *population* is driven by the difference between the *birth rate* and the *death rate*…

…so suppose that, before the focus on *public health*, the *birth rate* is 10 live births per 1,000 people, and that the *death rate* is 9 deaths per 1,000 people. The net *birth rate* is therefore 10 - 9 = 1 person per 1,000 people, and so the *population* will grow at this rate.

Suppose further that a *public health* programme has the result of reducing the *death rate*, and increasing the *birth rate*, each by about 10%. The *death rate* therefore decreases from 9 to 8 deaths per 1,000 people, and the *birth rate* increases from 10 to 11 live births per 1,000 people. The net *birth rate* therefore changes from 10 - 9 = 1 person per 1,000 people to 11 - 8 = 3 per 1,000 people. A 10% change to both the *birth rate* and the *death rate* causes a *300%* increase in the growth rate of the *population*. The *population* explodes…



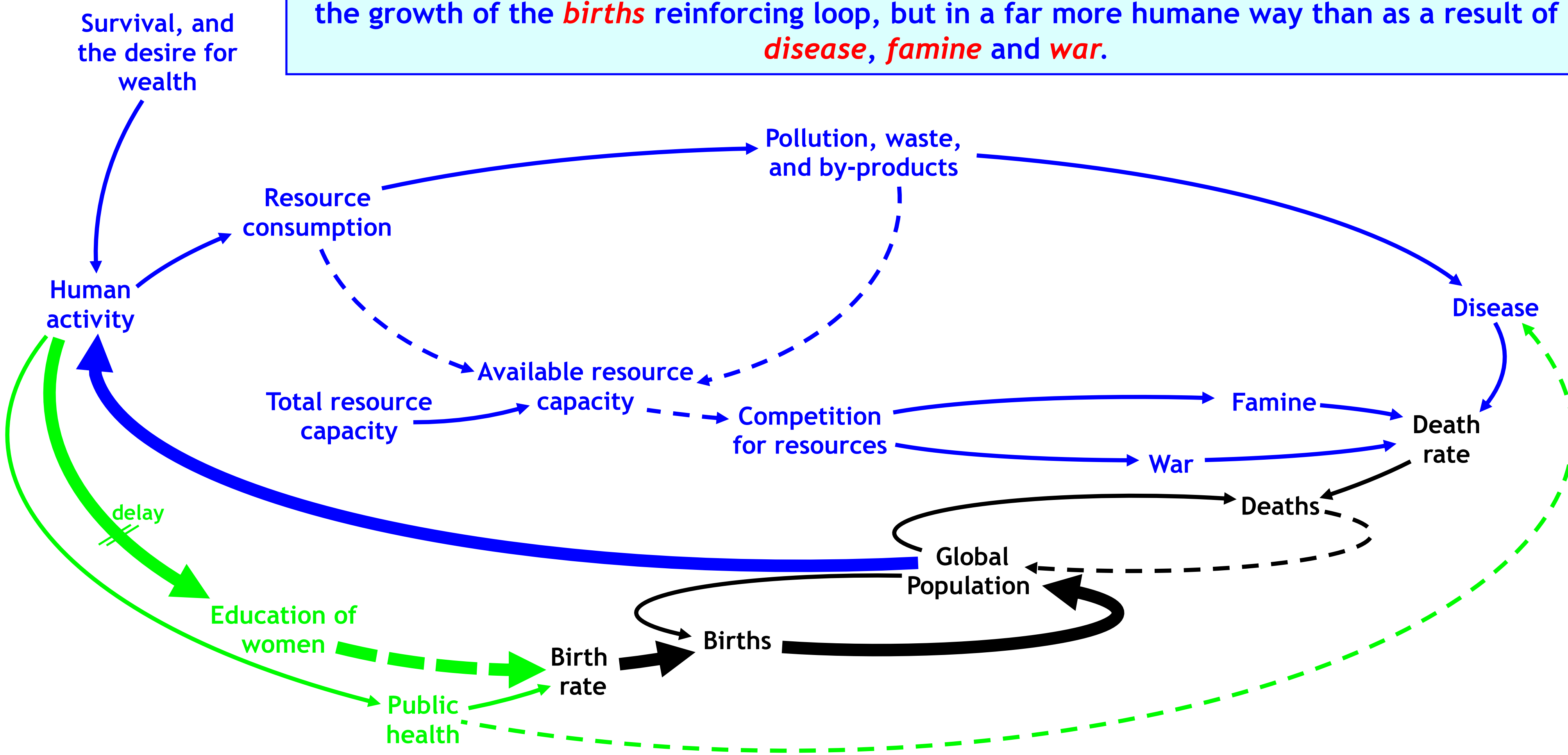
Source: The United Nations Population Division, Department of Economic and Social Affairs



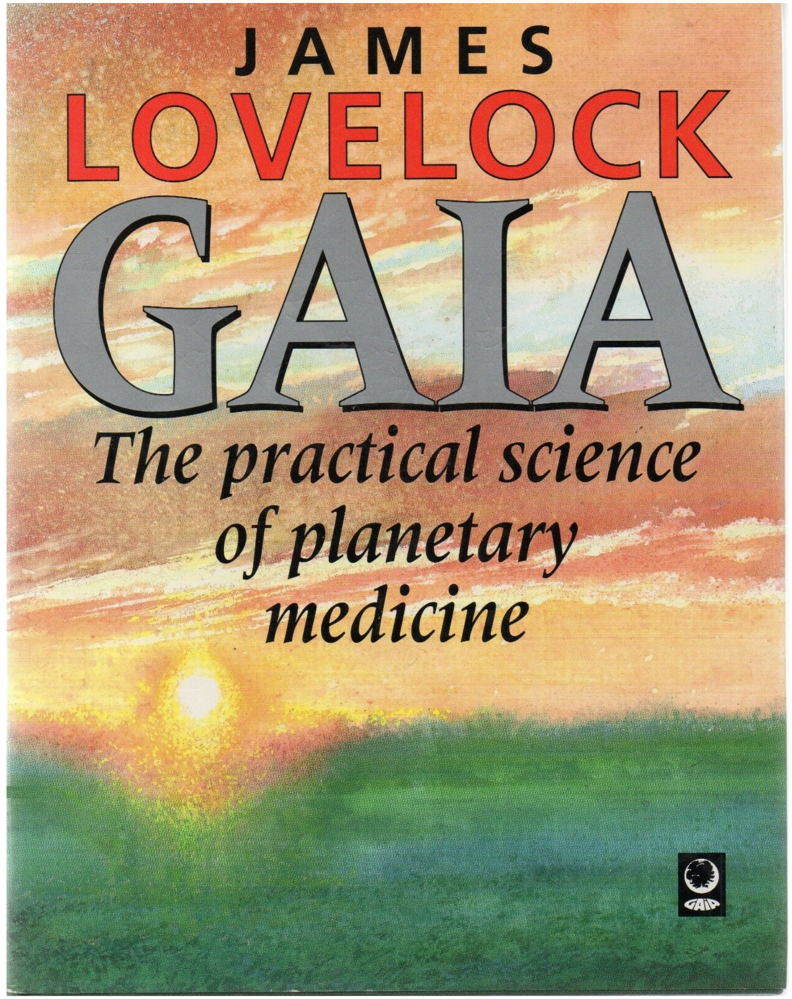
The story so far…

The most effective current way of limiting the *birth rate* is by devoting some of the *human activity* to the *education of women*, but this can take a long time, and has significant cultural implications.

From a systems perspective, this introduces another balancing loop - *population* to *human activity* to *education of women* to *birth rate* to *births* and back to *population*. This limits the growth of the *births* reinforcing loop, but in a far more humane way than as a result of *disease*, *famine* and *war*.

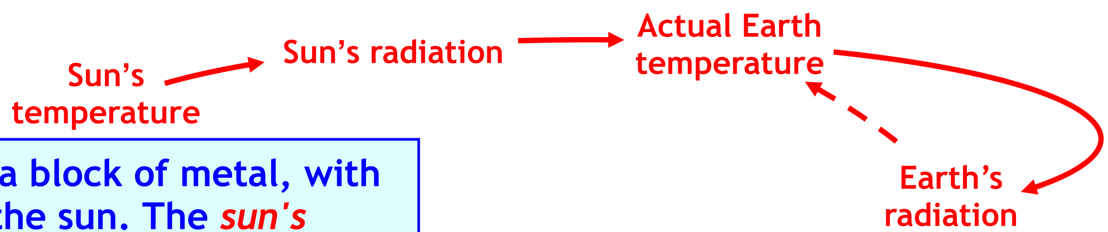


Gaia


JAMES
LOVELOCK
GAIA
The practical science
of planetary
medicine

Why isn't the Earth getting hotter?

If you heat a block of metal, it's gets hotter. But not indefinitely - sooner or later, the metal's temperature stabilises. This happens because the metal's temperature is the net result of two opposing effects: the rate at which energy is absorbed by the metal from the external heat source, and the rate at which energy is lost from the metal as a result of its own radiation. If more energy is absorbed than is lost, the metal gets hotter, as happens when the metal is relatively cool. But as the temperature of the metal increases, the rate of energy loss also increases, until the rate at which energy is lost equals the rate at which energy is absorbed, at which point the temperature of the metal stabilises.



The Earth is rather like a block of metal, with the heat source as the sun. The *sun's radiation*, attributable to the *sun's temperature*, heats the Earth, so increasing the *actual Earth temperature*. But as the Earth warms, the intensity of the *Earth's radiation* increases too, progressively slowing down the rate at which the *actual Earth temperature* rises. This forms a balancing loop, such that when the *actual Earth temperature* has risen to a value at which the rate of heat loss attributable to the *Earth's radiation* equals the rate of heat input from the *sun's radiation*, the *actual Earth temperature* stabilises.

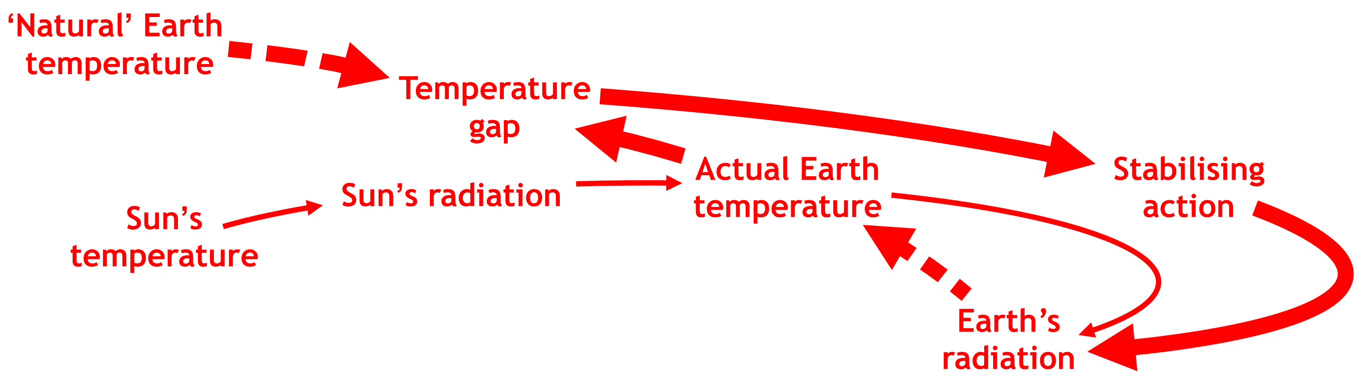
According to this balancing loop, the stabilised *actual Earth temperature* should track the *sun's temperature*: if the sun becomes warmer, the Earth should become warmer too; if the sun becomes cooler, the Earth should become cooler.

But over geologic time - *billions* of years - this is *NOT* what has happened. Over this time, the sun has been getting hotter, and the intensity of the *sun's radiation* has been steadily increasing. But the geologic evidence is that the *actual Earth temperature* has stayed more-or-less constant at about 14°C (see, for example, *The Ages of Gaia*, by James Lovelock, Oxford University Press, 2nd edition, 1995, page 143).

The balancing loop shown on this page is therefore not the whole story.
Something else must be happening too…

There must be another balancing loop

Geologic evidence shows that the *actual Earth temperature* has been more-or-less constant at about 14°C for billions of years, whilst, over that time, the intensity of the *sun's radiation* has been increasing. This cannot be explained by the balancing loop shown on page 19 alone. Rather, it suggests the presence of *another* balancing loop acting to stabilise on the *'natural' Earth temperature*, 14°C.



The action of this second balancing loop is best understood by considering what happens as the intensity of the *sun's radiation* increases, causing the *actual Earth temperature* to rise above the *'natural' Earth temperature*. This opens a *temperature gap* which triggers some type of *stabilising action* to increase the intensity of the *Earth's radiation*, so reducing the *actual Earth temperature*. This then closes the *temperature gap*, and brings the *actual Earth temperature* into line with the *'natural' Earth temperature*.

This form of temperature control is similar to that which we experience in our own bodies: when we are too hot - when our actual temperature exceeds our 'natural' temperature of 36.9°C - we invoke the stabilising action of sweating, which acts to reduce our actual temperature back to the 'natural' value.

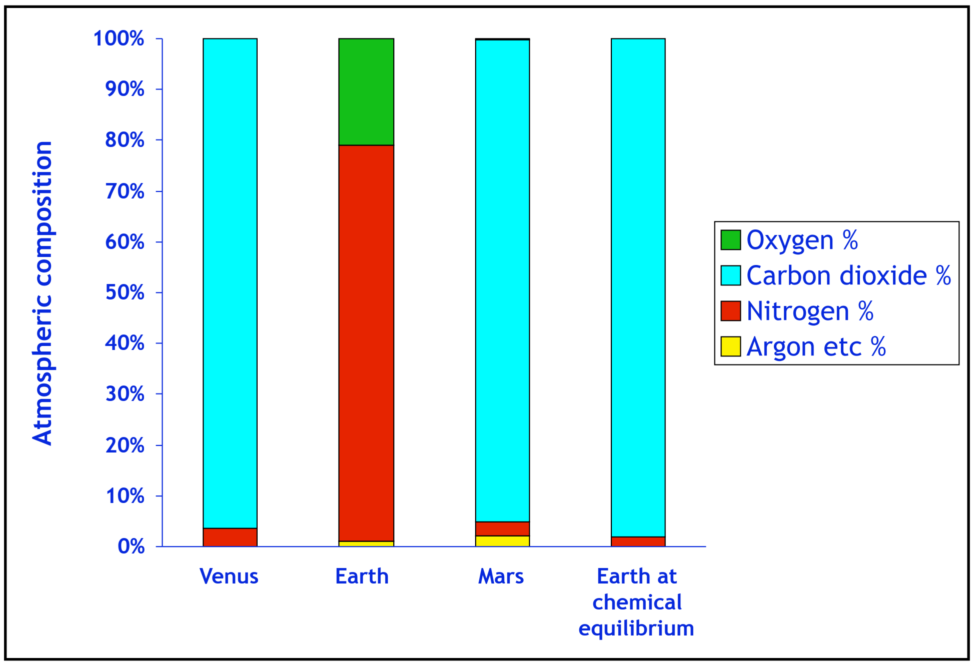
But what is the Earth's *stabilising action*?
The answer lies in James Lovelock's Gaia theory…

Planetary atmospheres

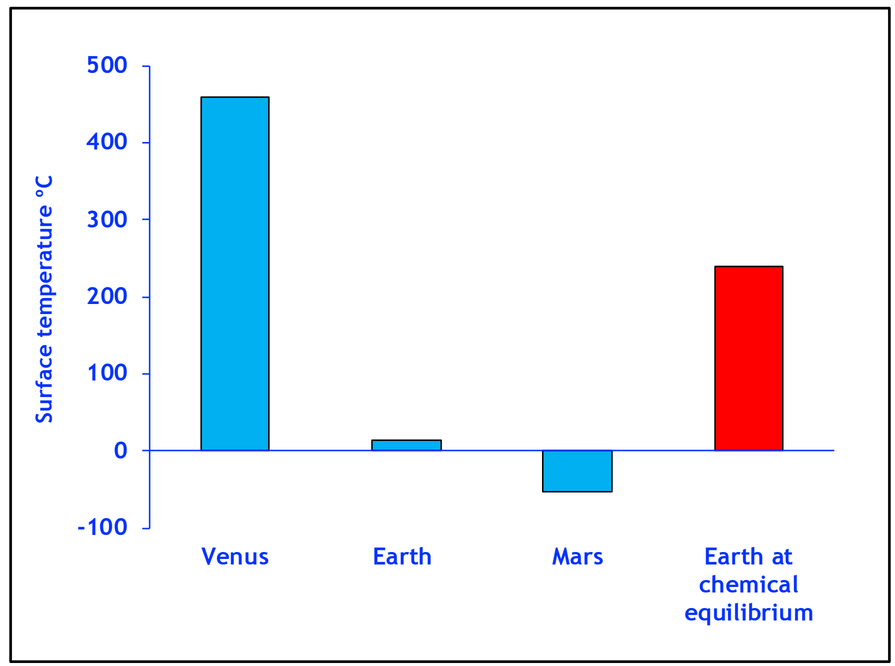
In the 1960s, James Lovelock was studying the atmospheres and surface temperatures of Venus, the Earth and Mars, and noticed that

- the composition of the Earth's atmosphere is very different from that of Venus and Mars and…
  - …very different from what it would be if the Earth were at chemical equilibrium;
- furthermore, the surface temperature of the Earth has been more-or-less stable at about 14°C over an extraordinarily long time…
  - …even though the sun has been getting hotter, so warming the Earth up…
- …and this actual stable temperature, 14°C, is considerably less than it would be if the Earth were at chemical equilibrium.

Lovelock then asked "why?"… and promptly answered his own question…



Source: *The Ages of Gaia*, by James Lovelock, published by Oxford University Press, 2[nd] edition 1995, page 9



Gaia

Lovelock's key observation was that the Earth maintains a stable state, far from chemical equilibrium. But he'd seen this before. As you and I have. For you and I are systems far from chemical equilibrium, and systems which maintain a stable state. One example of this is how human beings maintain a stable internal temperature of 36.9ºC. If our environment is hot, we sweat, or we increase the flow of blood to our skin so as to enhance heat loss; if our environment is cold, we shiver, or decrease the flow of blood to our skin so as to reduce heat loss. As a result, our internal body temperature is maintained stable at 36.9ºC even if our immediate environment is significantly warmer or cooler.

Lovelock's great insight as to why the Earth can maintain itself away from chemical equilibrium is because the Earth as a whole - its structure, its rocks, its oceans, its weather, its living beings - collectively behave as a living 'super-organism', which he named 'Gaia'. And as a 'super-organism' (more formally, as a self-organising complex system), Gaia acts to maintain the conditions necessary for survival, such as a stable temperature.

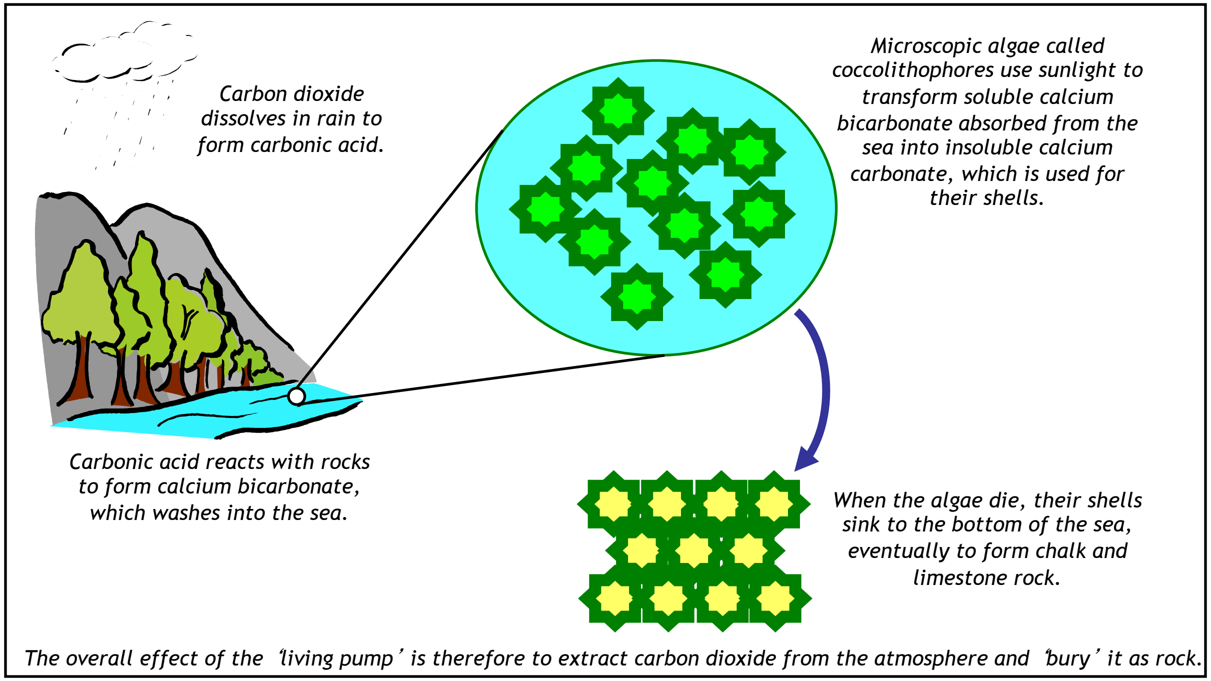
He also identified the primary mechanism by which the Earth keeps its temperature stable at 14ºC, despite the increasing intensity of the sun's radiation. The key factor is the quantity of carbon dioxide in the atmosphere. As a 'greenhouse gas', carbon dioxide acts as an atmospheric 'blanket' such that the greater the quantity of carbon dioxide in the atmosphere, the warmer the Earth. For us to keep cool, we sweat; for the Earth to keep cool, carbon dioxide needs to be removed from the atmosphere.

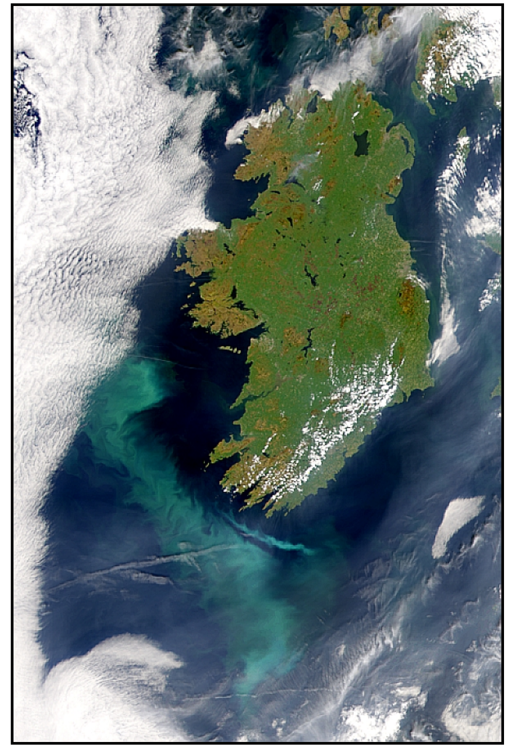
Page 23 shows the mechanism Lovelock identified. Carbon dioxide in the air dissolves in rain to form a weak solution of carbonic acid. When the rain falls to Earth, the carbonic acid reacts with calcium silicate in rocks to form silicic acid and calcium bicarbonate. This is known as the 'weathering of rocks', and is much speeded up by micro-organisms in the soil. Calcium bicarbonate is soluble, and flows into the sea, where algae known as 'coccolithophores' absorb it, using the energy of sunlight to transform it into calcium carbonate. Calcium carbonate is insoluble, and forms shells around the living algae. When the algae die, the calcium carbonate shells fall to the bottom of the sea, and over geological time, form the rocks we know as chalk and limestone.

All the chalk and limestone in the world originates from this process, which has the effect of 'pumping' carbon dioxide out of the air, and 'burying' it as rock - a life-mediated process which Lovelock called 'the living pump'. And by removing carbon dioxide from the atmosphere, the Earth can keep cool.

The living pump

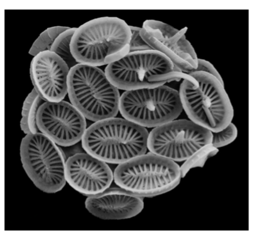
Schematic representation of the living pump

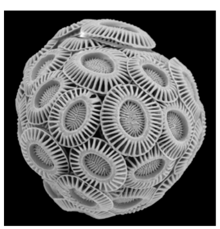




A summer bloom of coccolithophores off Ireland

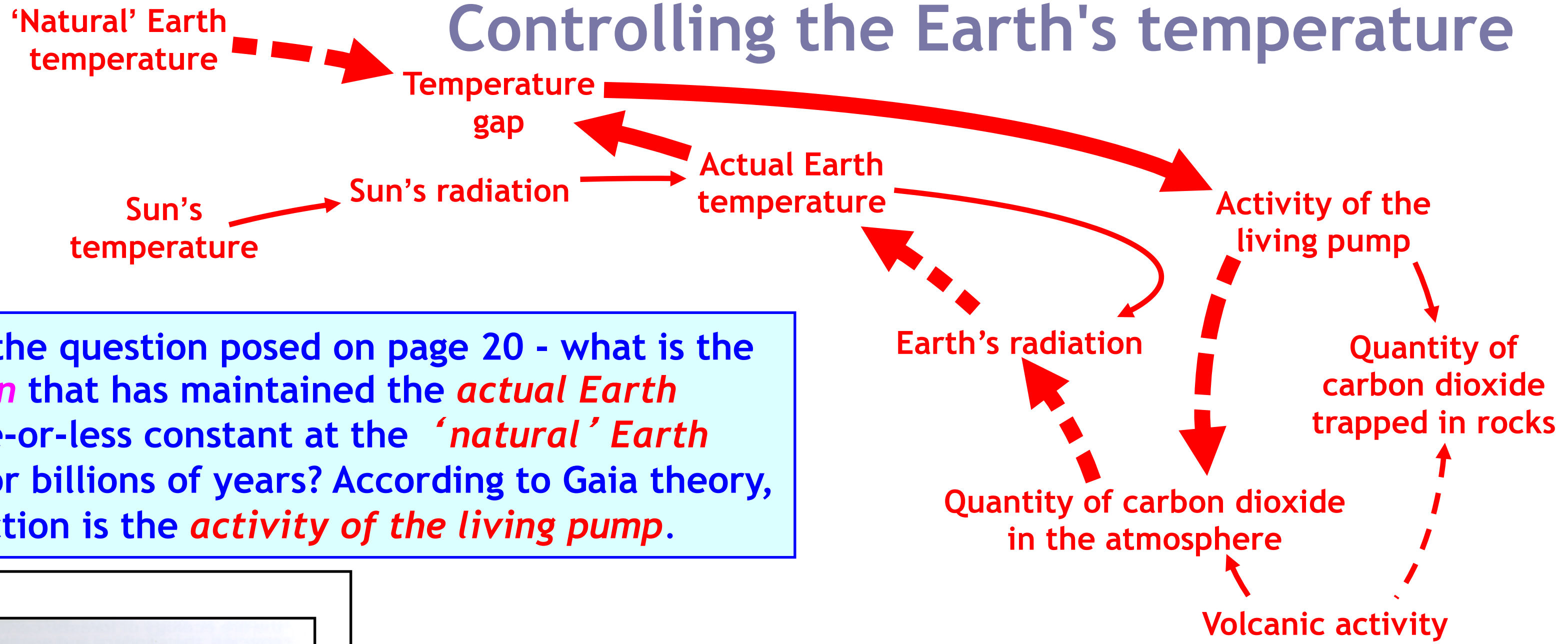
Electron microscope images of coccolithophores



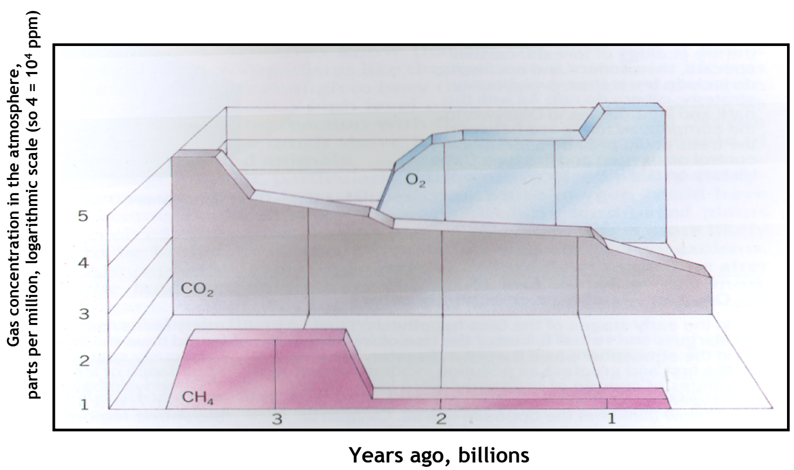


Chalk cliffs, formed from the shells of countless billions of coccolithophores

Controlling the Earth's temperature



We can now answer the question posed on page 20 - what is the *stabilising action* that has maintained the *actual Earth temperature* more-or-less constant at the *'natural' Earth temperature*, 14°C, for billions of years? According to Gaia theory, the stabilising action is the *activity of the living pump*.



Source: *Gaia: The practical science of planetary medicine*, James Lovelock, Gaia Books Limited (1991), page 113

Over billions of years, as the sun has been getting hotter, the living pump has steadily reduced the quantity of carbon dioxide in the atmosphere, so keeping the Earth's temperature at about 14°C.

When the *actual Earth temperature* rises above the *'natural' Earth temperature*, as caused by an increase in the intensity of the *sun's radiation*, the *temperature gap* stimulates the *activity of the living pump*, so reducing the *quantity of carbon dioxide in the atmosphere* and simultaneously increasing the *quantity of carbon dioxide trapped in rocks*. Reducing the *quantity of carbon dioxide in the atmosphere* increases the intensity of the *Earth's radiation*, and so reduces the *actual Earth temperature* to close the *temperature gap*.
This loop has three inverse links, and so is, as expected, a balancing loop, stabilising on the *'natural' Earth temperature*.

For completeness, this causal loop diagram also shows the effect of *volcanic activity*, which releases carbon dioxide trapped in rocks back into the atmosphere. Although the living pump and volcanoes work against one another, until very recently, the living pump worked fast enough to counteract the effect of volcanoes.

Man v. Gaia

Who will win?

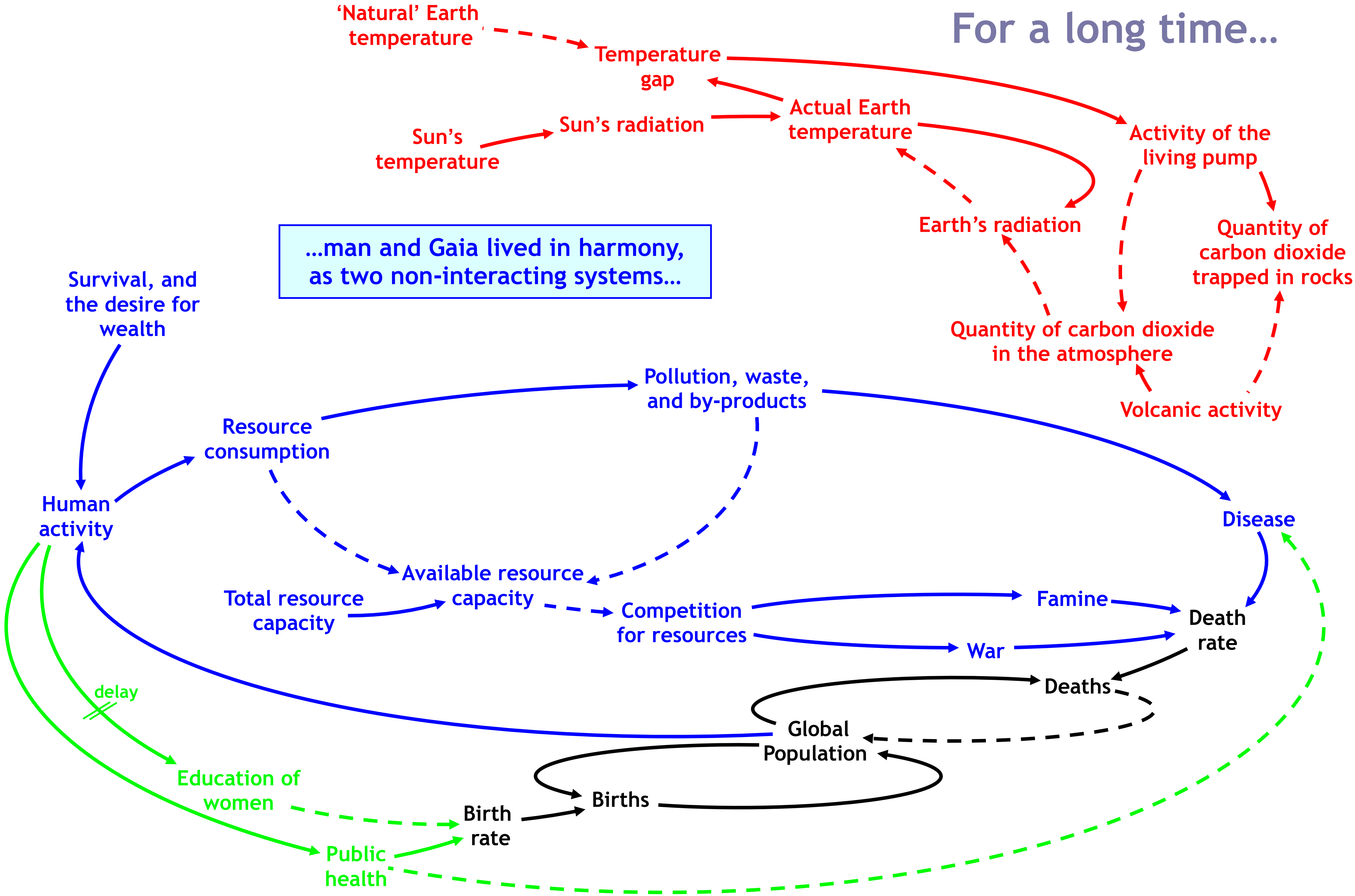
Some visions of the future...

See, for example...

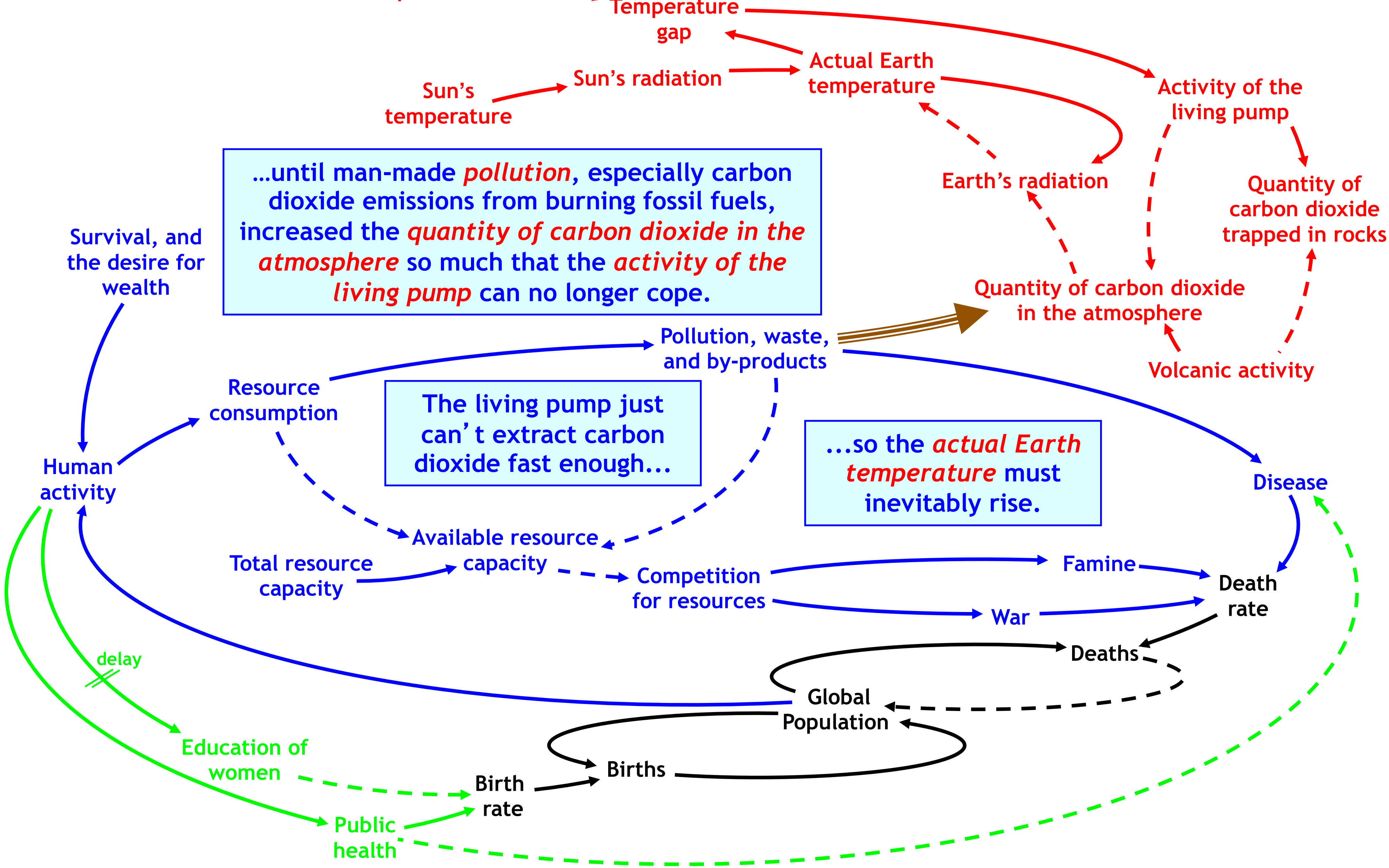
https://www.climeworks.com/
https://www.bbc.co.uk/news/world-43789527
http://www.geoengineering.ox.ac.uk/www.geoengineering.ox.ac.uk/what-is-geoengineering/what-is-geoengineering/
https://geoengineering.environment.harvard.edu/geoengineering
http://www.geoengineeringmonitor.org/wp-content/uploads/2018/05/Geoengineering-factsheet-DirectAirCapture.pdf

For a long time…

…man and Gaia lived in harmony, as two non-interacting systems…

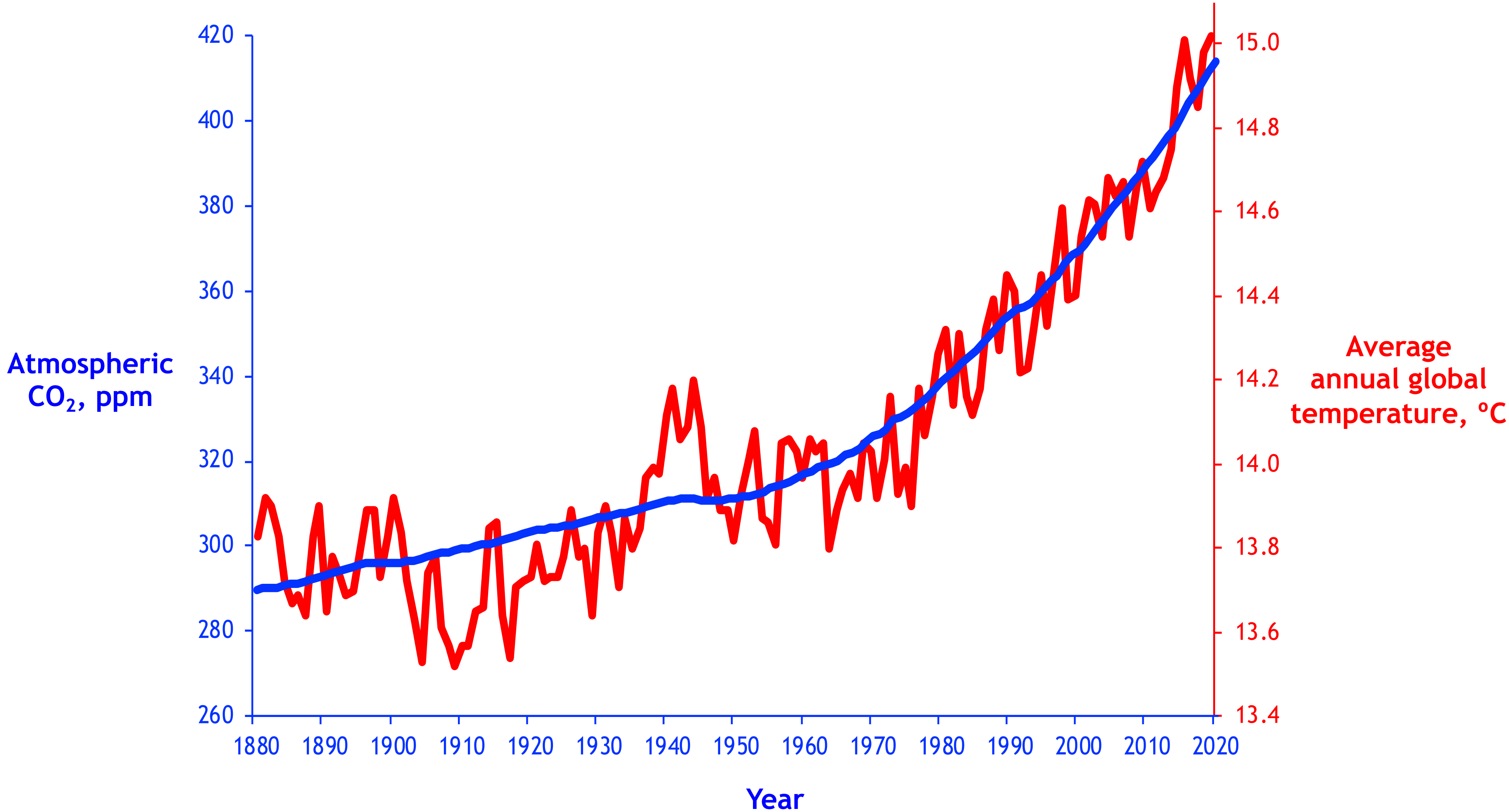


…but then…



'Natural' Earth temperature
Temperature gap
Actual Earth temperature
Sun's radiation
Sun's temperature
Activity of the living pump
Earth's radiation
Quantity of carbon dioxide trapped in rocks
Quantity of carbon dioxide in the atmosphere
Volcanic activity
…until man-made pollution, especially carbon dioxide emissions from burning fossil fuels, increased the quantity of carbon dioxide in the atmosphere so much that the activity of the living pump can no longer cope.
Survival, and the desire for wealth
Human activity
Resource consumption
Pollution, waste, and by-products
The living pump just can't extract carbon dioxide fast enough…
…so the actual Earth temperature must inevitably rise.
Disease
Available resource capacity
Total resource capacity
Competition for resources
Famine
War
Death rate
Deaths
Global Population
Births
Birth rate
delay
Education of women
Public health

Global warming is real



Sources: CO_2 - US National Oceanic and Atmospheric Administration
Temperature - NASA Goddard Institute for Space Studies

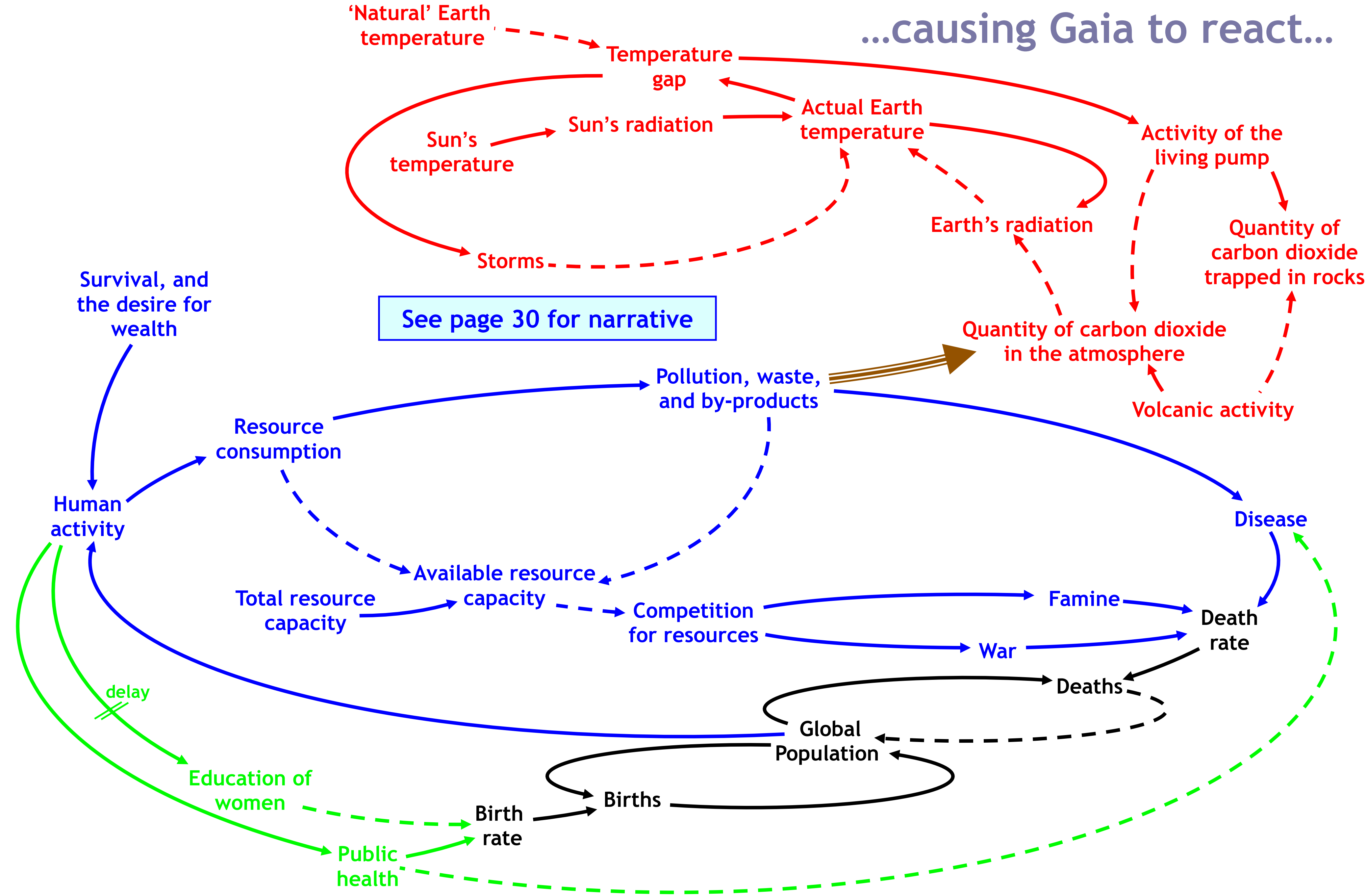
...causing Gaia to react...

Many living systems have more than one way of maintaining stability. In our bodies, for example, if we become hot, we firstly sweat, and if that doesn’t lower our temperature sufficiently, our bodies then enhance the flow of blood to our skin to increase heat loss.

Gaia, too, has more than one way of maintaining the Earth's temperature stable. The *activity of the living pump* is the principal way, but if the pump just can’t pump fast enough, and the *actual Earth temperature* begins to rise, then another mechanism is triggered: an increase in the incidence of *storms* and violent weather, for these act to dissipate energy, so reducing the *actual Earth temperature*.

Even though many living systems have more than one way of maintaining stability, ultimately, they break. As we have seen, if we get hot, we sweat, and increase the supply of blood to the skin so as to maximise heat loss. But if we get too hot - heatstroke, for example - we die. By the same token, Gaia has mechanisms that can maintain the Earth's temperature stable - but they too have limits, beyond which Gaia, and the entire planet, will die.

…causing Gaia to react…



See page 30 for narrative

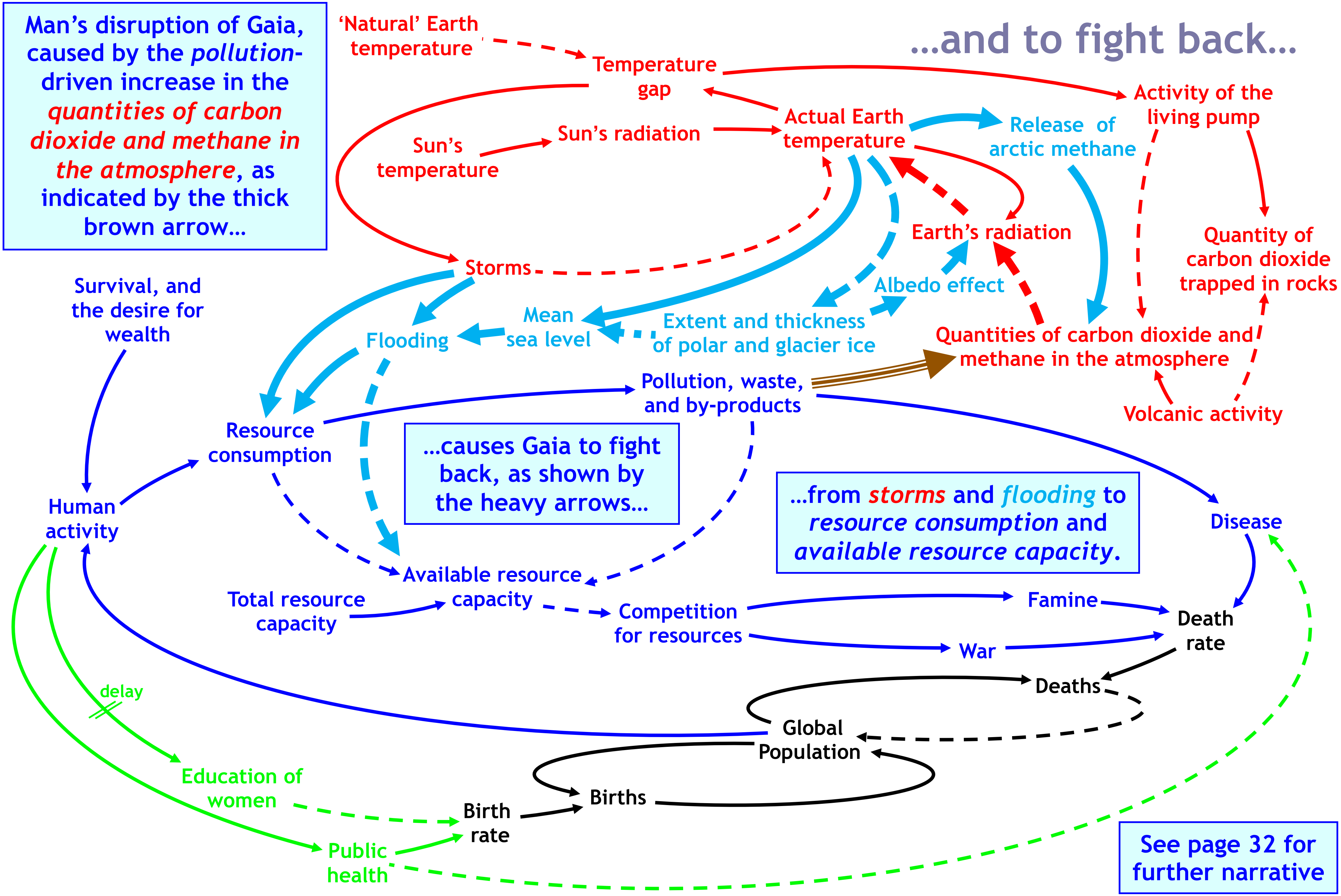
…and to fight back…

As the actual *Earth temperature increases*, *methane* trapped in arctic permafrost, lakes and seas is progressively *released*. Although methane has a lower atmospheric concentration than carbon dioxide, and remains in the atmosphere for a shorter time, it is substantially more powerful as a greenhouse gas - so a sudden release of large quantities, resulting from the reinforcing loop from *actual Earth temperature*, through *release of arctic methane*, *quantities of carbon dioxide and methane in the atmosphere* and *Earth's radiation* back to *actual Earth temperature*, could be truly catastrophic. Also, as the *actual Earth temperature* increases, polar ice sheets and mountain glaciers progressively melt, and the *extent and thickness of polar and glacier ice* reduces.

This has two consequences. The first concerns the *albedo effect*, the phenomenon whereby light-coloured surfaces reflect the sun's energy, in contrast to dark-coloured surfaces, that absorb energy. Ice sheets are white, and so the greater their extent, the greater the *earth's radiation*; conversely, the greater the extent of darker land and sea, the lesser the *earth's radiation*, with the absorbed energy acting to increase the *earth's actual temperature*. The melting of ice therefore ultimately replaces a white, reflecting, surface by a darker one, which absorbs more heat, causing the *earth's actual temperature* to rise, so melting even more ice… as shown by the reinforcing loop from *actual Earth temperature* through *extent and thickness of polar and glacier ice*, *albedo effect* and *Earth's radiation*, back to *actual Earth temperature*.

Secondly, the melt waters from land-based ice cause a rise in *mean sea level* - something that also happens directly from the rise in the *actual Earth temperature* resulting from the thermal expansion of the water in the surface levels of the oceans. Note that the melting of the North Polar ice cap won't affect sea levels - the ice around the North Pole is floating on the waters of the Arctic Ocean, and as it melts, the resulting water 'fills' the volume previously occupied by ice.

The rise in *mean sea level* results in the *flooding* of lower-lying areas, such as Britain's East Anglia, the Netherlands and Northern Germany, Bangladesh, and many islands. *Flooding* is also aggravated by the effects of *storms*. *Flooding* directly reduces the *capacity of key resources*, such as land and drinking water; *flooding* and *storms* both cause an increase in *resource consumption* as increasingly scarce *resources* are used to build, for example, sea defences to stop the flooding, and to re-build houses after a severe *storm* or *flood*.



Man's disruption of Gaia, caused by the pollution-driven increase in the quantities of carbon dioxide and methane in the atmosphere, as indicated by the thick brown arrow…
…and to fight back…
'Natural' Earth temperature
Temperature gap
Activity of the living pump
Actual Earth temperature
Sun's radiation
Sun's temperature
Release of arctic methane
Earth's radiation
Quantity of carbon dioxide trapped in rocks
Storms
Albedo effect
Survival, and the desire for wealth
Mean sea level
Extent and thickness of polar and glacier ice
Flooding
Quantities of carbon dioxide and methane in the atmosphere
Pollution, waste, and by-products
Volcanic activity
Resource consumption
…causes Gaia to fight back, as shown by the heavy arrows…
…from storms and flooding to resource consumption and available resource capacity.
Human activity
Disease
Available resource capacity
Total resource capacity
Competition for resources
Famine
Death rate
War
Deaths
delay
Global Population
Births
Education of women
Birth rate
Public health
See page 32 for further narrative

…with a vengeance

In the diagram on page 35, follow the closed figure-of-eight-shaped loop highlighted in magenta. There are five inverse links - from *flooding* to *available resource capacity*, *available resource capacity* to *competition for resources*, *deaths* to *population*, *quantity of carbon dioxide in the atmosphere* to *Earth's radiation*, and *Earth's radiation* to *actual Earth temperature*. This loop is therefore a balancing loop - a balancing loop that seeks to converge on a target. But what is the target? Targets are defined by target dangles, of which there are two - the *'natural' Earth temperature*, and man's *desire for wealth*. These two targets are in competition: if man's *desire for wealth* dominates, then the *actual Earth temperature* must rise; but if the *'natural' Earth temperature* dominates, then the result, inevitably, is an increase in *deaths*.

Yes. The action of this loop is to increase *deaths* by virtue of the *famine* resulting from the depletion of the global *available resource capacity* caused by the devastation of land and fresh water supplies resulting from *flooding*. The *flooding* is caused by *storms*, in turn caused by an increase in the *temperature gap* attributable to the rise in the *actual Earth temperature* driven by an increase in the *quantity of carbon dioxide in the atmosphere*, caused by *pollution*, caused by… *man*. So, by increasing *deaths*, and therefore causing a decrease in *population*, Gaia is directly addressing the cause of its problem…

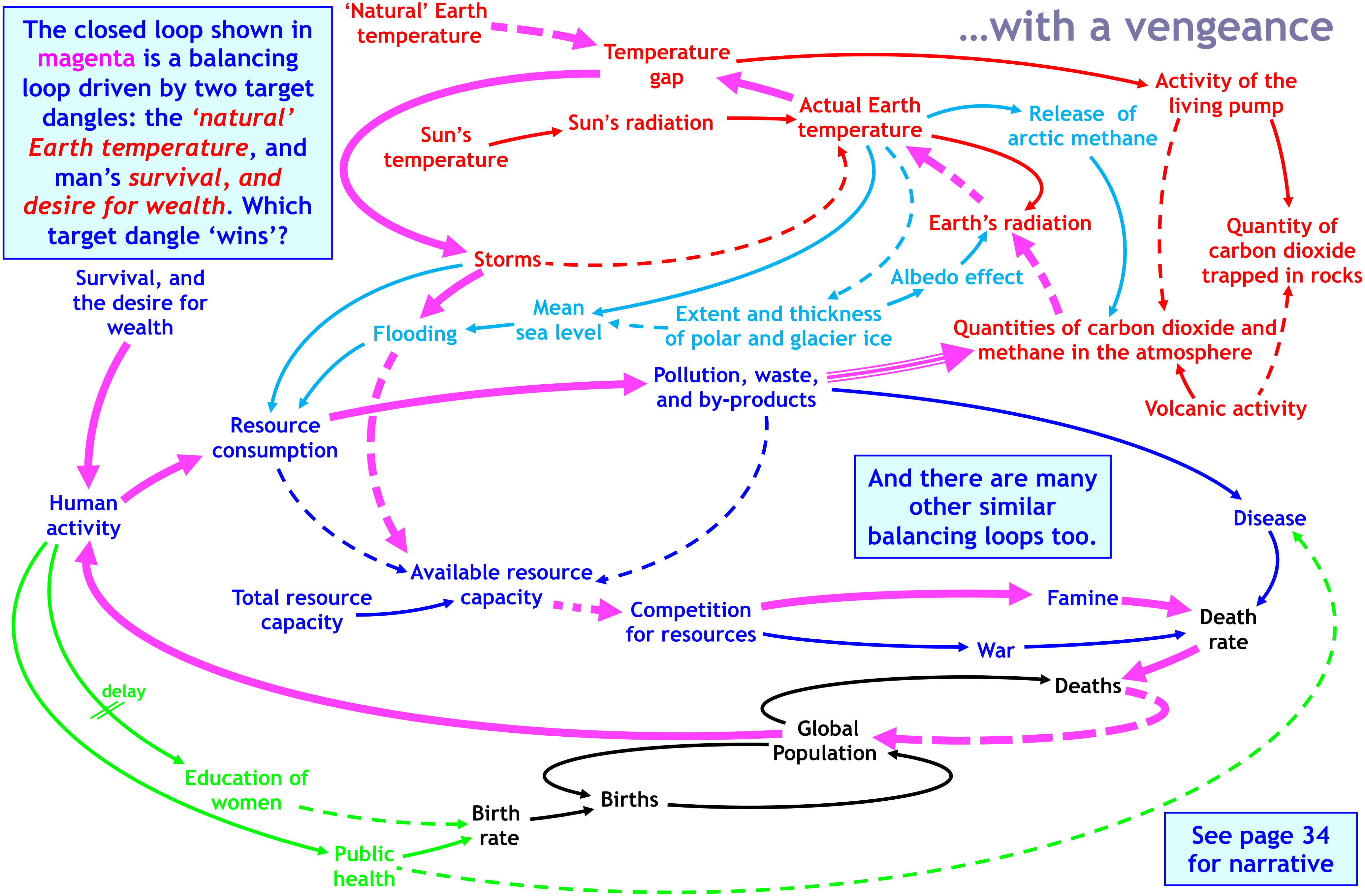
Just as man will swat an annoying gnat, Gaia will deal with whatever it finds annoying. Gaia, after all, has existed for far, far longer than man, and if man were no longer to exist, life in other forms will continue. Gaia does not need man. But man surely needs Gaia.

The loop highlighted in magenta is not the only loop acting in this way. For example, there is another through *disease* (the threat, for example, to clean water); another through *war* (if a nation is threatened by floods, what are all those people going to do?); and another through *mean sea level*. Furthermore, there are many other phenomena that are not shown, such as the 'albedo' effect, whereby sunlight is reflected more strongly from lighter surfaces (such as snow) than from darker ones (such as the sea).

What do we conclude? One very sobering thought. If man seeks to 'take on' Gaia, man sill surely lose. Gaia will solve its own problem - by depleting the human population - of its own accord. Unless we act first.

…with a vengeance

The closed loop shown in magenta is a balancing loop driven by two target dangles: the *'natural' Earth temperature*, and man's *survival, and desire for wealth*. Which target dangle 'wins'?



And there are many other similar balancing loops too.

See page 34 for narrative

Some good things to do...but not the right things to do...

To survive, man must find ways to counteract the destructive feedback loops shown on page 35. Fundamental to this is the need for the *political will* to recognise that the observed *temperature gap* is a trigger for a *radical reassessment of economic and political priorities* so as to drive a fundamental *re-thinking of human activity*...

...firstly, and very importantly, by enhancing the *education of women* - *and men too*, this being by far the most powerful method of controlling the *birth rate*...

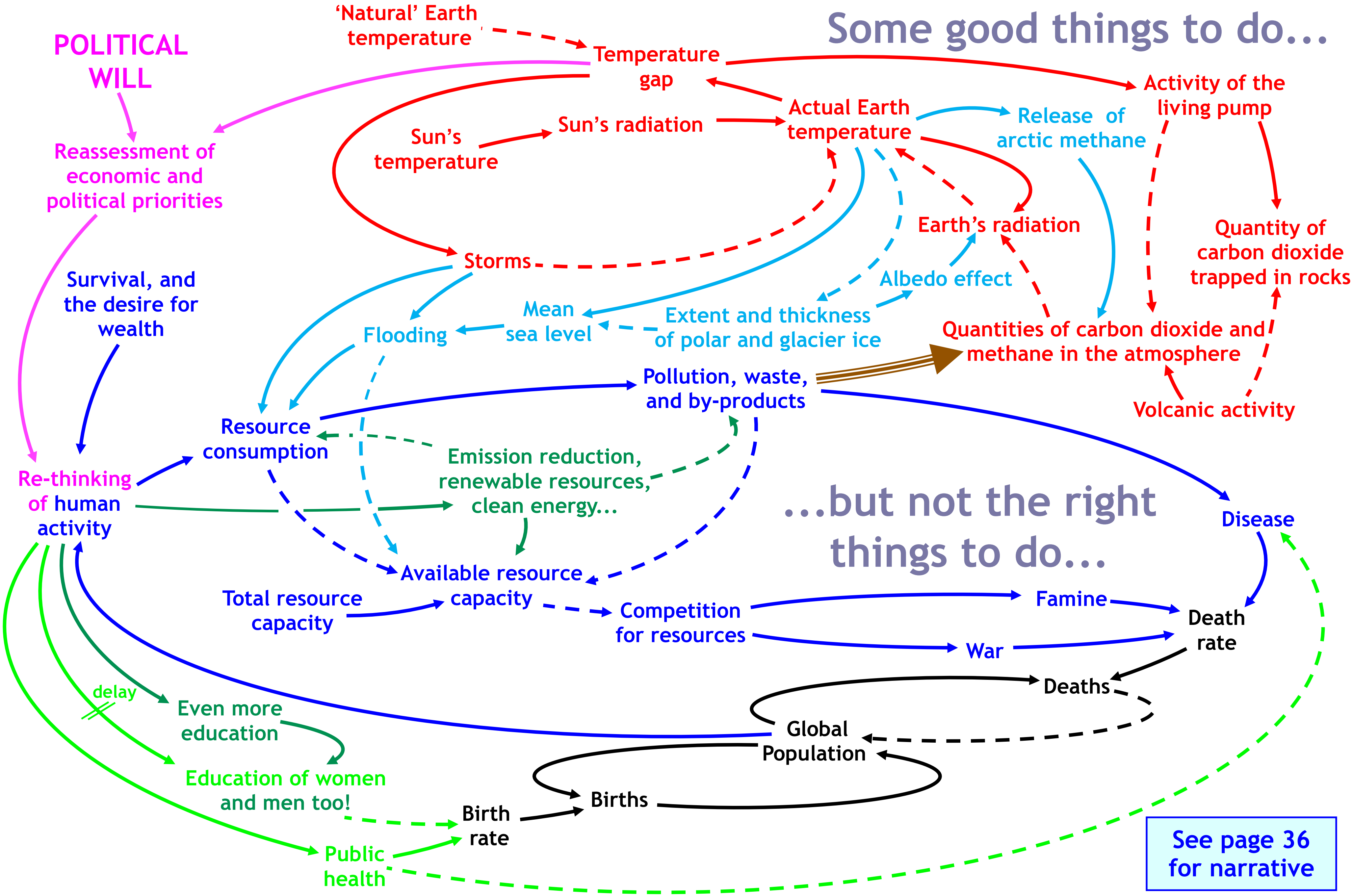
...and secondly, by implementing policies for *emissions reduction*, *renewable resources*, *clean energy* and the like, so reducing overall *resource consumption*, increasing the *available resource capacity*, reducing the *competition for resources*, and reducing *pollution*, *waste*, *and by-products*, especially the emissions of greenhouse gases in general, and carbon dioxide in particular. Indeed, targets for reducing emissions have been a central feature of all the major national and international initiatives, such as the 1997 Kyoto Protocol, the 2009 Copenhagen Accord and the 2016 Paris Agreement.

Reference to page 37, however, will show that although reducing emissions is undoubtedly a good thing to do, it is not the right thing to do.

Why so? Because the *actual Earth temperature* is determined by the *actual quantity of carbon dioxide in the atmosphere* at any time. Technically, this *quantity* is known as a stock in that it accumulates over time, rather like the quantity of water in a bath.

Emissions, by contrast, are a flow, causing the corresponding stock to accumulate - just like the flow of water through a tap, filling the bath. Reducing emissions *just makes the tap run more slowly* - but the *actual quantity of carbon dioxide in the atmosphere* still continues to increase, as does the *actual Earth temperature*, albeit more slowly. Reducing emissions, though a good thing to do, does not solve the climate crisis problem. So what does? The answer is 'geoengineering'.

Some good things to do...



See page 36 for narrative

Geoengineering

Geoengineering is the overall term for large-scale technologies that directly affect the atmosphere and the climate - technologies such as *solar radiation management (SRM)*, *carbon dioxide removal (CDR)* and *greenhouse gas removal (GGR)*.

The objective of *solar radiation management (SRM)* is to reduce the quantity of solar radiation that strikes the Earth's surface over any time - for example, by applying suitable coatings to the sun-facing surfaces of clouds so as to make them more *reflective* of sunlight.

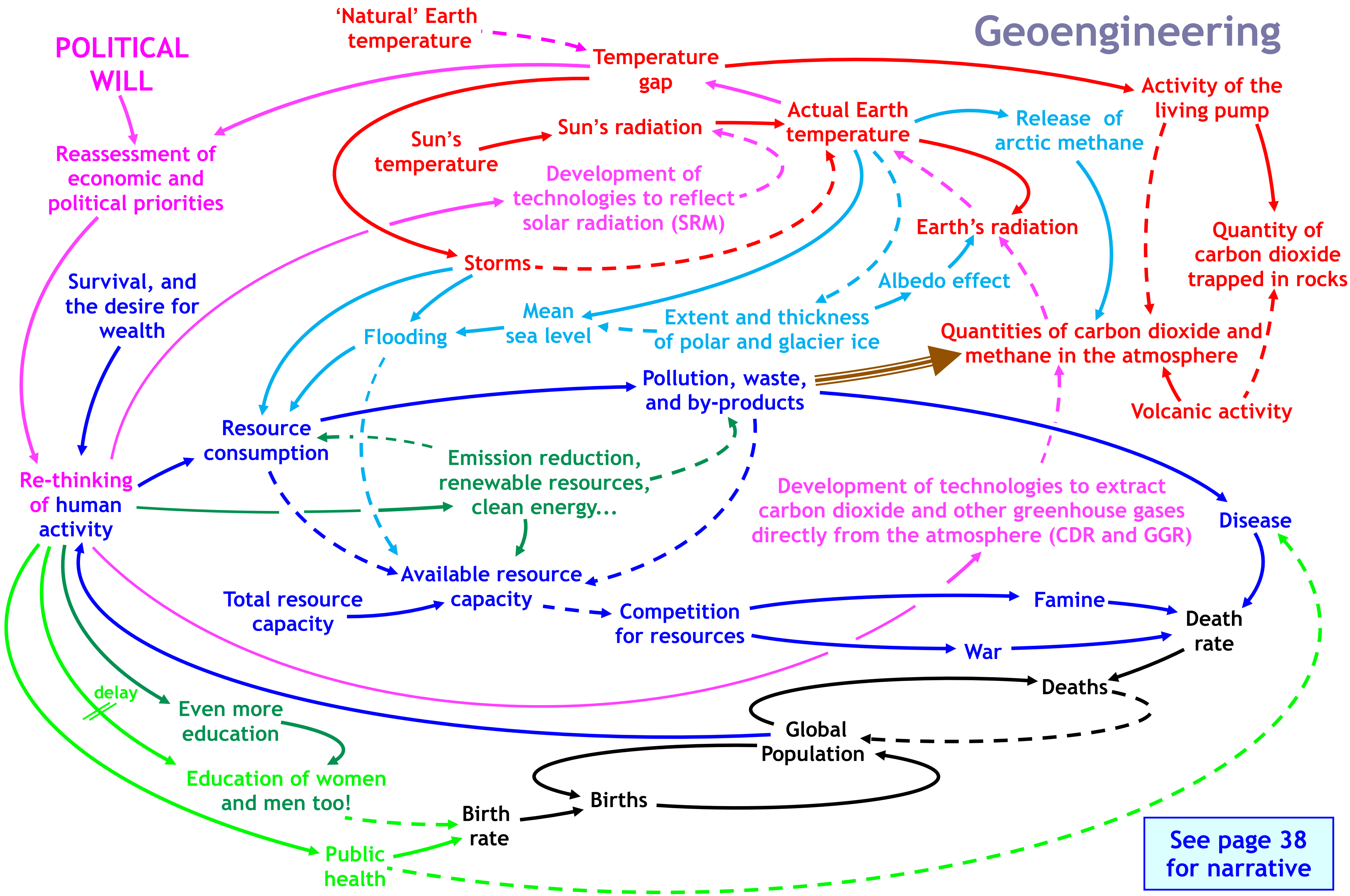
The objective of *carbon dioxide removal (CDR)* and *greenhouse gas removal (GGR)* is to *extract carbon dioxide (and greenhouse gases in general) directly from the atmosphere*.

In principle, *CDR* mimics the natural action of coccolithophores (see page 23), which extract carbon dioxide from the atmosphere, transforming it into inert limestone or chalk - a much more permanent sequestration of atmospheric carbon dioxide than that achieved by plant photosynthesis, which forms sugars and other organic products.

CDR therefore supplements Gaia's 'living pump', and, if carried out at sufficient scale, could in principle *reduce* the *actual quantity of carbon dioxide in the atmosphere* and so cause the *actual Earth temperature* to *decrease*.

Overall, *CDR* and *GGR* are the only approaches that will not only solve the climate crisis, but could enable the *actual Earth temperature* to be controlled. And as long as the rate of 'pumping' achieved by *CDR*, *GGR* and the living pump collectively is just greater than the rate of emissions, then it does not matter what the rate of emissions actually is...

Geoengineering



See page 38 for narrative

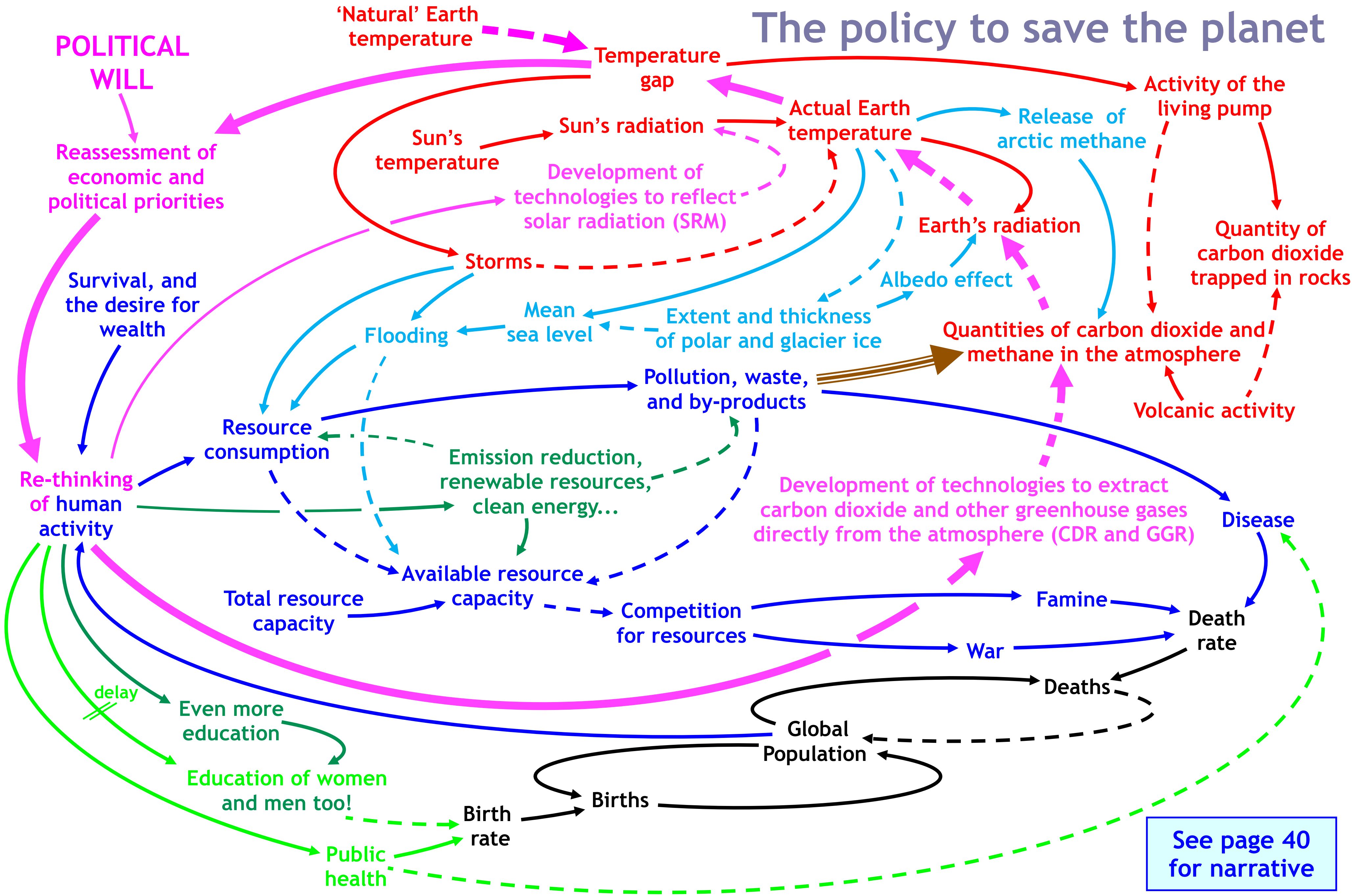
The policy to save the planet

Fundamentally, *there is too much carbon dioxide in the atmosphere now* - that's why the living pump can't cope. So cutting back on emissions isn't enough*. Certainly, reducing emissions will help stop the problem from getting worse, but it can't solve the problem that's already there. It's rather like a ship that has sprung a leak, and has a considerable quantity of water already in the hold. Staunching the flow of water into the hold is a sensible thing to do, but if there is already too much water on board, the ship will sink, even if the hole is plugged. As well as ordering that the inflow be staunched, the wise captain *also* orders "all hands to the pumps", for the captain knows that the water already in the hold must be baled out. And the captain also knows that, as long as the crew can pump the water out faster than the leak is letting it in, the ship is safe. The analogy is apt, for it's all about pumps. And in our case, the 'water in the hold' is the *quantity of carbon dioxide already in the atmosphere*, the 'leak' maps on to greenhouse gas emissions, and the 'pump' is the living pump, enhanced by technology so that it has a much greater capacity. This is shown by the balancing loop highlighted in magenta on page 41, which stabilises the *actual Earth temperature* on Gaia's *'natural' Earth temperature*, 14°C.

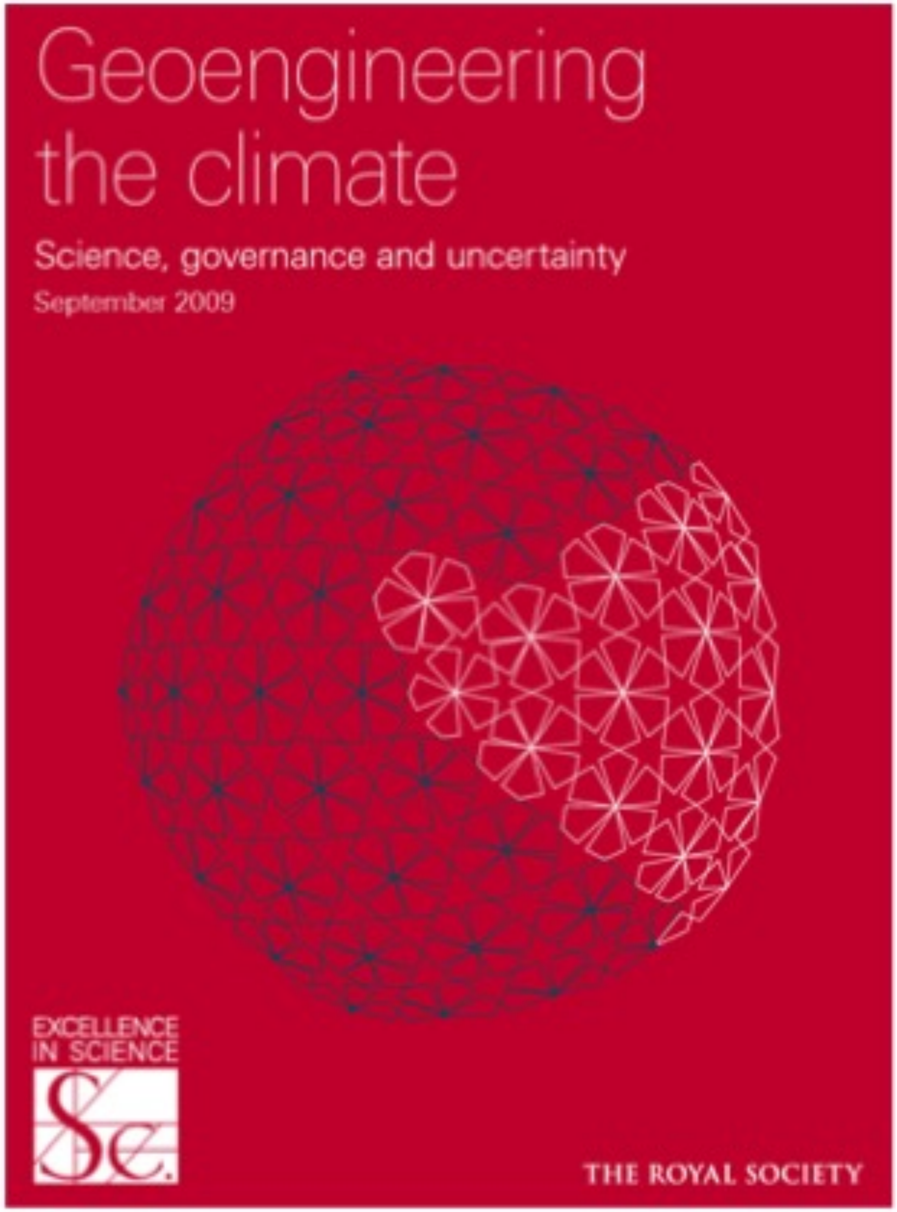
WE MUST DEVELOP CDR AND GGR.
AND WE MUST DO THIS NOW.

* More accurately, reducing emissions is an effective policy only if the rate of emissions produced (currently some 9 x 10^9 tonnes of carbon injected into the atmosphere per year) is consistently less than the maximum rate of the living pump (estimated at about 1 to 2 x 10^9 tonnes of carbon removed from the atmosphere per year). This, however, requires emissions to be reduced by at least 75% (and possibly as much as 90%): a reduction far beyond - as vividly demonstrated at the Copenhagen 2009 Conference - any feasible economic or political possibility.

The policy to save the planet



See page 40 for narrative



"Carbon dioxide removal techniques address the root cause of climate change by removing greenhouse gases from the atmosphere"

page 4

https://royalsociety.org/~/media/royal_society_content/policy/publications/2009/8693.pdf

Some simulations

Some system dynamics simulations

Pages 45 to 56 show the structure of, and results derived from, a very simple system dynamics simulation of the causal loop diagram shown on page 24, which represents Gaia.

The purpose of the model is to illustrate the general dynamic behaviour of the causal loops of page 24, and in particular how the activity of the living pump can maintain temperature stability whilst the intensity of the sun is increasing, and also whilst economic activity is driving carbon dioxide into the atmosphere.

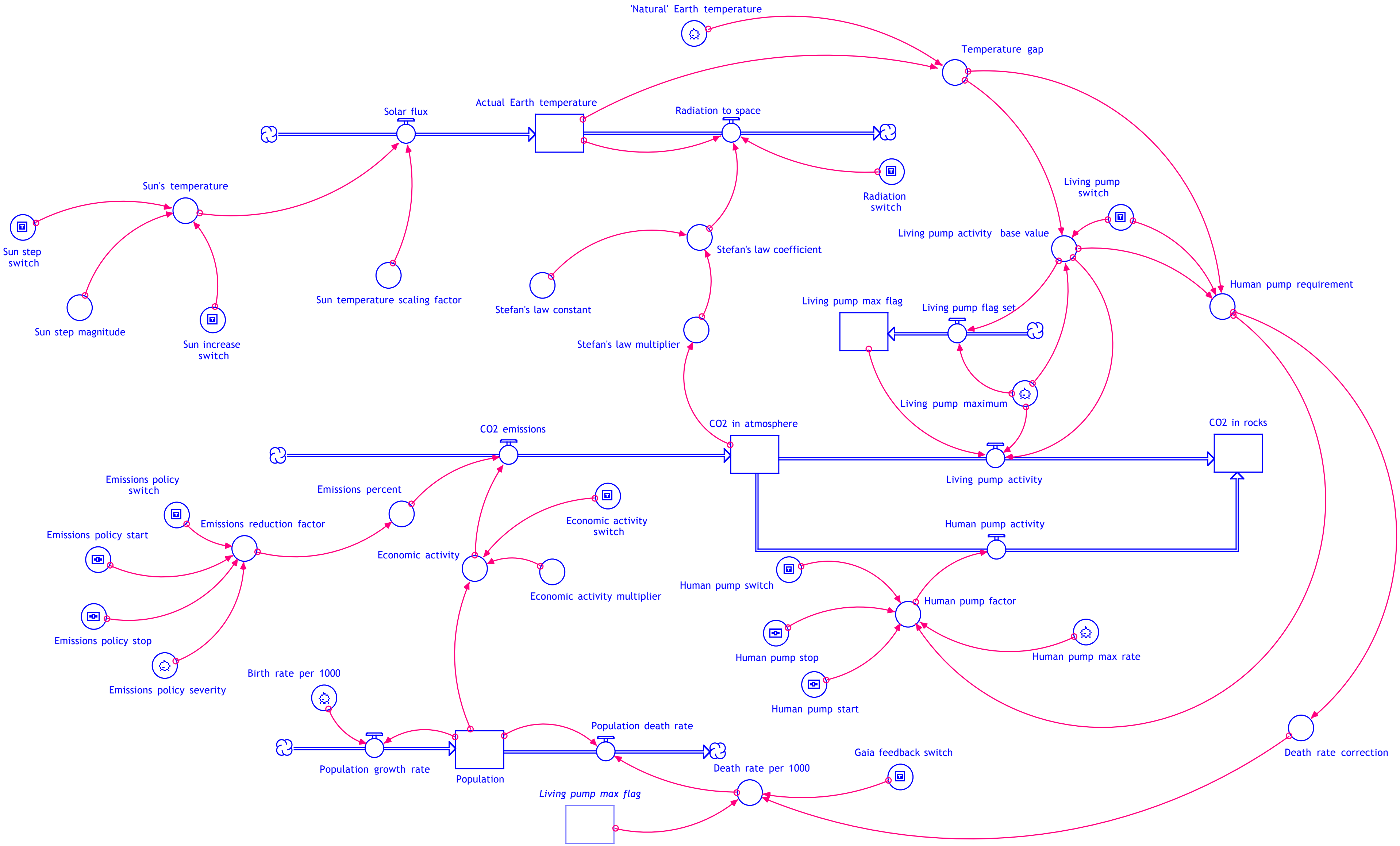
Please note that the model has been written for illustrative purposes only, and has neither been calibrated to use actual data (for example, for the intensity of the sun), nor has it been validated against historic data.

The model therefore has no value in addressing qualitative questions such as "how long is it likely to be until the actual Earth temperature has risen by 4°C?"; rather, the benefit of the model is in demonstrating qualitative effects, such as the limitations of using emission reductions as a policy to limit climate change.

The model has been written in *iThink* - the model's structure is shown on page 45, and the underlying equations on pages 46 and 47. The control panel is shown on page 48, and some results on pages 49 to 56.

The model runs were carried out over an (arbitrary) time horizon from 1 to 1499 time periods, with dt = 7 and using the Runge-Kutta 4 integration method.

The model's structure



The model's equations

Actual Earth temperature(t) = Actual Earth temperature(t - dt) + (Solar flux - Radiation to space) * dt
INIT Actual Earth temperature = 14
INFLOWS:
    Solar flux = Temperature of the sun / Sun temperature scaling factor
OUTFLOWS:
    Radiation to space = Radiation switch * Stefan's law coefficient * ((Actual Earth temperature + 273) ^ 4)

CO2 in atmosphere(t) = CO2 in atmosphere(t - dt) + (CO2 emissions - Living pump activity - Human pump activity) * dt
INIT CO2 in atmosphere = 5000
INFLOWS:
    CO2 emissions = Economic activity * Emissions / 20
OUTFLOWS:
    Living pump activity = if (Living pump max flag >= 1) then (Living pump maximum) else (Living pump activity base value)
    Human pump activity = Human pump factor

CO2 in rocks(t) = CO2 in rocks(t - dt) + (Living pump activity + Human pump activity) * dt
INIT CO2 in rocks = 2000
INFLOWS:
    Living pump activity = if (Living pump max flag >= 1) then (Living pump maximum) else (Living pump activity base value)
    Human pump activity = Human pump factor

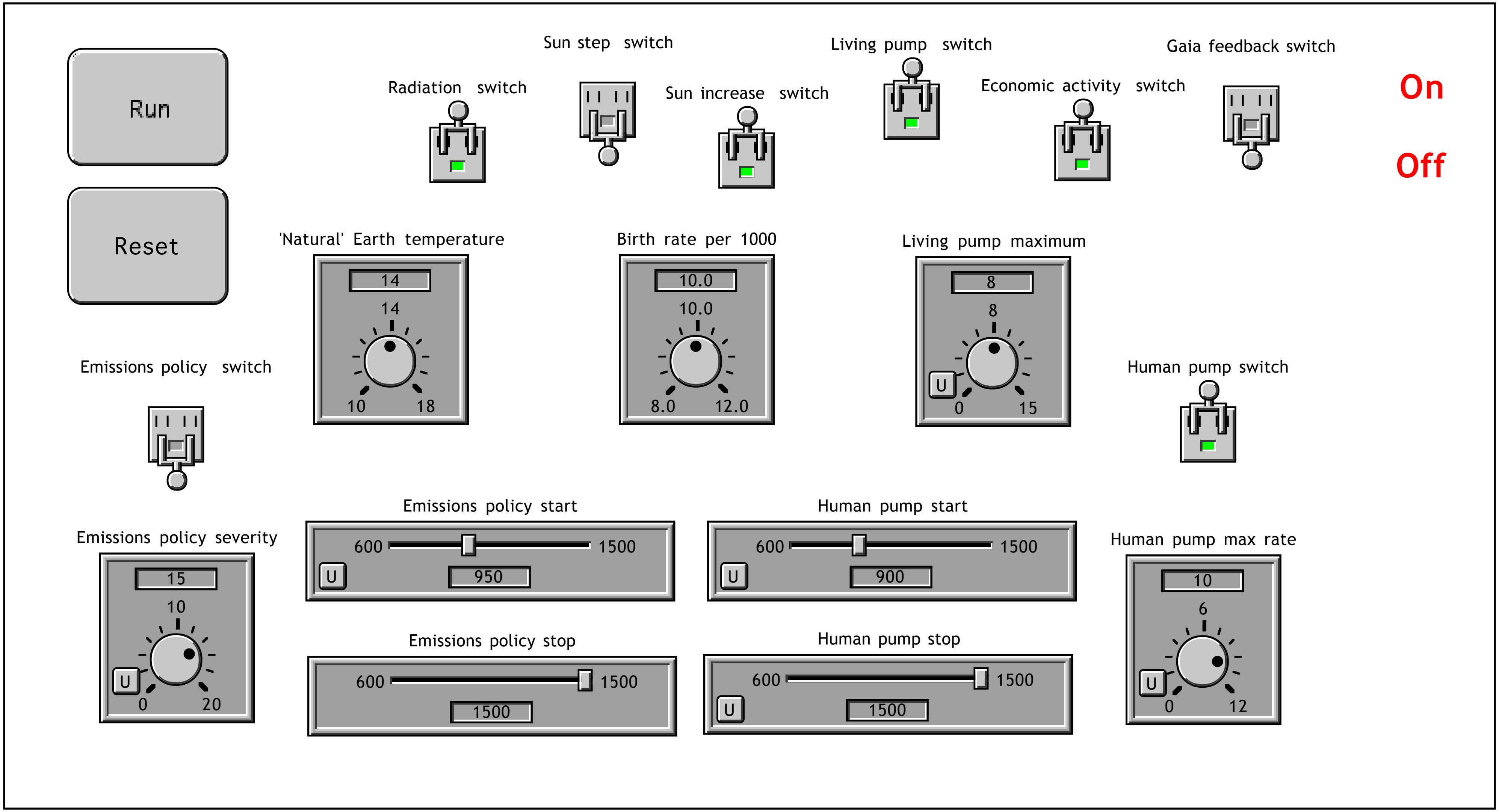
Living pump max flag(t) = Living pump max flag(t - dt) + (Living pump flag set) * dt
INIT Living pump max flag = 0
INFLOWS:
    Living pump flag set = if (Living pump activity base value = Living pump maximum) then (1) else (0)

Population(t) = Population(t - dt) + (Population growth rate - Population death rate) * dt
INIT Population = 10000000
INFLOWS:
    Population growth rate = Population * Birth rate per 1000 / 1000
OUTFLOWS:
    Population death rate = Population * Death rate per 1000 / 1000

The model's equations - continued

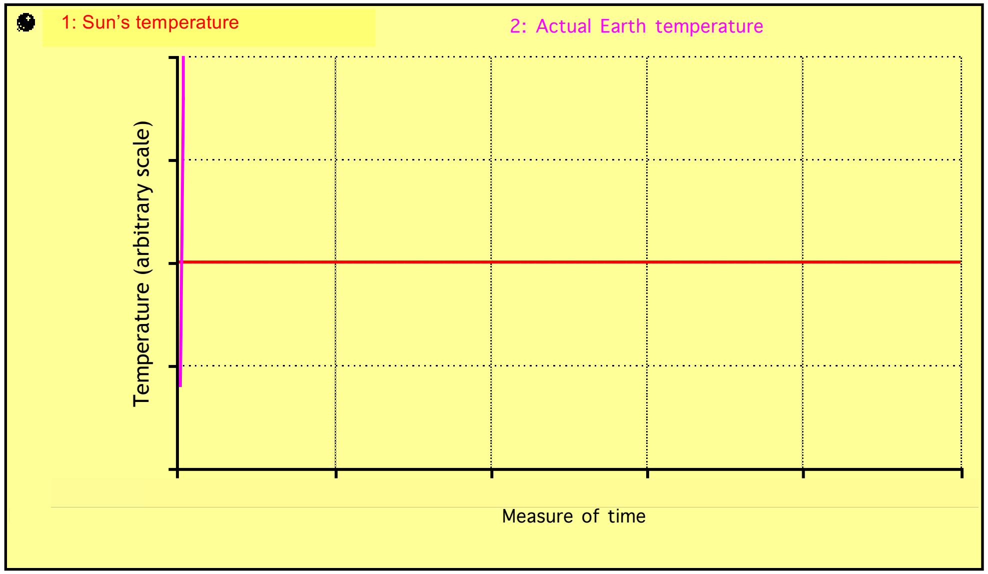
'Natural'_Earth_temperature = 14
Birth rate per 1000 = 10
Death_rate_correction = Human_pump_requirement * 1e-3
Death rate per 1000 = if (Gaia_feedback_switch = 0) then (9) else (if (Living_pump_max_flag >= 1) then (9 + 3 * Death_rate_correction) else (9))
Economic_activity = (Population * Economic activity multiplier/1000) * Economic_activity switch
Economic_activity_switch = 1
Economic_activity_multiplier = 3e-4
Emissions_percent = SMTH3(Emissions_reduction_factor, 100)
Emissions_policy_switch = 0
Emissions_policy_severity = 0.5
Emissions_policy_start = 1100
Emissions_policy_stop = 1500
Emissions_reduction_factor = if (Emissions_policy_switch = 0) then (20)
    else (if (time) < (Emissions_policy_start) then (20)
    else (if (time) > (Emissions_policy_stop) then (20)
    else (20 - 0.3 * Emissions_policy_severity)))
Gaia_feedback_switch = 0
Human_pump_factor = if (Human_pump_switch=0) then (0)
    else (if (time) < (Human_pump_start) then (0)
    else (if (time) > (Human_pump_stop) then(0)
    else (min (Human_pump_max_rate, Human_pump_requirement))))
Human_pump_max_rate = 5
Human_pump_requirement = max (200 * Temperature_gap * Living_pump switch - Living_pump_activity base_value, 0)
Human_pump_start = 100
Human_pump_stop = 300
Human_pump_switch = 0
Living_pump_switch = 1
Living_pump_activity_base_value = min (200 * Living_pump_switch * Temperature_gap, Living_pump_maximum)
Living_pump_maximum = 10
Radiation_switch = 1
Stefan's_law_coefficient = Stefan's_law_constant * Stefan's_law_multiplier
Stefan's_law_constant = 2.94783E-10
Stefan's_law_multiplier = 5000 / CO2 in atmosphere
Sun's_temperature = 20 * (1 + Sun_step_switch * step (Sun step magnitude/100, 500)) * (1 - Sun increase switch)
    + Sun_increase switch * 20 * (1 + time/6000)
Sun_increase_switch = 0
Sun_step_switch = 0
Sun_step_magnitude = 5
Sun_temperature_scaling_factor = 10
Temperature_gap = Actual_Earth_temperature - 'Natural'_Earth_temperature

The control panel



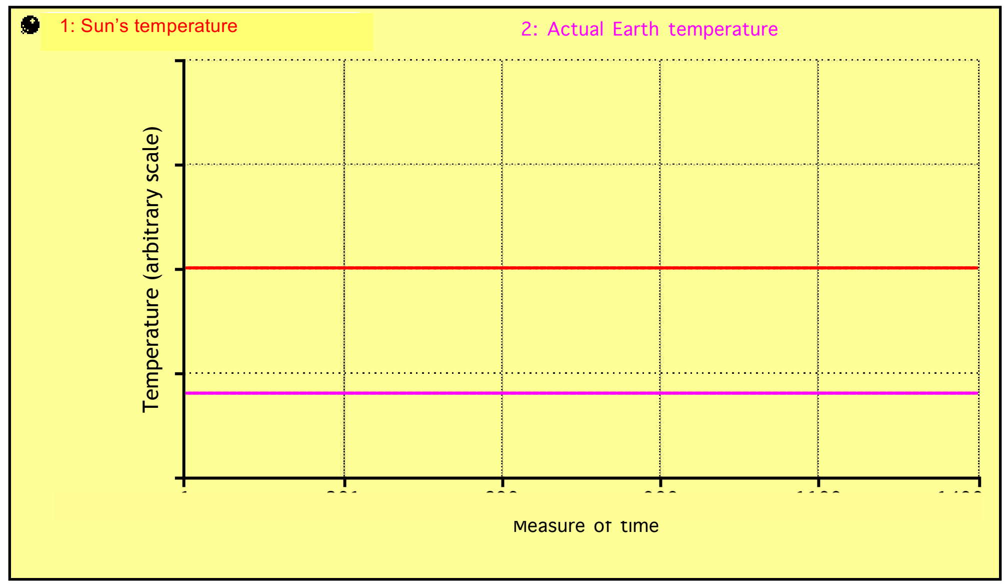
This 'control panel' specifies the parameters for any single run of the model: the settings shown here correspond to the outputs depicted on page 52.

The effect of the Earth's radiation

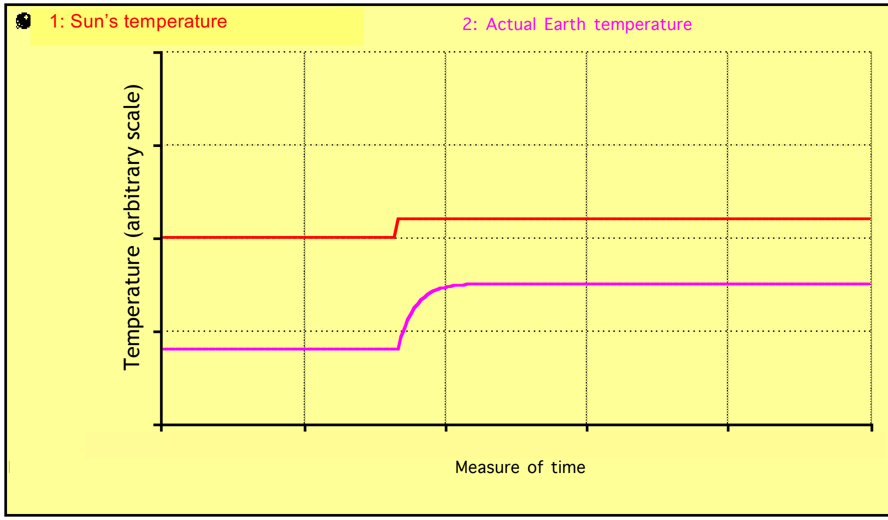


If the Earth does not radiate heat, the intensity of the sun's energy increases the temperature of the Earth very quickly, and without limit. (See page 19)

If the Earth does radiate heat, the temperature of the Earth stabilises when the the rate of energy absorbed from the sun equals the rate at which energy is lost by radiation. (See page 19)

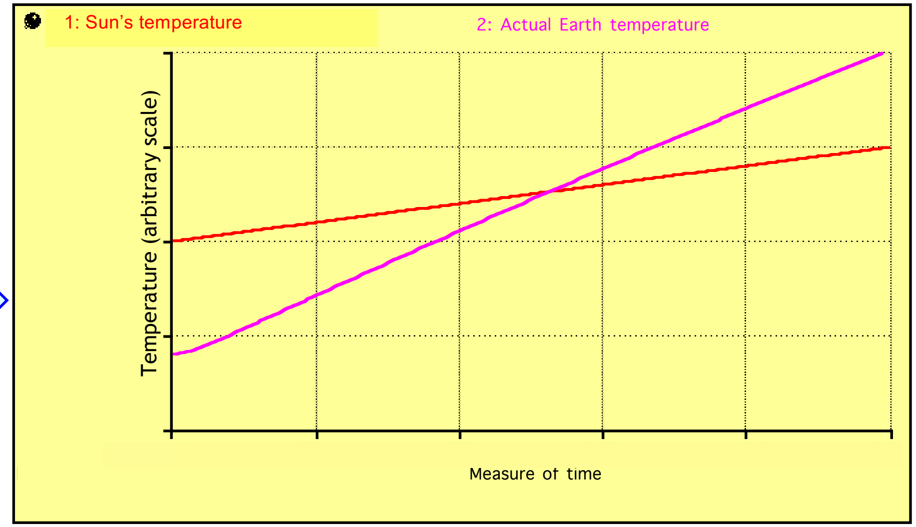


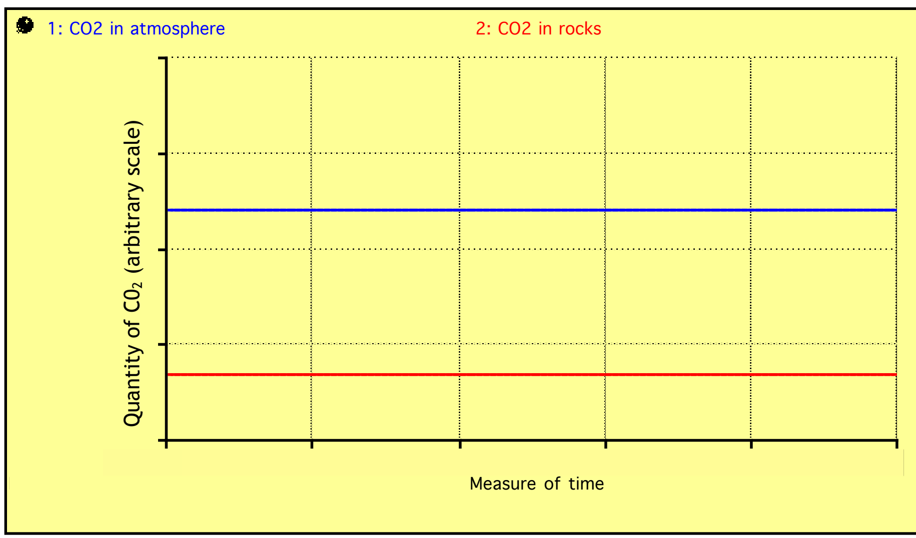
The Earth's temperature will follow the sun's



A step increase in the sun's temperature causes a step increase in the Earth's temperature… (See page 19)

…and a steady increase in the sun's temperature causes a steady increase in the Earth's temperature. (See page 19)



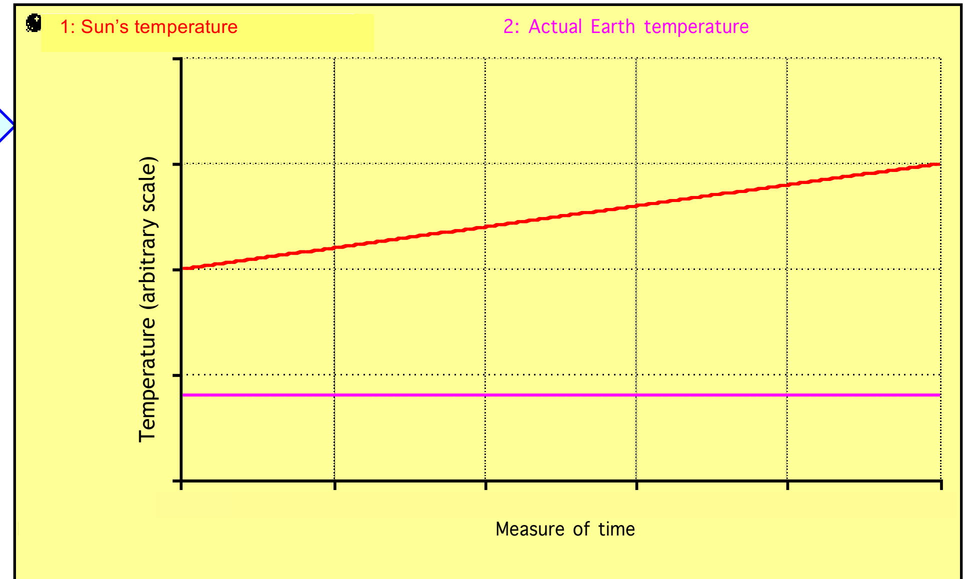


In both cases, the quantities of CO_2 in the atmosphere, and trapped in rocks, remain constant.

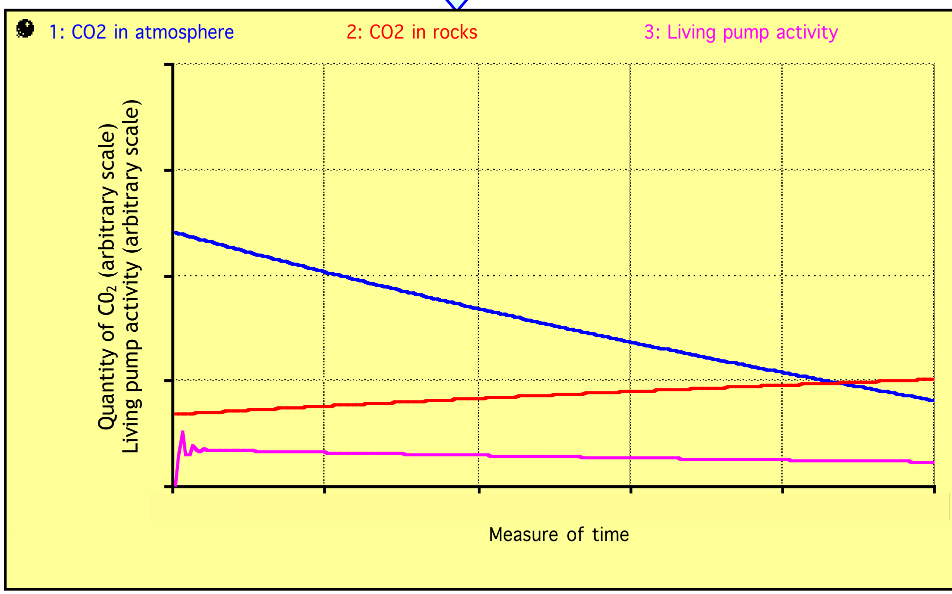
The effect of the living pump

Over geologic time, the sun's temperature has been increasing, but the Earth's temperature has remained sensibly constant. Why? Because of the living pump. (See pages 20 to 24)

As the temperature of the sun increases…

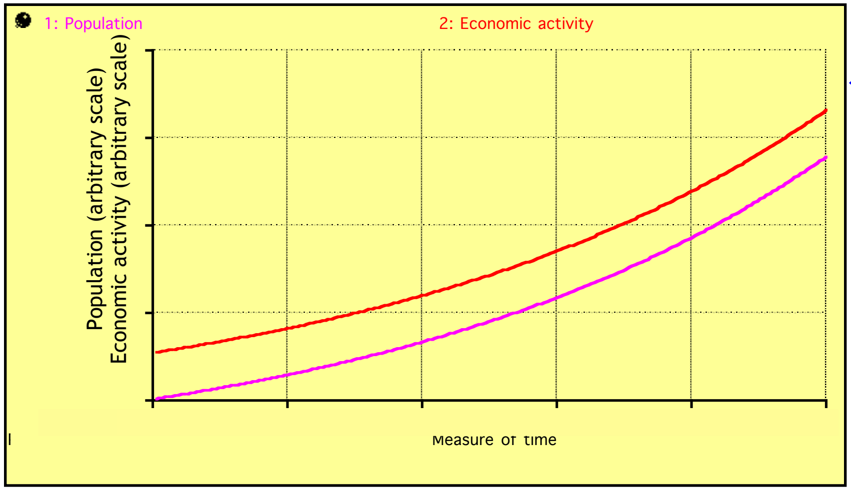


…the living pump steadily extracts carbon dioxide from the atmosphere, burying it as rock …



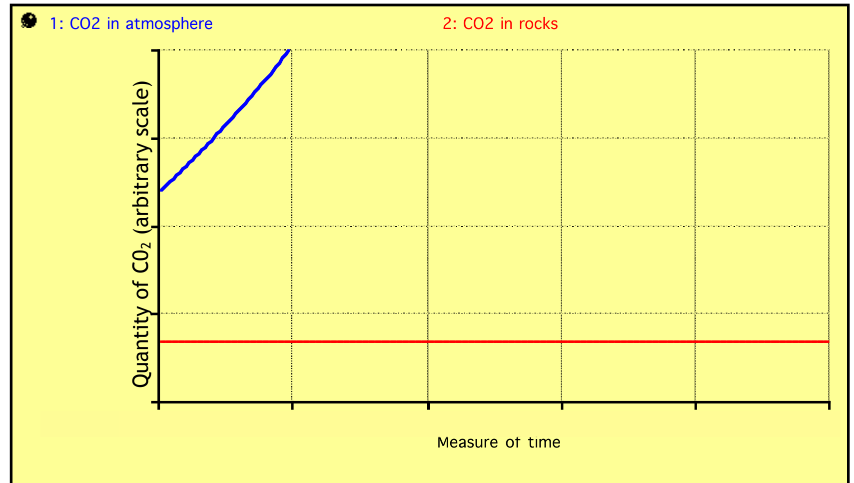
…so keeping the Earth's actual temperature constant.

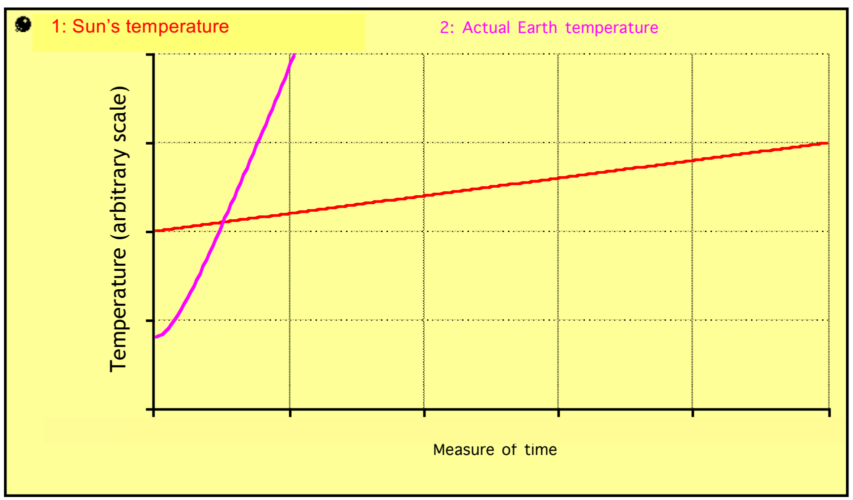
The effect of economic activity alone



As the population increases, so does economic activity…

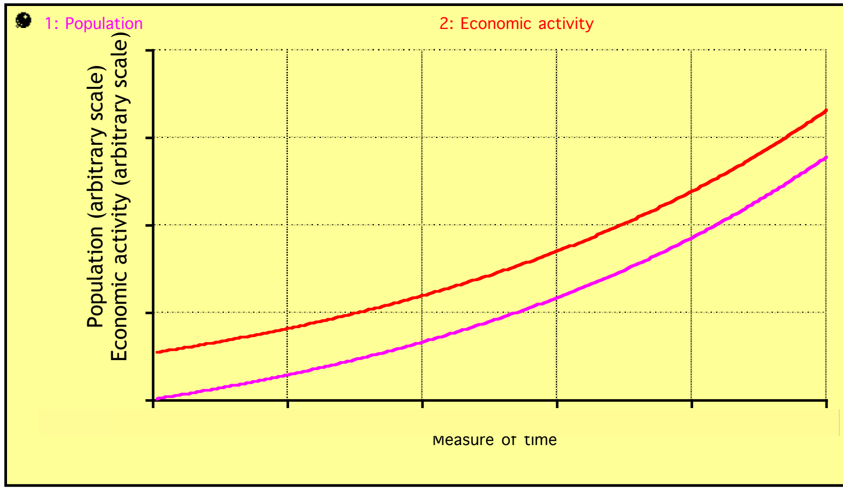
…driving carbon dioxide into the atmosphere…





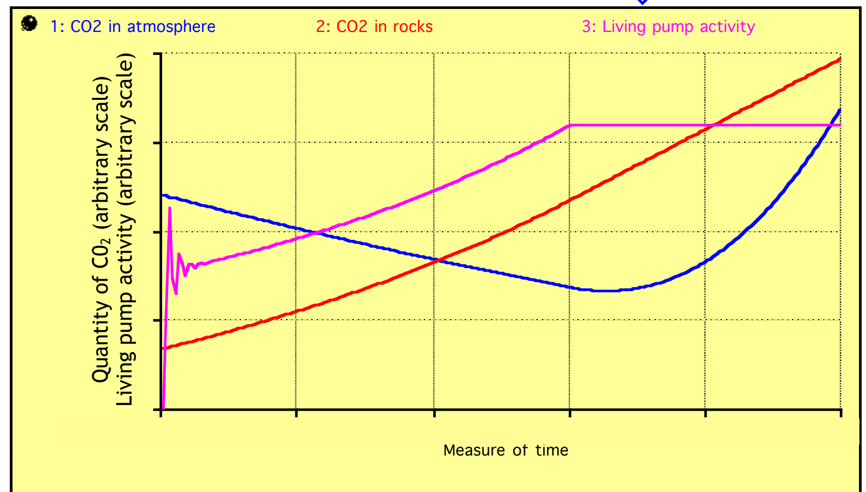
…resulting in a catastrophic increase in the Earth's temperature.

The effect of economic activity, with the living pump

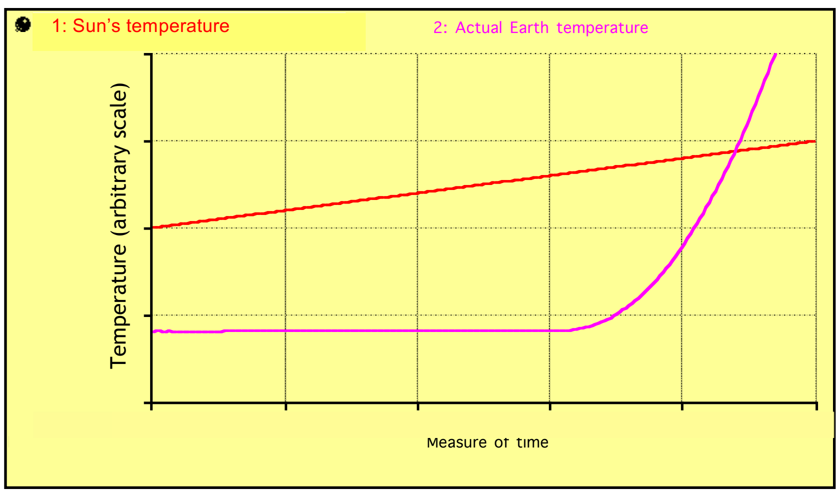


As the population increases, so does economic activity...

...driving carbon dioxide into the atmosphere...

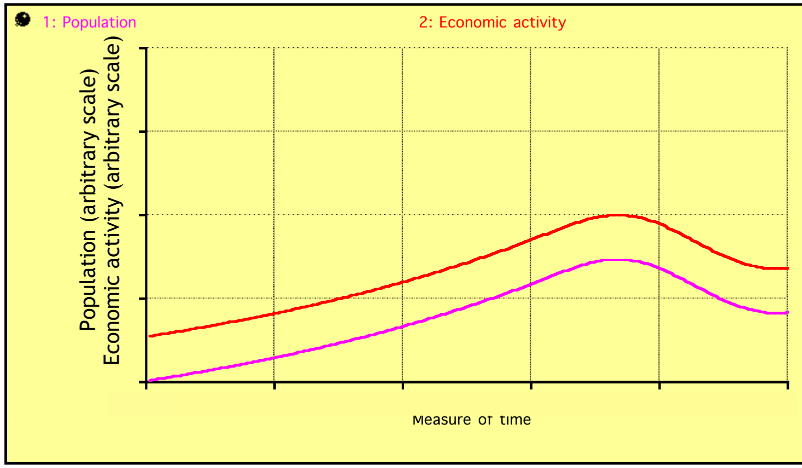


......which the living pump extracts, until such time as the living pump can no longer cope. Atmospheric carbon dioxide then accumulates...

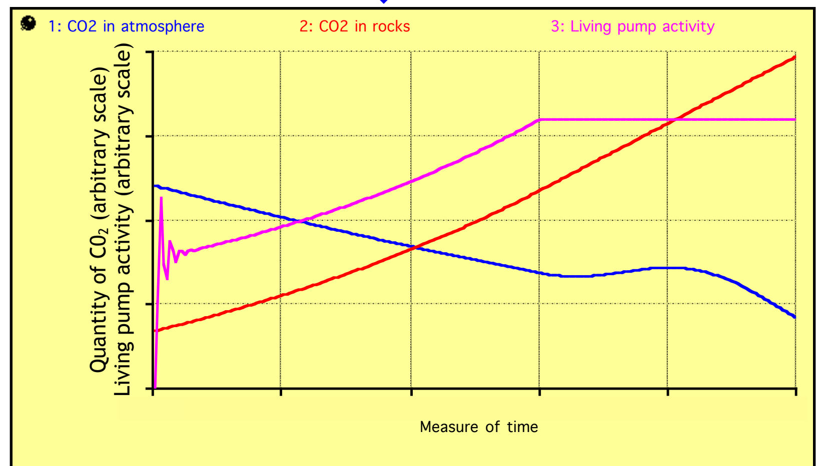


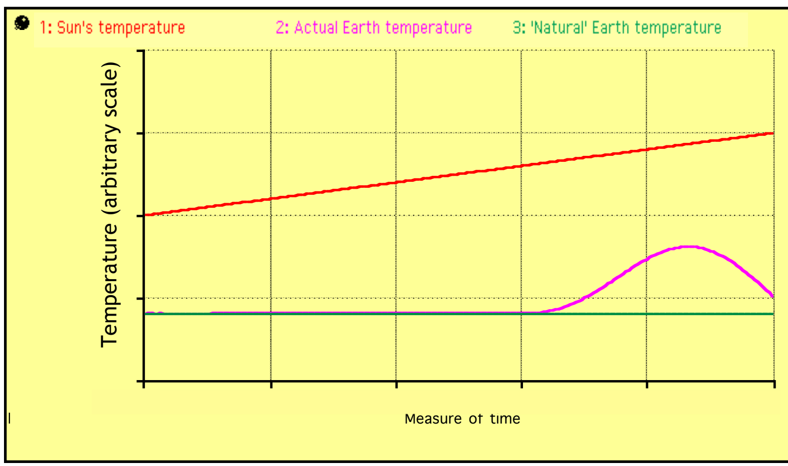
...resulting in a catastrophic increase in the Earth's temperature, but at a time much later than as shown on page 48.

The effect of reducing the human population



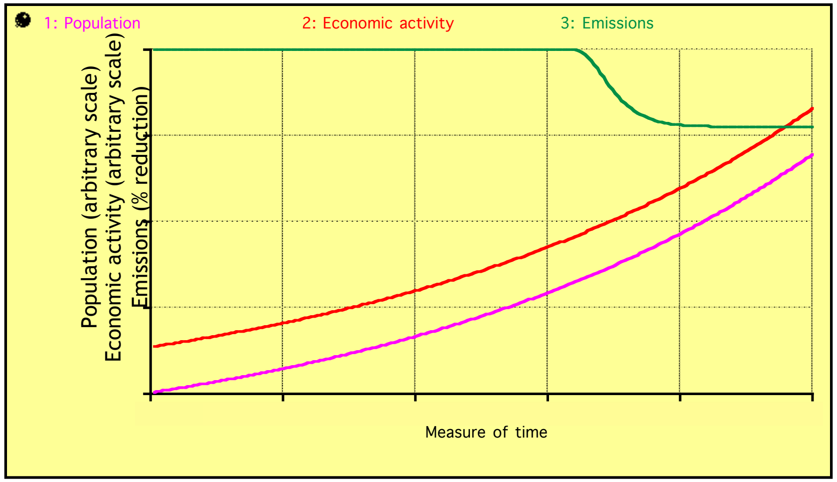
In this example, when the limit of the living pump is reached, Gaia invokes the feedback loop, highlighted on page 34, which increases the death rate, so reducing the human population, thereby reducing economic activity…





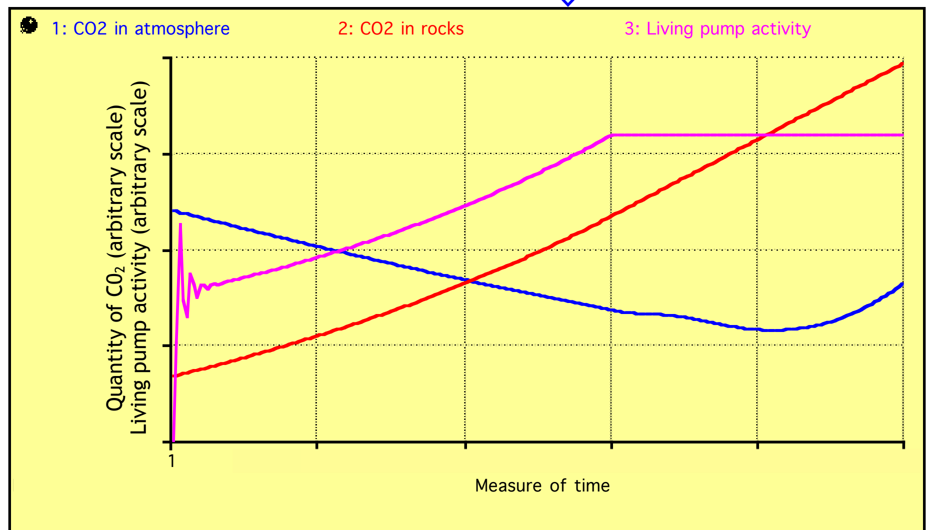
…with the result that the Earth's temperature returns towards its target level.

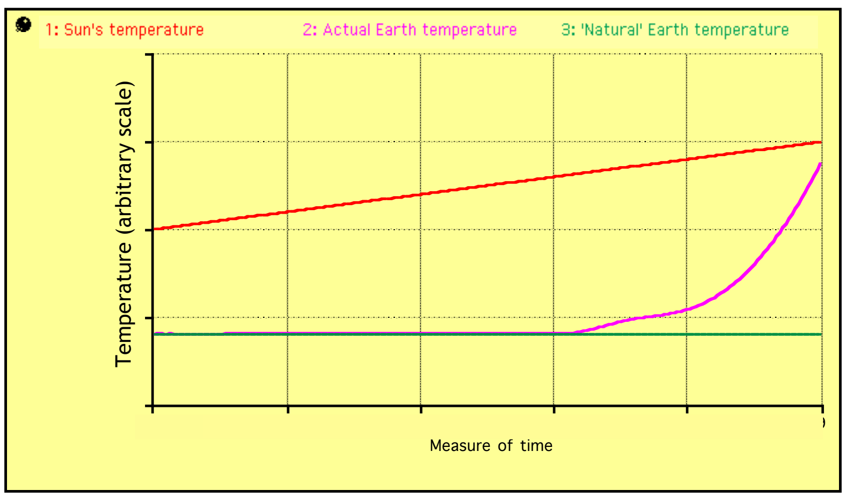
Curbing emissions helps…for a time…



A rise in the actual Earth temperature triggers a reduction in emissions…

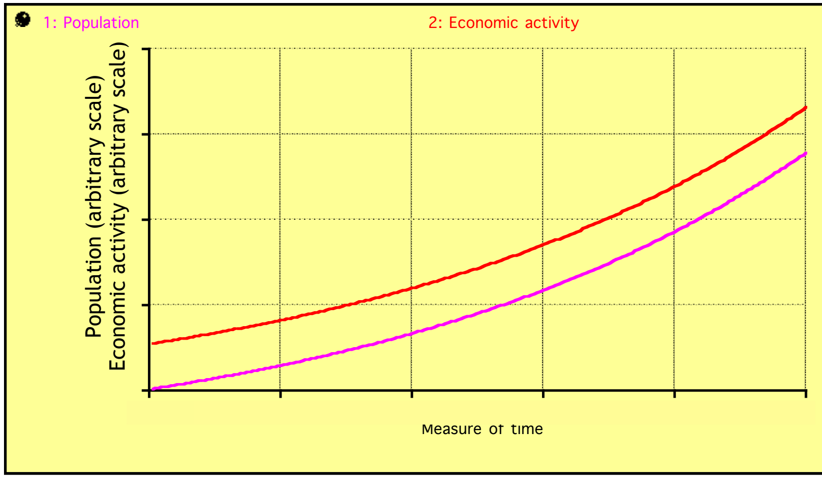
…which slows down the accumulation of carbon dioxide in the atmosphere…





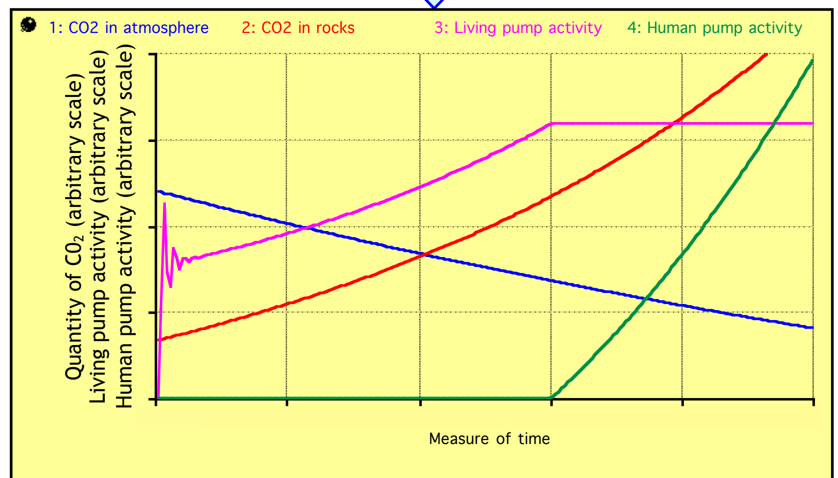
…but the Earth's actual temperature still rises, albeit rather more slowly.

…but direct extraction of CO_2 using a 'human pump' is much better

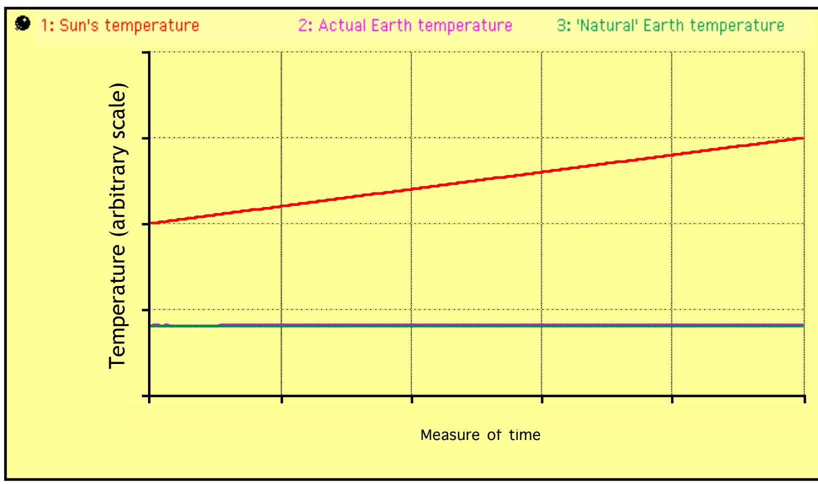


In this example, the global population and the global economy continue to grow, for the saturation of the living pump triggers the development of technologies to extract CO_2 directly from the atmosphere…

…so that the effect of the living pump, working together with the 'human pump', is to continue to reduce the amount of CO_2 in the atmosphere…



…so keeping the Earth's actual temperature stable.



Some good things to read

On systems thinking…

Seeing the Forest for the Trees: A manager's guide to applying systems thinking, by Dennis Sherwood, published by Nicholas Brealey Publishing, 2002.

On Gaia...

Gaia: The practical science of planetary medicine, by James Lovelock, published by Gaia Books Limited, 1991.

The Ages of Gaia, by James Lovelock, published by Oxford University Press, second edition, 1995.

The Revenge of Gaia, by James Lovelock, published by Penguin, 2006.

The Vanishing Face of Gaia: A final warning, by James Lovelock, published by Allen Lane, 2009.

A Rough Ride to the Future, by James Lovelock, published by Allen Lane, 2014.

On global warming, climate change and the climate crisis…

There is a huge quantity of material available: these are just three...

A Farewell to Ice, by Peter Wadhams, published by Allen Lane, 2016.

The Uninhabitable Earth - A story of the future, by David Wallace-Wells, published by Allen Lane, 2019.

There is no Planet B - A handbook for the make or break years, by Mike Berners-Lee, published by Cambridge University Press, 2019.

On geoengineering...

Geoengineering the Climate: Science, governance and uncertainty, published by The Royal Society, 2009.

Greenhouse gas removal, published by The Royal Society, 2018.

Drawdown: The most comprehensive plan ever proposed to reverse global warming, by Paul Hawken, published by Penguin, 2018

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Building high-performing teams

Training and knowledge transfer

Conferences

Business and market modelling