population matters for a sustainable future

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We cannot come to terms with the fact that as a species we have gone beyond the ability of the planet to accommodate us. We have bred ourselves beyond the limits. We have consumed, polluted, and expanded beyond our means, and after centuries of superficial technological solutions we are now running short of answers. Biologists explain such expansion in terms of “carrying capacity”: lemmings and snowshoe hares — and a great many other species — have the same problem; overpopulation and overconsumption lead to die-off. But humans cannot come to terms with the concept. It goes against the grain of all our religious and philosophical beliefs.

The Coming Chaos by Peter Goodchild, 2010

Unfortunately, common expectations of energy futures — shared not only by poorly informed enthusiasts and careless politicians but, inexplicably, by too many uncritical professionals — have been, for decades, resembling more science fiction than unbiased engineering, economic, and environmental appraisals.

Vaclav Smil, *Energy Transitions*, p148, 2010.

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<http://tinyurl.com/optj2>

INTRODUCTION

In the April 2010 issue of this journal (volume 10/1), comprehensive extracts were given from Clive Ponting's and David Montgomery's books concerning the fact that soil is the foundation of civilizations, and that over centuries many civilizations have collapsed due to destroying those foundations. David Pimentel's warnings on the subject go back even further. Chapter 15 of David and Marcia Pimentel's book *Food, Energy, and Society* is titled *Soil Erosion: A Food and Environmental Threat* (the first edition was in 1979). Extracts from the first half of this important chapter are on pages 4–6.

Pages 7-13 contain an overview from a Canadian, Paul Chefurka, of the energy and climate change problems that are a recurring theme in the pages of the OPT Journal. His final thoughts — on the fact that most humans are hard-wired to choose short term benefits rather than make sacrifices for the benefit of future generations — are reflected in the first quotation on the title page, taken from Peter Goodchild, another acute thinker on these matters. This thought that humans are hard-wired to be unable to act with foresight must be some consolation to that rather small fraction of humans who do concern themselves about future generations, yet who see that their efforts are little more effective than an all out effort to stop the tide coming in!

Renewable energy is a many faceted problem with inadequate empirical data to allow definite judgements. One man, Paul-Frederick Bach (http://pfbach.dk), stands out as a brilliant expositor of such lessons as it is possible to extract from the Danish and German experience of wind power and photovoltaics. Drawing from Bach and other sources, pages 14-17 comprise two short pieces looking at various aspects of the wind turbine problem. Recently, Bach has indicated that he is hopeful for one possibility of solving the problems that would arise were the energy that Denmark generates from wind to amount 50% of its electrical energy consumption. The 'solution' would arise from using the excess electrical input to heat water. Bach describes it as an 'integration of heat and electricity production'. At this stage, it can only be said that we should be grateful to the Danes for exploring this possibility. But even if it turns out to be acceptable to use 50% wind power, the Danish experience will not be directly transferable to other nations which do not have Norwegian and Swedish hydropower to use for balancing. Also note that the other 50% would still need to come from a controllable energy source, which at present is fossil fuels. So that would not solve the longer term problem arising from scarcity of fossil fuels. The second of the short pieces looks at why an oft-mooted 'solution' to relying entirely on renewables, namely storing excess electricity in hydrogen, is likely to run into practical difficulties.

The next article has a long history. I wrote one draft of it back in the 1990s. I recall that David Willey, founder of the Optimum Population Trust, thought I should publish it within our organization. However, I rather wanted to have a longer perspective on what would actually happen in China, because I thought that then it would provide an even better salutary lesson to the West about the freedom of action that is lost when population gets out of balance with natural resources.

As it has turned out, what has happened in China is something that neither Smil nor I envisaged, namely that there would be an explosion of manufacturing in China, and that China would have the cash available to buy energy rights, food, and even arable land from other nations. The lesson from China is therefore more diffuse, and needs to take into account that Europe and America cannot also buy up biocapacity from other nations

Vaclav Smil and Paul Chefurka are arguing that lifestyles and population sizes are eventually determined by natural resources, or, as Walter Youngquist puts it in his book *GeoDestinies*, "Earth's resources exercise inevitable control over nations and individuals."

A well researched article by Chris Clugston, January 2013, provides further evidence for that proposition, which is reason enough to include an extract in this introduction:

> By 2008, immediately prior to the Great Recession [2009-2012], global NNR [Non-renewable Natural Resource] scarcity had become epidemic. Sixty three (63) of the 89 NNRs that enable our modern industrial existence — including aluminium, chromium, coal, copper, gypsum, iron/steel, magnesium, manganese, molybdenum, natural gas, oil, phosphate rock, potash, rare earth minerals, titanium, tungsten, uranium, vanadium, and zinc — were scarce globally.
>
> During the mid/late 20th century (1960-1999), a barrel of oil cost $19 on average; during the years prior to the Great Recession (2000-2008), the average price of a barrel of oil had increased to $47; and during the years immediately following the Great Recession (2009-2012), the average price of a barrel of oil had further increased to $75.
>
> During the same three time periods, the average price of a metric ton of copper increased from $3,085, to $3,715, to $6,281; the average price of a metric ton of iron ore increased from $36, to $57, to $113; and the average price of a metric ton of potash increased from $114, to $185, to $401. (All prices are adjusted for inflation.)
>
> The simple fact is that we cannot grow our global economy and improve our global material living standards on $75 oil, $6,281 copper, $113 iron ore, and $401 potash like we did on $19 oil, $3,085 copper, $36 iron ore, and $114 potash.

The main point of course is that the divergence between demand and supply has already started. Almost inevitably it will get worse.

Eric Rimmer brought the work of Paul Chefurka and the Chris Clugston piece to my attention, and Ted Trainer gave me the lead to Paul-Frederick Bach. David Pimentel as always has been helpful to my endeavours, and I have Yvette Willey to thank for her careful proof reading. Matthew Nayler was the stimulus for an exchange of thoughts on Thomas Malthus, leading to the final one-page piece in this journal.

All internet addresses given in previous OPT Journals as pointers to the availability of these journals on the internet are now superseded. The webpage to access all OPT Journals, current ones and previous ones, is now: http://tinyurl.com/optj2

When David Willey founded the Optimum Population Trust (OPT) in 1991, he set out the two main aims of the OPT as:

- To promote and co-ordinate research into criteria that will allow the optimum population of a region to be determined.
- To increase awareness, particularly among those who influence opinion, of the results of this research.

The OPT Journal, which started publication in 2001, has remained focused on these aims. However OPT spread its aims to cover wider matters. To reflect this, the ‘working name’ of the organization has been changed to *Population Matters*. The OPT Journal retains its name, in part because it has now become a familiar name amongst its readers, and in part because it remains the best description of what the journal is about. The website of Population Matters is to be found at www.populationmatters.org

FOOD, ENERGY, AND SOCIETY (3rd edition), Part 9

by David Pimentel and Marcia H. Pimentel, compiled by Andrew Ferguson

Chapter 15. Soil Erosion: A Food and Environmental Threat

201.2 The loss of soil from land surfaces by erosion is widespread globally and adversely affects the productivity of all natural ecosystems as well as agricultural, forest, and rangeland ecosystems. Concurrent with the escalating human population, soil erosion, water availability, energy, and loss of biodiversity rank as the prime environmental problems throughout the world.

201.5 The changes inflicted on soils by human-induced erosion over many years are significant and have resulted in valuable land becoming unproductive and often eventually abandoned. Simply put, soil erosion diminishes soil quality and thereby reduces the productivity of natural, agricultural, and forest ecosystems. In addition, the valuable diversity of plants, animals, and microbes in the soil is damaged.

In this study, the diverse factors that cause soil erosion are evaluated. The extent of damage associated with soil erosion is analysed, with emphasis on the impact these may have on future human food security as well as the natural environment.

CAUSES OF EROSION

201.7 Erosion occurs when soil is left exposed to rain or wind energy. Raindrops hit exposed soil with great energy and easily dislodge the soil particles from the surface. In this way, raindrops remove a thin film of soil from the land surface and create what is termed *sheet* erosion. This erosion is the dominant form of soil degradation. The impact of soil erosion is intensified on sloping land, where the surface soil is carried away as the water splashes downhill into valleys and waterways.

Wind energy also has great power to dislodge surface soil particles, and transport them great distances. A dramatic example of this was the wind erosion in Kansas during the winter of 1995–1996, when it was relatively dry and windy. Then approximately 65 t/ha was eroded from this valuable cropland during one winter. Wind energy is strong enough to propel soil particles thousand of miles. This is illustrated in the photograph by NASA which shows a cloud of soil being blown from the African Continent to the South and North American continents.

THE ROLE OF VEGETATIVE COVER

203.2 Land areas covered by plant biomass, living or dead, are more protected and experience relatively little soil erosion because raindrop and wind energy are dissipated by the biomass layer and the topsoil is held by the biomass. For example, in Utah and Montana, as the amount of ground cover decreased from 100% to less than 1%, erosion rates increased approximately 200 times.

In forested areas, a minimum of 60% forest cover is necessary to prevent serious soil erosion and landslides. The extensive removal of forests for crops and pastures is followed by extensive soil erosion.

Loss of soil vegetative cover is especially widespread in developing countries where populations are large, and agricultural practices are often inadequate to protect topsoils. In addition, cooking and heating there frequently depends on the burning of harvested crop residues for fuel. For example, about 60% of crop residues in China and 90% in Bangladesh routinely are stripped from the land and burned for fuel. In areas where fuel wood and other biomass are scarce, even the roots of grasses are collected and burned.

ASSESSING SOIL EROSION

204.8 Myers (1993) reports that approximately 75 billion tons of fertile soil are lost from world agricultural systems each year, with much less erosion occurring in natural ecosystems. In fact, the 75 billion tons is probably a conservative value. Soil scientists Lal and Stewart (1990) and Wen (1997) report 6.6 billion tons of soil per year are lost in India and 5.5 billion tons are lost annually in China. Considering these two countries together occupy only 13% of the world's total land area, the estimated 75 billion tons of soil lost per year worldwide is conservative. The amount of soil lost in the United States is estimated to be about 3 billion tons per year.

LOSS OF PRODUCTIVITY IN MANAGED ECOSYSTEMS

Approximately 50% of the earth's land surface is devoted to agriculture; of this about one-third is used for crops and two-thirds as grazing lands. Forests occupy about 20% of the land area. Of these two areas, cropland is more susceptible to erosion because of frequent cultivation of the soils and the vegetation is often removed before crops are planted. This practice exposes the soil to wind and rain energy. In addition, cropland is often left without vegetation between plantings. This practice intensifies erosion on agricultural land, which is estimated to be 75 times greater than erosion in natural forest areas.

WORLDWIDE CROPLAND

205.2 Currently, about 80% of the world's agricultural land suffers moderate to severe erosion, while 10% experiences slight erosion. Worldwide, erosion on cropland averages about 30 t/ha/year and ranges from 0.5 to 400 t/ha/year. As a result of soil erosion, during the last 40 years about 30% of the world's arable land has become unproductive and much of that has been abandoned for agricultural use.

The nearly 1.5 billion ha of world arable land now under cultivation for crop production are almost equal in area to the amount of arable land (2 billion ha) that has been abandoned by humans since farming began. Such land, once biologically and economically productive, now not only produces little biomass but also has lost considerable diversity of the plants, animals, and microbes that it once supported.

U.S. CROPLAND

205.9 The lowest erosion rates on cropland occur in the United States and Europe where they average about 10 t/ha/year. However, these low rates of erosion greatly exceed the average rate of natural soil formation from the parent material; under agricultural conditions that range from 0.5 to 1 t/ha/year.

206.1 Soil erosion is severe in some of the most productive agricultural ecosystems in the United States. For instance, one-half of the fertile topsoil of Iowa has been lost by erosion during the last 150 years of farming because of erosion. These high rates of erosion continue there at a rate of about 30 t/ha/year, because of the rolling typography and type of agriculture practiced. Similarly, 40% of the rich soil of the Palouse region in the northwestern United States has been lost during the past 100 years of cultivation. In both these regions, intensive agriculture is employed and mono-cultural plantings are common. Also, many of these fields are left unplanted during the late fall and winter months, further exposing the soil to erosion. Yearly in the United States, several thousand hectares of valuable cropland are abandoned because rain and wind erosion has made them unproductive.

The economic impact of soil erosion is significant. Uri (2001) estimates that soil erosion in the United States costs the nation about $37.6 billion each year in loss of productivity.

PASTURE AND RANGE LAND

206.5 In contrast to the average soil loss of 10 t/ha/year from U.S. cropland, U.S. pastures lose about 6 t/ha/year. However, erosion rates on pastures intensify wherever overgrazing is allowed to occur on the pastures. Even in the United States, about 75% of non-Federal lands require conservation treatments to improve grazing pressures. More than half of the rangelands, including those on non-Federal and Federal lands, are now overgrazed and have become subject to high erosion rates.

Although erosion rates on U.S. cropland have decreased during the past two decades, erosion rates on rangelands remain relatively high or about 6 t/ha/year. High erosion rates are typical on more than half of the world's rangelands. In many developing countries, heavy grazing by sheep and goats has removed most of the vegetative cover, exposing the soil to severe erosion. In Africa, about 80% of the pasture and rangeland areas are seriously eroded and degraded by soil erosion. The prime causes of this are overgrazing and the practice of removing crop residues for cooking fuel.

FOREST LAND

206.8 In stable forest ecosystems, where soil is protected by vegetation, erosion rates are relatively low, ranging from only 0.004 to 0.05 t/ha/year. Tree leaves and branches not only intercept and diminish rain and wind energy, but also cover the soil under the trees to further protect the soil. However, this changes dramatically when forests are cleared for crop production or pasture. For example, in Ecuador, the Ministry of Agriculture and Livestock reported that 84% of the soils in the hilly forested northeastern part of the country should never have been cleared for pastures because of the high vulnerability of the soils to erosion, their limited fertility, and the overall poor soil type that resulted.

[Soil is of fundamental importance, and there remains more from this Chapter 15 which must not be skipped over. The rest will be covered in the next issue of the OPT Journal.]

WORLD ENERGY AND POPULATION — TRENDS TO 2100 by Paul Chefurka

A review essay by Andrew Ferguson

Abstract. Paul Chefurka concludes that by the year 2100 the world could only support a population of about 1 billion people living a simple but perhaps still civilized lifestyle. His evidence that this is the number of people that could be supported in that lifestyle is basically sound, but it is argued in this review that more people besides — making the overall figure somewhat imponderable — are likely to be able to support themselves in a pre-industrial lifestyle, and continue to do so provided that the remaining forest resources are used sustainably. However, since Chefurka published this piece (2007), the perceived situation has changed. Unconventional oil and gas may extend fossil fuel energy for several decades, but — somewhat caused by that — hugely damaging climate change has become a virtual certainty. Chefurka not only updates us on the science, but makes the point — not made often enough — that there is nothing that "we" can do to stop it.

Only a few scientists have engaged in the task of relating the size of human population to the availability of *non-food* energy. Pre-eminent among them is David Pimentel, not only with the book *Food, Energy, and Society*, but also with other books that he has edited, and the many scientific papers he has published. However, the number of such scientists is sufficiently small that it is always pleasing to find another. Paul Chefurka's twenty-page paper is an impressive attempt to collect together energy data into a *World Energy and Population* Excel spreadsheet model, which is available to all on the internet. [1]

Of course the vital question with any model is whether the assumptions are valid. Chefurka makes it clear that he is doing his best to choose valid data. He writes, "For each component I will define as clearly as possible the factors and parameters I have considered in building its scenario. This will allow you to decide for yourself whether my assumptions seem plausible." In this review we will be taking an independent look at their plausibility.

The energy metric he uses is 'tonnes of oil equivalent per person per year' (toe/p/y). For most people tonnes of oil are harder to envisage than the units that most people are familiar with from paying their electricity and gas bills, namely kilowatt hours (kWh). A specific number of kWh used over a specific time can also be expressed as an average power in kilowatts (kW). All the conversions are simple : 1 toe/p/y = 1.33 kW/p, and 1.33 kW/p = 1.33 x 24 = 32 kWh per person per day (Current use in the UK is about 125 kWh/p/d, and in the USA 250 kWh/p/d). Readers may prefer to make mental conversions to provide a clearer picture in their minds, but I will keep to Chefurka's metric, as this will facilitate the task of readers who wish to look at his text and graphs alongside this review.

Although we will not dwell on the matter, it is useful to bear in mind that a kilowatt hour of electricity (kWhe) is — in today's world — more valuable than a kilowatt hour of primary energy in the form of natural gas or coal, for otherwise we would not be prepared to use gas and coal to produce electricity, as the conversion process entails losing about two-thirds of the energy. But although electricity is *more* valuable in today's world, it may not be so in a world in which electricity is the easiest renewable energy to produce, because in such circumstances we will use electricity not because it is better than say natural gas heating, but because we do not have the gas. Moreover, we may be forced to use electricity as a substitute for oil, even though electrical energy is lost in storage, and storing electricity is costly in money and energy terms. After defining a ‘tonne of oil equivalent’, Chefurka makes a brief reference to the above complication: “While this approach doesn’t take into account the varying efficiencies of different sources like oil and hydroelectricity, it does provide a well accepted standard for general comparison.”

In order to see the relevance of *non-food* energy to population, it is necessary to determine how much energy each person needs as a minimum. Chefurka draws on an analysis by Western Oregon University, to note that the *non-food* energy consumption of an “advanced agricultural man” from northern Europe in the 1400s was about 0.75 toe per year. It is interesting to set this in the context of our own oft-repeated estimate that civilization could continue in a satisfactory way with an *average* energy use of 2 kW/p = 1.5 toe/p/y. A doubling of the 0.75 toe/p/y would surely be necessary to preserve many of the things we take for granted in modern civilization, such as washing machines, vacuum cleaners, communication facilities, and especially education and health care. Thus the Western Oregon University study lends support to our estimate which is based largely on work by Vaclav Smil, of the need for 2 kW/p, or 1.5 toe per person per year, as an *average*. Prior to the introduction of electricity and railways, *non-food* energy consumption per person in the USA has been estimated at 3.7 kW, or 2.8 toe/y (Hayden, 2004, p.20), but parts of the USA get very cold in winter and the situation would be quite different close to the tropics.

Chefurka gives other data in order to put 0.75 toe/p/y in perspective:

> There is of course a great disparity in global energy consumption. The combined populations of China, India, Pakistan and Bangladesh (2.7 billion) today use an average of just 0.8 toe per person per year, compared to the global average of 1.7 and the American consumption of about 8.0.

We can take an overview of these data to say that the lifestyle of “ ‘advanced agricultural man’ from northern Europe in the 1400s” could be maintained with an average 0.75 toe per person per year (provided sufficient food could be grown), but an average of 1.5 toe/p/y is a likely minimum to maintain a satisfactory lifestyle, including maintaining educational and health facilities. We will henceforth refer to this as a ‘civilized lifestyle’.

The matter of the *non-food* energy that is necessary is of vital importance, so we have taken a look at that first, but now we must take a long look at Chefurka’s estimate of the energy that is likely to be available through the rest of the century.

Oil. At the time he was writing, 2007, Chefurka thought that there was already evidence that the peak of crude oil production had been reached. That has proved not to be quite accurate, but few of the experts expect the delay to reach much beyond 2030, so the error is not particularly significant.

Chefurka admits that the rate of decline after the peak is hard to forecast, but he argues persuasively that he is following the most reliable estimates available.

Natural gas. After covering in detail the difference between gas production and oil production — especially the more rapid decline of gas after the peak — Chefurka settles for this gas profile: “A plateau from 2025 to 2030. This is followed by a rapid increase in decline to 8% per year by 2050, remaining at a constant 8% per year for the following 50 years.” Successful fracking in some parts of the world, particularly the USA, somewhat changes the picture but probably not very significantly in the worldwide context.

Coal. In August 2012, Robert Bryce, author of *Power Hungry* (reviewed in OPJ 12/2 pp.23-28), wrote in a newspaper Commentary that, “Over the last decade, global coal consumption has increased by more than the growth in oil, natural gas and hydro and nuclear power combined." In the face of that, and the fact that coal experts do not agree at all about coal resources, it is hard to predict a coal peak. Chefurka admits as much, and settles for a somewhat precautionary view based on the analysis of the Energy Watch Group. While nothing can be held as certain in this field, this does seem the best guesstimate available. In the OPT Journal 9/2, pp.13-17, we arrived at an almost identical result to Chefurka, who puts the coal peak at 2025. His model "has the annual decline in coal use increasing evenly from 0% in 2025 to a steady 5% annual decline in 2100."

Nuclear. Chefurka goes into considerable detail about his reasons for predicting the path of nuclear power generation, but the essence is well summed up in the legend to one graph:

> The drop in capacity between now and 2030 is the result of new construction not keeping pace with the rapid decommissioning of large numbers of old reactors. The rise after 2030 comes from my prediction that we will double the pace of reactor construction in about 2025 when the energy situation starts to become visibly desperate and we realize that most of the reactors from the 1970-1990 building boom are out of service. The final decline after 2060 comes from my expectation that we will start losing global industrial capacity in a big way in a few decades due to the decline in oil and natural gas. As a result, by 2060 we won't have the capability we would need to replace all our aging nuclear reactors.

A key discussion point from the above is the assertion, "The final decline after 2060 comes from my expectation that we will start losing global industrial capacity in a big way in a few decades due to the decline in oil and natural gas." This is also relevant to hydro and 'renewable energy'. It is something we will discuss later.

Hydro. Chefurka looks in detail at the restrictions to developing hydro. Oddly Chefurka does not mention the fact that dams have a limited life as they gradually silt up, but the more important points regarding the reasons for his projection are given an overview in the legend to his Figure 9:

> The model for hydro power shown in Figure 9 has capacity growing to about double its current level by 2060. It then declines back to the current level by 2100. The peak and subsequent decline in the second half of the century is attributed to the full occupancy of virtually all high-value hydro sites, a general loss of global industrial capacity and a reduction in water flows due to global warming.

Again we may note the important "general loss of global industrial capacity" which we will look at more fully in the next section.

Renewable Energy. Chefurka admits that when it comes to the multiple sources of renewable energy, "Assessing their probable contribution to the future energy mix is one of the more difficult balancing acts encountered in the construction of this model." Chefurka sets out many reasons for being both pessimistic and optimistic before choosing what he deems to be a balanced view. Let us consider the end result as shown in his Figure 12. Between 2010 and 2070 he shows production increasing from about 30 million tonnes of oil equivalent (Mtoe) per year to 480 Mtoe. That equates to an annual exponential growth rate, over the 60 years, of 4.7%. Many would argue that this is unduly pessimistic, especially in view of the fact that, as Chefurka observes, "Wind power, for example, has experienced annual growth rates of 30% over the last decade." At a rate of increase of only a third of that, 10% per year, it would take only 30 years to reach 480 Mtoe per year.

With this possible rate of expansion, it is crucial to decide whether Chefurka's judgement is correct when he asserts that, "we will start losing global industrial capacity in a big way in a few decades due to the decline in oil and natural gas," with the consequence that renewables expansion will cease after about 2070. We have frequently discussed in the pages of the OPT Journal that insuperable problems will probably arise in the high tech activities of building and installing and maintaining wind turbines and transmission lines, when we do not have 'cheap energy' available from fossil fuels. But we have not attempted to put figures on what the precise effect will be. Chefurka's estimate of the problems being insuperable by 2070 is sensible, but it should be recognized as being no more than a judgement.

What would, to our minds, be a firmer basis for restricting the contribution of renewables in 2100, based on current knowledge, is to start from Chefurka's Figure 13 which shows total energy use. By 2100 the energy available *without* renewables is about 1500 Mtoe/y. with a substantial part of that being contributed by nuclear and hydro. The *variable* input from wind (photovoltaics inputs are even more variable) restricts the contribution that 'uncontrollable' renewables can make to about a third of the total. By no means all 1500 Mtoe/y could be used to produce electricity with which to balance the variable inputs from renewables. However, if sufficient could be allocated to produce 1000 Mtoe/y of controllable electricity; then renewables could only add 500 Mtoe/y to that, which is close to the 400 Mtoe/y that Chefurka predicts for renewables in 2100. Thus what is shown in his Figure 13 as the final energy use in 2100, of around 1800 Mtoe, is likely to be at least in the ball park of what we can estimate on the basis of what we currently know about renewable technologies (other than biomass which we will discuss later).

Population based on non-food energy

The biggest flaw in Chefurka's paper appears to be when he estimates that by 2100 there will be a 40% reduction in biocapacity, and *that this will cause a 40% reduction in what the population would be due only to the limited amount of non-food energy*. But he is establishing carrying capacity *on the basis of non-food energy*, and a drop of 40% in biocapacity will not affect hydro, wind and solar energy. Moreover the decrease in population that he envisages being forced on society by lack of *non-food* energy should result in more land being left to reforest, thus providing *more* non-food energy.[2]

From Chefurka's estimate of energy availability, it looks at first that the population that could be supported at 1 toe/p/y in 2100 would be about 1.8 billion, but he then decreases this to about 1 billion based on a 40% reduction in biocapacity. This last is a dubious logical step. However, the difference is not particularly important. Moreover the estimates that he has established for future energy availability provide all we need to take a look at what populations could be supported according to varying standards. Chefurka recognizes that he is limiting the scope of his own commentary on 'varying standards' when he says, "It is reasonable to expect that a declining world energy supply would affect countries at opposite ends of the consumption spectrum quite differently. … [but] a rigorous analysis of these effects is beyond the scope of this paper."

Drawing again on our earlier datum from an analysis by Western Oregon University that the *non-food* energy consumption of an " 'advanced agricultural man' from northern Europe in the 1400s" was about 0.75 toe per year, we can deduce that a population of (1800 million / 0.75) = <u>2.4 billion</u> could be supported in this lifestyle. However, that eventuality does not seem a particularly likely *political* prospect for the following reasons.

We have noted that civilization could continue in a satisfactory way with an average energy use of 1.5 toe/p/y (2 kW/p). Those nations which have already achieved the satisfactions of health care and education will be unlikely to want to drop below an average of 1.5 toe/p/y if they can possibly avoid it. Thus a population of only 1800 / 1.5 = 1.2 billion could be supported in a civilized lifestyle. That appears to leave no *non-food* energy for any remaining population, but in reality it won't work out that way. In the absence of oil, and the transport it facilitates, richer nations — trying to maintain some aspects of civilization — will not be able to acquire fuel wood from every corner of the globe, and in warmer climes, fuel for cooking is the main need for *non-food* energy to sustain life. While Chefurka's estimate of the number of people that could be supported in a civilized lifestyle may be fairly near the mark, there is another flaw in his analysis, namely the important factor of energy from biomass, which he appears to omit. We will now turn to that.

Energy from biomass

There are nearly 4 billion hectares of forest in the world. If we anticipate that half of this will be left for wildlife, that still leaves 2 billion hectares available for the use of humans. But with a great scarcity of *non-food* energy there will be a considerable requirement for timber, so let us suppose that only a quarter of the total is available for energy, i.e. 1 billion hectares. The natural regeneration of forest occurs so as to produce, on average, about three dry tonnes of biomass per hectare per year. Three dry tonnes of wood has a calorific value such that it provides about 2 kW or 1.5 toe/y.[3] Thus 1 billion hectares would provide 1500 million toe per year. That is close to the 1800 million toe per year of *non-food* energy that is estimated by Chefurka. The difficulty is that without oil to power trucks, wood is not easily transported. Thus human life will only be supportable where there is not only cropland and pasture to provide food, but also forest nearby to provide *non-food* energy (omitting consideration of animal dung which is widely used as a form of *non-food* energy, but is also important for fertilizing the land). The number of places around the world where food is available as well as *non-food* energy is very hard to estimate, but it is clear that Chefurka's analysis of the size of population that could be supported at a uniform 1 toe/p/y is only a part of a reasonable approximation to what is likely to actually happen.

It could be argued that a large part of the aforementioned extra 1500 million toe/y could go to supporting greater use of renewables, such as wind turbines. However the wood needed to run power plants would have to be collected over such a wide area that it seems an unlikely proposition without the benefit of oil for transport. Moreover converting wood to electricity is particularly inefficient, even if the wood is left to dry for a couple of years.

The actual use of this biomass is the hardest thing to predict. On the basis of historical evidence it seems unlikely that humans will be wise enough to use it sustainably. Two millennia ago, Herodotus said that, "Man stalks across the landscape, and desert follows in his footsteps."[4]

The effects of climate change

While it may have been obvious for the last two decades to people who are not wilfully blind, it has only just been widely accepted that there is very little chance of stopping the increase in the amount of fossil fuel being burnt. This extract from *Nature*, 29 November 2012, is an example of that acceptance:

> Calculations suggest that emissions of CO_2 must stay below 1000 billion tonnes between 2000 and 2050 to give the world a 75% chance of containing the temperature rise to 2ºC. But emissions from fossil-fuel burning and deforestation since 2000 have already pumped more than 450 billion tonnes of CO_2 into the atmosphere. If the

> current trend continues, the 1000-billion-tonne margin will be surpassed in a little more than a decade.

Combining climate change with the energy problems he outlined in his 2007 paper, Chefurka, in early 2013, updated his assessment of our present situation. He deals with the nature of the dilemma we face, and the very important human factors which not only mean that 'we' cannot do anything significant about it, but that 'we' should not be blaming ourselves for what is essentially a hard-wired weakness in human nature:

> We face a choiceless choice. Without the energy provided by fossil fuels we can't maintain our existing population or the civilization that supports us. We need that much energy to support this level of organization and activity for this many people. Without fossil fuel we would have only 13% of the energy we currently enjoy - assuming we could even maintain industrial-scale hydro and nuclear power without oil or gas. Because of our intrinsic dependence on energy, our population would eventually, inevitably be reduced to the same extent — down to perhaps one billion people, similar to the world's population in the early 1800s. Because we are so invested in our 10,000 year old story of human exceptionalism, we will not make any choice that might result in such a decline.
>
> If we do *not* make that choice however, we will continue following our current climate trajectory as described by the IPCC's RCP8.5 and A1FI scenarios. That curve passes through a temperature increase of +6C or better by the end of the century. Mark Lynas' description of a +6C world makes it abundantly clear that such a rise is utterly incompatible with a large, complex, global industrial civilization — or the number of people it currently supports.
>
> The necessary sacrifice entails cutting *all* fossil fuel use within a couple of decades, and in the process reducing our energy supply to perhaps a tenth of what it now is. That reduction would entrain the premature deaths of billions before the end of the century. Who would make such a choice? Who would elect a democratic leader who promised it? What autocratic leader would even bother with it?
>
> I don't think either a middle road of gradualism or a 'World War IV' level of effort to build renewable energy supplies would help. Both would encounter significant political, economic and social roadblocks, and would take far too long. Not to mention that as long as we keep burning *any* significant amount of carbon the climate will end up where it's headed.
>
> I'm trying on a new idea right now — a new way of looking at the whole process we're going through. One of my biggest sources of angst eight years ago, as I tried to come to terms with the forces that have been unleashed, was the idea that it is our fault. That we broke it, so we have to fix it. That we broke it, so *I* have to fix it. Of course I can't fix anything this big, any more than I could fix a coming ice age. And for anybody who has looked deeply into the situation, it's just as obvious that *we* can't fix it either. We're too far down the road for the small changes of direction that are within our grasp to do much good. Our brains aren't wired appropriately even to recognize a problem like this in time, let alone do anything about it. It seems to me that this qualifies the event more as a natural catastrophe. Thinking of it as a 'man-made' disaster that is by definition under our control, that we are to blame, that we are at fault, that this occurrence is evidence of a failure of rationality that we 'should' have been able to avoid — all that seems (to me anyway) to miss the point.
>
> For me the point is that we are involved in an entirely natural set of events. Natural because man is in no way separate or different from nature, and to think of things we do as somehow artificial or unnatural is hubris. We have triggered a global shift, much

> the same way that an ibex pursuing a potential mate across a mountaintop may trigger a rockslide that becomes an avalanche. Shit happens. The arrow of time only flows one way (in this universe, anyway), so we deal with the outcome as best we can, and keep going as long as we can. It's what natural life always does.

Conclusion

Many people will continue to just hope that there will be a breakthrough in the production of renewable energy, but the responsible thing to do is to look at what is likely to happen *on the basis of what we already know*. Chefurka neatly brings together the facts to support the argument that by 2100 it may only be possible to support less than two billion people in something approaching a civilized lifestyle. The additional number that might continue their lives in warmer climes using *non-food* energy only for cooking, perhaps supported by oxen for agriculture, is difficult to assess, but in view of the possibility that about 1500 million toe/y might be available from biomass, the total population that could be supported in 2100 may be in the region of a *further* one or two billion, although without healthcare, any prediction remains no more than a guess. However, all these figures are so far below the present 7 billion that the essential message remains the same.

Although the extent to which climate change will change the opportunity for humans to exist is impossible to estimate, Chefurka recognizes that this may be as important a factor in bringing about a crash of human population as lack of energy.

This does not mean that humans cannot achieve anything useful in the population field, for as will be noted at the end of the review of *China's Environmental Crisis*, the decision of Chinese leaders to put limits on the number of children that are allowed will most likely end up by saving 800 million lives that would have ended in the misery of starvation.

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1. Chefurka's paper is dated 2007, and is available at http://www.paulchefurka.ca/WEAP/WEAP.html However, it should be said that the Excel spreadsheet which is the basis of the article is no longer in its original form and it currently provides data only up to 2050. On making enquiries, Eric Rimmer and I found that Chefurka has lost the complete spreadsheet.
2. The assertion that there will be more land made available per person by a falling population is perhaps controversial and deserves amplification. If numbers fell purely due to lack of an ability to produce enough food then a decreasing biocapacity would have a direct relation to falling population, but the falling population is more likely to occur through lack of transport, lack of suitable grain storage, lack of medical care, with malaria, tuberculosis and other diseases re-emerging, and a general breakdown in law and order, probably involving tribal fighting.
3. 1 tonne of dry wood has a calorific value of about 20 gigajoules, thus 3 dry tonnes per year provides about 60 gigajoules per year and that is close to $60 \times 10^9 / (31.54 \times 10^6) / 1000 = 1.9$ kW, or say 2 kW. 2 kW = 2 / 1.33 = 1.5 toe/y.
4. For this quotation I have Dave Foreman to thank. It appears in his book, written in 2011, *Man Swarm and the Killing of Wildlife.*

OPERATIONAL PROBLEMS WITH WIND TURBINES

by Andrew R.B. Ferguson

The website of Paul-Frederick Bach — at http://pfbach.dk — is a mine of information regarding not only Denmark, but also about several nations which generate electricity via photovoltaics and wind power. One problem with his website is that it contains so much information it is hard to get to the essence, but these are the key points as I see them.

Denmark exports electricity to the extent of 31% of the electricity that it generates from wind, and Bach shows that there is a close correlation between exports and wind generation. However, those who wish to put this in a favourable light say that Denmark generates a fair amount of its electricity from coal-fired power stations, and in order to accommodate high inputs from wind turbines, as it has the option of exporting excess electricity to Norway (and adjacent nations), it finds it better to take this option instead of reducing the power output of its coal-fired power stations. One weakness in this argument is that hydro electricity is about the cheapest available, so it is likely to be selling its excess output to Norway at a loss. However, there is some validity in this explanation, and all that can be definitely concluded is that because Denmark has this special export facility, Denmark's experience does not prove that countries without its special facility could get to the same level of wind penetration as Denmark has achieved, namely about 20% to 25%. Note, too, that although Manfred Lenzen (2009) puts the penetration at which one starts to get difficulties at 20%, I usually put the upper limit at 30%, anticipating some improvements, such as a greater proportion of wind coming from *offshore* wind turbines, which, Bach shows for Denmark achieve a good capacity factor (45%) for wind turbines.

There is another important point of uncertainty. I did not note Bach attempting to deal with it, but it is important so let us look at it. Consider the case of wind turbines in Denmark generating 25% of the total electricity demand. If this did not result in any increase in exports, then 25% less electricity would need to be generated from fossil fuels. But this does not imply that 25% less fossil fuels would be used in Denmark. The best gas power stations are currently 49% efficient when producing a steady output of electricity. Open cycle gas turbines are far less efficient, and efficiency cannot be maintained without a steady production of electricity, and a steady production is certainly not possible when having to accommodate a significant amount of input from wind turbines (as Denmark's unwillingness to cut back even its coal-fired power stations illustrates).

Let us suppose, for example, that currently Denmark's fossil fuel plant is, on average, 40% efficient. A 25% reduction in that efficiency would result in a power plant efficiency of 30%. To produce 100% of a given amount of electricity at 40% efficiency would require 100 / 0.4 = 250 units of fossil fuel. And to produce (100% - 25%), i.e. 75% of electricity at 30% efficiency would require the same amount of fossil fuel, i.e. 75 / 0.30 = 250 units of fossil fuel. So no fossil fuel would be saved; but establishing the data is likely to be almost impossible. It takes a long time to install sufficient wind turbines to produce 25% of the total electricity demand, and during that time there will be huge changes in the rest of the electricity system, including changes to using more CHP and updating older gas power plants. Thus the detrimental effect on the efficiency of the fossil fuel plant is almost impossible to establish, but the above illustrative figures show that it could even go so far as cancelling out the hoped for benefit of installing wind turbines.

The impact of Germany's wind turbines on adjacent nations

The point has often been made in the pages of this journal that the price that wind turbine operators need to be paid to make a profit is a poor indication of the true cost of electricity from wind turbines, because their erratic output (as well as the need for back-up when there is no wind) causes further costs. Evidence for this was brought out by an article in *Die Welt* by Daniel Wetzel, 28 December 2012, under the heading, "Poland and Czech republic ban Germany's green energy." The key paragraph reads: .

> Germany considers itself the environmental conscience of the world: with its nuclear phase-out and its green energy transition, the German government wanted to give the world a model to follow. Blinded by its own halo, however, Germany overlooked that others have to pay for this green image boost and are suffering as a result. Germany's 'eco-miracle' simply used the power grids of neighbouring countries not only without asking for permission but also without paying for it. Now Poland and the Czech Republic have pulled the plug and are building a huge switch-off at their borders to block the uninvited import of green energy from Germany which is destabilizing their grids and is thus risking blackouts.

The maintenance of wind turbines and a possible limit to producing them

A report commissioned by the Renewable Energy Foundation, published in Dec 2012 by Professor Gordon Hughes, an economist at Edinburgh University and a former energy adviser to the World Bank, makes surprising reading. Indeed Hughes said his analysis had uncovered something that was not even known to the industry. His report was sent to an independent statistician at University College London who confirmed its findings.

Professor Hughes examined, in the UK, the output of 282 wind farms, about 3000 turbines in total, and in Denmark, a further 823 onshore wind farms and 30 offshore wind farms. The key finding is that the capacity factor was reduced from 24% in the first 12 months of operation to just 11% after 15 years.

Based on a study of Danish wind farms, the decline in the output of *offshore* wind farms appears even more dramatic. The capacity factor for turbines built on platforms in the sea reduced from 39 per cent to 15 per cent after 10 years.

The report noted that, "larger wind farms have systematically worse performance than smaller wind farms."

The study also looked at onshore turbines in Denmark and discovered that their decline was much less dramatic even though its wind farms tended to be older. Prof Hughes said that may be due to Danish turbines being smaller than British ones and possibly better maintained, but also that "British turbines have got bigger and wind farms have got bigger and they are creating turbulence which puts more stress on them. … It is this stress that causes the breakdowns and maintenance requirements that is underlying the problem in performance that I have been seeing."

The report does not look into all the reasons for this loss of performance. One other problem with wind turbines may be at the root of it. It is a problem which may put an upper limit on constructing wind turbines. As reported in *New Scientist* 27 October 2012, a turbine with a one megawatt capacity requires two-thirds of a tonne of the rare earth metal neodymium. Neodymium magnets are hugely powerful, but they have one disadvantage: unless they contain a few percent of another rare earth metal, dysprosium, then, when above room temperature, they start losing their magnetism. Currently dysprosium is only available from China, and it is using nearly all it has for its own construction purposes.

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[*Clean Slate* is a magazine produced by the Centre for Alternative Technology in Wales. This article was sent to the organization by way of comment, but it usefully continues from the previous article.]

CONTROLLABLE ELECTRICITY FROM RENEWABLE SOURCES

by Andrew R.B. Ferguson

In issue 84, Winter 2012, of *Clean Slate*, it was pleasing to see Tobi Kellner's two articles on renewable energy, for both were addressing matters of fundamental importance. They were titled *The Right Kind of Power Station* and *Modelling a Future Energy system*. The weak point in his analysis was the lack of a quantitative examination of the efficiencies of the various processes involved.

Without researching all the latest data on these matters, it is easy to demonstrate how important it is to be quantitative about efficiency. In a 184 page paper, Manfred Lenzen (2009) stated that to satisfy the "requirements for supply-load balance and grid stability, the maximum economic potential appears to be in the order of 20% of electricity consumption. At such rates of wind energy penetration, and without storage and supply-matched demand, the integration of wind power into electricity grids and long-distance transmission begins to present significant challenges for system reliability and loss-of-load expectation."

Measures to smooth demand might increase this somewhat. So for the sake of the present analysis we can take, as an example, an upper limit of wind penetration of 30%, leaving 70% to come from controllable inputs. Kellner's articles suggest that these controllable inputs might come from biomass, biogas or hydrogen. The UK cannot even support itself with food, and it imports much of the wood it uses, so it is a mistake to think that burning biomass in power stations can make a significant contribution to electrical supply. There is some prospect for increasing the use of biogas (generated from waste), but the scope is limited when placed within the context of needing to provide 70% of the UK's electrical energy demand. Thus the main burden of the task falls on wind turbines producing hydrogen. For this simple overview, let us assume that 10% can be satisfied from biogas, leaving 60% of electrical energy demand to be supplied from hydrogen (generated via wind turbines).

The efficiency of electrolysis — the means by which hydrogen is produced from water — is about 71% (Pimentel and Pimentel, 2008, p266). The hydrogen gas needs to be compressed to very high pressures for storage.[1] Although I have no precise data on this, a 15% loss (85% efficiency) is probably about right. The compressed hydrogen then needs to be converted back to electricity. Converting hydrogen into direct current electricity using a fuel cell is about 40% efficient (Pimentel and Pimentel, 2008, p267). Cost would likely prohibit the use of fuel cells in this context, but we need not concern ourselves with fuel cells. The most efficient combined-cycle natural-gas turbines are very nearly 50% efficient, when they are being run continuously. To follow large changes in demand, combined-cycle gas turbines will have to be used less efficiently, or open-cycle gas turbines might have to be used to some extent. With significant wind penetration, the problems of changes in consumer demand will be exacerbated by uncontrollable (and less predictable) changes in inputs of wind-generated electricity. Thus it would probably be optimistic to assume that gas turbines (using hydrogen) could in practice be run at an efficiency of 45%. Nevertheless for the sake of this example, it will suffice to make that assumption. The overall efficiency then calculates as 0.71 x 0.85 x 0.45 = 27%

Now let us consider producing, for example, 100 megawatt hours (MWh) of electricity, using the combination just discussed.

30 MWh can come directly from the wind turbines.

10 MWh can come from biogas.

60 MWh can come from wind turbines via hydrogen storage, but this will require that the wind turbines produce 60 / 0.27 = 222 MWh of electricity.

Thus to produce 30 + 60 = 90 MWh of electricity from wind turbines, requires the production of 30 + 222 = 252 MWh of electricity. So the wind turbines need to generate 252 / 90 = 2.8 times what would be required if all the electrical output from the wind turbines could be supplied directly.

In producing that 222 MWh of electricity, there are several costs additional to building and installing the wind turbines, namely the cost of the plant used for electrolysis, the compressors, the containers for storing hydrogen under pressure, and the gas turbines needed to regenerate the electricity. These costs are all additional to the cost of the transmission lines needed to take the wind-generated electricity to the electrolysers and thence to the consumers.

The above calculations are illustrative. The important point is that any analysis, such as that suggested in the second article *Modelling a Future Energy system*, will only be valid if it takes account of the efficiencies of these various conversions, and then looks at the cost of the total system, to see if such costs are likely to be feasible in a renewable energy future. It is important to bear in mind that if — as seems obvious — the costs considerably exceed the cost of generating electricity from fossil fuels, then almost everything will go up in price. It will not only increase the costs of the materials and energy needed to produce energy producing plant, but everything will be involved. For example, it will be more expensive to light and heat shops, to deliver food, and to mine and deliver construction materials. To put it another way, everyone will be poorer, including the government. Expensive electricity will therefore be more difficult for us to pay for than it is today. Peering into a renewable energy future is difficult for many reasons, not least because of these ‘feedback’ factors.

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1. The energy density of diesel fuel is nearly 3300 times that of hydrogen gas at ambient pressure, and the energy density of hydrogen gas is about 28% of the energy density of natural gas.

CHINA'S ENVIRONMENTAL CRISIS: AN ENQUIRY INTO THE LIMITS OF NATIONAL DEVELOPMENT, by Vaclav Smil (published in 1993)

A review essay by Andrew Ferguson

This review essay was written in 1994. I recall our founder, David Willey, advising me to publish it (within the Optimum Population Trust). However, I came to feel that it would benefit from a longer perspective. Now, twenty years after Vaclav Smil's book was published, we have some perspective. Smil's chief areas of expertise are energy and China.

The title I gave the review essay was *What China can teach the West*. I sent the essay to Vaclav Smil for comment. Smil graciously gave his approval of my précis, saying that it does not distort his message, but he suggested that China had nothing to teach the West with respect to population growth. I must not have made myself sufficiently clear, because my intention in choosing that title was to point out that the West must try to avoid getting itself into an overpopulation situation as serious as China's. The text below is largely unchanged from my 1994 draft, but I have made a few updates, and added one page of additional comment at the end.

Jung Chang's acclaimed *Wild Swans* — the story of her family through three generations; Channel Four's *Beyond the Clouds* — Phil Agland's magical portrait of family life in China; the Channel Four documentary, *China in Revolution*; and BBC 2's three part series, *The Giant Awakes*, are all indications of a growing Western interest in China. And this is as it should be; for apart from the temporary insanity of the Cultural Revolution, China is a country with an intellectual and cultural history which the West can respect and should be able to learn from. Anyhow a country with a fifth of the world's population deserves attention. Few books could help us better to learn from China than Vaclav Smil's, *China's Environmental Crisis: An Enquiry into the Limits of National Development*; it combines a sympathetic respect for Chinese culture with encyclopaedic scientific knowledge.

As I had been waiting for three months for Smil's book to come from the library, and as it arrived with a requirement to return it rapidly, being a "Heavily Requested Item", it seems that Western interest in China is indeed deep. However, the main text of the book must contain a thousand facts, and the 518 end-notes another thousand, so without meaning any disrespect to it, and without undervaluing its informative diagrams, I suggest that there may be those who would be pleased to share its messages with me via keynote extracts from the book. Note that 1 Mha, or million hectares is equal to 10,000 km^2, and it may be helpful to know that the United Kingdom occupies about 24 Mha. Quotations from the book can be recognized easily, since the relevant page numbers are given; they are taken from the edition published by M. E. Sharpe, Armonk, New York, 1993, The Chapter headings appear below in capitals.

Smil starts off by positioning himself as one who takes a balanced view. In the process he derides Dr Paul Ehrlich's *The Population Bomb*, as being an example of the work of a "catastrophist"; at the same time he derides Julian Simon as being a "cornucopian". Derision of Julian Simon's unlimited population expansion view is certainly justified, but perhaps Smil could be more generous in his assessment of Ehrlich. He quotes Ehrlich, writing in 1968, as follows: "The battle to feed all humanity is over. In the 1970s and 1980s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now." Instead of criticising this, one could acknowledge that a plausible case can be made out for it being true: for it is a plausible estimate that 40 million people are dying world-wide each year, from starvation or diseases related to undernourishment. Over a decade that amounts to 400 million. However, whether it is fair to call Ehrlich a catastrophist is not important; the point is that Smil himself leans over backwards to take a ‘balanced view’. His favourite adjective to describe looming disaster is ‘worrisome’. I hope that my selection of quotations from Smil are equally balanced, although there is some imbalance in that I do incline towards those matters which have relevance to the Western world.

CHINA’S ENVIRONMENT

During the demonstrations which took place in Tiananmen square, in 1989, our media seemed to accept the narrow-minded view that if the demonstrations were pro-democracy, then they must be worthy of our support. Wisely, Smil was thinking in broader terms, as he makes clear, by quoting what he wrote a few weeks after the massacre:

p. xviii There can be little doubt that, in the coming years, the particulars of sociopolitical arrangements will be less important in determining China’s fate than the country’s treatment of its badly deteriorating environment. Of course, one can hope for the eventual transition from one-party dictatorship to genuine democracy — but this evolution may bring little relief to China’s environmental ills.

p. xix To me, the country’s future is obviously circumscribed both by its inherent environmental limitations and by the environmental consequences of its bold, belated quest for modernity. This book presents an extended, but obviously far from exhaustive, set of analyses and arguments illustrating this critical reality.

PEOPLE’S MOUTHS

p. 3 Is the astonishing rate of population growth during the past five generations — tripling the global total in less than a century, from 1.7 billion in 1900 to more than 5 billion in 1990 — the principal source of massive destitution afflicting at least three-quarters of mankind?

p. 4 By 1990 China... could rely on less than one-tenth of a hectare per capita for its food. [i.e. 1,000 m^2]

p. 10 The list of major worries is led by gradual degradation — wind and water erosion, decline of nutrient content and organic matter in agricultural soils, salinization and alkalization of irrigated farmland, overdrawing of groundwater, deforestation and desertification — leading to a progressive reduction or a complete loss of invaluable environmental services...

Advanced stages of degradative processes — be it excessive soil erosion, extensive forest clearcutting, or severe desertification — have no satisfactory technical solutions capable of restoring the damaged ecosystems. There is no shortage of remedial management methods... but these measures can bring notable improvements only after decades of sustained application.

p. 11 Those Chinese who have looked closely at the links among population growth, material well-being, and environmental quality have no doubts... that of the three major crises that mankind faces today — population growth, depletion of natural resources, and degradation of environment — the first “is the most serious one, and is the root of the others.”

Mao Zedong’s early thoughts about population were clear. In 1949, at the founding of the People’s Republic, when China had 540 million people, he said:

p. 14 It is a very good thing that China has a big population. Even if China’s population multiplies many times, she is fully capable of finding a solution; the solution is production.

The greatest famine in human history, during 1958-61, which killed about 30 million, must have been a cause for him to somewhat revised that notion.

p. 22 The one-child campaign started in January 1979, and its effectiveness rested on a combination of rewards and penalties. ... After a decade of vigorous, successful, but still relatively lenient birth controls, China thus entered the 1980s with the world’s most comprehensive population control program designed to reduce the fertility in a way unprecedented both for its sweep and for its coercive nature.

p. 27 In April 1984, after roughly five years of the one-child program, the party’s Central Committee issued revised population control guidelines that were more realistic, and hence easier to implement and to accept. ... Individual provinces have subsequently expanded the number of conditions permitting second births, and by 1986 Greenhalgh was able to identify more than a dozen reasons for such ‘openings’.

p. 29 Bringing the rules closer to the limits of realistic expectations should make for better long-term compliance, but it meant the open abandonment of the 1.2 billion goal for the year 2000.

China’s population growth path provides a useful example of the problem of inertia that follows a period of rapid population growth. The Population Reference Bureau put the 2012 population of China as 1.35 billion, and despite a fertility rate of 1.5, well below replacement, the demographers estimate further growth to 1.4 billion by 2025. Only in 2050, do they expect the population to drop below their 2012 figure of 1.35 billion — to 1.3 billion.

EXISTENTIAL NECESSITIES

p. 43 [regarding Beijing] In the 1950s the water table was in places just five meters below the surface, but today the city’s more than forty thousand wells draw water from depths around 50 m. During the 1980s the annual drop during the driest years surpassed 2 m, and the surface subsidence extended over more than 1,000 km^2. ... Surface subsidence resulting from excessive underground water pumping now affects virtually every major Northern city. ... There are also cases of major subsidence in urban areas in the much rainier East: Changzhou in Jiangsi, Ningbo in Zhejiang, and Shanghai, some of whose parts have sunk by up to 2.6 m since 1965 and 1.8 m during the 1980s.

p. 47 One quarter of Shanxi’s irrigated fields cannot be guaranteed water during the vegetation period; about 10 percent of the province’s peasants have chronic shortages of drinking water; and overpumping of ground water has caused water table drops of over 70 m in the Yuncheng basin in the Southwest.

p. 48 Compared to huge volumes of water used in irrigation, household water supplies for the rural population are almost negligible, but the extension of an adequate and safe water supply to most of China’s population remains a distant goal. ... By 1990 about one-fourth of rural population had access to tap water, although only a fraction of this population had the water actually piped into their homes.

Even during the years of normal precipitation, at least fifty million people in China’s rural areas have to live with extreme scarcity of even drinking water, necessitating long trips to the nearest water source and minuscule per capita availabilities.

p. 49 During most years, water shortages and drought will be the country's most extensive environmental stress affecting commonly one-tenth of the densely inhabited territory.

p. 50 In spite of the absence of flooding for nearly half a century, potentially the most dangerous situation is along the lower course of the Huang He in Henan and Shangdong. … With higher erosion on the Loess Plateau, the ... average river bed rise has been 1 m a decade. [Smil tells us that 274,000 km^2 of the Plateau lose topsoil at a rate of 2 cms a year] The latest Chinese estimates are that a breach south of Hinan (in the most vulnerable area) would flood up to 33,000 km^2 affecting eighteen million people and cutting all north-south railways and highways. ... An estimate by the Shandong Institute of Oceanography illustrates the enormity of the control problem; some 700 million m^3 of silt would have to be dredged from the river's estuary to eliminate the need for further dike elevation and reinforcement.

p. 57 A surge of construction in the 1980s increased the loss attributable to settlements, industries and transport to at least 34 Mha during 1957-90, and the total loss has most likely surpassed 40 Mha. ... Given the early 1990s productivity [of food] and given that the actual cultivated area is around 120 Mha, ... the loss of 40 Mha is equivalent to losing a food production base capable of supporting some 370 million people!

p. 60 New plantings made an important difference in slowing down the depletion rate of China's mature forests and in providing timber and fuelwood for local consumption. ... But, so far, they have not been able to reverse deforestation and concomitant erosion losses in China's mountainous regions, or to change fundamentally China's wood supply prospects.

p. 63 The current Chinese annual per capita consumption of commercial timber is a mere 0.05 m^3 per capita, only about one fortieth of the huge U.S. consumption.

p. 66 Many more figures, descriptions, comparisons, and calculations could have been gathered in the preceding pages surveying water and land resources, the two irreplaceable existential necessities. The evidence presented is, I believe, indisputably clear : the environmental foundations of China's national existence are alarmingly weak, and they continue to deteriorate at high rates.

CHINA'S MODERNIZATION

p 95 The first representative survey of urban housing, carried out between July 1985 and July 1986, found... 1/4 of all urban inhabitants had less than 4 m^2 of housing space. This figure means little more than a single bed with an equally narrow strip alongside! Merely to bring China's urban housing to the level of notoriously cramped Japanese homes would require a roughly 70 percent increase in the average living space.

p. 97. The paucity of the country's transport links can be appreciated by noting that the total length of its railways (about 53,000 km in 1990) corresponds to the U.S. railroad total in 1863! This comparison makes spatial sense as the two countries have an almost identical area. ... As with so many socioeconomic indicators, doubling of the current aggregates would appear to be a precondition of any incipient affluence.

p. 97 Taking rural per capita income of less than 200 renminbi in 1987 as an indicator of abject poverty, no fewer than 8.3 percent of peasant households, or over sixty million people, were below that line, and it is unlikely that the total dipped below fifty million by 1990. For these people a well-padded coat, a well-heated room, or a well-built chair are still beyond reach.

ENERGISING THE ADVANCES

p. 101 Every year for several months more than three hundred million people have difficulties finding enough fuel just to cook three simple meals a day.

A table, on p. 135, lists total generation of carbon dioxide from combustion of fossil fuels, first in 1950 and then in 1989. This shows that per capita, in China, output increased by a factor of 22 over the 40 year period. So one can surely deduce that it could easily increase by a *minimum* factor of three (300%) over the next forty years. Yet if the world decides that carbon dioxide is such a threat to global warming that current output must not be increased, then a threefold Chinese increase (to only two-thirds of current U.K. per capita levels) would mean that the United States, Soviet Union, U.K., Germany, France, and Japan would need to decrease their current consumption by 38%, over the same period. However a 38% decrease in the U.S. would leave the States output at about twice the lowered U.K. level. With such different ideas of what might be equitable, the chances of getting satisfactory international agreements must be slim. Smil does not deal with global warming at length, because, as he rightly points out, its ramifications are not yet firmly established (though increase of carbon dioxide is). Smil is surely correct when he says in the final chapter:

p. 202 The biosphere may be an equilibrating supersystem more resilient than we can imagine; but it may be also more vulnerable than we can anticipate to the multipronged attack we have loosened during this century. *Wu ji bi fan* — when things are at their worst, they begin to mend — goes a Chinese saying, but in this unfolding drama, nothing guarantees that crisis will be followed by catharsis.

What will be required is collective commitment and determination to understand and to do better, much better, than we have done so far.

GROWING FOOD

p. 147 Requisitions of less than 0.2 hectares [2,000 m^2] of garden plots (and less than 1.33 hectares of other land can be simply approved by the local county or municipal bureaucrats. ... If only 1 percent of all China’s rural families were to convert a mere 0.1 hectare to non-agricultural use each year, the loss of arable land would amount to nearly 200,000 hectares, enough land to grow vegetables for at least five million people.

p. 165 With existing consumption patterns, roughly half of humanity survives thanks to industrial ammonia synthesis. Even if the rich meat-eating Western nations were to revert to predominantly vegetarian diets ... global farming without synthetic nitrogen would feed no more than 3.5 billion people, or roughly two-thirds of the current total. Every third, or certainly at least every fourth, inhabitant of the Earth is now thus alive only to the ingenuity of Fritz Haber and Karl Bosch. [For 2013, that fraction (now 3.5 out of 7.0) needs revising to ‘every second’ inhabitant, and note that producing nitrogen fertilizer is usually based on fossil fuels.]

An analogical calculation for China reveals, hardly surprisingly, an even greater dependence. ... The highest practical rates of organic recycling could sustain only about one third of China’s more than 1.1 billion people at the late-1980s’ level of food intakes and natural fibre consumption! [By 2013, the per capita level of food intake is far higher, due mainly to eating more meat, and also the population has increased to 1.35 billion.]

p. 167 [Smil calculates that the Chinese are using almost 200 kg of nitrogen for every hectare of cultivated land. He then goes on to make these comparisons] This is a very high average surpassed in Asia only by the two Koreas (North Korea with about 250, South Korea with some 210 kg), and elsewhere only in Europe by the Dutch (500 kg), Belgian, British and German farmers (220-240 kg). The U.S. mean is just 50 kg nitrogen per hectare, the Japanese average does not surpass 150 kg, and India and Indonesia apply, respectively, just 35 and 70 kg nitrogen/hectare.

But unlike in the intensively fertilized West European fields, where the high rates of nitrogen applications are a direct function of extravagant state farming subsidies ... the high rates of Chinese nitrogen application is driven largely by the necessity to produce enough grain just to cover basic nutritional needs with a still small proportion of animal foods.

p. 171 With intensified cropping and rapid increases of nitrogen applications ... the soil concentrations of phosphorus are inadequate for optimal growth of most field crops over about three-quarters of China's cultivated land, while the share of K-deficient farmland is now at least 30 percent. [The point to note is that as well as nitrogen there must be the correct balance of phosphorus and potash (K). Producing and delivering this entails more industry, more water, more transport, and more energy].

p. 179 After decades of cropping intensification based on expanding monocultures and increasing applications of synthetic fertilizers and pesticides, the 1980s brought a wave of reappraisals throughout the Western world. These critiques and calls for change are not a matter of joining the fashionable environmental movement : they are firmly based on a coalescing and sharpening realization of the unsustainability of many widespread post-1945 practices.

p. 184 [regarding China] The reason for abandoning green manure cultivation [the ploughing back of nitrogen-fixing crops] is clearly the higher pressure to produce more food on limited land. To return to the peak plantings [of green manures] of the 1970s would mean to forego the grain harvest... sufficient to feed some 75 million people.

p. 185 The organic matter in Chinese soils is now typically just between 1 and 1.5 percent, and in many areas even below 1 percent, compared to the desirable range of 2-3 percent. Hardening of soils and higher runoffs are the companion consequences of this degradation.

p. 187 In every Western country, food production relies on a set of unsustainable practices incompatible with the perpetuation of productive agroecosystems,... Farming-induced environmental degradation and price distortions are not a Chinese speciality, but of all the major agricultural powers none risks as much in continuing these malpractices as does China.

LIVING WITHIN THE LIMITS

p. 190 Land, the irreplaceable foundation of China's food production, is degrading in many ways. Soil erosion incompatible with sustainable farming is affecting at least one-third of China's fields; desertification and toxifications have much smaller nationwide impacts but are of growing regional and local importance; combination of such degradative processes and takeovers for housing and industries is diminishing the arable land by an annual rate of nearly 0.5 percent (yet already among the populous poor nations only Bangladesh and Egypt have less farmland per capita than China); inadequate crop residue and manure recycling and less frequent and simpler crop rotations are depriving the soils of essential organic matter.

p. 191 The long history of massive deforestation has not been reversed during the past two generations. Instead of moving toward a long-term goal of 20-25 percent forest coverage, the opposite happened, as all of the still relatively richly forested provinces (above all Sichuan, Yunnan, and Hainan) lost between a third and two-thirds of remaining tree cover in just forty years, as the area of mature forests decreased by one-third in just seven years between 1982 and 1989, and as the current wood removal is about 100 million m^3 above the sustainable rate. There is a very real chance that the country will have no mature natural forests to cut by the year 2000; neither will it have a sufficient volume of new plantings ready for harvesting.

It would have been very hard to say how much wood is going to be available for harvesting in 2000. By 1988 about 47,000 km^2 of shelter belt plantings, about ten million trees, were seriously affected by pests (ranging from pine moths to rats). And since Smil was writing, we have become aware of the impact of many varied diseases and pests on trees.

p. 191 China's comparative success in achieving adequate average provision of basic nutrition is marred by the realization that much of this food output comes from unsustainable farming. Too much monocropping, too few crop rotations, inadequate cultivation of legumes, drastically reduced organic matter recycling, unbalanced fertilization, and very high levels of nitrogen applications are all major concerns.

p. 192 There is no doubt that the overall state of China's environment will be more precarious by the year 2000 than in 1990, and that this unfavorable trend will continue during the first decades of the new century. ...

There are no solutions within China's economic, technical, and manpower reach that could halt and reverse these degradative trends — not only during the 1990s but also during the first decade of the new century.

A table, on p. 193, shows the *additional* annual output which would be required by the year 2000 if there is to be a 2% growth per year, starting from the 1990 level. Smil says that he had difficulty in attaching a proper adjective to the figures; for my part, I think the best one is 'impossible'! On the next page Smil produces a table using the same assumptions, which shows increased demand/output related to four factors; he comments on these: "Every one of these comparisons is stunning. Securing as much additional water as Egypt is using, emitting as much additional particulate matter as the United States is releasing, ... all in a single decade."

It is clear, in retrospect, that what China *should* have done, many generations ago, is to have thought about the sort of society that they wished to create, and then calculate what population could be sustained in the lifestyle to which they were aspiring. Now, because of their population, only a proportion of them will be able to achieve that lifestyle.

p. 196 During the 1990s nothing short of an unprecedented catastrophe (stemming from social disintegration leading to civil war, or from enormous recurrent crop failures leading to famines) could prevent the addition of at least 125 million people, and this total will grow to a quarter of a billion during the next generation.

With the 2012 population at 1.35 billion, Smil was right regarding population growth. The lesson which the Western world can draw from the Chinese experience may not appear to be immediately obvious. But with a little thought it becomes clear. Population, for a given area of land, can only be thought of as not excessive once the following conditions are fulfilled:

1. Account has been taken of the need to subtract from the current stock of arable land the amount of land needed to allow for housing of the population to an agreed

acceptable standard (for example China has currently an unacceptably low average of only 6 m^2 per capita).

2. Account has been taken of the need to subtract from the current stock of arable land the amount of land needed to allow for roads, airports, aqueducts, sports facilities and industrial enterprises, as needed to reach an agreed acceptable standard of provision.
3. Allowance has been made for the lower production of arable land which will result from using sustainable methods of agriculture (which chiefly means those which retain an adequate level of organic matter by ploughing back nitrogen-fixing crops).
4. Account has been taken of the need to subtract from the current stock of agricultural land the amount of land needed to provide sufficient timber for the population (for construction, for paper, and for firewood).
5. Account has been taken of the amount of water which needs to be made available for industrial enterprise and farming irrigation; and it should be possible to use this amount without degrading the water quality in rivers or plundering (on a long term basis) underground aquifers.
6. The final requirement must be something of a guess, but account should be taken of the fact that occasionally (as in 1815) volcanic eruptions cause world wide disruptions to agricultural production, which can last for several years. For this reason it should be possible to produce the necessary amount of food from, say, a mere 50% of the available arable land.

If people are to agree with the precautionary view implicit in paragraph 6, they may need to fight, within themselves, that natural tendency to reject any notion which has not become part of the accepted wisdom of their society; for nowhere does one seem to hear warnings of making allowance for the extreme vagaries of the weather which occur due to natural phenomena. Yet why should we be so foolish as to ignore this known fact simply because we cannot predict when it will occur?

While admitting that item 6 leaves room for dispute as to the exact percentage to be applied, the rest of the items, in principle, are no more than commonsense. Reading Smil's book, with its vast amount of detailed knowledge, makes one appreciate that the sort of calculation needed to establish a sensible maximum population in the Western world, on the basis of the above factors, should not be unduly difficult. So it is incumbent upon all of us to press our governments to get the necessary assessments made, and then to press them to take action to control population within those limits. Nations must hope that when the calculations are done they will reveal that, unlike China, the amount of land which is needed is less than that which is required by the *existing* population. China provides the supreme example of the mistake that the rest of the world must *not* make. China contains a fifth of the world's population and has a fifteenth of the world's arable land. As already stated it has got itself into a position in which the life-style that it aspires to is impossible. Let's look at a few more reasons as to why that to which it aspires is so far out of reach (some of the quotes are chosen to demonstrate the sort of way in which assessments can be made).

p. 51 A repeat of the 1954 flood, assessed by the Chinese water management experts as one of forty year probability, could lead to a displacement of up to 7 million people, and to unprecedented economic losses.

p. 233 Although not excessively demanding in terms of flooded farmland, the project [*Three Gorges Water Control*] could require resettlement of up to 1.2 million people, by far the highest total in dam building history.

p. 239 In 1988, the builtup area of Chinese cities averaged just over 40 m^2 per capita. I assume an increase to 50 m^2 per capita during the 1990s, an increase reflecting the construction of new apartment buildings with associated service infrastructure, new roads, recreation facilities, and water treatment plants. The shortage of roads and parks is especially great and readily apparent: roads average only 5 m^2 per capita, parks just 2.5 m^2 per capita.

p. 250 Reforestation, agroforestry, grass restoration, and better agronomic practices can repair even seriously degraded environments as long as a relatively low population density allows the introduction of such more appropriate land uses. But in localities where environmentally ruinous cropping of all accessible land still cannot assure even subsistence nutrition, there is practically no hope for locally driven solutions. Unfortunately, such places are becoming more, rather than less, common in China.

When considering the Western world, it may be hard to decide how to group areas together. Will the United States take steps to limit their own population before the population in the USA has expanded to the point at which it can only feed itself, and will it do this for the sole purpose of ensuring that it can continue to feed Europe? As with the vagaries of the weather, surely the principle of taking the cautious approach should apply. Countries which cannot rely on food from abroad *need to be able to feed themselves*.

Clive Ponting started his book, *A Green History of the World*, by telling us the story of the Easter Islanders, who destroyed their environment to the point of having to live in caves. He suggested that this might be a paradigm of what was happening to the world as a whole. I guess that most people would be inclined to think that man, in the twentieth century, was not prone to such foolishness. But both the fact that by the 1970s the United States had lost a third of its topsoil, and some of Smil's figures, suggest that is not the case.

If one is still inclined to think that the West is less likely to charge headlong into disaster, then just consider the lack of sensible action which has followed the recent farm surpluses in the European Common Market. The opportunity *should* have been taken to move towards sustainable farming practices, and to set aside sufficient farm land for woodland, so that in the future we can be self-sustaining in all our timber needs. In practice our bureaucrats have failed to act on this obvious commonsense. A more complete picture of what should have been done is well summed up by Smil:

p. 180 Farming in a sustainable manner cannot be done without respecting the limitations of particular agroecosystems, and without always preserving and preferably enhancing their critical environmental services rather than merely extracting their goods. These two grand strategies have the common denominator of diversification: in matching various crops with suitable growing conditions, in avoiding monocultures, in regularly inserting nitrogen-fixing legumes into cultivation cycles, in maximizing the recycling of organic wastes, in taking advantage of agroforestry benefits, in combining staple grain production with local animal husbandry, aquaculture, and apiculture, and in finding appropriate uses (be it grazing, agroforestry, wood production, or permanent tree cover) for lands not suitable for field farming.

Politicians and bureaucrats in the West cannot give cost as an adequate excuse for inaction; for in the West the outlay on food falls in the range 13% (United States) to 21% (Japan), as compared to China, where expenditures for food took nearly 55 percent of average rural disposable incomes in the late 1980s, and just over 50% of urban incomes.

Let us return to the theme of the original title — that China has something to teach the West — and also ask how useful Smil's insights have been.

What Smil could not have foreseen is that China would industrialize and become suppliers to the developed world. Moreover the Chinese people have been such good savers that China has wealth available to buy up land in other countries, including even ones which are themselves short of food, such as in Ethiopia. Thus China's problem of overpopulation has become a world problem, because in a world of globalized food and energy shortage, the people who suffer are those who do not have enough money to pay for it.

We, in the West, are somewhat dazzled by the economic growth rates achieved in China, but those who live in China are well aware of the many problems that Smil mentions. Even the very expensive solutions that China can now engage in are unlikely to satisfactorily solve the problems of wind and water erosion, salinization and alkalization of irrigated farmland, desertification, overdrawing of ground water, and pollution of rivers and the air. For as we have already seen, the fundamental problem is over population:

p. 11 Those Chinese who have looked closely at the links among population growth, material well-being, and environmental quality have no doubts... that of the three major crises that mankind faces today — population growth, depletion of natural resources, and degradation of environment — the first "is the most serious one, and is the root of the others."

A problem that China is beginning to notice, deriving from the application of its one-child policy, is that because of the rapid population growth that occurred some time back, there are going to be many old people for the younger generation to look after. That is a lesson for the West: It is a mistake to allow population growth on the grounds that it eases current problems (as has been done by governments in the UK and US), because there must come a time when population growth has to stop, and then there is an age-balance problem.

We noted earlier that Smil said, "China thus entered the 1980s with the world's most comprehensive population control program designed to reduce the fertility in a way unprecedented both for its sweep and for its coercive nature." It is now clear that this policy was extremely valuable. According to US Census Bureau figures, between 1950 and 1970 the annual rate of population growth in China was 1.9%. Between 1970 and 1990 it was 1.7%. If population had been allowed to continue at even that lower rate of 1.7%, by 2030 it would have reached 2.2 billion. Projections are only best guesstimates, but it currently looks as though China's population will peak at about 1.4 billion around 2030. If the arguments put forward in this journal are approximately correct, namely that population will collapse when energy resources become scarce, then China's 1979 policy will have saved the lives of 800 million people because without it they would have been born to starve or cause someone else to starve. David Willey promoted the idea that China deserved the Nobel Peace Prize for having adopted their one-child policy. Given that figure of 800 million lives saved, who can disagree with this suggestion?

Developed nations do not need to use anything in the least draconian to achieve the same desirable result. All that is required is that governments should see the need for balanced migration, and, *in some cases*, also give a mild incentive for smaller families. Most governments do the reverse, becoming concerned about short-term problems as soon as they see their population falling.

Vaclav Smil's study of China should teach the West something of vital importance about population being ultimately limited by resources, but the evidence so far is that the West will ignore the lessons, and instead choose what Margaret Hefferman terms *Wilful Blindness* (see the last issue of the OPT Journal for a review of her book).

MALTHUS AND HIS ESSAYS ON THE PRINCIPLE OF POPULATION

by Andrew R.B. Ferguson

In the April 2011 issue of the OPT Journal, I wrote these words, "The famous *Essay on the Principle of Population* by Thomas R. Malthus in 1798, and its later editions, have proved to be accurate in the predictions about how world population would increase if its expansion were to be largely unconstrained." I was taken to task on this by someone who knows much more than I do about what Malthus actually wrote. I must admit that it was a mistake to use the word 'prediction', as Malthus invariably made 'projections' of population rather than 'predictions'. All one can ask of projections is that they should be relevant to real life. A quotation from Malthus — supplied by my critic — allows further comment on the subject. He told me that in a later edition of his work Malthus wrote:

> In this country it has appeared that, according to the returns of the Population Act in 1801, the proportion of births to deaths was about 4 to 3. This proportion with mortality of one in 40 would double the population in 83.5 years; and as we cannot suppose that the country could admit of more than a quadrupled population in the next 166 years, we may safely say that its resources will not allow of a permanent rate of increase greater than that which was then taking place.

The next consideration is whether population growth in Britain towards the end of the eighteenth century can be properly described as "*largely* unconstrained." A case can be made for that, insofar as contraceptives were not easily available, abortion and infanticide were not permitted, and there were no punishments for excessive births (as applied for a millennium in the small island of Tikopia and in recent decades in China).

If we admit that the population growth depicted by Malthus was "*largely* unconstrained", and make a projection from the 83.5 year doubling time given by Malthus (equating to annual growth rate of 0.834% per year), and assume a world population in 1800 of 950 million, this indicates a world population two hundred years later of about 5 billion. That is a projection which accords surprisingly well with what has actually happened.

In his first essay, Malthus dwells at length on the fact that in various places in America, population was doubling in only 25 years. That is an annual expansion of 2.8% per year. Applying that to a population of 950 million for a 200 year period would take us to a world population of 240 billion, but there is no reason to suppose that Malthus regarded that as a projection relevant to the *whole world*. The situation of America, with its unlimited room for expansion, was a special case. However, the need to warn about special cases is evident in that the 2011 growth rate covering the 19 countries of Western Africa, comprising a population of 340 million, was 2.8% per year.

While the population projections given by Malthus were realistic, that cannot be said of his agricultural 'predictions' of what he deemed to be likely limits to population size. But he had no crystal ball, and it is hardly surprising that his surmises proved wrong in view of these facts: (a) the amount of nitrogen now applied to agricultural land is twice the natural amount, and this has only been made possible by the Haber-Bosch process of synthesising ammonia; (b) the advent of tractors and vehicles to replace horses has freed up huge areas of land for food production and facilitated rapid harvesting at the optimum time; (c) the application of pesticides and herbicides is now widely used; and (d) the availability of energy, wherever needed, allows irrigation by pumping underground water. All these have served to expand food production beyond what Malthus could have envisaged. Malthus's chief concern was that the exponential growth of population would lead to poverty. Looking at Africa and India today, who can say that he was wrong?