The Energy and Climate Emergencies

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by Jim Adams

THE WORK IS INTENDED TO BE PICTORIAL.

THIS IS AN OUTLINE OF THE TEXT.

(1) *Introduction*. This little book shows where our energy comes from and why it is running out. We describe Doly García's model of the interaction of resource depletion (particularly fossil fuels) with the energy economy, and what we need to change to solve some of these problems. We look from the general to the particular – to where the authors live in Brighton & Hove.
The book also demonstrates the very dangerous changes to our climate due to burning fossil fuels, which emits carbon dioxide, a greenhouse gas. We describe the feedback models of climate due to David Wasdell and necessary ways the world will have to adapt to and mitigate the climate phenomena that we have produced due to Hans Schellnhuber. The action needed on climate change is imperative, it requires international agreements, and these agreements must be adequate and enforced. The energy resource depletion and climate models show a large part of humanity faces extinction, together with a vast number of other species unless concerted international action is taken with great urgency.

(2) *Units*. Definition of units: What is 1 watt (example), a kilowatt, a megawatt, a gigawatt (giga = giant) and a terawatt (tera means monster).
Likewise for years, a megayear is a million years, and a gigayear is a thousand million years.

(3) <u>Energy, the Big Picture</u>: Where do we get our energy from, and why is some of it about to disappear?

- *The sun, the moon and the Earth*.
    a. The sun, thermonuclear energy.
    We start, not from the beginning, but from the middle. Our galaxy of stars had formed. One of these stars exploded in a supernova explosion, and the debris of this explosion formed the heavier material for our own star – the sun.
    The sun is very dense and very hot. Its main constituents are hydrogen and deuterium. These atoms can collide and fuse to form an element of higher atomic weight – helium, and this gives off energy. This is known as thermonuclear fusion. This is why the sun shines and gives us heat.
    b. The creation of the moon and the Earth in a collision.
    Computer simulation shows that the heavier material that forms the sun was surrounded by an envelope of gas which condensed into planets.

One of these planets was larger than the Earth and was hit by a planetoid or meteor, which split this planet in two and formed what are now the Earth and the moon.

- *Energy resource depletion*. We will describe later in more detail energy coming from the sun, the moon and the Earth, and show how we are consuming finite resources of oil, gas, coal and some other energy sources.

(4) Climate, the Big Picture: Why is the climate changing?

- *Greenhouse gases*. Our atmosphere contains mainly oxygen and nitrogen, but it also contains a small amount of carbon dioxide, which is vital. The carbon dioxide absorbs and scatters radiation from the sun, and so keeps our thin atmosphere and the Earth's surface warmer than it otherwise would be.
  Our recent civilisation has been burning oil, gas and coal, and so the carbon dioxide emitted is warming the planet.
- *Milankovitch cycles*. The Earth rotates with its axis at an angle to the vertical and around the sun in an ellipse. What we understand about gravitation tells us this axis wobbles and then comes back again and the ellipse gets squashed and then becomes more circular. There is also a change of the plane of this ellipse with the average for that of other planets. Over Milankovitch cycles of 40,000 and 100,000 years, this changes the angle at which radiation hits the Earth, and so leads to cold glacial periods and warm interglacial periods.

(5) Computer Models of Energy and Climate, the Big Picture: The García Global Climate, Resources and Energy model. Limits to Growth. Energy Economics. ERoEI. Feedback models of climate.

- *The García Global Climate, Resources and Energy model*.
  This is an updated systems model of global climate, resources, and energy extending the original World3 ("Limits to Growth") model by inclusion of climate change and its interaction with resources and energy. Outcomes are derived for total energy resources, human population, nutrition, consumption, economic activity and other parameters. Long-term outcomes are derived for a 1900 to 2100 time sequence, with human population decline.
- *Feedback Models of Climate. Adaptation and Mitigation.*
  The Wasdell and Schellnhuber models.

ENERGY.

(6) Energy from the sun: Wind, waves, heat, rainfall.

- *Wind.* Wind turbines. Horizontal and vertical. Why size matters. Kites.
  The energy from the sun and the rotation of the Earth creates wind. This energy is called renewable because it has continued over the history of the Earth.
  Wind energy can be harnessed by wind turbines. Shown in the diagrams are a horizontal and a vertical wind turbine. For a wind turbine, as the blade size doubles the area swept out goes up four times, and the energy goes up four times as well. As the wind speed doubles the energy goes up eight times. That is why for wind turbines size matters, and why farms of large offshore wind turbines are important, because wind speed is usually greater offshore than inland.
  Wind velocity is very much higher in the stratosphere, so if a set of kites were launched into high altitude a lot of energy could be obtained.

- *Waves.* Britain has much energy reaching its shores in waves, particularly in Scotland. Shown is a diagram of a wave power machine called the Pelamis.
- *Heat from the sun*. Food and agriculture. Photosynthesis. Solar thermal panels. Photovoltaics.
  Sunlight is absorbed by plants in the green substance chlorophyll in a process known as photosynthesis. This, directly or indirectly, is the source of our food.
  A way of collecting solar energy, for example on a roof, is to use a solar thermal panel. Sunlight heats a liquid in the panel and can be used to heat water for the house throughout the year.
  Photovoltaics capture the energy from sunlight and convert it to direct current electricity. At the moment, the technology and efficiency is rapidly advancing.
- *Rainfall*. The energy in the Amazon. Rivers and dams.
  Evaporation from the oceans causes clouds which fall as rainfall. A typical thunderstorm liberates as much energy as a 20 kiloton nuclear warhead – 10 gigawatt-hours. The energy circulating from evaporation from trees in the Amazon is as much as 950 terawatts. By cutting down tropical rainforests we are changing this energy circulation and changing the climate.
  We can collect the energy from rainfall in rivers and dams. The dam in Dinorwig in Wales serves the use for variable storage and release of 1.6 gigawatts of power in Britain.

(7) Energy from the moon: Tides.

- *Gravitational pull of the moon on the Earth, and tides*.
  Shown in the diagram, much exaggerated, is the envelope of the oceans under the gravitational pull of the moon. As the moon circles the Earth, this causes the tides.
- *Tidal barrages*.
  The Bristol Channel acts as a funnel for tidal energy, potentially one of the most significant sites in the world. If implemented, the Severn barrage could generate over 8 GW of electricity, and even store and release much more energy than Dinorwig.

(8) *Energy from the Earth: Oil, gas, coal, geothermal, uranium, thorium, thermonuclear*.

- *Oil, gas, coal and the Permian extinction*.
  Oil is derived from ancient biomass – prehistoric zooplankton and algae. Coal comes from the compacted remains of ancient forests.
  250 megayears ago the Earth had many creatures. Some of them looked rather strange compared with modern lifeforms. As the ‘tectonic plates’ – the movable crust of the Earth – moved to create the ancient continent of Pangaea, covering greater than modern-day Europe and Asia, a series of volcanic eruptions took place in the Siberian Traps covering 200,000 square kilometers with lava. These spewed volcanic greenhouse gases into the atmosphere (at a lesser rate than we are emitting CO_2 at the moment). This, and other events over a long period of time raised the temperature of the Earth, deoxygenated the atmosphere, and led to a mass dying of species. In this Permian extinction even algae in the oceans died, and fell to what became later deposits of oil and gas.
- *Depletion of fossil fuels*. The industrial revolution. Energy consumption in Africa. Why China wants energy consumption like the West.

Oil depletion is like drinking a pint of beer. When the glass is full, there is plenty of beer there. When it is half drunk, there is only half the amount of beer there, and when the pint has been consumed, there is no beer left. The difference with oil is we cannot get a replacement glass. [picture of the main Saudi oil field, with salt (in white) indicating sea water pumped in and areas (in black) indicating the nearness to the centre of the field of oil being extracted – extraction from a field proceeding from the periphery to the centre – further description of economics, from Half Gone]. Oil production peaked or plateaued in 2008. Peak gas will happen about five years after that, and the decline is expected to be steeper. Peak coal is more long term, but will follow the same pattern. The effect of coal on climate is more devastating than oil and gas.

Britain led the world in creating, in the Industrial Revolution, a high-energy economy based on coal. This liberated human energies to replace them with machines and led to an Empire with economic and military dominance over other civilisations. In Africa today, the per capita consumption of energy is one tenth of what we have in Britain today. Many countries want the standard of living we enjoy in the West, and China and India are cases in point. This means more energy usage, competition for energy resources with other counties, and internally in China the use of wind energy and coal on a massive scale.

- *Geothermal*. Iceland. Britain.

  Because of radioactivity in the Earth's core and slow internal circulation the Earth is self-heating. This heat can be trapped from underground sources and used as energy. This is known as geothermal energy. An example of the use of geothermal energy in Britain is a district heating scheme in Southampton. Iceland, being volcanic, has very much greater sources of geothermal energy, and so it would be sensible to site industrial processes there which consume a large amount of heat energy. Electricity derived from Icelandic geothermal sources could be exported to Britain and Ireland.
- *Uranium and plutonium. Weapons. Thorium. Reserves. Reactors and waste*.

  Some atoms are so big in their nucleus that they spontaneously decay. Another reason big atoms can decay is when they are bombarded with neutrons. Uranium is an example of such a heavy atom. When a type of uranium decays it gives off neutrons that can cause a chain-reaction of further decays. This is known as nuclear fission. In fact, there can be a series of decays to lower elements, finally leading to the stable element lead. One of the intermediate stages in this decay chain can be the production of the radioactive element plutonium, which is also highly toxic. Uranium and plutonium can be used to create nuclear weapons.

  Thorium: Another element that is radioactive is thorium, but its decay chain is very much less toxic.

  Reserves: There is twice the amount of thorium in the world as uranium, which like oil is finite.

  Reactors and waste: Uranium reactors which produce energy leave plutonium as waste. These and other products cannot be thrown away. The plutonium can also be used as fuel for reactors using liquid sodium as coolant. They are stored in a type of glass and kept cool. This permanent storage is very expensive. Reactors that use thorium have been built, but the decay products cannot be used for nuclear weapons. Uranium and thorium take much energy to mine and process, so the energy cannot be said to be entirely renewable. The permanent storage of radioactive materials should be considered in the economics of nuclear power. If the ancient Egyptians had used nuclear power to build the pyramids, they would still have to store the nuclear waste today.

- *Thermonuclear energy*.
  A large project to create the processes that provide energy in the sun is the ITER project in Europe. If the world runs out of energy, it is unlikely a solution like ITER will be available in time, or even, because of the high technology costs, that the energy produced will be commercial.

(9) *Energy in the UK.*

- *Wind Turbines*. Offshore Sussex Array. Onshore – legislation changes. The National Park. Sites in Brighton & Hove. Cooperatives, other medium sized companies and large companies.
  We have said that big is beautiful for wind turbines, especially offshore, because of the greater energy produced. The picture shows what the Sussex Offshore Array will look like. There are many areas in and around Brighton & Hove where wind turbines could be erected, for example near Shoreham Power Station. The situation used to be that planning procedures had stopped or considerably delayed the introduction of onshore wind turbines in England (much less so in Wales and Scotland), so England was the most difficult place in Europe to erect wind turbines. A part of the reason the Vestas factory for the production of wind turbines in the Isle of Wight was closed was because of local opposition to wind turbines. The planning regime has now changed, and it is well feasible that a large number of wind turbines, by many companies and cooperatives, small, medium and large, can now be put in place to provide the energy we need. It is now unlikely that wind turbine construction will take place in the South Downs National Park.
- *Localising food production*. Food airfreight and Mexican lettuce.
  Aircraft are likely to use fuel from oil for a long time to come (small nuclear reactors to propel aircraft have been built successfully, but the project was abandoned and long-term there are big safety issues here). We know the oil is running out, so it is prudent at first to increase aircraft fuel efficiency and also to limit use. I remember seeing in a supermarket a local and a Mexican lettuce on the shelf at the same price. We need to change our habits so we consume local food to reduce transport costs, especially airfreight.
- *Solar thermal panels* – a local industry?
  There are now many local companies providing solar thermal panels on roofs, and it is even possible as do-it-yourself. It is still more efficient to insulate your loft, reduce drafts, put in an energy-efficient gas boiler and take your TV and PC off standby at night, but this is the next best thing.
- *Photovoltaics* – the promise of the near future.
  Photovoltaics are wafers sometimes containing silicon which turn sunlight into electricity. They can be put on your roof and the technology is advancing rapidly so that in the not-too-distant future they will be economical means of supplying electricity to your home compared with the electricity grid. They can also be used to export electricity to the local distribution system.
- *Tidal power off Brighton & Hove. The Severn barrage*.

Tidal power generators could be attached below water to the towers of the projected Sussex Offshore Wind Power Array, to provide further energy from the current in the Channel.

The 'Two lagoons' solution for the Severn Barrage would not only provide over 8 giawatts of electricity for the South of England, thereby reducing grid transportation inefficiencies from the North of the UK, it could also act as a site for wind turbines and the lagoons could act as storage for wind turbine energy, say at minimum consumption at night, should such energy be introduced on a massive scale, as has already been done in Denmark and will be in Sweden.

- *Oil and gas depletion in Brighton & Hove*. Shoreham Gas-Fired Station. Gas depletion from the North Sea, gas from Norway, from Algeria and gas for Europe from Russia. Competition for gas resources. Japan. Oil depletion. Dependency of transport.

  Most electricity generated near Brighton & Hove comes from Shoreham gas-fired power station. The gas produced from the North Sea is already in steep decline. The gas we need could come from Norway, but other European countries want this too and we are not providing the Norwegians with long-term contracts, so, quite simply, we will not get this. Algeria is a major source of gas which would be brought here in tankers in liquefied form. There will also be competition for Algerian gas, for example from Japan. Europe is dependent on Russian gas, supplies of which have been intermittent. Global gas production will reach a plateau in 2013 and thereafter drop steeply.

  Just under 40% of our oil consumption goes in transportation.
- *Electric vehicles*.

  We do not have the electricity generating capacity, or the fuel reserves, to transfer all oil consumption in transport to electricity use in vehicles. To maximise the use of our current capacity for this use on a large scale, electricity charge-up will have to be at low electricity generation time at night. We also need to develop ecologically friendly efficient batteries for cars.
- *Coal*. The effect on climate. Government policy. Chinese policy.

  Coal is less efficient than oil and gas, both in terms of extraction, transportation and comparable burn efficiency. Shown below are the chemical reactions for burning methane, the ethanol component of petrol and the carbon component of coal. To generate the same amount of heat, coal liberates large amounts of the greenhouse gas carbon dioxide compared with oil and gas. The UK government is committed to decommissioning coal-fired stations and not introducing new ones unless means to dispose of the carbon dioxide is in place. China, which does not have significant oil reserves but has coal in abundance is increasing production coal-fired stations by 8% a year, currently without disposal of the carbon dioxide.
- *Thorium* – a better alternative.

  We have already indicated that compared with uranium, provided one is not concerned with weapons production, thorium reactors make more sense than uranium or 'breeder' reactors using plutonium. There are various sorts of such reactor suggested and operational. Shown below is Carlo Rubbia's scheme for a thorium 'energy amplifier'.
- *Thermonuclear* – is there any time left?

  Thermonuclear reactors have been at the experimental stage since project Zeta began in the UK in 1954. The ITER megaproject for a fusion reactor is sited at

Cadarache in France. There is plenty of deuterium present in seawater, so on the naïve face of it, this is almost an unlimited amount of energy available by this means. Because of the high temperatures and the expensive high-technology containment features of such devices, and the question of maintainability, it is questionable that such solutions will be of use before the major climate crises discussed later really hit.

(10) *Energy Efficiency*.

- *An energy efficient National Grid*.
  High voltage direct current electricity transmission is more efficient than AC transmission – and 1 megavolts is now possible. Grid transmission losses reduced this way would enable us to save substantial amounts of energy in transmission. This could be used to transmit electricity from geothermal sources in Iceland to Scotland. The UK loses 35% of electrical energy in transmission, or in refining or extraction.
  The longest undersea cable at present is the NorNed link between Feda in Norway and Emmshaven in the Netherlands, a distance of 580km. It allows Norway to export its spare hydropower. This works at ±450kV DC, is rated at 700MW and cost 550M Euros. It started operation in May 2008. It has had a number of breakdowns but has been up for most of the time. This earned its operators 50M Euros in the first two months of operation.
  The Iceland Scotland link would be pushing the distance limit by 40% but it is not impossible or even wildly uneconomic. NorNed is not the highest voltage undersea cable. The SAPEI link from Sardinia to the Italian mainland runs at ±500kV and the 1100MW proposed power of the Iceland Scotland link is not the highest power undersea link. The cross channel link to France runs at 2000MW and the undersea portion of the Sumatra-Java link will run at 3000MW in 2011.
  The first commercial superconducting power link was installed on Long Island, America in 2008, 575MW at 138kV but only 600m long. It used a cuprate superconductor cooled with liquid nitrogen.
- *Smart grids. Efficient appliances. Standby*.
  Smart grids which turn off appliances from standby in your home when you are not using them and don't need them are quite feasible. You can check the efficiency of your appliances by using a smart meter. If you turn off your PC at night, so it is not on standby – especially the monitor, and if you can do the same with your TV without having to reprogram the video recorder each time, then you can save on average ¼ off your electricity bill.
- *Local production, local consumption*.
  Consuming locally produced food substantially reduces transportation costs. We live in a global economy, but still many consumer goods can be produced locally comparable in cost and quality to those transported from across half the world.
- *Energy from waste. Bioreactors*.
  Methane from waste can be burnt, producing heat and electricity. The Newhaven incinerator serving Brighton & Hove will produce poisonous dioxins in the reduced temperature of the stack to capture the heat generated and convert it to electricity, and will generate immense amounts of poisonous ash which will have to be safely buried. Bioreactors, which 'steam' waste to

convert it to biodiesel are a practical and a very much more economical alternative.

- *Reduce, reuse and recycle*.
  This is a whole philosophy and way of life!
- *District heating from Shoreham Power Station*.
  Most of the electricity generated for Brighton & Hove comes from Shoreham Gas Fired Power Station. Waste heat from it, which is currently dumped in the sea, could be used to heat homes in district heating schemes.

CLIMATE.

(11) The Climate:

- *Greenhouse gas effect*. The greenhouse effect is the heating of the surface of the planet due to the presence in the atmosphere of gases that absorb and emit infrared radiation. Thus, greenhouse gases trap heat within the surface-troposphere system. The greenhouse effect was discovered by Joseph Fourier in 1824, first reliably experimented on by John Tyndall in 1858, and first reported quantitatively by Svante Arrhenius in 1896.
  In the absence of the greenhouse effect and an atmosphere, the Earth's average surface temperature of 14 °C could be as low as −18 °C, the black body temperature of the Earth. Anthropogenic global warming, a recent warming of the Earth's lower atmosphere, is believed to be the result of an "enhanced greenhouse effect" mainly due to human-produced increases in atmospheric greenhouse gases.
  The Earth receives energy from the Sun mostly in the form of visible light. About 50% of the sun's energy reaches the Earth and is absorbed by the surface. Like all bodies with a temperature above absolute zero the Earth's surface radiates energy in the infrared range. Greenhouse gases absorb infrared radiation and pass the absorbed heat to other atmospheric gases through molecular collisions. The greenhouse gases also radiate in the infrared range. Radiation is emitted both upward, with part escaping to space, and downward toward Earth's surface. The surface and lower atmosphere are warmed by the part of the energy that is radiated downward, making our life on earth possible.
  Carbon dioxide is the main gas given off when carbon fuels burn. The effect of combustion-produced carbon dioxide on the global climate is a special case of the greenhouse effect first described in 1896 by Svante Arrhenius.
  Because it is a greenhouse gas, elevated CO_2 levels will contribute to additional absorption and emission of thermal infrared in the atmosphere, which could contribute to net warming. In fact, according to Assessment Reports from the Intergovernmental Panel on Climate Change "*most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations*".
  Over the past 800,000 years, ice core data shows unambiguously that carbon dioxide has varied from values as low as 180 parts per million (ppm) to the pre-industrial level of 270ppm. Certain paleoclimatologists consider variations in carbon dioxide to be a fundamental factor in controlling climate variations over this time scale.
  A runaway greenhouse effect occurs if positive feedbacks lead to the evaporation of all greenhouse gases into the atmosphere. A runaway

greenhouse effect involving carbon dioxide and water vapor may have occurred on Venus.

- *CO_2. Methane. Water vapour. Sulphur dioxide. CFCs.*
  The following greenhouse gases have a contribution to the greenhouse effect: water vapor, which contributes 36–72%, carbon dioxide, which contributes 9–26%, methane, which contributes 4–9% and ozone, which contributes 3–7%. The major non-gas contributor to the Earth's greenhouse effect, clouds, also absorb and emit infrared radiation and thus have an effect on radiative properties of the atmosphere. Carbon dioxide is the human-produced greenhouse gas that contributes most of radiative forcing from human activity. CO_2 is produced by fossil fuel burning and other human activities such as cement production and tropical deforestation. Measurements of CO_2 from the Mauna Loa observatory show that concentrations have increased from about 313 parts per million in 1960 to about 383 ppm in 2009. The current observed amount of CO_2 exceeds the geological record maxima (~300 ppm) from ice core data.
  There are 3 teratonnes of carbon dioxide in the atmosphere and 50 times more in the oceans. Methane (CH_4), which is the fuel of natural gas, is 22 times more potent than carbon dioxide as a greenhouse gas, but is under 2 ppm of the atmosphere compared with 387 ppm for carbon dioxide. Water vapour also acts as a greenhouse gas contributing 36-72% of radiative forcing, but in daytime the presence of cloud reflects sunlight. Sulphur dioxide, which can be given off when coal burns, which contributes to 50% of global emissions – this was the source of smog in London in the 1950s – has a cooling effect as a greenhouse gas. It comprises 0.001 ppm of the atmosphere. When the Mt Pintubo volcano in the Philippines erupted in 1991, the sulphur dioxide given off cooled the planet by 0.5 °C between 1991 and 1993. Roughly half of the carbon dioxide stays in the atmosphere when emitted for over 100 years, but CO_2 has a variable atmospheric lifetime that cannot be specified precisely. The corresponding figure for methane is 7 years.
  CFCs (chlorofluorocarbons), which were used as refrigerator coolants and in cans of hair spray until they were abolished by the Montreal Protocol in 1989, depleted the ozone layer (which prevents dangerous ultraviolet radiation reaching the ground) above the Arctic and Antarctic leaving the largest ozone hole in the winter of 2006. The situation has now greatly improved and is expected to recover by 2050.
- *The Arctic and Antarctic. Greenland and ice-melt.*
  Shown below is the Artic sea ice in summer 19HH and 20JJ. The GRACE satellites have measured the melting of Greenland ice from the effects of the mass of the ice on their polar orbits. There are K cu km of Greenland ice. On the left is shown the approximately straight-line increase in the *rate* of ice-mass melt in Greenland – so the amount of ice melting is *accelerating*, shown on the graph on the right, extrapolated to hit zero ice in year 21LL.
- Rise in temperature - the model A1FI.

- Sea level rise. Climate refugees. Bangladesh, Egypt, Florida, London and Brighton & Hove.
  Sea level rise will be mainly due to the expansion of seawater as oceanic world temperature rises. Another effect is the melting of Arctic and Antarctic ice.

There are 143 million Bangladeshis. The fence built between India and Bangladesh.

- Melting glaciers. Effect on the Ganges and the Bramahputra.
- Species extinction. Noah's Arks.
  The Stern Review quotes "".
  Seed banks and zoos are needed to preserve the plant and animal diversity that would perish with such a rise of temperature.
- Political action and inaction. Education. Vested interests.
- Solutions.
  - Tree planting worldwide – 1/5th the answer.
    Professor Philips calculates that tree planting worldwide can only at most be 1/5th the solution to the CO_2 problem. Selection of species of plants and trees more efficient at photosynthesis than the average, or genetic modification of trees to produce more intense absorption of CO_2 could increase this proportion.
  - Injecting SO_2 into the stratosphere.
  - Creating clouds artificially to reflect sunlight.
    The Philips-Salter device.
  - Feeding oceanic algae.
    These experiments seem to have failed.
  - Cutting emissions of CO_2 to zero, and the thermal inertia effect.
    The thermal inertia effect means that CO_2 remaining unabsorbed in the atmosphere would continue to feed global warming for over 100 years under the scenario that human CO_2 emissions were stopped completely.

<u>A GLOBAL CLIMATE, RESOURCES AND ENERGY MODEL</u>.

(12) *A Global Climate, Resources and Energy Model, by Doly García*:

- 1. Introduction. Perhaps the best known global model of all is World3, popularized in the book *The Limits to Growth, A report to the Club of Rome*, by Donella H. Meadows, Dennis L. Meadows, Jørgen Randers, and William W. Behrens III. I have taken some of the equations in the latest version of the World3 model (World3-03) and I have added some more data and feedback loops to reflect some of our present knowledge of climate change and energy issues (there aren't any energy variables in the model, the closest one is "non-renewable resources"). The aim is to have a model that is more useful for the purpose of testing in theory different policies that could be applied to resolve some of the current challenges our world is facing, that have all at the root the fact that we are reaching the limits to growth.

- 2. The broader issues. Before going into the details of the model I propose, it's worth asking if there's any purpose in the exercise at all. Specifically, these two questions need asking:

  Is a global model useful at all?

  If global models can be useful, is it appropriate to use the equations of World3 as a base for a new model?

  These are my personal answers to those questions:

2.1. Is a global model useful at all?

One of the criticisms levelled at World3, that has been often repeated with other global models, is that there is so much uncertainty in so many of the relevant variables, that there isn't any point in the exercise of modelling at all. While it's true that there is a lot of uncertainty, it's worth remembering that this won't stop people making models of the world. Even if there were no computer models of the world at all, people still have mental models, rough ideas of where the world is heading in many different aspects. And what's more, decision-making and policies will be based on those mental models. So there is a very valid justification for any attempt to make those mental models as correct as we can, with whatever tools we have. A computer model containing the best available data and reviewed by experts seems likely to produce insights into the future of a better quality than the hunches of policy makers.

2.2. If global models can be useful, is it appropriate to use the equations of World3 as a base for a new model?

Modelling has advanced a lot since the original World3, and there are good arguments to say that incorporating new equations and variables to World3 isn't appropriate. However, I believe there are several advantages to this approach, the main one that many experts have already studied World3 and are familiar with it, and their observations may be also relevant to a new model that contains many of its equations.

3. The proposed model

3.1. Energy variables

Energy variables are conspicuously absent from World3. The closest thing to an energy variable is "non-renewable resources", that is meant to include not only fossil fuels, but also minerals and other resources. When considering how to best include energy in the model, I chose to eliminate the variable "non-renewable resources", on the grounds that, in a world with unlimited energy, any chemical compounds useful as a raw material but not as an energy source could be easily obtained (if necessary, elements found rarely on Earth could be mined from other parts of the Solar System, or created with the appropriate nuclear reactions). Fossil fuels are the only true non-renewable resources.

To incorporate energy issues in the New World Model, I had to create three new sets of equations: equations about energy supply, equations about energy demand, and equations about energy source allocation. Most models I have seen model only energy demand or supply, but this is clearly insufficient. Modelling energy demand and assuming that it will somehow be met ignores the important issues of fossil fuel depletion. Modelling energy supply and ignoring demand doesn't help to judge the soundness of policy proposals to switch usage of fossil fuels by "clean electricity", which often sweep under the carpet the question of where the electricity may come from and the energy losses of any conversion of other energy sources to electricity.

3.1.1. Modelling energy supply

To model energy supply, I distinguished six types of energy sources: coal, oil, gas, nuclear power, renewable electricity, renewable thermal and biomass. The distinctions were made based on the differences between them in renewability and usability for the different types of demand. Energy sources similar in both counts were grouped together.

The estimates on ultimate reserves for fossil fuels were taken from Jean Laherrere. Fossil fuel production was determined by two factors: demand and possibility of supply. When it's possible to supply the demand, production equals demand. When demand falls sharply, production will drop but keep some inertia. When demand goes up, production may or may not increase, depending on the amount of fossil fuel remaining. The equation that determines the maximum increase in production for fossil fuels is:

Increase in production = 0.2*(fraction of fossil fuel remaining-0.5)*current production

This means that at the beginning of exploitation of a resource it's possible to increase production very quickly, up to 10% a year. When half of the reserves have been produced, production reaches its peak and can't increase any more. From that point onwards, production will always decline.

One important aspect of the modelling of energy supply was calculating declining EROEIs (Energy Returned On Energy Invested) of non-renewable resources. The available data on EROEI is very spotty, but it's such a crucial concept to explain what may happen in the future with energy sources that I believe a model would be inaccurate if it didn't include it in some way. The energy source that has been most studied for declining EROEI in time is oil. Available data for oil in the USA is the following (Charles Hall, 2008):

- 1930 – About 100:1
- 1970 – About 30:1
- 2000 – About 11-18:1

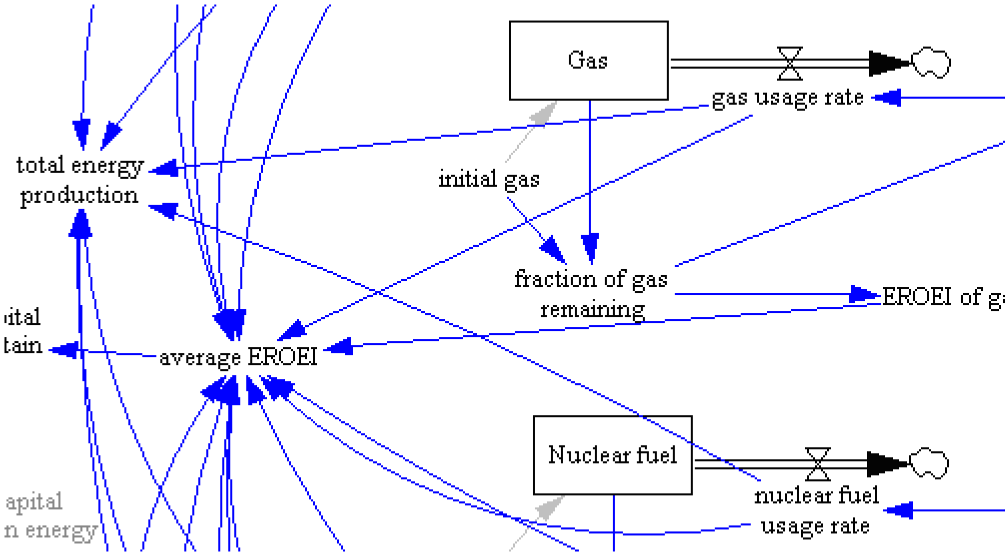
This suggests a relationship between EROEI and the fraction of remaining oil that is approximately proportional to the square of the fraction of oil remaining:

EROEI of oil = (fraction of oil remaining^2)*100

An additional reason to go for this simple relationship is because it has the following property: it takes the same amount of energy to extract the first half of the oil as it takes to extract half of the remainder (a quarter), and so on. This fits well with the intuitive idea of declining EROEI.

However, the data is too limited to say this formula holds true with any certainty, and I'm using it only as a best guess. The results of the model are similar if other declining functions are used.

Once the EROEIs of all energy sources are calculated, the weighted average is then used to estimate the fraction of industrial capital needed to obtain energy. This again is speculative, but a couple of datapoints are known: at an EROEI of 1:1, 100% of the industrial capital would be needed. At high EROEIs, it appears that 5% of the industrial capital is used (from the "cheese slicer model" by Charles Hall, Robert Powers, and William Schoenberg, 2008). The intermediate points can be estimated by assuming that the fraction of industrial capital needed is roughly proportional to the amount of energy needed as an input for energy production.

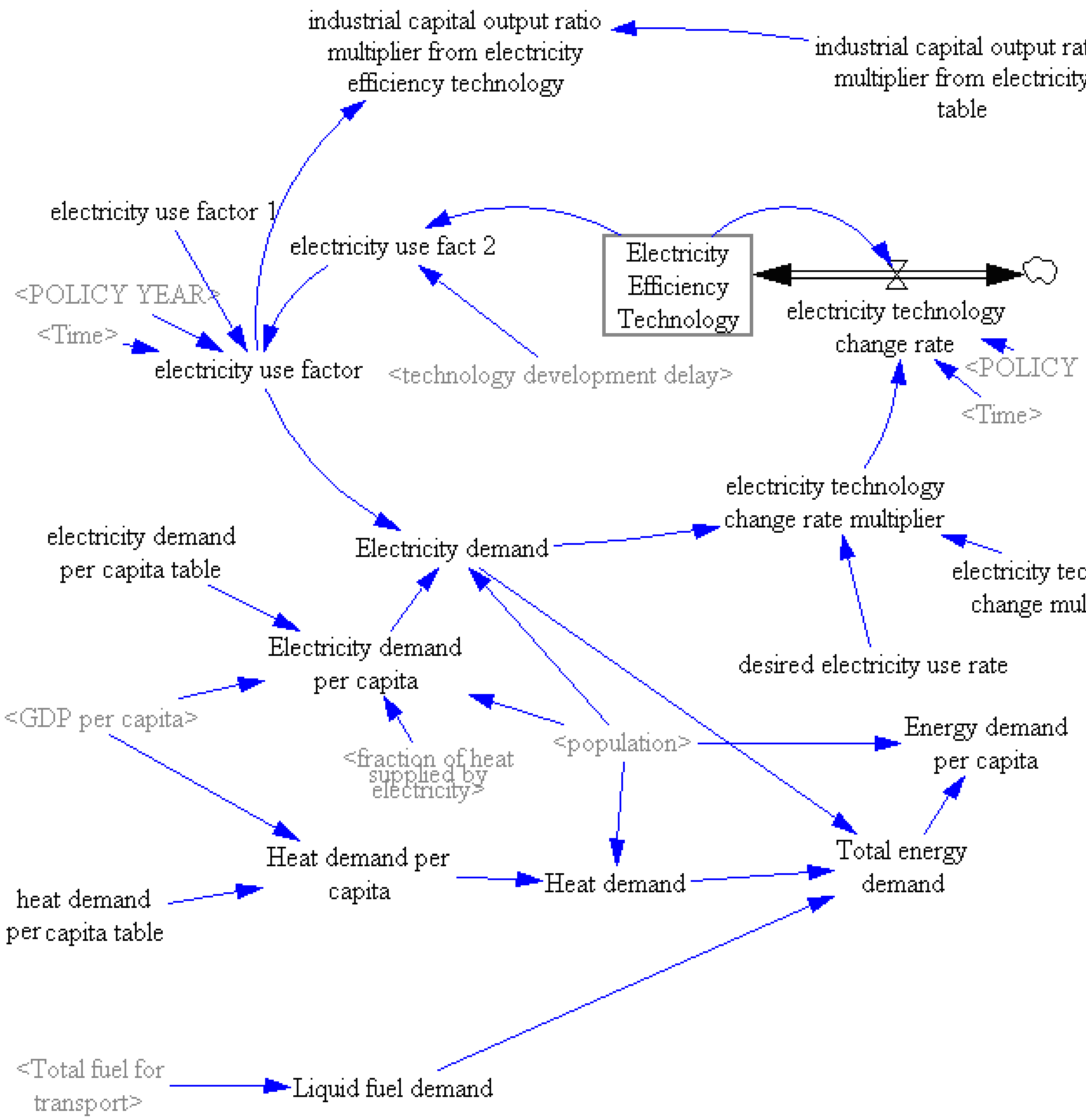


Graph 3.1.1.1 – A section of the flow diagram of the equations used to model energy supply. Click to see whole flow diagram.

<u>3.1.2. Modelling energy demand</u>

One factor that many energy models seem to forget is that people don't demand energy sources like oil, nuclear power or hydro. What people actually demand is electricity, heating and transport.

Electricity demand is calculated in the model as a function of GDP, with the data based on historical data for electricity consumption from the World Development Indicators Database. Heating demand is calculated as a constant of 400kg oil eq. per capita per year. Transport demand is calculated as the sum of the transport needed for freight and for passenger transport. I couldn't find world data on freight and passenger transport, but it appears that both in the USA and the EU about 25% of the energy use goes into freight and 75% into passenger transport. So I assumed the relationship holds for the rest of the world. The total energy used for transport was deduced from the historical data on oil consumption.



Graph 3.1.2.1 – Flow diagram of the equations used to model energy demand. Click to open in a new window.

3.1.3. Modelling energy source allocation

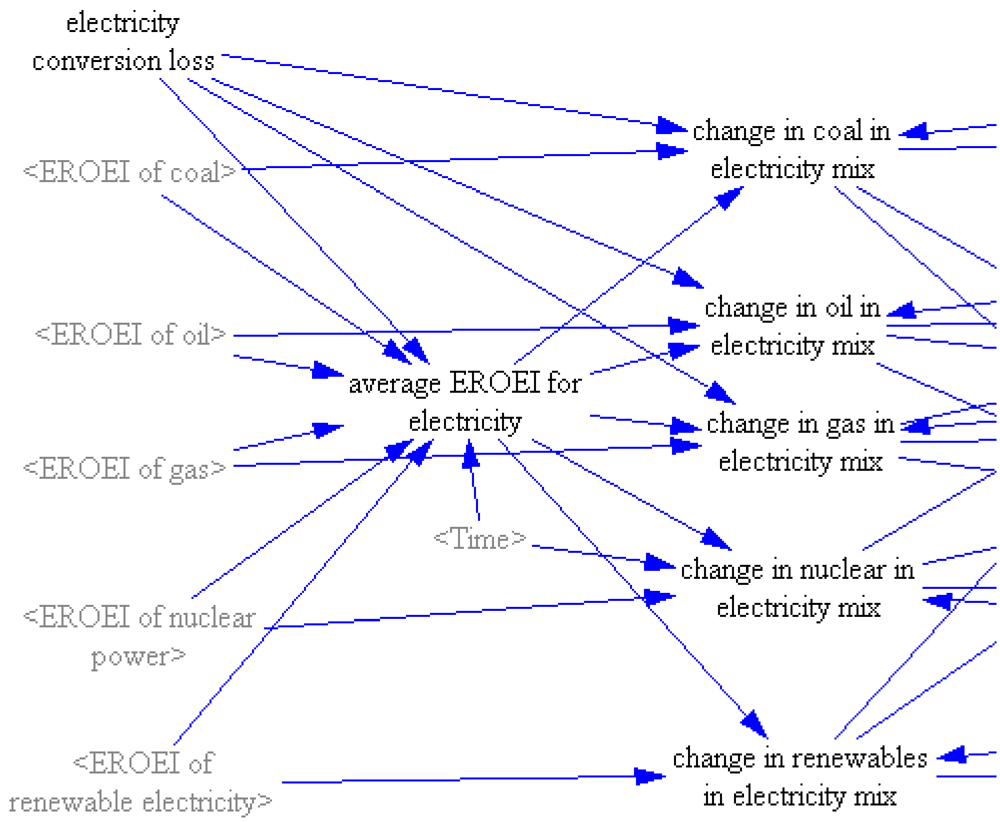
Once demand and supply are calculated, matching them is a non-trivial exercise, as anybody who has looked at the electricity mix of any country can tell.

There are two fundamental ideas that I have used to do the matching:

1. Market forces follow EROEI: the most efficient sources of energy are also the most profitable. This seems to make sense intuitively but is disputed.

2. Energy companies are conservative: they will not start reducing the usage of an energy source until its EROEI falls below the average of all sources. Also, the reduction or increase in any energy source is gradual.

My model successfully reflects historical changes in use of different energy sources with no other input but the variations of EROEI in time, which suggests that the approach can't be entirely misguided. The production data the model generates is only a rough approximation of the real data, but clearly on the right track, and further work on the relevant parameters could refine the results. For a comparison, historical data on world production of fossil fuels can be found in work by the Netherlands Environmental Assessment Agency.



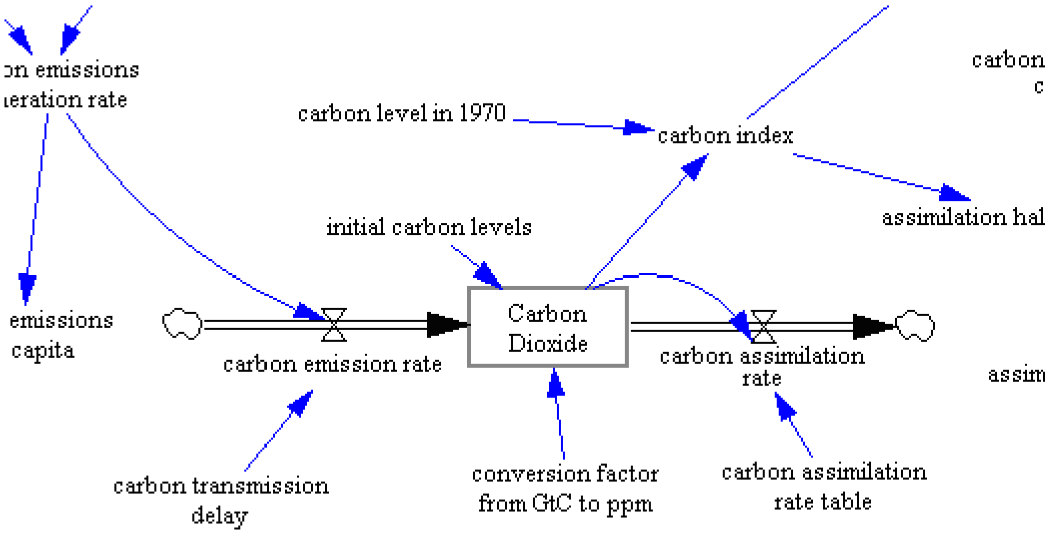
Graph 3.1.2.2 – A section of the flow diagram of the equations used to model energy source allocation.

<u>3.2. Carbon emissions</u>

Carbon emissions and climate change are absent from World3, mostly because there wasn't much knowledge on the matter at the time. For the purposes of including carbon emissions in the model, I took the equations for pollution in World3 and modified them. Unfortunately, this means that the New World Model lost the original pollution equations (clearly designed to represent chemical pollution), which may need to be re-introduced.

The calculation of carbon emissions is, of course, fundamentally different than the calculation of pollution, and is made by adding up the emissions from each of the fossil fuels and from land development (deforestation). Another important difference is the assimilation rate, which is clearly different for carbon dioxide and for chemical pollutants. I couldn't find reliable information on carbon sinks, so the model only contains data for the known historical levels of carbon assimilation by the Global Carbon Budget Team, and extrapolates linearly from there, which is probably excessively conservative.

The model doesn't attempt to make any detailed analysis of climate change, but only an estimation of the levels of carbon dioxide in the atmosphere and its possible consequences for food production. Climate change models can provide much greater detail into specific consequences of climate change, but this isn't the aim of this model. The aim, instead, is to estimate how climate change may affect other important variables in the world.



Graph 3.2.1 – Flow diagram of the equations used to model carbon emissions. Click to see whole flow diagram.

3.3. Food production

The equations for agriculture were taken straight from the World3 model, with two importnt changes:

1. The land yield is affected by the levels of carbon dioxide in the atmosphere. There is still a lot of uncertainty on the effects on food crops of different levels of carbon dioxide, but there is agreement that climate change will reduce crop yield. The model assumes 2% reduction on yield at 370 ppm, based on current data on the reduction in crop yield so far (David B Lobell and Christopher B Field, 2007). There is still a lot of discussion on future reductions on crop yield due to climate change. This model assumes a 10% reduction at 500 ppm, which seems like a reasonable figure based on the IPCC data. If there are better figures available, I will include them.
2. Food production is reduced in proportion to the amount of biomass production.

3.4. Economy

World3 has several variables measured in dollars and some variables relevant to the economy, such as jobs. This was never meant to model the economy such as understood by financial institutions, but rather the physical economy, the real things on the Earth that have physical limits.

Even so, it's surprising that the model didn't contain a GDP variable, representing in some way the "real" GDP, meaning with this not inflation-adjusted but representing some aggregate measure of agriculture, industry and services produced. I have added this variable to the New World Model, which also helps in the calculation of other minor variables that traditionally are based on GDP but that in World3 were using industrial output as a proxy for GDP.

3.5 Demographics and carrying capacity

Because population is such a critical variable in the model, additional demographic variables were added to track if the historical values of population were on the right track: the global crude birth rate and the global crude death rate. Adjustments were done whenever the demographic variables were going far off the track.

Two calculations of the carrying capacity of the Earth were added to the New World Model:

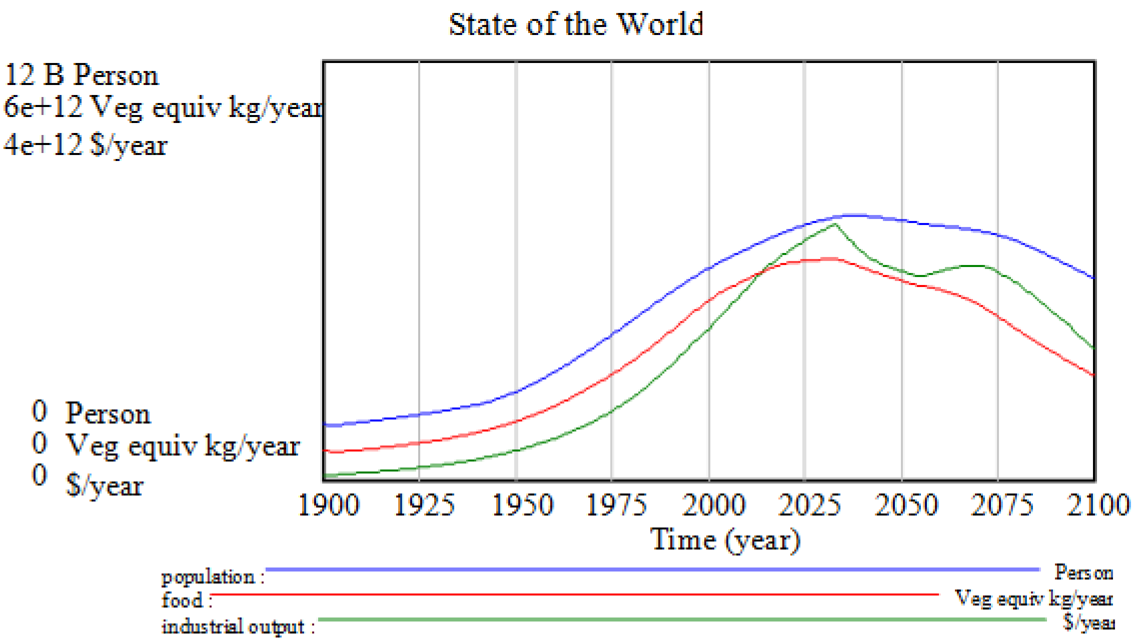
1. The maximum feedable population, representing the maximum population that could be fed at subsistence level with the current food production.
2. The maximum sustainable population, representing the maximum population that could live on the planet if the total human footprint was allowed to rise to 1 planet. The calculation of human footprint was done by adding arable land, urban land and the land needed to absorb the current rate of generation of carbon emissions.

Both values vary with time as food production and human footprint change with time.

4. The results of the model for the "business as usual" scenario

4.1. Main variables: population, food and industrial output

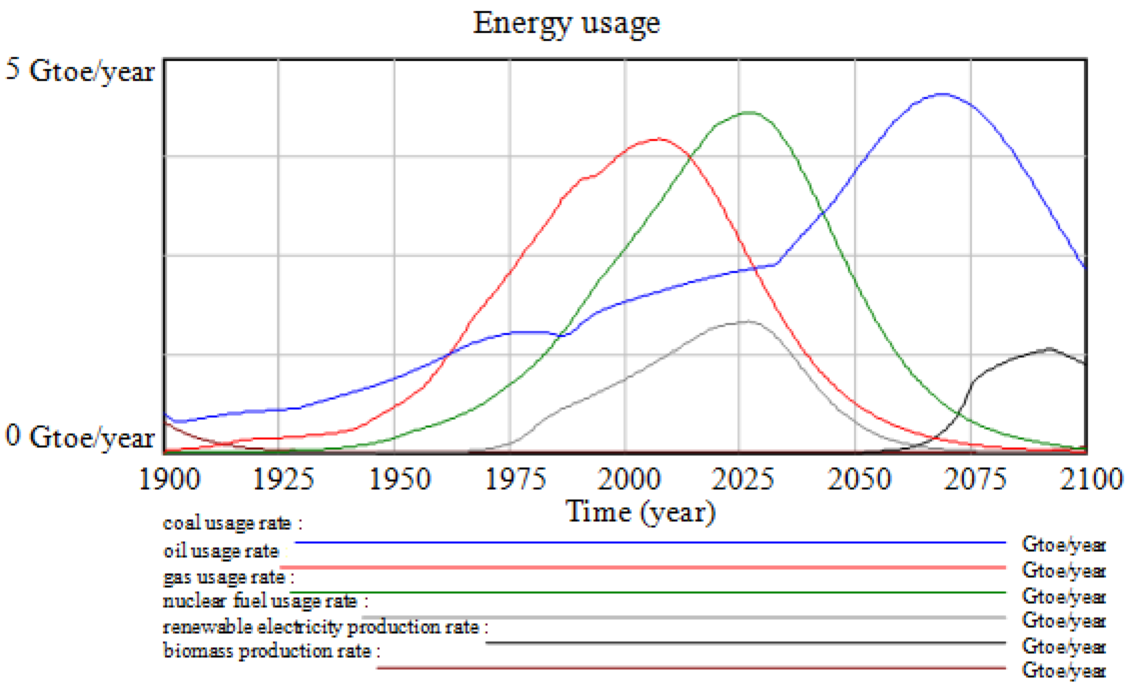
In the "business as usual" scenario the pattern was one of collapse of human population, food production and industrial output, in a way similar to what happens in the World3 business as usual scenario. The decline is gradual, starting somewhere around 2030:



Graph 4.1.1 – Food production and industrial output in the New World Model

4.2 Energy usage

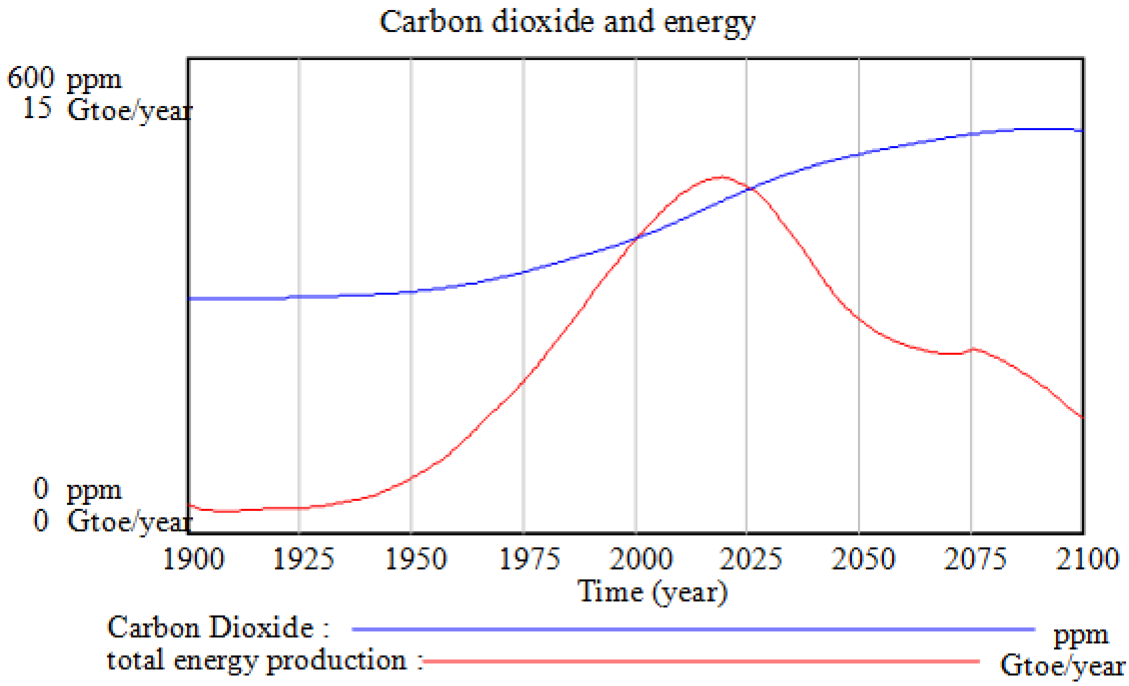
Energy supplies are substituted for each other as EROEI declines, but eventually all fossil fuels and nuclear fuels are used up. Renewables aren't used until the end of the 21st century, due to their low EROEI:



Graph 4.2.1 – Energy usage graph

4.3 Carbon dioxide

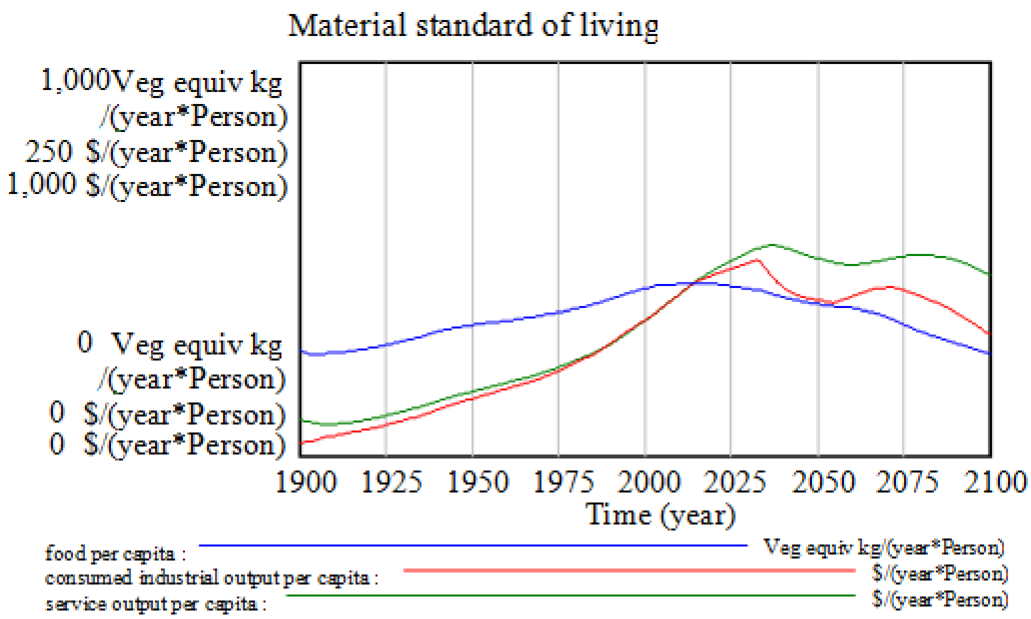
A remarkable result of the model in the business as usual scenario is that carbon emissions don't go very high, peaking at 510ppm, which is lower than some of the emissions scenarios of the IPCC. The reason for this is double: Firstly, the limits on fossil fuel reserves mean that not as much carbon can reach the atmosphere as assumed by the IPCC even when all fossil fuels are burned. Secondly, the estimations of carbon sinks may be too favourable in the model.



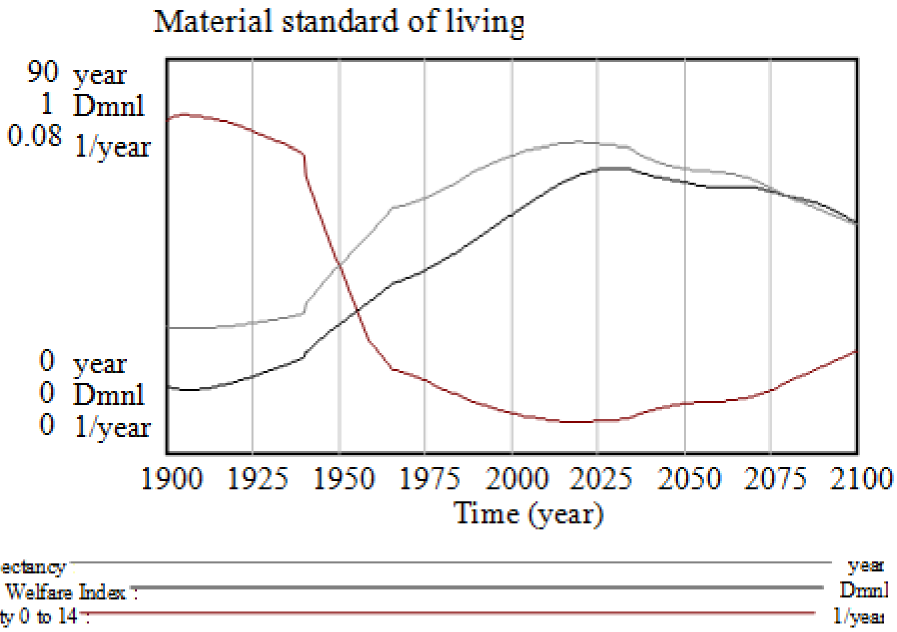
Graph 4.3.1 – Carbon dioxide and energy

4.4. Standard of living

The standard of living declines clearly by all the reasonable measures that can be made in the model: food per capita, industrial output per capita, services per capita, life expectancy, human welfare index and child mortality. The levels of food per capita by the end of the 21st century are similar to the beginning of the 20th century and are in a path of continuous decline. However, this shouldn't be taken as any kind of prediction, because the model cannot possibly include all the relevant data.



Graph 4.4.1 – Food per capita, industrial output per capita and service output per capita in the New World Model

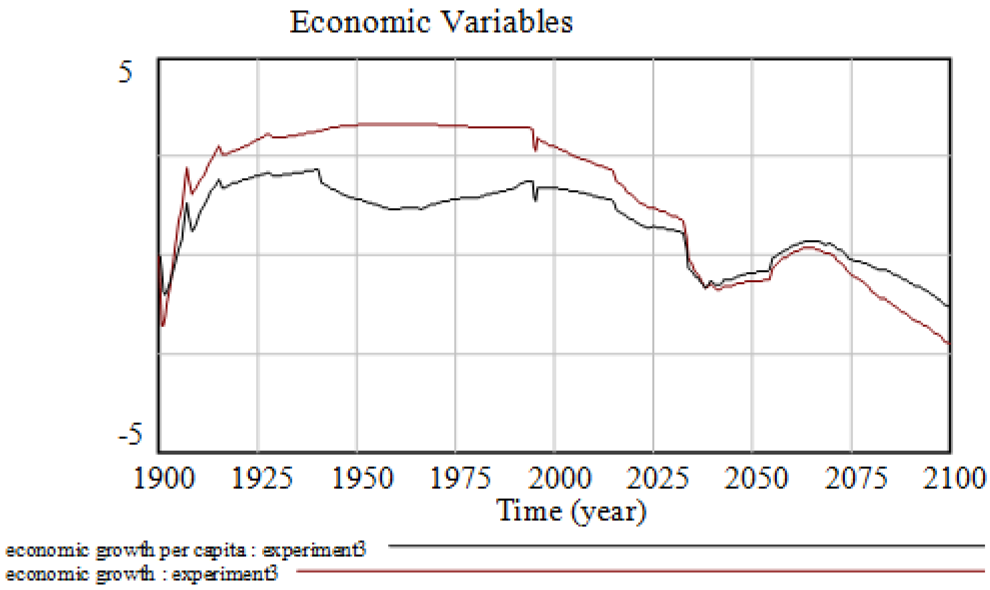


Graph 4.4.2 – Life expectancy, human welfare index and child mortality

4.5. Economic growth

The most interesting result of calculating GDP is that it allows for the estimation of economic growth. This should not be understood as the figure that economists produce, but some kind of numeric estimate of the yearly change in all the goods and services produced in the world. Interestingly, at the point of collapse, it falls dramatically, but it starts declining many years before that, providing an early warning signal.

It's also worthwhile noting that the point of peak oil is marked by a drop in economic growth. It's very tempting, but not really justified, to relate this to our current economic crisis. Certainly, if we were at the early stages of the collapse in economic growth that the model estimates, it's to be expected that a major economic crisis would happen, and a big overhang of debt is one of the logical ways for it to happen, as a result of an effort from central banks to maintain a level of economic growth that isn't justified by the fundamentals. But I don't have enough data at present to confirm or deny if our current situation reflects that we are at the beginning of the great contraction estimated by the New World Model.



Graph 4.5.1 – Economic growth in the New World Model

5. Conclusions

The main conclusion of the results of the New World Model is that, if the world continues behaving as we have so far, decline is inevitable in the long run. This isn't a surprise and the fact that we are on an unsustainable path can be deduced from much simpler and reliable calculations. What this model provides is some slightly more refined ideas about how this could happen and, more importantly, it's a tool where we can experiment with our ideas on how to solve this problem.

I am aware that I may have made many mistakes in producing this model, and I may have used data that is out of date or otherwise incorrect. Please consider this as a first draft, and I welcome any input you may want to provide. I would like to make this a collaborative effort. The whole model can be downloaded from here.

The software to run the model is Vensim PLE, that can be downloaded from: www.vensim.com

Finally, I would like very much to receive input on possible policies to avoid decline and eventual collapse (when all fossil fuels are consumed) that could be included in this model to see what results they produce. The Transition Network has already expressed interest in using this model for the timeline they are writing for all Transition Towns to help them design their own Energy Descent Action Plans. Of course, this will only be useful if the model includes the policies that need to be implemented for a successful transition to a sustainable world.