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The world's WROG (*Weak Restraints On Growth*) period has been an anomalous never-to-be-repeated 2.5 centuries during which humans have multiplied their numbers ten times by plundering Earth's finite resources, especially fossil fuels. The Industrial Revolution unlocked vast storehouses of wealth, enough to ensure prosperity for everyone throughout the WROG period if world population had remained at its late eighteenth century level (less than 1 billion). But population growth has outpaced economic growth globally, so most world citizens are poverty stricken.

William I. Stanton, 2003. *The Rapid Growth of Human Populations 1750 — 2000.*

The Optimum Population Trust (UK): Manchester

<www.optimumpopulation.org>

INTRODUCTION

The synopsis of Clive Ponting's *A Green History of the World*, by Martin Desvaux, is now available as a single file on the OPT website. Martin is working on an appraisal of Ponting's 2007 update, *A New Green History of the World: the Environment and the Collapse of Great Civilizations*, which will soon appear in the OPTJ. In the meantime, *Food, Energy, and Society*, by David and Marcia Pimentel, takes pride of place to start this edition — having now reached Part 4 of this series.

Pages 7-10 contain a review — from an OPT perspective — of James Lovelock's book *The revenge of Gaia: Why the Earth is Fighting Back – and How We Can Still Save Humanity*, published in 2007. Although my name appears as the author of the review, credit is also due to John Nunn, a friend of Lovelock, with whom I had extensive discussions about the review of the book.

Pages 11-12 contain a summary review of a short paper by the American Institute for Economic Research (AIER), *Green Dreams versus the Energy Dilemma*. The AIER paper, echoes the oft expressed analyses in the OPT Journal regarding the problems of introducing renewables. I have tried to make the original paper more accessible by using units that most people will find easier to grasp.

Controllable Power Limits Total Power, page 13-20, overlaps to some extent with the article, *The Problem with Uncontrollables*, in the April 2010 issue of the OPTJ, but this subject — the problems associated with integrating uncontrollable inputs into the grid in the absence of controllable inputs from fossil fuels — has had inadequate treatment in the media and academia. This study also looks at the population implications of a much reduced energy supply.

On pages 21-25, the booklet, *Searching For A Miracle: "Net Energy" Limits & The Fate Of Industrial Society*, by Richard Heinberg, is reviewed. Heinberg focuses on another aspect of the problems of renewable energy sources, namely the need for substantial inputs, detracting from the outputs, and sometimes leaving little over. The booklet is somewhat narrow, as it fails to consider power densities, and the related problem of integrating 'uncontrollables' into the grid, i.e. the main feature of the previous article. However the booklet gives an opportunity to dwell on some of the shortcomings of energy analysis, in particular the failure to take adequate account of the *type* of energy, e.g. liquid or electrical. Once again there is some reiteration of the lower power densities achievable when integrating uncontrollables into a grid. This is a main focus of this issue. If anyone knows a more authoritative source focusing on these problems, which does not glibly assume that means to store electricity will be found, I would be glad to hear of it.

The final three pages look at the huge uncertainties that surround population projections. With respect to undeveloped nations, this is mainly due to unpredictable changes in Total Fertility Rate. In the developed world, uncertainty arises through migration policies.

As usual there are many people to thank. John Nunn helped me with the Lovelock review. Walter Youngquist keeps me constantly supplied with interesting material, and sent me the AIER paper. Edmund Davey had the Heinberg booklet printed and sent me a copy, prior to discussing my take on it. Martin Desvaux made valuable comments on *Controllable Power Limits Total Power* Eric Rimmer stimulated me into producing the final piece, *The Perils of Population Projections*, and was able to provide some feedback via his contacts within the Population Reference Bureaux.

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FOOD, ENERGY, AND SOCIETY (3rd edition), Part 4

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

Chapter 10. Energy use in Grain and Legume Production Energy inputs in grain production

99.2 Although some plant foods eaten by livestock, such as grasses and forages, are not suitable for human foods, grains and legumes most certainly are. In the United States, about 816 kg of grains and legumes produced per person and suitable for human consumption are diverted to livestock. Almost 90% of the plant calories/protein consumed by humans come from 15 major crops: rice, wheat, corn, sorghum, millet, rye, barley, cassava, sweet potato, potato, coconut, banana, common bean, soybean, and peanut.

99.7 By eating combinations of cereals and legumes, humans can obtain sufficient quantities of the essential amino acids. In fact, grains and legumes have long been staple foods for people in many areas of the world.

102.6 Although the yields of corn produced by hand are significantly lower than yields of corn produced by mechanization in the United States, the reason is not related to the type of power used. The lower yields for hand-produced corn can be attributed to the reduced use of fertilizers, lack of hybrid (high-yielding) varieties, poor soil, and prevailing environmental conditions. With the use of suitable fertilizers and more productive varieties of corn, it should be possible to increase crop yields employing only human power.

105.9 The fossil energy inputs into U.S. corn production are primarily from petroleum and natural gas. Nitrogen fertilizer, which requires natural gas for production, represents the largest single input, about 30% of the total fossil energy inputs.

Machinery and fuel together total about 25% of the total fossil energy input. About 25% of the energy inputs in U.S. corn production are used to produce human and animal labor inputs, the remaining 75% to increase corn productivity.

106.6 Wheat farmers in the Uttar Pradesh region of India use human/bullock power. A total energy input of about 2.8 million kcal [per ha] is required to obtain a wheat yield of 2.7 million kcal [821 kg] of food energy, for an output/input ratio of 0.96:1. Thus, the wheat energy produced is less than the energy expended, and the system appears to create no net gain. However, this output/input ratio may be somewhat misleading, because one of the largest inputs in this production system is for the two bullocks. Because the bullocks consume primarily grasses and little or no grain, they are in fact a type of food conversion system. The bullocks convert the grass energy into wheat energy through their labor in the wheat fields. If the bullock input is removed from the analysis, then the output/input ratio increases to 5:1, which is a more favorable and realistic representation of this mode of production.

108.9 Rice is the staple food for an estimated 3 billion people, mostly those living in developing countries. … As in corn production, yields decline as human labor input increases, except in Japan and China. In those countries, high yields of rice can be grown employing human power because appropriate high-yielding varieties, fertilizers, and other technologies are used.

In the Philippines, both human and animal power are used in rice production. Total energy inputs of 1.8 million kcal/ha produce 1650 kg/ha of rice, which has the equivalent of 6.0 million kcal of food energy. The resulting output/input ratio is 3:1, about half that of the Iban [a tribe in Borneo that cultivates rice by hand] rice production system. However, like the bullocks used for wheat production in India, the Philippine carabao used in rice production convert grass energy into rice energy. If the energy input for the carabao is removed from the accounting, the output/input ratio rises to 10:1.

As with other grains, the United States uses large inputs of energy, particularly fossil fuel energy, to produce rice. Based on data on rice production in the United States, the average yield is 7367 kg/ha (26.5 million kcal), significantly greater than yields from the other systems discussed. However, the high energy input of 11.8 million kcal/ha results in a low 2.2:1 output/input ratio. Although most of the energy input is for machinery and fuel, fertilizers account for about 50% of the total fossil fuel input. The other inputs are for irrigation, seeds, and drying. The human labor input is only 24 h/ha, still a relatively high figure for U.S. grain production.

By comparison, rice production in Japan is still relatively labor intensive, requiring about 640 h/ha of human labor. Fossil energy inputs are lower in Japan than in the United States, but rice yields in the two countries are about the same. As a result, Japanese production methods achieve an output/input ratio of 2.8:1, reflecting more efficient use of energy than the U.S. system.

Energy inputs in legume production

114.1 Peas, beans, and lentils, all members of the Leguminosae family, are extremely important plant foods, especially in those areas of the world where animal foods are scarce and expensive or where religious or cultural reasons dictate the avoidance of animal flesh as food. Most legumes have a high carbohydrate content of 55%–60% and a high protein content of 20%–30%. The 30% protein content of soybeans is exceptionally high for plants. Legumes are excellent plant sources of iron and thiamine in addition to protein.

115.2 Legumes need less nitrogen than most other crops. For example, soybeans require only one-tenth the nitrogen input needed for corn. Soybeans and other legumes obtain nitrogen from the atmosphere through their symbiotic relationship with microbes in the soil. … Overall it is more economical for plants to provide their own nitrogen than for humans to make and apply nitrogen fertilizer. The 100 kg of soybean yield that is lost to nitrogen fixation is worth about $9.25, much less than the $58 cost of the 100 kg/ha of nitrogen produced by the plants.

PEANUTS

116.7 Data on production of peanuts employing a large input of labor (936 h) for northeast Thailand have been reported by Doering (1977). Total inputs, including a large labor input, total 1.9 million kcal/ha, and the peanut yield is 5.6 million kcal/ha. Thus the output/input ratio for this peanut production system is 2.6:1.

Peanut production in the United States (Georgia) yields 15.3 million kcal/ha, or about three times that in Thailand. However, with the large energy expenditure required, the system achieves an output/input ratio of only 1.4:1.

Chapter 11. Energy use in Fruit, Vegetable, and Forage Production

121.5 Apples are an economically valuable crop in many parts of the world. In the United States, petroleum products are used to operate machinery employed in apple orchards, and the inputs for this machinery account for a large percentage of the total energy input. The next largest input is for pesticides, which represent nearly 17% of the total energy input in apple production. … The total labor input is calculated to be about 17.1 million kcal, which represents only 34% of the total energy input for apple production. The yield in fruit is about 30.7 million kcal/ha making the output/input ratio only 0.61:1.

POTATOES

123.5 Based on data from the United States, the greatest energy input in U.S. potato production is fertilizers, which represent about one-quarter of the total inputs. … The total energy input for potato production is 17.5 million kcal/ha. Potato yield equals 23.3 million kcal/ha, resulting in an output/input ratio of 1.3:1, slightly lower than the 1.6:1 reported by Leach (1976) for the United Kingdom.

SPINACH

123.9 Although it is not a major vegetable throughout the world, it is nutritionally valuable. Like other dark green leafy vegetables, spinach contributes iron, riboflavin, and vitamins A and C to the diet.

The largest energy input in U.S. spinach production is for nitrogen fertilizer, amounting to nearly 50% of the total energy input. The next largest inputs are for fuel and machinery. The overall energy cost is 12.8 million kcal/ha, and the spinach yield is 2.9 million kcal/ha. The output/input ratio is 0.21:1. This negative ratio means that about 5 kcal of fossil energy is required to produce each kcal of spinach.

TOMATOES

126.7 Based on U.S. data, one-third of the energy inputs in tomato production are for fuel and machinery that reduce labor inputs. The second largest input is for fertilizers. The total energy input is 32.4 million kcal/ha, and the average tomato yield is 8.4 million kcal/ha. These figures result in an output/input ratio of about 0.26:1, or about 4 kcal of energy expended for every kcal of tomato produced. Because the yield of tomatoes per hectare is so high [41,778 kg/ha], the protein yield of 496 kg/ha is excellent, even though tomatoes average only 1% protein and have a high water content.

CASSAVA

128.8 The low protein content is one of the reasons the crop can grow in soil that is low in nutrients, especially nitrogen. The data for cassava production are from the Tanga region of Africa. Cassava grown in that region has the efficient output/input ratio of 23:1. The root of the cassava shrub is harvested 9–12 months after the planting of stem cuttings. Production of this crop requires about 1300 h of hand labor per hectare. Total energy input is calculated at about 838,300 kcal/ha, and the yield is about 19.2 million kcal/ha. This high energy yield comes mainly from the starch content of cassava. The protein yield, as mentioned, is low, only 58 kg/ha. Furthermore, the quality of cassava protein is considered the lowest of all plant proteins. Given the efficiency of cassava production and the breadth of its consumption in the tropics, it is unfortunate the quality and quantity of the protein is so inadequate.

133.6 Do some diets use more fossil energy than others? Humans seldom eat just one or two foods; rather, they make dietary choices from a variety of available foods. Basically, however, eating patterns can be classified as to the type of protein eaten. Non-vegetarian diets include both animal and plant proteins, often, as in the United States, with a predomination of animal protein. In the lacto-ovo diet, eggs, milk, and milk products represent the only animal protein eaten, whereas in the complete vegetarian diet no animal protein is eaten.

The following analysis illustrates some of the differences in the fossil fuel requirements of these three dietary regimes. The calculations are based on data for various foods produced in the United States. The average daily food intake in the United States is 3500 kcal, so we assumed a constant intake of 3500 kcal/day for all three types of diet. The protein intake is over 100 g per day in the non-vegetarian diet and declines to about 80 g in the all vegetarian diet. Both protein intakes significantly exceed the recommended daily allowance of 56 g/day.

Nearly twice as much fossil energy is expended for the food in a non-vegetarian diet as in the vegetarian diet. As expected, the lacto-ovo diet is more energy intensive than the all-vegetarian diet. Based on these sample calculations, the pure vegetarian diet is more economical in terms of fossil energy than either of the other two types of diets.

Energy expenditure is not the only factor to be evaluated when dietary choices are made. Decisions are often based on individual preferences and tastes. In addition, there are significant nutritional differences between the pure vegetarian diet and those that include animal products. Pure vegetarian diets lack vitamin B_{12}, an essential nutrient, so this must be taken as a dietary supplement. Further, the quality of protein depends on the combination of foods consumed. When the essential amino acids from a variety of plant foods are combined, then the protein quality of a vegetarian diet will be satisfactory. A pure vegetarian diet usually consists of greater volume and bulk than a mixed diet, making it difficult for young children to consume the quantities necessary to meet all nutritional needs. In addition, nutritionally vulnerable people such as infants, rapidly growing adolescents, and pregnant and lactating women may need nutritional supplements of vitamins A and D, calcium, and iron while on a pure vegetarian diet.

LOVELOCK AND "THE REVENGE OF GAIA"

a review from an OPT perspective, by Andrew Ferguson

James Lovelock has written many books related to his Gaia hypothesis, which he defined in 1979 as follows: "The physical and chemical condition of the surface of the Earth, of the atmosphere, and of the oceans has been and is actively made fit and comfortable by the presence of life itself." Since there is ample evidence of the negative feedbacks which operate — e.g. when the air contains more carbon dioxide this encourages tree growth, increasing the oxygen and decreasing the carbon dioxide — that hypothesis is widely accepted by scientists. But Lovelock, even in his latest book *The revenge of Gaia: Why the Earth is Fighting Back – and How We Can Still Save Humanity*,[1] talks of that part of the Earth which engages in these transactions, namely the biosphere, or as he would have it the goddess Gaia, as though she somehow has goals of her own. Even though Lovelock does mention, from time to time, that the notion of Gaia is only a metaphor, his fellow scientists naturally object to his terminology of Gaia having goals. I must say that I also found the book caused me frequent mental glitches, when I had to translate in my mind what Lovelock appeared to be saying into what he really intended (with the metaphor removed).

We will dwell on the Gaia hypothesis no further. Reviewers of the book have already done a good job of praising its virtues, while objecting to certain aspects of the presentation. My purpose here is to attempt to look at the extent to which Lovelock's judgements about the human condition, as set out in *The revenge of Gaia*, either support, or fail to support, the assessments which have been made — somewhat laboriously — in the pages of the OPT Journal, in particular with regard to the following OPT conclusions:

1. While fossil fuels are available, it will be *practically* impossible to reduce carbon dioxide emissions to below 4 tonnes per person per year. That per capita figure implies the need to reduce the human population to around 2 billion, because it is nevertheless necessary to achieve atmospheric stabilization at a safe level, which entails reducing carbon dioxide emissions to about 9000 Mt (million tonnes),.
2. The estimate in the previous paragraph of carbon emissions per capita is predicated on the further OPT judgement that renewable energy is unlikely to play a significant part in reducing the use of fossil fuels, so long as fossil fuels are available.
3. When accessible fossil fuels are exhausted, the low power density of *controllable* renewable energy sources (e.g. biofuels) and the moderately low power density and *uncontrollability* of those renewable energy sources which produce electricity, means that without fossil fuels — that is relying entirely on renewable energy sources — no more than about 2 billion humans could be supported in modest comfort.
4. While it would transform the situation if a method of storing electricity on a large scale could be found, on the available evidence such large scale storage should be regarded as only an outside chance.
5. While the dangers inherent in using the fission of uranium and thorium to generate energy are unquantifiable, due to the human factors involved, it is inevitable that this source of energy will be exploited as fossil fuels become scarce.
6. The possibility of extracting useful energy from fusion should be regarded only as an outside chance, since it is fairly likely that even if a positive energy return could be achieved on a commercial scale, the amount of heat generated in the process would prohibit the use of the process (this is already a problem with fission).

There are other reasons for arguing that the human population needs to be a fraction of what it is today. This need is evident from the existing manifestations of degradation of the environment and its diminishing suitability to support life, for instance: (a) soil erosion;

(b) salination leading to abandonment of irrigated land; (c) lowering of water tables and the draw down of aquifers; (d) pollution of rivers particularly by fertilizers and pesticides; (e) deforestation; (f) loss of biodiversity and contamination of animals with man-made chemicals; (g) loss of fish stocks; (h) humans choosing to live in flood plains despite the obvious dangers to people and property.

For the purposes of comparing OPT judgements with those of Lovelock, the previous list of six items will suffice, and let us now turn to that.

Regarding point 1, Lovelock seems as unwilling as Al Gore and all the environmental organizations to contemplate this inconvenient truth. The IPCC mentioned long ago that we need to reduce emissions from burning fossil fuels to between 20% and 40% of the 1990 level, and that reality has not changed, but ever since then this has been either ignored or meets with resolute obfuscation of the implications. For instance, the UK government are under the illusion that if the UK reduces emissions to 40% of the present level, this will be all that we need to do. They do not consider that the level would then be about 4 t/cap/yr, which implies a world population limit of about 2 billion. Lovelock's belated statement on the subject of population (as given below) appears lacking in urgency, especially as population is the key to mitigating the multiple problems likely to ensue from a combination of global heating (as he prefers to call it) and a deteriorating environment.

Lovelock is much better on point 2. He is not too precise, but gives various clear pointers to his judgement on the matter. For instance, regarding wind turbines he says:

> Niels Gram of the Danish Federation of Industries said, 'In green terms windmills are a mistake and economically make no sense … many of us thought that wind was the 100 per cent solution for the future but we were wrong. In fact, taking all energy needs into account it is only a 3 per cent solution.' (p 106)
>
> If we allow it, the remaining countryside will become an industrial site filled with massive wind turbines in a vain attempt to supply the energy demands of urban life. (p 11)
>
> To supply the UK's present electricity needs would require 276,000 wind generators, about three per square mile, if natural parks, urban, suburban and industrial areas are excluded; also needed would be an efficient way of storing the electricity they produced. But in no way is it efficient and economic; the intermittency of the wind means that, at best, energy is available from wind turbines only 25 per cent of the time. During the remaining 75%, electricity has to be made in standby fossil-fuel power stations. … (p 106)

Actually that is an imprecise way of describing the reality. In fact, a wide group of wind turbines generally produces *something* during about 90% of the time, but most of that time that production is so much below the peak output, that over the course of a year output is only around 25% of what it would be if all the turbines were operating all the time at their rated capacity. This continuous variability is one of the things that makes it difficult for the rest of the system which has to work 'in harness' with the uncontrollable wind input. However the figure, of about 25%, mentioned by Lovelock is crucial, because it is the difference between this and peak output (close to rated capacity in the UK) which is the main problem with wind. Perhaps Lovelock appreciates this when he goes on to say:

> We might have been wiser to seek to use the energy in the ocean in the form of waves and tides.

The same point has been noted on occasions in the OPT Journal. Whether waves and tides can be made economic is another question, but they would have several advantages over wind, certainly being more predictable, and probably achieving better load factors.

Relevant to both point 2 and point 3 is the consideration of the potential for biofuels, a matter which has filled many pages of the OPT Journal. This is what Lovelock has to say:

> Just imagine that we try to power our present civilization on crops grown specifically for fuel, such as coppiced woodland, fields of oilseed rape, and so on. These are the 'biofuels', the much-applauded renewable energy source. Even if these natural products were used only for transport, to fuel our cars, trucks, trains, ships and aircraft, it would require us to burn every year about two to three gigatons of carbon as biofuel (a gigaton is a thousand million tons). Compare this quantity with our yearly food consumption of half a gigaton; to grow this much already uses more of the Earth's land surface than may be safe. (p 85)

But Lovelock speaks of the subject only in generalities, and does not give any idea of the much lower population which could be supported using only renewable energy. This is almost all that he says on that subject:

> Since the beginning of the nineteenth century we have taken more from the Earth than it could provide. Sustainable development and renewable energy might have worked in earlier times, but I think that to expect them and energy saving to sustain our numbers today is no more than a romantic dream. (p 101)

He does mention his own personal choice for a sustainable population, but it is hard to disentangle this from his judgement that much of the world is likely to be made uninhabitable for humans due to global heating. Anyhow this is what he says:

> The root of our problems with the environment comes from a lack of constraint on the growth of population. There is no single right number of people that we can have as a goal; the number varies with our way of life on the planet and the state of its health. It has varied naturally from a few million when we were hunters and gatherers to a fraction of a billion as simple farmers; but now it has grown to over six billion, which is wholly unsustainable in the present state of Gaia … Personally I think we would be wise to aim at a stabilized population of about half to one billion, then we would be free to live in many different ways without harming Gaia. (p 180)

While, of course, it is true that there are various 'right numbers' dependent on lifestyles and the state of Gaia, OPT's view is that it is essential to attempt to arrive at some idea of the populations which could be supported in moderately comfortable style in *every country*. While some countries will of course prefer to let nature take its course regarding population expansion (believing perhaps that it all depends on God's will), others may be wiser, and thus able to preserve something of civilization despite global heating.

Regarding point 4, Lovelock does recognize that while the ability to store electricity would transform the usefulness of uncontrollables, that desirable achievement is not a prospect that we would be wise to assume is going to come about:

> If an economic, 25 per cent efficient converter of sunlight into electricity could be made available as roofing material it would provide a fine and sensible energy supplement. But as with wind, the intermittency of solar supply would necessitate efficient storage, and so far this too is unavailable. (p 111)

However, it should be mentioned that he does at times appear to have a blind faith in the prospect that given forty years or so technology will always be able to come up with an answer. We in OPT would agree that major developments do indeed take at least forty years, but we also take the view that no development that is not clearly on the cards should be assumed as being likely to occur.

With respect to point 5, and nuclear installations, Lovelock disregards such dangers as the breakdown of society, as for example in Somalia and Afghanistan, and points, probably correctly, at an excessive fear of radiation in general. He has no doubts at all that we need to press ahead rapidly with the use of nuclear power:

> For the immediate future, and starting now, we need to exploit fission energy as much as we can as a temporary measure, while looking to a future when, having served our need, it can be replaced by clean energy from other sources. (p 133)

His essential arguments are that to run short of electricity would be a disaster, and that using power from fission would reduce emissions of carbon. With regard to avoiding the situation of running short of electricity, it could be argued that what the western world badly needs is for that to happen, for such an event may awaken us all to the impossibility of supporting our present population without fossil fuels. Note his final words, "it can be replaced by clean energy from other sources" imply an undue degree of certainty.

Regarding point 6, Lovelock does make it perfectly clear that he sees fission energy as only a short term palliative, but based on a single visit made by himself and his wife to the Culham Science Centre, he seems to have excessive faith in the development of fusion power. He reports:

> We were amazed and delighted to discover that their fusion reactor had proved itself by sustaining for two seconds a nuclear flame that burnt deuterium and tritium, isotopes of hydrogen, and generated 16 megawatts of energy. Admittedly it was only 64 per cent of the energy needed to ignite the flame, but it proved that the physics and the engineering were sound and worked as expected. (p 114)

Lovelock appears to regard this as hopeful, but note that the power generated was about 8900 kWh (about 53 seconds of output from a 600 MW plant) and it took 13,900 kWh to produce it. There is clearly a long way to go in development, because the output needs to be higher not lower than the input, and *considerably* higher if the whole process is not to produce an impossible amount of heat. Thus for several reasons the possibility of producing useful energy from fusion remains speculative.

In summary, Lovelock seems to be thinking in similar terms to OPT. He does not doubt the reality of global heating, any more than we do, and he does an admirable job of explaining the dire effects of global heating. It was news to me, for instance, that the oceans become almost devoid of life once the temperature in the upper layer reaches about 10ºC. This absence of life has the disastrous feedback effect of causing the loss of a vital carbon sink. He shares the OPT view that we should try to do something about it, and perhaps by implication even our view that in all probability we will actually achieve only minimal restrictions in the present carbon emissions (which are about three times what they need to be), for he stresses that preparedness for rising sea levels and the other effects of global heating should be our priority.

While James Lovelock regards a hotter world, which can support far fewer humans, as almost inevitable, for all he says about the matter, he might be aligned with those who think we should allow God to decide matters of procreation, for he does not even point out that in much of the developed world populations could decrease naturally, if only the politicians (encouraged by economists and the commercial world) would welcome that reduction, rather than regarding it as an economic problem.

1. James Lovelock. *The Revenge of Gaia: Why the Earth is Fighting Back – and How We Can Still Save Humanity.* First published by Allen Lane 2006, and by Penguin Books 2007.

GREEN DREAMS VERSUS THE ENERGY DILEMMA

an AIER Research Report by Kerry A. Lynch, reviewed by Andrew Ferguson.

Walter Youngquist, author of *GeoDestinies* (1997), kindly sent me a copy of a report by the American Institute for Economic Research (AIER), published in Volume 77 No. 12, July 5, 2010. It contains useful data, but it is expressed in large numbers, such as quadrillions of Btu, which are difficult for most people to grasp. Thus I will adopt the system used by David MacKay in his outstanding book *Sustainable Energy ... without the hot air* (2008), and express energy in terms of kilowatt hours per day per person, symbolized as kWh/d/p. For comparison with the U.S., in the U.K. total energy use is about 125 kWh/d/p. Incidentally that could be expressed in terms of average power as 125 / 24 = 5 kW, but let's keep to the energy units that people are familiar with when paying their electricity and gas bills, namely a kilowatt hour (i.e. 1 kilowatt used for an hour). Even in the UK energy use is large: directly and indirectly, on average, each person is using, *during every hour*, 5 kWh of energy. As we shall see, the figures are more alarming in the USA. But even the lower European use of energy makes it obvious that modern civilization is highly dependent on energy, insofar as *on the most modest assumptions* the power of thirty people is needed to supply that amount of power. [1]

In the paper under review, its Figure 1, stemming from the Energy Information Administration (EIA), shows the energy flow in the United States in 2008. Total *supply* amounts to 281 kWh/d/p. Of this, domestic production is 194 kWh/d/p, while imports supply a further 87 kWh/d/p. With regard to petroleum, the *imports*, amounting to 73 kWh/d/p, represent 74% of the 98 kWh/d/p of petroleum used in the USA.

The total *consumption* of energy (a small amount of the supply is exported) is 262 kWh/d/p, breaking down as 220 kWh/d/p fossil fuels, 22 kWh/d/p from nuclear electricity, and 19 kWh/d/p from renewable sources. This makes renewable energy appear a significant part of the whole, but a large part of it is hydro, which is partly controllable. When it comes to the uncontrollables, the situation looks different, as the paper states:

> For all the hype over wind and solar, the reality is that they contribute very little to our energy supply. Wind accounts for less than 1 percent [less that 2.6 kWh/d/p] of total U.S. energy consumption. Solar accounts for just one tenth of 1 percent [0.3 kWh/d/p].

In terms of energy use per sector, 57 kWh/d/p is for residential purposes, 49 kWh/d/p for commercial purposes, 82 kWh/d/p for industrial purposes, and 74 kWh/d/p for transportation. Thus transportation represents 28% of energy use. A particular problem is that 95% of the energy used for transportation comes from oil. To put it another way, without oil, the replacement energy needed amounts to 70 kWh/d/p. As the paper points out, it is very important to consider *types* of energy, as they are not interchangeable. These paragraphs sum up the point that the paper makes about the difficulty of replacement:

> Renewables are extremely expensive relative to fossil fuels, partly because developing them on a large scale requires huge up-front capital investments. The only way to promote their use is to lower their relative price — through market forces or government policies — or to mandate their use without regard to price. Government policy is already doing this. The stimulus package included $80 billion tax credits [$263 per person] and other subsidies for clean energy. A national carbon tax or a "cap and trade" policy would directly raise the price of fossil fuels. Many states now require that a growing share of their energy be generated by renewable sources, regardless of price. And the Energy Information Administration (EIA) projects that fossil fuel prices will rise in the next two decades.

> The EIA projects that as a result of these subsidies, mandates, and higher fossil fuel prices, the strongest growth in fuel use over the next 25 years will be renewables. However, EIA also projects that in the absence of greater policy or price changes, by 2035 the U.S. will still get three-fourths of its energy from fossil fuels.

This forecast is highly plausible, and chimes with analyses published in the OPT Journal. For instance, because of their intermittent nature, uncontrollables are unlikely to be able to provide more than about 25% of the electrical supply. As to the replacement of liquids, the low power density of biomass production in general, and the very low power density (even without considering inputs) of ethanol from corn, indicate the lack of a satisfactory answer to the replacement of liquid fuels used for transport.

The paper is sound on substitution problems. Having noted that the oil man T. Boone Pickens has been promoting his plan to harness domestic wind and solar power to reduce the reliance on foreign oil, the paper goes on to say that Pickens proposes,

> to breach the oil-wind gap with a third energy source, natural gas. First, he would ramp up wind power enough so that it displaces some of the natural gas that is now used to generate U.S. electric power. Then the natural gas would be used to displace the diesel we now use to run trucks and other commercial vehicles.
>
> Here again cost and capacity are a big challenge. Trucks can't travel nearly as far on natural gas as on diesel. There is also no national distribution network of natural-gas filling stations.

The paper does not make the obvious points that Pickens' plan only involves a *reduction* in fossil fuel use, and natural gas supply has a limited life. However the paper does make the sound point (often overlooked), that if plug-in electrical vehicles come into widespread use it will increase the demand for electricity, and thereby increase the use of fossil fuels. This is something that MacKay (2008) considers in some detail, showing that the use of fossil fuel would be diminished, *but far from eliminated*. Neither does the paper raise the point that has been aired recently, that many renewable technologies rely on rare earth elements which are known to exist mainly in China. The paper finishes by saying:

> The driving force for change is a substantial increase in the prices of fossil fuels relative to renewable energy sources. How much such an increase will be driven by market forces (shrinking supplies of oil, rising demand for energy) or by government policy (taxes, subsidies, regulations, and mandates) remains to be seen.

No one could disagree with that conclusion, and there is the problem that democratic governments have little power to inflict present pain for the benefit of future generations.

References

MacKay, D.J.C. 2008. *Sustainable Energy — without the hot air*. UIT Cambridge. ISBN 978-0-9544529-3-3. £20. Available free online from www.withouthotair.com

Youngquist, W. 1997. *GeoDestinies: The inevitable control of Earth resources over nations and individuals.* Portland, Oregon: National Book Company. 499 pp. (revised edition in preparation).

1. The "modest assumption" is that the fossil energy we use is converted, for instance by an internal combustion engine, to useful power only at an efficiency of 20%, so the 5 kW power of fossil fuel will only supply 1 kW of *useful* power. 1 kW over 24 hours is 24 kWh. A man working for a 10 hour day supplies about 0.75 kWh. Thus 24 / 0.75 = 32 men provide the same average power. The issue is more complicated, as human labour cannot directly replace heat, but the calculation is indicative of our reliance on energy.

CONTROLLABLE POWER LIMITS TOTAL POWER

by Andrew R.B. Ferguson

Abstract: There is little recognition of the fact that the amount of *uncontrollable* power, for instance in the form of wind power and photovoltaics, that can be used in an electrical system is determined by the amount of *controllable* power that is available. Currently fossil fuels provide controllable power, but as they become scarce we will need to fall back on controllable power from renewable sources. Part 1 and Part 2 of this paper are concerned with establishing an analysis using the UK as the example. The conclusion at the end of Part 2 is that the upper limit on population that could be supported in the UK, with the minimum comfort of a supply of 2 kilowatts (48 kWh/day) per person, is 20 million people, about a third of the present population. The estimate is lent credibility by being within the range that the Optimum Population Trust has made based on eco-footprinting. On the same basis, Part 3 takes a brief look at the world, and the USA. The upper limits for how many could be supported with a minimum level of comfort is 3.4 billion and 200 million respectively. Admittedly these are very rough estimates, based on surmises about how much land could be spared for growing energy crops, but again the results are given additional credibility by being supported by other estimates.

Part 1 The consequences of needing controllable power in a renewable energy system

The basic idea, that the limits to the total power which can be produced via renewable energy sources will be determined by the amount of *controllable* power, could be expressed simply in terms of numbers and ratios. But the idea occurred to me when considering the impact of the 30 gigawatt (GW) capacity of what is planned as the largest offshore wind farm in the world, known as the London Array. It is somewhat easier to hold ideas in mind if a less abstract background is provided, so I will set out my two propositions, and how I support them, using the London Array as an example, with a close approximation to UK energy demand. Here are the two propositions:

1. If the London Array is built, it will constitute about the limit of what wind can contribute to an electrical system in the UK.
2. The corollary of item 1 is that wind power can contribute only about one third of the amount of electricity that can be provided to the grid from controllable sources, and that without fossil fuels, the amount of electricity that can be produced would be less than a quarter of the electricity we are consuming today.

Let us address the first proposition. The London Array is to have a capacity of 30 gigawatts. On past experience the actual output would be about a third of this, i.e. an 'average 10 GW'. UK electricity demand is about an average of 45 GW, but as we are essentially interested in fractions, and to keep the arithmetic simple, let us set a 'supposed' UK electricity demand of an average 40 GW, which makes the 'average 10 GW' from wind turbines amount to 25% of the total demand.

Because the wind turbines are not widely spread over the country, we could expect that sometimes they will collectively produce 90% of their capacity, i.e. 0.9 x 30 = 27 GW.

Low demand on an electrical system is about 60% of average demand, thus low demand on a system delivering an average 40 GW will be 24 GW. It is evident, therefore, that on occasions the wind array will produce 3 GW more than the low demand. It might be justifiable to let this go to waste or it might be accommodated by pumped storage capacity.

Note that the above is a best case scenario, since to allow all the 27 GW to be put into the system at times of low demand, all the controllable plant would have to be closed down, and if there is nuclear plant providing part of the mix, that would not be practical. However, as we are mainly looking at a longer term fossil-free and nuclear-free age, we might assume that nuclear plant does not add to the problem.

Turning now to the second proposition, in the above analysis *controllable* plant provides an average 30 GW while wind contributes an average 10 GW, i.e. wind is limited to contributing one third of what the controllable plant can contribute. Fossil fuels give an almost unlimited capacity to introduce controllable electricity into the system, but in their absence, burning biomass would provide the largest source of controllable electricity. To set an upper limit to controllable electricity, let us suppose that we could devote 6 million hectares, that is one third of all the UK's agricultural land, to providing controllable electricity, and that we can achieve the high yield of 8 tonnes of dry matter per hectare per year. That yield would produce a power density of 5 kW/ha, but some allowance must be made for harvesting it, so the *net* power density would be about 4.8 kW/ha.

Biomass does not burn as efficiently as gas; indeed the efficiency of producing electricity from biomass is only about 25%, so the *net* power density when producing electricity is 4.8 x 0.25 = 1.2 kW_e/ha. Thus the 6 Mha would produce an average 6 x 1200 = 7200 million watts, or 7.2 GW_e.

As previously established, wind could add one third to that amount of controllable electricity, making the total an average 1.33 x 7.2 = 9.6 GW_e. This is 9.6 / 40 = 24% of our 'supposed' UK electricity consumption. Note also that wind turbines actually occupy little land, a sufficiently small amount that we could approximate by ignoring it, so with the boost of a third from wind power, the *net* power density is 1.2 x 1.33 = 1.6 kW_e/ha.

Having used 6 million hectares to produce biomass for burning to support the wind turbines, there is little room to produce any additional energy, so it is relevant to consider this 9.6 GW_e (gigawatts of electrical energy) within the context of the UK's present *total* energy consumption. Averaged over the whole population, each person in the UK uses about 5 kW (5 x 24 = 120 kWh/day). For 60 million inhabitants, that amounts to 5 x 60 = 300 GW. Thus without allowing for the difference between electrical energy and thermal energy, the 9.6 GW represents only 9.6 / 300 = 3% of our present energy use. Two things are clearly going to be necessary: (a) To consider whether it makes sense to have such a large proportion of electrical energy; (b) To plan for a less extravagant use of energy.

Both of those matters are best tackled within the framework of considering the possible objections to the above conclusions. That is what we will do in Part 2.

Part 2 Considering possible objections to the analysis.

Every scientist should give serious consideration to possible objections raised against a proposed analysis. That is particular necessary when the conclusion is important and shocking; and surely both those things apply to the conclusion that the upper limit of energy that's likely to be supplied from renewable sources is somewhere in the region of 3% to 4% of what is being used today.

On frequent occasions, we in OPT have conceded the point that energy is used extravagantly in the UK, and that a civilized lifestyle could be maintained on two-fifths of the average 5 kW/person (5 x 24 = 120 kWh/day) that is currently used. As mentioned above, the overall use of energy in the UK is about an average 300 gigawatts. Two-fifths of that is 120 GW. Calculations in Part 1 showed that the total electricity that could be produced from renewable sources, using wind and biomass, had an upper limit of 9.6 GW_e. There are some advantages in having the power as electricity, advantages which we will explore, but the gap between 9.6 GW and 120 GW is alarming. It can be improved but not closed by the fact that the energy is being produced as electricity.

2.1 It is a mistake to generate so much electricity

This objection can be separated into two components. The first concerns heating. As stated above, the *net* power density that could be achieved when using wind and biomass together is 1.6 kW_e/ha, so it would seem apparent that, for heating purposes, it would be better to burn biomass directly, since the *net* power density estimated for that was 4.8 kW/ha. While that is possibly a valid objection, it is probably not, partly because it depends on the efficiency of burning biomass for heating, but more importantly because of the benefits that could be derived from using heat pumps. This is what MacKay says about them (2008, p. 147):

> Heat pumps are roughly four times as efficient as a standard electrical bar-fire. Whereas the bar-fire is 100%, the heat pump is 400%. The efficiency of a heat pump is usually called its *coefficient of performance* or CoP. If efficiency is 400% the coefficient of performance is 4.

He mentions elsewhere that some heat pumps have a CoP of 3 but the latest ones, produced in Japan, are as high at 4.9, so 4 seems a useful intermediate number to use. Thus the 1.6 kW_e/ha could be used to produce a heat of 1.6 x 4 = 6.4 kW/ha. Moreover when burning biomass directly, the full 4.8 kW/ha would not be obtained, because the useful output would be determined by the efficiency of the wood stove. MacKay (2008, p. 49) says that even a good wood boiler loses 20% of the heat up the chimney.

On the other hand, since there would be embodied energy in providing and maintaining heat pumps, as well as building and maintaining wind turbines, the advisability of first producing electricity must be in some doubt, but without including embodied energy, it seems reasonable to conclude that when it comes to producing heat, the aforesaid 9.6 GW_e can be multiplied by four, making it 38 GW. That is still far short of 120 GW, but a significant move towards it. But that 38 GW is a misleading simplification — one which we must rectify later — because it would not be desirable to use all the electricity to produce 'low level' heat via heat pumps.

The next question to address is how useful is the electricity from wind and biomass going to be to provide transport. Without the gain from a heat pump, the *net* power density for wind together with biomass is 1.6 kW_e/ha. That is better than the *net* power density which might be obtainable by using ethanol, 1.3 kW/ha.{1} Considering that electric motors are at least 80% efficient whereas internal combustion engines are only about 25% efficient, that would appear to make electricity a clear choice, but the high energy density of ethanol as compared to batteries (7.5 kWh/kg versus 0.1 kWh/kg) would probably mean that for certain tasks, for instance when using tractors, harvesters, and ground moving plant, ethanol would be preferable. Where electric cars can be used there is likely to be an advantage in using electricity. Once again the difference may not be clear cut when the embodied energy — with batteries needing fairly frequent replacement — is taken into account. Nevertheless there is a useful conclusion arising from these considerations, namely that since not all 9.6 GW_e is actually going to be used for 'low level' heat, we cannot legitimately, on the basis of heat pumps, increase that value by four to 38 GW, as mooted in the previous paragraph. We can get an idea of the scope for some increase if we allocate say three-quarters to producing heat, leaving the remaining quarter to be used for 'high level' heat and driving motors of one kind or another. Then the 9.6 GW_e can be increased to (9.6 x 0.75) x 4 + (9.6 x 0.25) = 31 GW. That is still only 26% of the 120 GW total energy required for a population of 60 million using much reduced energy.

2.2 There are already other renewables contributing to the system

It is true that hydropower and biogas contribute to the existing system, and both have a potential to increase slightly, but probably not dramatically. Moreover their current contribution is negligible. MacKay (2000, p. 111) puts the combination of small hydro and large hydro at 0.212 kWh/d/person, which is 0.4% of the 2 kW/p (48 kWh/d/p) that we are aiming to achieve in a reduced energy world. Biogas, including landfill gas, sewage, and waste incineration amount to 0.3 kWh/d/p which is 0.6% of that same reduced energy usage. So hydropower and biogas together contribute 1.0% of the total energy demand, of an average 120 GW, that would occur if all 60 million people reduced their energy demand by two-fifths, to 48 kWh per day per person.

2.3 There are other renewables in use which could contribute more to the system

We know enough about photovoltaics to make an analysis, but it makes little sense to include a significant amount of power from photovoltaics, because that is another uncontrollable, moreover a more troublesome uncontrollable than wind for two reasons. First, and most importantly, because in the UK it would have a capacity factor of only about 10%. That is to say there is a ten-fold difference between the average power it delivers and the peak power. (Incidentally even in places in the world with high insolation, the capacity factor is no higher than 20%, and although this is rarely appreciated, improvements in *efficiency* of the modules won't improve the *capacity factor*). Wind is usually considerably better in respect to capacity factor. Secondly, the power output from photovoltaics can change very rapidly, so that with extensive use it would probably be impossible to balance the rapid changes with controllable sources. Although it does not concern us in the UK, in countries which have a high electrical demand due to air conditioning, there is some advantage for photovoltaics because of the coincidence of the time of high output with a reliably high demand during the day. However the improbability of having enough electricity to spare to use air conditioners in a renewable energy world will already be apparent from this analysis.

2.4 Wave energy, although not fully controllable, could help

The extent of knowledge about capturing wave energy is too limited to allow us to put any trust in it at present. Excerpts from Heinberg (2009, p.54) will explain some of the problems:

> For current designs of wave generators the economically exploitable [global] resource is likely to be from 140 to 750 TWh per year [an average 16 to 86 GW]. The only operating commercial system has been the 2.25 MW Agucadora Wave Park off the coast of Portugal (however, this was recently pulled ashore, and it is not clear when it will be redeployed). …
>
> PROSPECTS: Wave power generation will need more research, development, and infrastructure build-out before it can be fairly assessed.

2.5 Solar thermal electricity (concentrating solar thermal) needs consideration

Satisfactory operation of solar thermal electricity plant depends on very high insolation. For Europe it would be a possibility only in the south, and by making use of land in north

Africa. At present, because of lack of storage capacity, it cannot be regarded as a source of *controllable* electricity. Because it is so dependent upon high insolation, there is a large difference between summer and winter output, even in the latitude of north Africa. Trainer (2007) produces figures on this derived from a long-standing experiment in the Mohave desert — about the same latitude as north Africa — with a collection of trough-mirror plants known as SEGS, but before considering the seasonal problem let us look at the diurnal problem.

Hayden (2004, p. 190) calculates the capacity factor of the SEGS plant as 22%. This is without storing sufficient hot fluid to be able to match demand throughout the 24 hours. With the heat losses involved in doing that, the capacity factor would be even lower, and of course the cost would rise because of the need to provide the storage facilities. But that problem is not the most severe. What looks to be an insurmountable problem is the seasonal variation already mentioned briefly.

Trainer (2007, p. 168) tells us that, "On a typical winter day output from SEGS VI reaches only one-quarter that of a typical summer day," and that the US National Renewable Energy Laboratory estimates SEGS VI's performance in winter to be only 20% of summer output. [2] There is no evidence so far that storage systems to flatten out this variation in output would be viable. Thus the use of solar thermal electric plant in distance lands remains a vague hope.

2.6 Demand could be flattened by the use of smart meters and intelligent devices

Without doubt this would be a help, but we need a handle on *how much* it could help. The most extreme hope would be to flatten out demand completely, so that on a summer weekend, demand is the same as on a winter work day. That seems well beyond the bounds of possibility, but it is nevertheless instructive to ask how much difference it would make.

It is possible to determine that by recalculating, after setting minimum demand equal to average demand, and ensuring that, as before, peak demand exceeds the average (now constant) demand by 3 GW. This steps up the fraction of the 'supposed' present *electrical* demand that could be satisfied from 24% to 30%. That 30% is an average 12.0 GW. As before, we can increase it by assuming the use of heat pumps for three-quarters of the electrical output: (12.0 x 0.75) x 4 + (12.0 x 0.25) = average 39 GW.

That is an improvement over the previous 31 average GW that was calculated without flattening demand completely, but it is still only 39 /120 = 33% of the average 120 GW which would be the demand of 60 million people each requiring only two-fifths of present total energy use, namely 2 kW per person (48 kWh/d/p). It would perhaps be more accurate to say that because demand is unlikely to be flattened completely, the output will be in the range 31 GW to 39 GW.

2.7 Why not use batteries to store the electricity?

The essential problem with batteries is their low energy density. Heinberg (2009, p. 20) puts the energy density of batteries in the range of 28 to 139 kWh per tonne. This compares to 11,700 kWh per tonne of oil. Let us look at the battery requirement for storing the output of a single 1000 MW power station operating at 60% of its capacity for 14 days. The output would be 202 million kWh. Even at 139 kWh/t that would require 1.4 million tonnes of batteries.

Reports in *New Scientist* have attempted to suggest that flow batteries, which allow large volumes of liquid to be stored in tanks, using vanadium sulphate as the electrolyte, will overcome the storage problem. That is a delusion: the energy capacity of the liquid is about

87 litres per kWh (Ferguson, 2008, p. 142), or an energy density of about 11 kWh per tonne — less than the lower limit of 28 kWh/t previously mentioned.

2.7 Pumped storage is already in use and could be expanded

It is almost impossible to do a theoretical calculation of the amount of storage that would be required, but some indications are available from an experiment funded by the German Economics Ministry that involved three companies and Kassel University. The experiment, called *Combined Renewable Energy Power Plant*, aimed to assess the potential contribution of combined pumped storage, wind, solar and biogas plant, scaling it to represent a 10,000th part of the electricity demand in Germany. As well as substantial wind and photovoltaics, biogas was available to supply 25% of demand. The biogas part was controllable, which of course is helpful. Based on the results of this experiment to mimic demand in the German system, it is possible to estimate that the amount of pumped storage capacity needed to deal with the uncontrollable input into the grid. On a per unit basis, it works out at about 41.6 MW/GWh of storage capacity. The UK has a pumped storage capacity of about 30 GWh. If all that were to be used to deal with uncontrollables, it would be able to support 30 x 41.6 = an average 1250 MW or 1.25 GW. As with batteries, the low energy density of pumped storage limits its usefulness.

2.8 Conclusion to Part 2

This analysis does no more than set a very loose upper limit to the size of population that could be sustained in the UK on renewable sources. The weakest link in the argument is the assumption — backed only by a general feeling for the matter, and choosing a high figure so as to avoid underestimation — that 6 million hectares, a third of UK agricultural land, could be used for growing energy crops. Nevertheless some guide is better than none, and on this premise the population that could be supported and provided with the minimum comfort of 2 kilowatts (48 kWh/day) per person would calculate as the 39 gigawatts of paragraph 2.6 divided by 2 kilowatts, amounting to 20 million people. What lends that estimate credibility is that it is of the same order as calculations we make based on eco-footprinting, which takes into account the need for food and fibres, and implicitly allows for energy on the basis of a *net* power density of 2.5 kW/ha. Excluding fishing grounds (probably not sustainable) our estimates for a Modest footprint lifestyle, using data from the Living *Planet Reports* 2002, 04, 06 and 08, were 22, 17, 19 and 19 million respectively. The most important conclusion is that the UK should be working towards a much smaller population, and other countries need to make similar assessments of their capacity to produce energy from renewable sources once fossil fuels no longer offer an almost unlimited amount of *controllable* power.

Part 3 Back-of-the-envelope calculations for the world and the USA

3.1 The world

Bearing in mind that the analysis provides only a loose idea of upper limits, a similar argument can be applied to the world. For these purposes we will not make the speculative assumption that demand can be flattened. In their 2003 assessment, the world Food and Agricultural Organization put the world forest area at 3.9 Gha. Let us make the wild, but undoubtedly optimistic, assumption that a third of this can be spared for growing energy crops. If this 1.3 Gha yields the aforementioned *net* 1.2 kW_e per hectare, the energy

captured would be an average 1560 GW_e. Wind power could add one third to this, i.e. 520 GW_e, for a total of 2080 GW_e. By either using heat pumps or by burning wood directly, on the same basis as before we can increase the value of this to:
(2080 x 0.75) x 4 + (2080 x 0.25) = 6760 GW.

The 2 kW per person figure — as a minimum — stems partly from Vaclav Smil, who showed, based on the experience of many countries, that this is a necessary minimum to maintain a fair standard of education and health care. But we should note that it is an average. Hayden (2004, p. 20) showed that prior to 1890, when electricity was introduced, energy use in the USA was 3.7 kW/person. Probably this is close to a minimum where the climate is more extreme. Nevertheless we can take 2 kW as an average. Dividing this into 6760 GW gives an upper limit to a population supportable at this minimum standard of 3.4 billion. Once again credibility is lent to this by it being within the range that emanates from eco-footprinting. Based on *Living Planet Reports* between 2000 and 2008 our estimates for numbers that could be supported at what we call a Modest footprint, that is a European lifestyle but with a drastic reduction of energy use from 5 kW to 2 kW per person, our estimates have been in the range 3.0 to 3.5 billion.

An important point to note is that even with the generous allocation of 1.3 billion hectares of forest, wind power could contribute only an average 520 GW_e. All 'true believers' in a smooth 'transition to renewable energy', which includes nearly all the media and all environmental organizations, estimate a huge contribution from wind. As the title of his paper suggests, Richard Heinberg is no 'true believer'; yet in *Searching for a Miracle* (2009, p. 55), while noting that the present contribution of wind is an average 18 GW, he gives it a "potential electricity production" (doubtless drawn from other sources) of 9500 GW, i.e. about 18 times the estimate given above based on taking account of the restraints imposed by the need for *controllable* power.

The point could be made that we have not included the significant contribution that comes from hydroelectricity. Heinberg (2008, p. 55) puts the annual electricity production from hydro at an average 330 GW_e. Dividing this between the above mentioned 3.4 billion people works out at 0.01 kW_e per person. Although there is also some potential for an increase in hydroelectricity, the amount per person would remain small.

3.2 The USA

If only the USA could stem the inward flow of immigrants, it would not be too difficult for it to achieve a sustainable population, although this would have been much easier if it were to have started in 1972 when the Presidential Commission recommended stabilization. Let us make the same very rough estimate for the USA of a population limited by the need for renewable power. The area of forest and woodland is 247 Mha and there is another 183 Mha categorized as "grassland in pasture (Pimentel, 200, p. 18). This time we include grassland because the Americans include an excessive amount of meat in their diet, and there is scope for using some of that for energy crops. Let us again allow that a third of all this 430 Mha can be spared for energy crops, i.e. 143 Mha. If this 143 Mha yields the aforementioned *net* 1.2 kW_e per hectare, the energy captured would be an average 172 GW_e. Wind power could add one third to that, i.e. 57 GW_e, for a total of 229 GW_e. By either using heat pumps or by burning wood directly, we can increase the value of this, on the same basis as before, to: (229 x 0.75) x 4 + (229 x 0.25) = 744 GW.

As mentioned previously, a 3.7 kW per person minimum would be more appropriate to the intemperate climate of the USA. The 744 GW thus allows a population of 201 million people. Again this is lent credibility by being not too far from such estimates as we have given based on eco-footprinting which we have only done with the caveat of the difficulty of making estimates for the USA because of the unsustainability of some of the farming methods employed, e.g. drawing down aquifers and loss of topsoil.

3.3 Main conclusions

The overarching point of this paper is that although uncontrollable power sources have a temptingly high power density, in a renewable energy world, their use is limited by the low power density achieved by photosynthesis — the main source of controllable power. And as to this section, the back-of-the-envelope calculations can be seen as just a rough check on our more rigorous eco-footprinting calculations, which use 2.5 kW/ha for energy calculations (OPTJ 2/2, p 2) . It is also necessary to reiterate the conclusion that with many countries barely aware of the need to control population, and with dire problems ahead associated with climate change, it is exceedingly improbable that the world as a whole will succeed in reducing population to a level that can be supported at a Modest lifestyle. As fossil fuels become scarce, there will not be the transport to allow us to maintain the globalization of the world that exists today. If civilization is to be preserved anywhere, it is very important that each nation considers what population it will be able to support without fossil fuels, and in making those calculations, that it remains aware of the difficulty of including a lot of uncontrollable power into its electrical system. Even the most impressive effort to date at looking at coming problems, David MacKay's *Sustainable Energy — without the hot air*, seems unaware of that particular difficulty.

References

Ferguson, A.R.B. 2008. Wind Power: Benefits and Limitations, in *Biofuels, Solar and Wind as Renewable Energy Systems: Benefits and Risks* (Ed. Pimentel D.). Springer. 504 pp.

Heinberg, R. 2009. *Searching for a Miracle "Net Energy" & the Fate of Industrial Society*, a joint project of the International Forum on Globalization and the Post Carbon Institute. (76 pp.)

Hayden, H. C. 2004. *The Solar Fraud: Why Solar Energy Won't Run the World* (2nd edition). Vales Lake Publishing LLC. P.O. Box 7595, Pueblo West, CO 81007-0595. 280 pp.

MacKay, D.J.C. 2008. *Sustainable Energy — without the hot air*. UIT Cambridge. ISBN 978-0-9544529-3-3. £20. Available free online from www.withouthotair.com

OPTJ 2/2. 2002. *Optimum Population Trust Journal*, Vol. 2, No 2, October 2002. Manchester (U.K.): Optimum Population Trust. 40 pp. Archived on the web at www.optimumpopulation.org/opt.journal.html

Pimentel, D, Pimentel, M. 2008. *Food, Energy, and Society*. Third edition. Boca Raton, Fl; London; New York: CRC Press. ISBN 978-1-4200-4667-0. CRC Press website http://www.crcpress.com

Trainer, T. 2007. *Renewable Energy Cannot Sustain a Consumer Society*. Dordrecht, the Netherlands: Springer. 197 pp. ISBN-13: 978-1-4020-5548-5 (HB); ISBN-13: 978-1-4020-5549-2 (e-book).

Endnotes

1. Since the inputs needed to produce ethanol from maize are about equal to the liquid output it could be said that the *net* power density is zero, but a less simplistic analysis, taking account of the type of input, puts the *net* power density at 1.3 kW/ha. Probably sugar beet would offer a better power density, but accurate input figures are not available for it.
2. Note that the whole of SEGS comprises nine units. SEGS VI is presumably one for which some precise summer and winter data has been collected.

SEARCHING FOR A MIRACLE: "Net Energy" Limits & the Fate of Industrial Society, by Richard Heinberg — a review essay by Andrew Ferguson

Abstract: Heinberg's booklet is a useful stimulus to thinking about the looming problems of energy. It uses data on Energy Return on Energy Invested to show that shortage of fossil fuels is likely to occur sooner rather than later. In addition to poor Energy Return on Energy Invested, it points out many of the possible obstacles, but its failure to consider power densities, and the related problem of integrating 'uncontrollables' into the grid, means that it does little to provide a guide to the limitations of energy supply, and hence the limits to population.

The 74 page paper under review, *Searching for a Miracle: "Net Energy" Limits & the Fate of Industrial Society*, by Richard Heinberg, with a foreword by Jerry Mander, was published in September 2009, as a joint project by the International Forum on Globalization and the Post Carbon Institute. For various reasons it does not fully address the fundamental question which is the focus of our activity in the Optimum Population Trust, namely to assess the size of national populations that might be sustained in moderate comfort without the benefit of fossil fuels. Nevertheless it produces some valuable insights, which is not surprising in view of its origins: Jerry Mander is co-author, with the late Edward Goldsmith, of *The Case Against the Global Economy*. Richard Heinberg has already tackled many aspects of our current problems, in books such as, *Power Down: Options and Actions for a Post-Carbon World* (2004), *The Party's Over*: *Oil, War, and the Fate of Industrial Societies* (2005), and *The Oil Depletion Protocol: A Plan to Avert Oil Wars, Terrorism, and Economic Collapse* (2006). An impressive collection, but *Searching for a Miracle* has shortcomings which we will now explore.

In the foreword, Jerry Mander says something with which OPT certainly agrees (p. 3):

> We are emphatically *not* against innovation and efficiencies where they can be helpful. But we are against the grand delusion that they can solve all problems, and we are against the tendency to ignore overarching inherent systemic limits that apply to energy supply, material supply, and the Earth itself.

The paper contains much of a similar nature, that we in OPT would heartily agree with, but I will focus on those areas where qualification and amplification seem necessary.

The paper is rather too focused on EROEI (Energy Return On Energy Invested). Important though that is, what is of equal importance is *net* power density (the amount of useful energy that can be steadily extracted from a given area of land). This is not addressed at all, at least not numerically. The nearest approach to addressing it is under the general heading *Energy Density*, where three aspects of energy density are treated:

A. Weight (gravimetric) density.

B. Volume (or volumetric) density.

C. Area density.

The first two are straightforward. Under C it is stated:

> This expresses how much energy can be obtained from a given land area (e.g., an acre) when the energy resource is in its original state. For example, the area energy density of wood as it grows in a forest is roughly 1 to 5 million MJ per acre.

The "as it grows in a forest" introduces some lack of clarity as to what is meant, but the figure of 1 to 5 million megajoules makes the amount of wood standing in a fully grown forest the most likely meaning. But if that is the case, the figures seem high. 1 million megajoules = 1000 GJ (gigajoules), and 1000 GJ per acre = 2470 GJ per hectare (ha). Dry wood has a calorific value of about 18 GJ/t so the lower figure of 1 million MJ represents 137 tonnes per hectare. 137 t/ha is just about plausible, but the higher figure of 685 tonnes per hectare seems implausibly high.[1] But that is not the main weakness: *energy density* measured this way is not nearly so important as the consideration of realistic yields per year. And when time is taken into account, what is being determined is the *power density*; or if one subtracts the inputs used in planting and harvesting, the *net* power density.

David MacKay (2008, p. 177) gives the power density of plants as 0.5 watts per square metre (W/m^2), or 5 kW/ha. Is that plausible? 5 kW/ha = 158 GJ/ha/yr, which represents nearly 9 tonnes of dried wood per hectare per year. Although that is high, it is about right for fast growing willow, and anyhow MacKay is referring only to "plants" in general. So overall 5 kW/ha is appropriate for farmed plants *when growing in close to ideal conditions*. The next point is how much that 5 kW/ha is affected by EROEI? On page 28 Heinberg gives the EROEI of firewood as about 30:1. That may be a bit high,[2] but it will do for this analysis, and it makes the *net* power density 29 / 30 x 5 = 4.8 kW/ha.

Heinberg says on page 8:

> Unfortunately, as we shall see in more detail below, research on EROEI continues to suffer from lack of standard measurement practices, and its use and implications remain widely misunderstood. …
>
> This report is not intended to serve as a final authoritative, comprehensive analysis of available energy options, nor as a plan for a nation-wide or global transition from fossil fuels to alternatives. While such analyses and plans are needed, they will require institutional resources and ongoing reassessment to be of value. The goal here is simply to identify and explain the primary criteria that should be used in such analyses and plans, with special emphasis on *net* energy, and to offer a cursory evaluation of currently available energy sources, using those criteria.

Thus the book is not attempting to give a full description of how EROEI is assessed. Nevertheless I think it is important to understand something the paper does not make clear, namely the relationship of EROEI to *net* power density, and in particular why EROEI is only one — and sometimes a small — part of the whole picture. To explain that point, let's take a specific example.

Suppose that the average ethanol yield is 3200 litres/ha/yr. That works out at a power density of 2.2 kW/ha (0.22 W/m^2 — the figure given by MacKay). Although the exact figure for inputs is open to dispute, it is generally found that for ethanol from maize the inputs are about equal to the output, i.e. the EROEI is 1:1. Now let us hypothesize (unrealistically) that all the inputs are required to be in liquid form. In that case all the 3200 litres of output would be required as input. Clearly there is no gain whatsoever, because all the output has to be used in the process of producing it. Nothing is left. The *net* power density is zero. In this hypothetical but *unrealistic* case the EROEI would be reflecting the *hypothesized* situation by showing that there was no gain whatsoever.

But now let us make the more realistic hypothesis that only 15% of the input is required to be in liquid form.[3] After subtracting that from the output we are left with a 'useful' output of 2720 litres/ha/yr, and the remaining input is reduced from 2.2 kW/ha to 1.87 kW. As this remaining input does not need to be in liquid form, we can use the aforementioned *net* power density for plants, 4.8 kW/ha, and thus satisfy the 1.87 kW using 0.39 hectares. The *net* power density now calculates as 1.87 / (1 + 0.39) = 1.3 kW/ha. That is a big improvement on the zero *net* power density previously calculated. However EROEI calculations take no notice of the *type* of input required, and thereby mislead. 1.3 kW/ha may seem so low that it is hardly worth bothering about anyhow, but having *some* liquid fuels when there are no fossil fuels available is likely to be so important that the point that ethanol can be produced *at that low power density* should not be artificially masked by EROEI calculations, as indeed it has tended to be, with many people thinking that an EROEI of 1:1 is a clinching argument that the process must be useless.

It might be thought that it would always be fairly easy to make the type of calculation just done, but in fact it would often be difficult, because the data available for embodied energy — in steel and cement for example — is not broken down into *liquid* input and *other* inputs. That is not surprising, as the matter only becomes of vital importance in a world in which producing energy in liquid form is the big challenge, as it currently looks as though it is going to be in a renewable energy world.

The unsatisfactory nature of considering EROEI without also considering *net* power density becomes apparent again when Heinberg says this about oils:

> Other researchers have claimed that the net energy of soybean biodiesel has improved over the last decade because of increased efficiencies in farming, with one study calculating an EROEI of 3.5:1. "Palm oil biodiesel has the highest net energy calculated by one study as 9:1.

Heinberg does lay stress on the fact that there are other factors to consider, such as environmental damage and dependence on additional scarce resources, but what is substantially lacking in the above information, and in the paper in general, is consideration of the *net* power density. For example, soybean oil might combine a high EROEI with a low *net* power density simply because the output of oil per hectare is low. Rapeseed oil and sunflower oil are also possible sources of liquid energy, but again the oil yield per hectare is as important as the EROEI in determining if they provide a practical solution.

Assessing the contribution of uncontrollables

What we have established so far is that:

(a) Substantially because of low yields, the amount of energy in liquid form that can be made available from renewable sources is low.

(b) Already low power density can be significantly attenuated by a need for high inputs, i.e. a low EROEI ratio produces an even lower *net* power density.

These two items suffice to mean that we must look assiduously at the possibilities of producing energy from sources which provide a higher *net* power density. Heinberg recognizes the problem of intermittency associated with these higher power density sources, but he does not produce an analysis of the extent of the problem yet, as MacKay (2008, p. 3) says, with respect to the possible contribution from renewable energy sources, "*We need numbers, not adjectives*" (my italics).

Once again the importance of a full analysis is best illustrated with an example. We have already seen that high *net* power density is the key to effectiveness. Let us focus on trying to produce the same amount of energy as a fair sized (1000 megawatt) power station, assuming that it operates at a capacity factor of 60%, i.e. it produces an average 600 MW, or 600 MWyr per yr (or 600 x 24 x 365 x 1000 kWh/yr). The reason that 60% is a typical figure is mainly that such power stations adjust their output according to demand. That is not possible with wind power, but let us look simply at producing the stated amount of electricity — that is producing an average 600 MW (an average 600,000 kW) in such a way that it is compatible with use on the grid.

The important difficulty about wind power is the problems it creates by its uncontrollable nature. On theoretical grounds it would seem likely that, because of this, wind can contribute no more than 25% of the total electricity requirement, the rest needing to be supplied from controllable sources. This conclusion is backed up by practical experience in Denmark, north west America (Bonneville Power Administration), and Spain. Let us now consider the difference it makes to the *net* power density to have to incorporate that proportion of controllable power.

MacKay (2008, p. 177) assesses the power density of wind as 2 W/m^2 (20 kW/ha). But that is taking into account the whole protected area needed around the wind turbine so as not to interfere with the adjacent wind turbines. The actual area that the wind turbine 'monopolises', combined with the required access roads, is variously estimated to be 2% to 5% of this 'protected' area. Moreover a substantial proportion of wind turbines will be offshore, using no ecologically productive land, so it is probably allowable to use the lower figure of 2% as an average, and thereby say that in terms of land monopolised wind turbines have a power density of 20 / 0.02 = 1000 kW/ha. It is now apparent why — uncontrollable though their output is — wind turbines appear to be a good prospect. But the momentous problem which is often overlooked, including in Heinberg's paper and for that matter in MacKay's book, is the almost fatal attenuation of the power density caused by the need for controllable inputs to balance the uncontrollable input from the wind turbines. That is what we will now try to analyse.

Heinberg mentions some *theoretical* studies, but then goes on to say (p. 41) that: "The average EROEI from just the operational studies is 18.1:1." There are several reasons why that ratio may be painting an unduly favourable picture, but for present purposes we can accept an average EROEI of 18 to 1. That reduces the *net* power density of average wind turbines to 1000 x 17 / 18 = 944 kW/ha. As noted, wind power can contribute 25% of the total electricity demand; thus wind can contribute an average 150 MW out of the 600 MW. At 944 kW/ha the area required is 150,000 / 944 = 159 ha. Put into the context of the UK's total area of ecologically productive land, about 19 million hectares, that is insignificant.

But then comes the problem. Namely the need to satisfy the remaining 75%, an average 450 MW, from *controllable* sources. When wind power is playing only a small part in the grid supply, then hydropower, which is partially controllable (not always available in dry periods) can be used, but that can quickly be exhausted as even the hydropower-rich Bonneville Administration has discovered (problems becoming apparent at 12% wind penetration). We need to use another controllable renewable source. Although biogas from trash can play some part, the main one that is apparent at the moment is based on using plant material in place of coal and gas. We calculated previously that the *net* power density of plants is 4.8 kW/ha, but we are now seeking to produce electricity. The efficiency with which plants can be converted to electricity is lower than for gas: 25% efficiency is in the ballpark. So the *net* power density when creating electricity from plants is 4.8 x 0.25 = 1.2 kW_e/ha. Thus the area needed to produce the remaining average 450 MW_e is 450,000 / 1.2 = 375,000 hectares. We can now combine that with the area needed for the wind turbines, to get an overall *net* power density of 600,000 / (375,000 + 159) = 1.6 kW_e/ha. We are near the 1.3 kW/ha *net* power density of liquid fuel. Electricity is in some ways valuable (for instance it can be turned into motion power more efficiently) but on the other hand, if we turn it into some form of portable fuel, perhaps hydrogen, then there would be further losses, and the *net* power density would be further attenuated.

As MacKay so wisely recognizes, it is helpful to turn overall large numbers into numbers that can be appreciated on a personal scale. Taking all uses into account — at home and in business — the average UK citizen uses about 5 kW (i.e. 5 x 24 = 120 kWh per day), which incidentally is about half that used by the average American. Suppose that by singular acts of frugality UK citizens manage to decrease their energy use to a mere 2 kilowatts of electricity per person. With a *net* power density of 1.6 kW_e/ha, each person would require 2 / 1.6 = 1.25 ha, or 12,500 m^2. Dividing the total area of the UK, 24 Mha, by the 60 million inhabitants, each person has only 4000 m^2. Certain things will alleviate that three-fold disparity. It may for instance be better to provide heat directly rather than turn it into electricity, and a little power will be available from hydropower, but since ecologically productive land is also needed for food and fibres, it becomes readily apparent why OPT estimates a sustainable population for the UK at around 20 million.

None of this comes out in Heinberg's analysis. The failure is due to: (a) not considering the *amount of controllable* input needed to operate an electrical system; (b) a failure to think in terms of *net power density*. To my mind, MacKay's mainly estimable book also suffers seriously from inadequate consideration of item (a).

An appreciation of these problems goes back a long way. In *Food, Energy, and Society* (Pimentel and Pimentel, 1996, p. 206) there is a table showing that to produce 1 billion kWh/yr of electricity from biomass requires 220,000 hectares. That works out as a power density of 0.52 kW_e/ha. That is much lower than the power density of 5 x 0.25 = 1.25 kW_e/ha which is implied by the figure of 5 kW/ha given by MacKay for "plants"; but as observed, MacKay's figure for "plants" is high. There is ample evidence, which is referenced by Pimentel, that the natural sustainable production of wood in both temperate and tropical forests is 3 t/ha/yr. Heinberg does point out that one of the main problems with assessing EROEI is in deciding what to assume as an appropriate yield.

Conclusion

Richard Heinberg steers his readers in essentially the right direction, namely to give earnest consideration to the looming problems of energy. He presents diminishing EROEI figures to make a sound case for the likelihood that fossil fuels will become scarce sooner rather than later. While it is useful to point out that EROEI is significant in relation to assessing renewable viability, Heinberg, in contrast to Vaclav Smil and David MacKay, gives no consideration to power densities, although as demonstrated above this is often the main key to assessing the extent of the problem.

References

MacKay, D.J.C. 2008. *Sustainable Energy — without the hot air*. UIT Cambridge. ISBN 978-0-9544529-3-3. 370 pp. (£20). Available free online from www.withouthotair.com

Pimentel, D, Pimentel, M. 1996. *Food, Energy, and Society*. Niwot Co., University Press of Colorado. 363 pp. (£30). This is a revised edition; the first edition was published by John Wiley and Sons in 1979.

Shapouri, H., Duffield, J.A., Wang, M. 2002. *The Energy Balance of Corn Ethanol: An Update*. United States Department of Agriculture (USDA), Agricultural Economic Report Number 813

1. 685 tonnes per hectare seems implausibly high because allowing say 60 years to grow to maturity that would indicate an astonishing growth rate of 11 t/ha/yr.
2. A useful value for the EROEI associated with harvesting wood is almost impossible to give, since a large part of the inputs would have to be in the form of liquids. In a renewable energy world it makes little sense to equate the calorific value of liquids with that of wood — a point dealt with at greater length in the main text.
3. In a USDA report, *The Energy Balance of Corn Ethanol: An Update* (Shapouri et al, 2002), 17% of the input was estimated to be in liquid form. However this is unlikely to be accurate, as the report did not try to deal with embodied energy at all, and anyhow were it to have tried it would have failed, as data to separate out the liquid inputs in embodied energy are not available.

THE PERILS OF POPULATION PROJECTIONS

by Andrew R.B. Ferguson

Abstract. Projections for the likely population of a country fifty years hence often vary wildly, because such projections depend on making a correct estimate of the intervening Total Fertility Rate. Even over a period of eight years, judgements about that rate can fluctuate sufficiently to paint an entirely different picture. For the undeveloped world, Total Fertility Rates are of prime importance. For the developed world, the vital factor tends to be migration, a subject that is treated elsewhere.

The perils faced by demographers in making population projections fade to insignificance when compared to the perils of overpopulation. Nevertheless projections shed some light on the overpopulation problem, so let's take a look at some projections made by the Population Reference Bureau (PRB) in their 2001 and 2009 World Population Data Sheets. The year 2001 is chosen because the PRB 2001 Data Sheet is the first one in my possession that shows projections for 2050. The most recent sheet available is 2009.

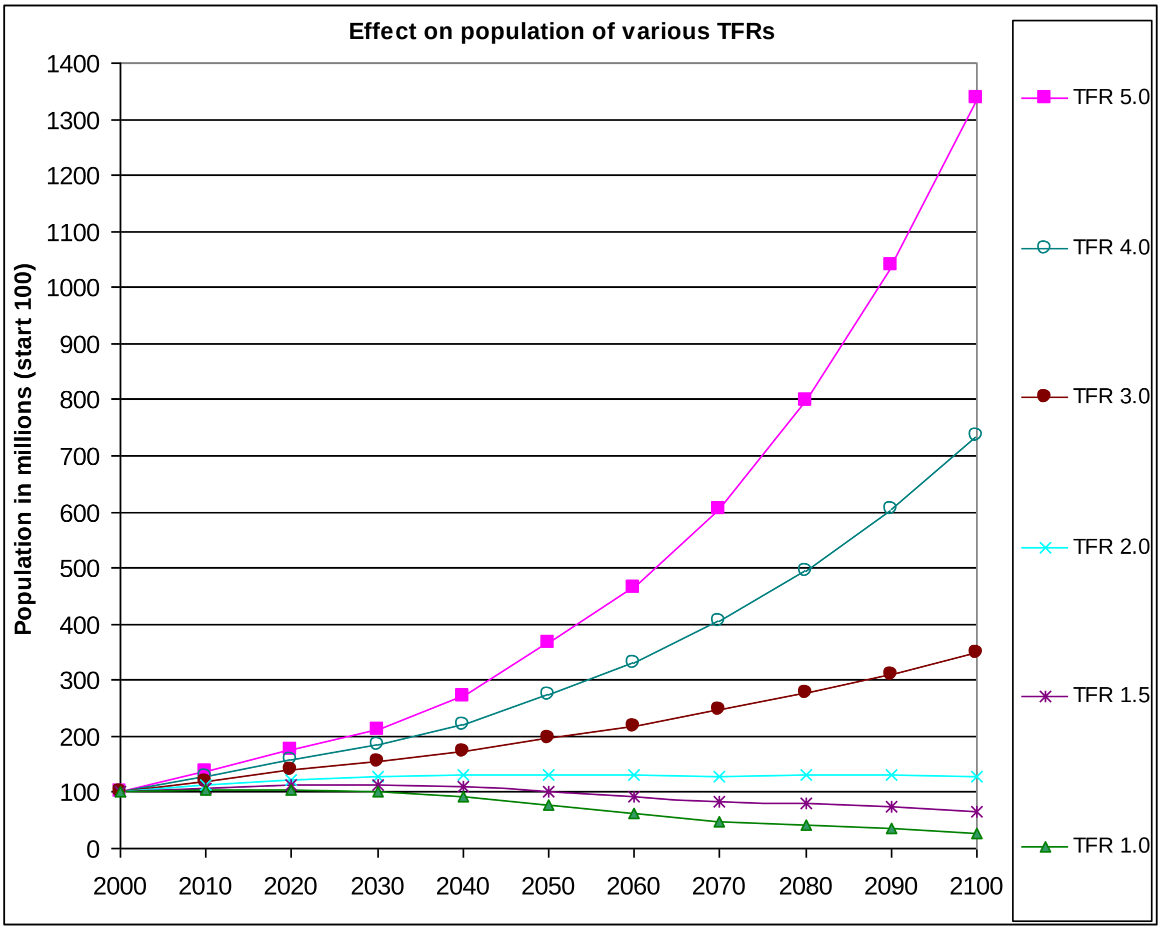
As will soon become apparent, much depends on the Total Fertility Rate (TFR) that is anticipated for the coming years. Figure 1 shows the dramatic differences in populations resulting from different TFRs. In the following text, I round figures to the nearest million (the PRB gives a decimal point figure because it is relevant to smaller nations).

I looked at the 19 states of east Africa, choosing three from the larger countries in which the 2001 projection was too *low*, and two where it was too *high*, when judged against the 2009 projection. Let us look at them in turn to see why the PRB decided that the earlier projections needed changing.

In 2001, Rwanda had a TFR of 5.8 and a population of 7 million. The PRB's projection for 2050 was 9 million. In order to achieve 9 million in fifty years time an average TFR of 1.9 would be required, so it is clear that in 2001 the PRB demographers were wildly optimistic. By 2009, with the TFR now 5.5, the population had risen to 10 million. In 2009 the PRB demographers raised their 2050 projection to 22 million, a 145% increase on the projection eight years earlier. To achieve that population in forty years, an average TFR of 4.0 would be required, so the PRB certainly learnt from their earlier 'error', raising the average TFR estimate from 1.9 to 4.0; but maybe they are still wrong, because death on a large scale is likely to occur long before a population of 22 million is reached.

Kenya presents a similar picture. In 2001, Kenya had a Total Fertility Rate (TFR) of 4.4 and a population of 30 million. The PRB's projection for 2050 was 37 million. In order to achieve 37 million in fifty years time an average TFR of 1.9 would be required, namely the same optimistic assumption as Rwanda. By 2009, the population had risen to 39 million. With the TFR now 4.9, the PRB raised their 2050 projection to 84 million, a 124% increase on the projection eight years earlier. To achieve that population in forty years, an average TFR of 3.9 would be required, so the PRB has learnt something, and raised TFR from 1.9 to 3.9, but recent droughts bring home the perils of any projections.

Figure 1. The effect of TFRs, starting from an age-spread of population that obtains at present, but assuming an improvement in infant mortality as per the developed world.



Using the projection made in 2001, Zimbabwe presents a picture of such extreme optimism that it seems likely to be just a slip by the PRB. The starting population of 11 million was projected to drop to 9 million by 2050. In order to achieve that an average TFR of 1.1 would be required! By 2009, the population was 12 million, and the PRB raised their 2050 projection to 19 million, a 105% increase on the projection eight years earlier. To achieve that in 40 years would require an average TFR of 2.5. There is some plausibility in that projection, but of course it is political realities that will determine what actually happens.

Ethiopia presents a reverse case in that the projection made in 2001 was *higher* than that made in 2009. The reason is apparent. The PRB demographers were very pessimistic about any drop in TFR. The TFR in 2001 was 5.9 and the population 65 million. The projection was for a population of 173 million. To achieve that in fifty years would need an average TFR of 3.9 (compare that with the 1.9 assumed for Rwanda and Kenya). It is not surprising therefore that by 2009 the 2050 projection could be brought down slightly, a 13% decrease to 149 million, implying a possibly realistic average TFR of 3.2.

Madagascar's situation is similar to Ethiopia. Its TFR in 2001 was 5.8 and its population 16 million. To achieve the 2050 projection of 47 million implies an average TFR of 4.1. It would seem at least possible that Madagascans might do better than 4.1. By 2009, the PRB thought that they could, but only slightly. The new projection of 42 million indicates an average TFR of 3.9.

To sum up the results of those five countries in east Africa, the 2001 estimates were revised eight years later, so that that the new projections, in relation to the earlier projections, were 145%, 124%, 105% higher, and 13% and 10% lower. The implication must surely be that projections should not be trusted, but rather there is a need to study in detail the efforts being made by each country to contain its population, and to appreciate that although some countries may succeed, many will fail. It is idle to assume that nations which control their populations will, in the longer term, be able to feed those which fail to do so. And it is indeed arguable that countries which feed nations, like the UK, where the population already exceeds the population that is sustainable, are only storing up a greater disaster for the future. But the UK is a developed nation, and because of migration developed nations are different from undeveloped nations.

While it makes sense to consider TFRs alone for some countries, such as those in east Africa, the problem for most of the developed world is different. In the developed world, a generally healthy TFR is threatened by unbalanced immigration, which problem is compounded by the newcomers bringing with them the higher TFRs of the nations from whence they came. That is an issue already covered in some detail in an article in the October 2009 OPT Journal, *International Migration and Overpopulation*, pages 19-23, by James Duguid and Andrew Ferguson, and will not be dwelt on here.

Acknowledgement

I have Eric Rimmer to thank for having stimulated me into thinking about the implications of widely varying population projections. Also for contacting a colleague in the PRB, who made some interesting background observations. Africa is the most difficult place because its high TFRs and variable death rate, and the PRB demographers often use UN or US Census Bureau projections after consulting with their demographers. For developed countries, they use country's official projections in nearly every case.