# Ecological Footprint, Energy Consumption, and the Looming Collapse

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## Abstract

This article explores dynamic relations governing population growth, resource depletion, and world economics by means of a few simple modeling and simulation exercises. To this end, we start out by exploring the concept of an ecological footprint, representing the amount of land that a person needs for producing everything that he or she consumes: food, clothing, energy, shelter, the tools that are needed to make the clothing, etc. and place it in relation with the human development index, a measure of the quality of life of an individual. We then relate the ecological footprint to the per capita energy consumption. This discussion serves to provide a quantitative understanding of the limited resources that are at our disposal.

The article continues by exploring the dangers and seductions of exponential growth, and uses a system dynamics approach to illustrate why we are moving at a rapid pace toward global collapse with our eyes wide shut.

The article ends by discussing what we would need to do in order to avoid the looming collapse.

## Carrying Capacity and the Ecological Footprint

You just finished preparing lunch for four people when your son storms in, asking whether his friend can stay for lunch. Hence the lunch prepared for four people must now feed five. There isn't much of a problem. The family members simply receive a bit less than they would have received otherwise.

This short story illustrates why the much discussed concept of the *carrying capacity* of planet Earth is flawed. It is entirely possible to distribute the available wealth among more people. The consequence will simply be that there is less available for each one.

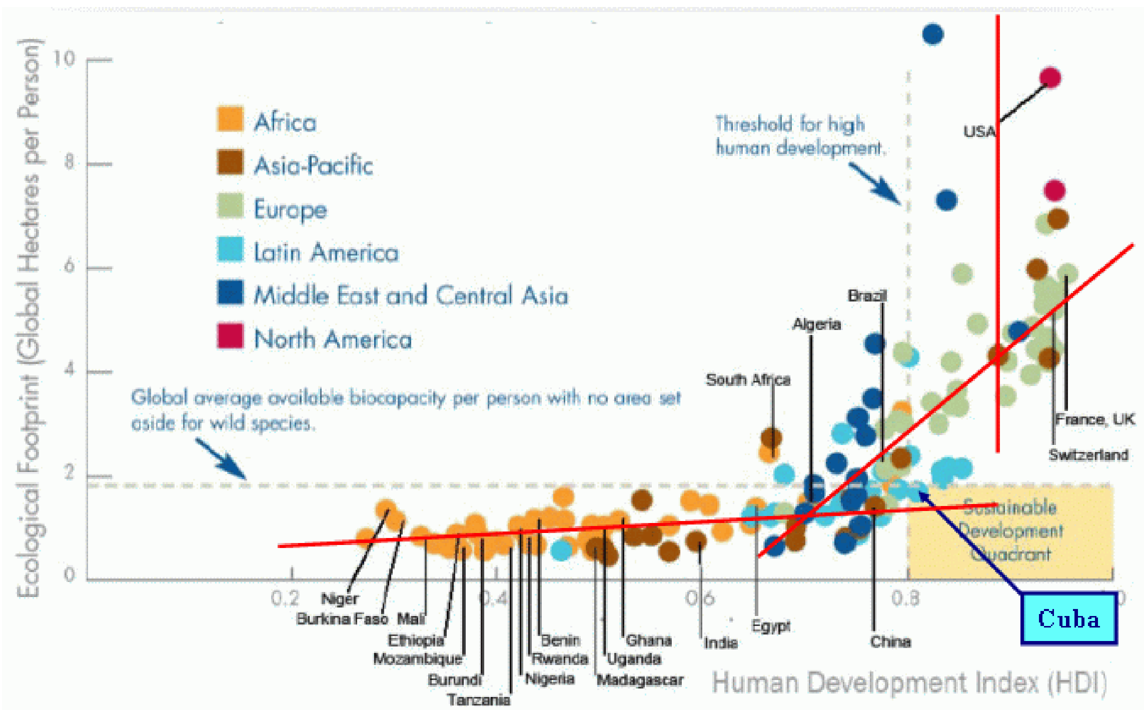
For this reason, Mathis Wackernagel, CEO of the Global Footprint Network, developed an alternative concept called the ecological footprint.

The ecological footprint of a person is a measure of the amount of land that a person needs in order to produce everything that he or she consumes: food, clothing, energy, shelter, the tools that are needed to make the clothing, etc. Under contract by the United Nations and the Swiss Government, Mathis and his team computed the average per capita ecological footprint of many nations on this globe. The average Swiss consumes roughly 5.5 hectares (13.6 acres), the average American occupies roughly 10 hectares (24.7 acres), whereas the average inhabitant of

Madagascar gets by with 0.5 hectares (1.2 acres) only. The average inhabitant on this planet currently makes use of 2.2 hectares (5.4 acres).

Mathis then took the entire available arable land of this planet and divided it by the current population of 6.5 billion people. This produces an available per capita footprint of 1.8 hectares (4.4 acres).

He then plotted the ecological footprint of different nations against their Human Development Index (HDI), a measure of the quality of life of their inhabitants.




In order for the inhabitants of planet Earth to lead a decent life without taxing the resources of the planet in an unsustainable fashion, each nation should consume less than the 1.8 hectares per capita of the ecological footprint available, while being granted an HDI of 0.8 or better. Hence all nations should strive to have their "dots" move to the orange box in the lower right corner of the graph.

Currently, there is only one nation that has its dot inside that orange box. That nation happens to be Cuba. In order to move towards a sustainable world, we all must become … not *Berliners*, but *Cubans*.

The banana-shaped curve can be approximated by three separate tangents. The almost horizontal red line at the bottom represents primarily the African nations. The good news is that it should be possible to move them further to the right, i.e., in the direction of an improved quality of life, almost without increasing their ecological footprint. These nations get by with such a small footprint because they cannot afford to waste anything. They are careful to use their few available resources in an almost optimal fashion.

The second (tilted) tangent further to the right represents the European nations. Their gradient is steeper because they live more wastefully. People in Switzerland heat their houses in the winter and cool them in the summer more than would be necessary; they maintain weekend houses that they heat and possibly cool even at times when they are not present; they keep their computers running 24/7; and finally, they buy food items that they then forget in their refrigerators and freezers until they are rotten and need to be thrown away.

Finally, there is a third vertical tangent representing the United States and the United Arab Emirates. They consume simply because they can without improving their quality of life any further.

So, what is the carrying capacity of the planet? If we wish to live in a sustainable fashion like the Cubans, we'll need to reduce our numbers by 20% to 5 billion people. If we wish to all live like Americans, we shall need to decrease our numbers to roughly 1 billion people. Finally, if we decide to live as poorly as the people of Madagascar, then we can triple our numbers to 20 billion and live unhappily ever after.

Unfortunately, expansion is in our genes. The Cubans would gladly vote to become the 51st State in the Union, if this would enable them to drive around in these sinfully gorgeous SUVs; if they could heat their houses to 24C in the winter while cooling them down to 18C in the summer; and finally, if their supermarkets would carry all the food that they can only dream about at an affordable price 24 hours per day and seven days per week.

## Energy Consumption and the Dependence on Fossil Fuels

At the current time, we are satisfying our energy needs almost exclusively by burning fossil fuels. Everything else is icing on the cake. Hence if the fossil fuels become unavailable, we have a real problem. Let me quantify our current energy consumption:

| **Energy Type** | **EJ/yr** | **%** |
|---|---|---|
| | | |
| Oil | 160 | 38 |
| Coal | 100 | 24 |
| Gas | 90 | 21 |
| Biomass | 30 | 7 |
| Nuclear | 25 | 6 |
| Hydro | 15 | 4 |

The three types of fossil fuels: oil, coal, and natural gas, together account for 83% of our entire energy consumption. The units used in the table, EJ/yr, represent exajoules per year. We are currently consuming 420 EJ/yr, corresponding to 13 TW (terawatts).

Although we are definitely hooked on fossil fuels, many of the uses that are currently covered by fossil fuels could equally well be met by other means. For example, it isn't necessary to heat our houses by means of central oil heating systems. We could utilize electric heat pumps instead. We use fossil fuels simply because they currently represent the cheapest solution. As long as electricity is sold at a price three times higher than heating oil, why should we consider changing our heating systems?

The problem is that we are running out of cheap oil fairly soon. Once the price of crude oil rises to $200/barrel, everyone in Switzerland will want to switch from oil to heat pumps. When that happens, where will we get the electricity from to meet the sudden increase in demand?

As it is possible to replace one type of energy with another, it makes sense to discuss energy consumption simply in terms of power units, rather than in terms of barrels of oil.

If we divide 13 TW by 6.5 billion people, we get 2 kW per person. Switzerland has currently a per capita energy consumption of 5.5 kW, whereas the U.S. shows a per capita energy consumption of 10 kW. If we plot the energy consumption of different nations against the HDI, we obtain a graph that is almost identical to the ecological footprint graph, simply replacing hectares by kilowatts. Energy consumption and footprint are proportional to each other. The footprint has the advantage that it can be interpreted in the context of sustainability, whereas the energy consumption has the advantage of being more easily and accurately computable.

Knowing that we live beyond our means, Switzerland has meanwhile espoused the goal of reducing the per capita energy consumption by 2050 by a factor of 2.75, creating a 2000 Watt Society. Being the good citizen that we are, we should stop living beyond our means and return to a sustainable life style.

This is tough. In 1950, shortly after the end of WW-II, the per capita energy consumption in Switzerland was 1 kW. However at that time, there were hardly any cars around; there were no computers and no TV sets; the average household had one radio and one record player; many houses didn't have central heating yet, i.e., only the living room was being heated by a woodstove. The beds were locally heated using jute bags filled with cherry-stones. The bags were previously heated in a special compartment of the woodstove in the living room.

A lot can be accomplished by better insulating our houses. New houses can and should be built as min-energy houses, whereas older houses ought to be upgraded. I expect the Swiss government to pass a law probably by 2010 that will force people who consume more than 10 liters of heating oil per year and per square meter of heated area to either upgrade their dwellings or reduce the room temperature accordingly. Tax incentives will be offered where needed.

The public transportation system of Switzerland is currently one of the best in the world. Nevertheless, most Swiss prefer to use private cars. Yet already, laws have been passed that will become effective in 2008, which will severely punish the owners of gas guzzlers, thereby hopefully convincing more people to buy smaller and more energy-efficient vehicles. Will this be sufficient?

I recently attended the annual meeting of the Swiss Academy of Engineering Sciences (SATW). At that meeting, a former CEO of the electricity company of the Canton de Neuchâtel, Charles Rognon, made a presentation about Swiss energy policies. Switzerland is in a fairly good position w.r.t. electricity production. We currently obtain 65% of our electricity from hydro-electric power plants, 30% from seven nuclear power stations, and the remaining 5% from everything else. In particular, we produce less than 2% of our electricity from fossil fuels. Of course, electricity only accounts for a small portion of our entire energy needs.

Rognon showed a graph on which he plotted the "proven" energy reserves in the year 2050. He assumed that our hydro-electric power plants shall continue to produce the same amount of energy by 2050 that they do now. This assumption holds, unless global warming will have melted our glaciers by then. He also accepted the (somewhat optimistic) assumptions made in the Road Map: Renewable Energies Switzerland that stipulate that we should be able to *double* our renewable (hydro, solar, wind, geothermal) energy production by 2050. He dropped the fossil fuels, because they may no longer be available by then, and he also dropped the nuclear energy due to the political pressure of shutting the nuclear power plants down.

Using the "proven" energy sources only, Switzerland will have available only 1 kW of per capita energy by 2050, i.e., even the envisaged *2000 Watt Society* is a pipe dream without additional sources of energy. The hidden message was that we cannot afford shutting down our nuclear power plants. In order to meet our goal of 2 kW per person, we would need to *double* our nuclear power *and* increase the efficiency of these power plants from currently 33% to 50% by using the excess heat for heating the houses in nearby villages rather than our rivers as we do now.

Yet, even if we manage to have 2 kW per person available by 2050, the 2000 Watt Society cannot be realized by better insulating houses and driving smaller cars alone. There is a direct relationship between energy consumption and productivity. Reducing the energy consumption, we'll have to move down the tilted red line in the footprint diagram, i.e., not only won't we be able to waste energy any longer, we'll all be significantly poorer as well. Our HDI will get reduced from 0.9 to 0.8. We'll become Cubans, and we won't like it a bit.

## The Seduction of Exponential Growth

Let us play a little game. We'll simulate a synthetic chain letter that obeys the following set of rules:

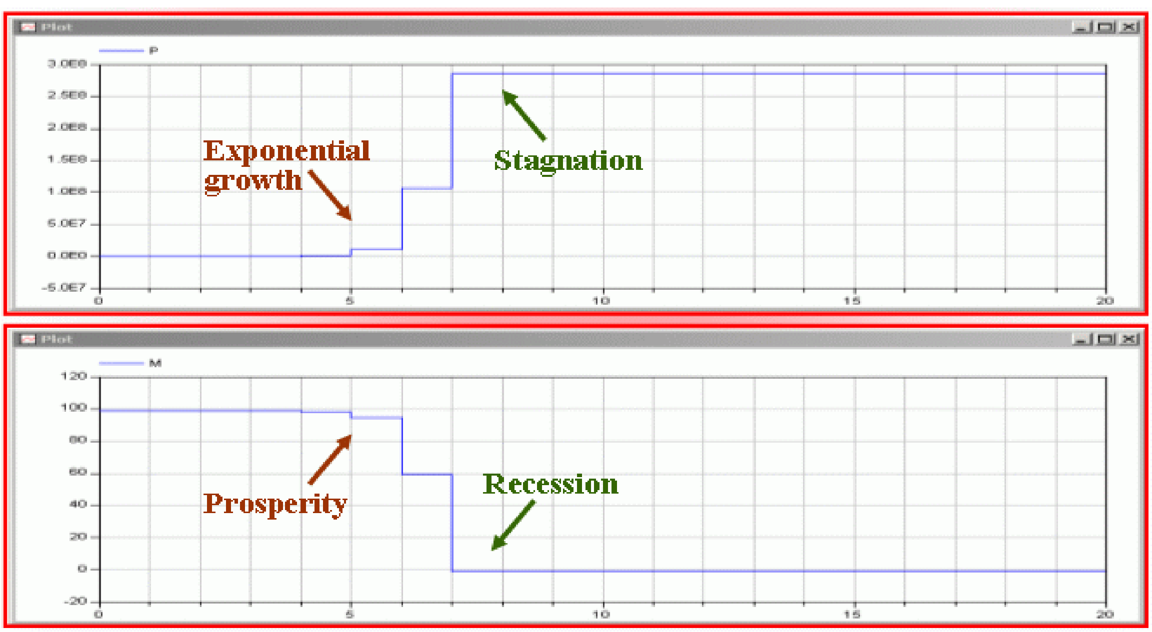
- A chain letter carries two addresses, the address of the sender, and the address of the sender's sender.
- After receiving the chain letter for the first time, the recipient sends $1 to the sender's sender. He then sends the chain letter on to 10 new recipients, again with two addresses, his own address as that of the sender, and the sender's address as that of the sender's sender.
- The letter is only mailed within the U.S.
- Every recipient answers the chain letter exactly once. If and when he receives the letter for a second time, he simply throws it away.

We need special rules to provide initial conditions:

- The originator sends out 10 letters with only one address, and doesn't send money to anyone.
- If a letter is received with only one address, the recipient sends it out to 10 new people with two addresses. Such a recipient doesn't send money to anyone either.

This is a wonderful, and totally illegal, way of making money. Each participant is expected to make $99 on the deal.

I quickly programmed that game and simulated it. Here are the results:



The top graph shows the infected population. Already after seven generations, the entire population of the U.S. has been contaminated. The bottom graph shows the amount of money that the participants made on the deal. Everyone who participates early on receives $99 as expected. Those who participate later lose $1.

Participants during the exponential growth phase of the game consume money sent to them by future generations, whereas those who participate during the stagnation phase send money to past generations.

This behavior is true for all exponential growth patterns. During the exponential growth phase, i.e., while the second derivative of the growth curve is positive (the curve is "u"-shaped), we borrow money from the future, and during the stagnation phase, i.e., while the second derivative of the growth curve is negative (the growth curve is "n"-shaped), we pay back our accumulated debt.

In fact, we are worse off during the stagnation phase than in steady state, because in the steady-state phase the second derivative of the growth curve is zero; we have meanwhile paid back all of our debt and are now debt-free.

Whereas sending out chain letters is totally illegal for individuals, it is not illegal for governments. In fact, this is how our entire economy works.

When we pay money into social security, it is not being invested in order to pay it back to us with interest once we retire. That money is used at once to pay retirement income to our parents and grandparents. The Social Security Administration simply relies on a growing number of young people to pay into their funds, so that we can receive an income once we retire.

The system lives off the exponential growth and *is designed to go broke* once the exponential growth pattern comes to an end.

Yet, this is not only a problem with social security. It is one of the main driving forces behind our entire economical system. Our economy has been optimized to exploit exponential growth, and once exponential growth ends, it is designed to fail.

For this reason, we cannot rely on market forces to get us out of the exponential growth dilemma. Our business managers and politicians have every (short-term) interest in preserving the exponential growth for as long as they can.

What we need is the EGA, an organization called *Exponential Growth Anonymous* with a strict "twelve-step program":

- We admit that we were powerless over exponential growth – that our world had become unmanageable.
- We have worshipped the chain letter principle.
- We stole money from our children to support our addiction to exponential growth.
- We lied shamelessly and remorselessly in order to support our addiction.
- We even were ready to start wars, if these allowed us to continue our addiction a little while longer.

We can rely on our business managers and politicians to fix the exponential growth problem as much as we can rely on junkies to fix the drug abuse problem.

## World Models and the Looming Collapse

For the past 35 years, researchers have attempted modeling world dynamics with the purpose of gaining a better understanding of the forces that drive population dynamics, resource utilization, waste management, and world economics.

One of the main contributors to this body of research is Dennis Meadows, one of the authors of the book Limits to Growth. Meanwhile in its third edition, the book continues to offer a useful, inexpensive, and easy-to-read introduction to our collective knowledge concerning world dynamics.

World models are based on plausible interactions between different variables that are considered key to governing the dynamical patterns. The interactions themselves are modeled using statistical data collected in different nations. For example, it is proposed that the birth rate is a function of the Human Development Index (HDI), as we have observed that in countries with a high HDI value, the birth rate is usually significantly lower than in countries with a low HDI value.

Different world models may use different relationships governing a different set of key variables, but they are all based on the same principles. A set of internally consistent relationships is formulated that can then be simulated to obtain sets of behavioral patterns that are compatible with these relationships.

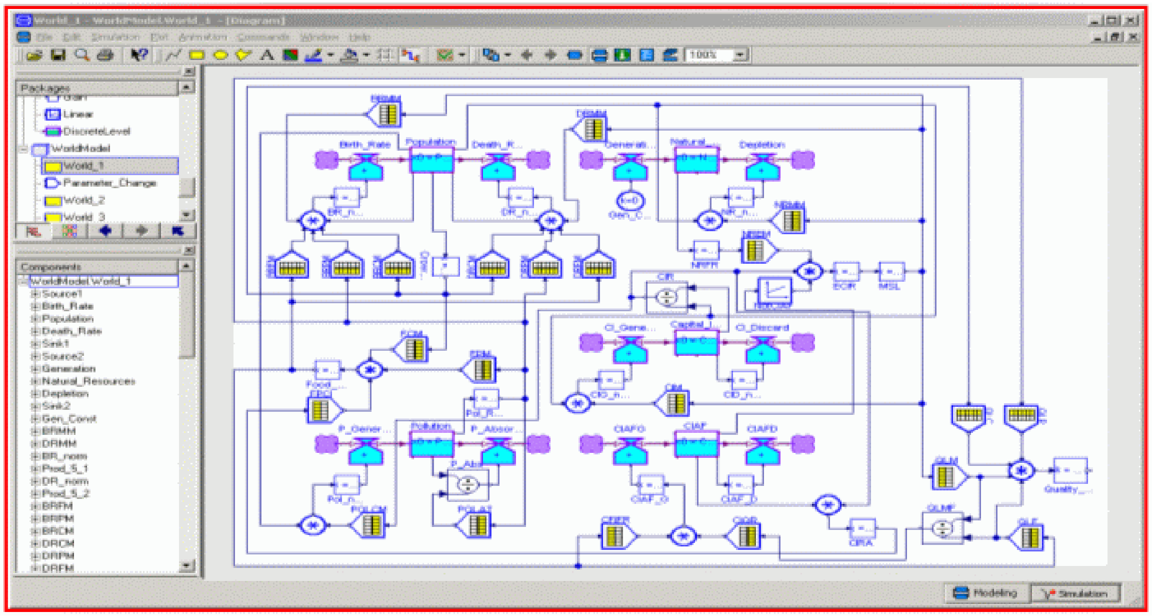
If you read the book *Limits to Growth* with the hope of finding a prediction of our future, you will be disappointed. No one can predict the future with any degree of reliability beyond a fairly short time horizon. What the book does demonstrate is how the model can be manipulated to generate different possible behavioral patterns that are all consistent with the assumptions (internal relationships) on which the model is based.

The book discusses 10 different scenarios, most of which, but not all, show a *collapse*, i.e., a rapid decrease of the world population sometime after the year 2030. Between 2030 and 2070, approximately, the world population decreases from somewhere around 7 billion people to somewhere around 1 billion people.

Dennis updated his world model (WORLD3) from one edition of the book to the next by adding new statistical data that have meanwhile become available. The behavioral patterns that the model exhibits haven't changed much by his doing so. The principal message of the original 1972 edition has not been invalidated by the new facts that were added between 1972 and 2004.

However in 1972, there were considerably more options available to avoid the collapse than are still available today. The window of opportunity is closing rapidly, and up to now, we seem to consistently have chosen paths leading to collapse.

Let me try to explain why this is the case. To this end, I shall employ an older world model, WORLD2, created by Jay Forrester and described in his 1971 book entitled World Dynamics. I am using this model because it is simpler and fits on a single graph. Here is the model:

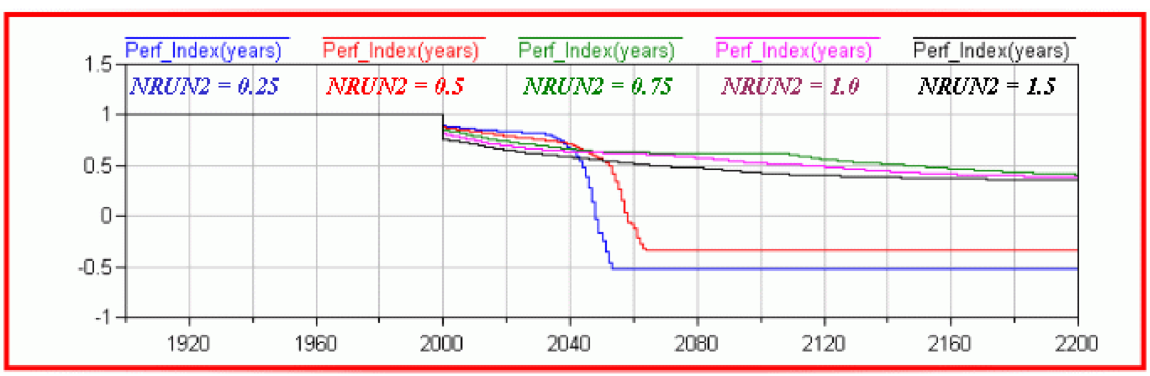


The model contains five "levels" (state variables), shown in the model as blue rectangular boxes, representing the population, the pollution, the unrecoverable natural resources, the money invested in the world economies, and the percentage of that money invested in the agricultural sector.

Each of these levels has an "inflow" and an "outflow," represented in the model by blue valve symbols, whereby the state derivative is the difference between inflows and outflows. These "rate" variables themselves are non-linear static functions of the states and other auxiliary (algebraic) variables.

Let us check what happens if we vary the rate at which the natural unrecoverable resources (like fossil fuels) are getting exhausted. We shall define a "performance index," i.e., a measure of goodness of the observed behavioral patterns. We wish to keep the world HDI value as high as possible, while punishing negative gradients of the population. We want a high living standard while avoiding the die-off.

Five different scenarios are shown below. The performance index is plotted over time.




The faster we use up the remaining fossil fuels, the better it is. The reason is that after the end of cheap oil the exponential growth pattern cannot be preserved any longer. The sooner we get out of the exponential growth pattern, the better we'll be off in the long run.

Two of the scenarios, the blue and the red, are plagued by massive die-off after the year 2040. The other three scenarios avoid the die-off. Hence we ought to prevent the blue and red scenarios from becoming our future. Yet, these are precisely the scenarios that offer the best short-term perspectives.

Since market forces always optimize with a short time horizon of two years or less, our politicians and business managers will invariably embrace the blue or red scenarios, and consequently, we are meeting our demise with our eyes wide shut.

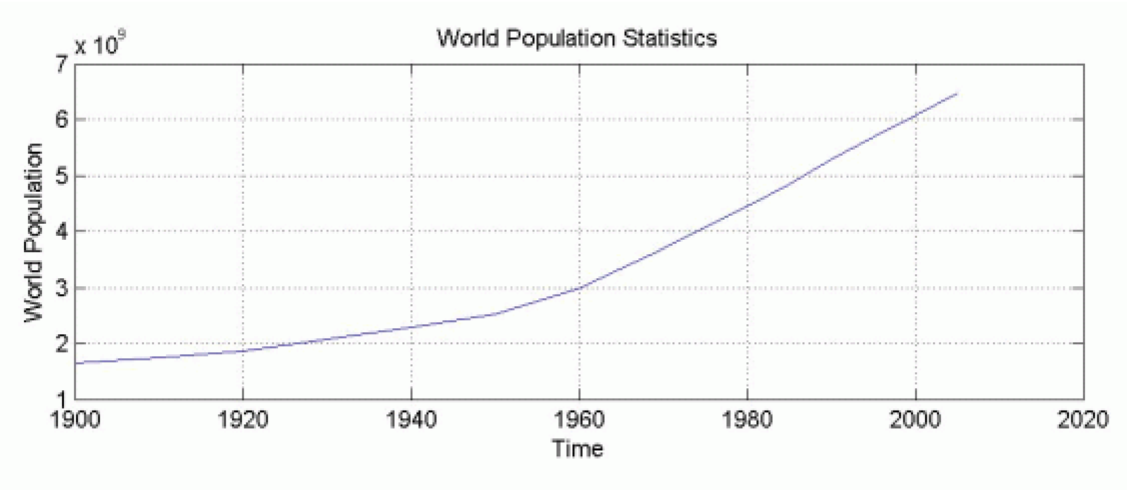
## The Consequences of Collapse

What does a collapse entail? GliderGuider demonstrated in a recent article published on The Oil Drum that, in order to "accomplish" a reduction in world population from 7 billion to 1 billion within a few decades, we would have to maintain an annual excess death rate of 3% or "better" over an extended period of time.

Let us look at Iraq, for example. We read every day that approximately 100 Iraqi die a violent death. Multiplied by 365 days, we get 36,500 dead Iraqi every year. Multiplied by 4 years since the invasion, we get 146,000 dead Iraqi. Yet, we read that the true number of Iraqi who have died since the invasion is closer to 600,000. That would be four times as many. Okay, so probably the daily deaths are underreported and, in reality, the number of Iraqi dying a violent death every day is closer to 400. So now, we have 600,000 dead Iraqi in 4 years, i.e., 150,000 dead Iraqi per year. Iraq has a population of 27,000,000. This gives an annual excess death rate of 0.56%.

In order to get an annual excess death rate of 3% or "better," we would need, on a global scale, a situation that is worse than that of current-day Iraq by a factor of six, and we would need to maintain these conditions for 50 years in a row.

Let us look at world population statistics of the 20th century:




What happened during WW-I and WW-II? In spite of the horrors of these wars, the world population kept growing. All of the horrors of these wars didn't even make a dent.

What about the Spanish flu of 1918? We don't know exactly, how many people died from that flu, but according to our best estimates, roughly 50,000,000 people died from the flu during the winter of 1918. This corresponds to 2.5% of the world population. So for once we came close to our “target” of 3%, and yet, there wasn’t even a dent left in the curve because we didn’t keep at it for sufficiently long.

Even Adolf Eichmann had to learn that killing millions of people and getting rid of their corpses is very hard work. Reducing our population from 7 billion to 1 billion in 75 years, that’s hell come to Earth.

## How Can The Collapse Be Avoided?

There is an old proverb: when you are already in a hole, stop digging. We have documented that we are already consuming an ecological footprint larger than that provided by planet Earth in a sustainable fashion. Thus, increasing our population further can only hurt us.

In order to avoid the collapse, we need to get out of the exponential growth pattern as fast as we can. We ought to behave as if fossil fuels had already become essentially unavailable, using this precious commodity only for purposes where they are absolutely essential and to help us create a sustainable energy infrastructure for the future.

Such an approach will immediately make us poorer. It will be uncomfortable; but remember, this will happen sooner or later anyway, whether we like it or not, and the longer we continue in our current exponential growth pattern, the more painful the subsequent adjustment will be.

By accepting the transition now, we will make it much easier, because as of now the fossil fuels are still available to help us cheat. Where a hard transition is too painful, we can make it a soft transition. Where fossil fuels can help us create better living conditions for the future, we can still use them. Finally, by weaning us off our addiction voluntarily now, we prolong the availability of the remaining resources substantially.

It is a bitter medicine, no doubt.
Can we understand its necessity? You bet!
Will it happen? I see no inkling of it.

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A Powerpoint presentation of mine about these and related issues can be found at the web address http://www.inf.ethz.ch/~fcellier/Pres/AGS_07.ppt