NPG NEGATIVE POPULATION GROWTH

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Land, Energy and Water:

The Constraints Governing Ideal U.S. Population Size

by David and Marcia Pimentel

This is the third of a series of NPG FORUM papers, exploring the idea of optimum population. As the United States' population continues to grow, NPG believes it essential to the national well-being that debate be initiated on the question: what is the optimum population? The question does not lend itself to formal proof. There are too many assumptions and variables and value judgements. Yet it should be addressed. We have asked several distinguished scholars in different areas of specialization to attempt an answer to the question, even if the answer must rest in part on intuition and feelings.

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Introduction

For most of this century, leading scientists, public officials, and various organizations have been calling attention to the rapidly growing human population and the deteriorating environment throughout the world (Ehrlich and Holdren, 1971; Meadows et al., 1972; CEQ, 1980; Keyfitz, 1984; Demeny, 1986; Hardin, 1986). Based on these assessments, genuine concerns about maintaining prosperity and quality of human life in the future have been expressed.

In the United States, humankind is already managing and using more than half of all the solar energy captured by photosynthesis. Yet even this is insufficient to our needs, and we are actually using nearly three times that much energy, or about 40% more energy than is captured by all plants in the United States. This rate is made possible only because we are temporarily drawing upon stored fossil energy. We are approaching the end of the petroleum era, and other fossil fuels are not inexhaustible. Moreover, the very use of these fossil fuels, plus erosion and other misuse of our natural resources, are reducing the carrying capacity of our ecosystem.

These are not sustainable conditions, and our natural resources cannot be expected indefinitely to maintain a population as large as the present one, without a remarkable decline in our living standards.

Thus far, our society appears unable to deal successfully with problems of the environment, resources, and population. It has a poor record of effectively managing and protecting essential environmental and natural resources from over-exploitation caused by ignorance, mismanagement, and the impact of growing human numbers. History suggests that these escalating problems exist because the United States has not developed a cohesive policy that recognizes a specific standard of living for its citizens, while clearly acknowledging that the attainment of such a standard depends on the interaction of environment, resources, as well as population density.

When decisions concerning the environment and natural resources are made in the United States, and indeed throughout the world, they are ad hoc in nature and are designed to protect or promote a particular or immediate aspect of human well-being and/or the environment. All too often solutions are sought only after a problem reaches a crisis status. As Benjamin Franklin wrote long ago in *Poor Richard's Almanac*, "it is not until the well runs dry, we know the worth of water." Based on experience, it will not be until the pressure of human population on the environment and resources becomes intolerable that some corrective action will be taken by individuals and governments. Then it may be too late to avert hunger and poverty.

In this essay, we examine the degradation of the environment, the consumption of nonrenewable resources, population growth, and the possible decline in U.S. prosperity. We also suggest that **dramatically reduced U.S. population densities would insure individual prosperity and quality environment for future generations.** The goal is to have sufficient information and understanding of the problems so that sound policies are possible.

Resources and Population Density

Innate human behavior indicates a strong will to survive and to achieve some level of prosperity and quality lifestyle. Nations as well as individuals differ in their perception of what they consider a good life for themselves. A comparison of some aspects of life in the United States and China reveals startling extremes and clarifies what Americans can expect in the future if our population continues to grow at its present rate. Both birthrates and immigration function in the population equation.

The present population of the United States stands at 246.1 million and is growing at a rate of about 1% per year (depending on one's estimates of emigration and illegal immigration). If the number of immigrants coming into the United States increases, the rate of U.S. population growth will increase. China has a population of 1.1 billion, and despite the government's policy of one child per couple it is growing at a rate of 1.4% or 15 million per year (PRB, 1988).

Statistics suggest that in the United States **we produce and consume about 47 times more good and services, per capita, than China does** (PRB, 1986). Because achieving and maintaining such consumption levels depends upon the availability of resources and the health of the environment that sustains them, our position is very tenuous when projections of future resource availability are considered.

Currently, approximately 1,500 kg of agricultural products are produced annually to feed each American while the Chinese make do with only 594 kg/capita/yr (Table 1). To produce food for each person in the United States, a total of 1.9 ha of cropland and pastureland is used, whereas in China only 0.4 ha/person is used (Table 2). The data in these tables confirm that each person in China is fed essentially a vegetarian diet and that they have nearly reached the carrying capacity of their agricultural system.

Since colonial times and especially after 1850, Americans have relied increasingly on energy sources other than human power for their food and forestry production. Relatively cheap and abundant supplies of fossil fuel have been substituted for human energy. Thus, man-made fertilizers and pesticides as well as machinery have helped our farmers and diminished the level of personal energy they must expend to farm. **The Chinese** have not been as fortunate and **still depend on about 1,200 hours/hectare (h/ha) of manual farm labor, compared with only 10 h/ha in the United States** (Wen and Pimentel, 1984).

Industry, transportation, heating homes, and producing food account for most of the fossil energy consumed in the United States (Pimentel and Hall, 1984, 1989). Most fossil energy in China is used by industry and a lesser amount for food production (Kinzelbach, 1983; Smil, 1984). Per capita use of fossil energy in the United States amounts to about 8,000 liters of oil equivalents per year or 20 times the level in China (Table 2).

China, with its population of 1.1 billion and a land area similar to ours, already is experiencing diminished per capita supplies of food and other essential resources, plus a deteriorating natural environment as evidenced by the loss of forests and intense soil erosion. The relative affluence presently enjoyed by Americans has been made possible by our abundant supplies of arable land, water, and fossil energy relative to our present population numbers. As our population escalates, our resources inevitably will experience pressures similar to those now experienced by China.

Table 1. Foods and feed grains consumed per capita (kilogram) per year in the United States and China (Pimentel et al., 1989).

Food/feed	USA[a]	China
Food grain	69	269[b]
Vegetables	112	204[c]
Fruit	63	11[d]
Meat and fish	103	25[d]
Dairy products	265	3[d]
Eggs	15	6[d]
Fats and oils	28	6[d]
Sugar	66	6[d]
TOTAL	721	530
Feed grains	801	64[b]
GRAND TOTAL	1,522	594
Kilocalories/person/day	3,500	2,484[e]

[a]USDA, 1985.

[b]Total grain production per capita in 1985 was 364 kg (CDAAHF, 1986). It is estimated on the basis of some unpublished data that 8.5% of the total grain production was used for seeds and industrial materials, 17.5% for feed and 74% for food (Wen, personal communication, 1987).

[c]Estimated on the basis of total vegetable planting area (Wen, personal communication, 1987).

[d]CDAAHF, 1986.

[e]CAA, 1986.

Table 2. Resources utilized per capita per year in the United States and China to supply basic needs (Pimentel et al., 1989).

Resources	USA	China
Land		
Cropland (ha)	0.6[a]	0.1[b,c]
Pasture (ha)	1.3[a]	0.3[b]
Forests (ha)	1.3[a]	0.1[b,d]
TOTAL	3.2	0.5
Water (liters x 10^6/yr)	2.5[e]	0.46[c]
Fossil Fuel		
Oil equivalents (liters)	8000[f]	413[g]
Forest Products (tonnes)	14[a]	0.03[c,d]

[a]USDA, 1985.
[b]Wu, 1981.
[c]Smil, 1984.
[d]Vermeer, 1984.
[e]USWRC, 1979.
[f]DOE, 1983.
[g]State Statistical Bureau PROC, 1985.

Status of U.S. Environmental Resources

Basic to making decisions about our future is the need to assess both the quality and quantity of land, water, and energy, as well as biological resources we will have at our disposal in coming decades. At our present population level of 246 million we are affluent consumers of all these vital resources, many of which are being depleted, with no hope of renewal after the next 100 years. Although these components function inter-dependently, they can be manipulated to make up for a partial shortfall in one or more. For example, to bring desert land into production, water can be applied to the land, but only if ground-water or river water is available and if sufficient fossil energy is available to pump the water. This is the current practice in California and many other western states, enabling some of our western agricultural regions to be highly productive.

Land, that vital natural resource, is all too often taken for granted; yet, it is essential for food production and the supply of other basic human needs, like fiber, fuel, and shelter. Currently, Americans use about 0.6 ha/capita of arable land to produce our food. Nearly all the arable land is in production, and in fact some marginal land is also in production (Pimentel and Hall, 1989). Thus, Americans do not have new arable land to open up to take care of a growing U.S. population.

At present the soil on U.S. cropland is eroding at rates that average 18 t/ha/yr (Lee, 1984). This is of particular concern because soil reformation is extremely slow; thus, **we are losing topsoil 18 times faster than replacement** (Pimentel et al., 1987). Even now, in what used to be some of our most productive agricultural regions, soil productivity has been reduced 50%, and in some areas it has been so severely degraded that it has been abandoned (Follett and Stewart, 1985).

All arable land that is currently in production, and especially marginal land, continues to be highly susceptible to degradation (OTA, 1982; Follett and Stewart, 1985). Although some marginal land has been withdrawn under the new Conservation Reserve Program, all marginal land cannot be removed from production because it is essential to feed Americans. Certainly, efforts should be made to implement soil and water conservation practices on both arable and marginal land (OTA, 1982).

Despite serious soil erosion, U.S. crop yields have been maintained or increased because of the availability of cheap fossil energy for inputs like fertilizers, pesticides, and irrigation (Pimentel et al., 1987). Currently on U.S. farms, **about 3 kcal of fossil energy are being spent to produce just 1 kcal of food.** Our policy of supporting this 3:1 energy ratio has serious implications for the future. One cannot help but wonder how long such intensive agriculture can be maintained on U.S. croplands while our nonrenewable, fossil energy resources are being rapidly depleted.

In addition to use in agricultural production and throughout our entire food system for processing, packaging, and transportation, fossil energy is used to fuel diverse human activities. Overall fossil energy inputs in different economic sectors have increased 20- to 1,000-fold in the past three decades, attesting to our heavy reliance on this energy (Pimentel and Hall, 1984, 1989).

Projections of the availability of these energy resources are not encouraging. In fact a recent study published this year by the Department of the Interior reports that, based on the most current oil drilling data, the estimated amount of oil resources has plummeted. This means that instead of having about a 35-year supply of oil we are now limited to a 16-year supply—if use remains at about the current rate. Concurrently, natural gas, an important energy resource, is being rapidly depleted (Mataré, 1989). Reliable estimates indicate that coal reserves are sufficient to last for more than a century (Schilling and Wiegand, 1987; USBC, 1988). Note that nuclear energy is also limited because uranium resources also are facing eventual depletion (Mataré, 1989). A larger population can be expected to put additional stress on usage of all energy resources. Thus, considering population growth and the forecasts about our nonrenewable energy supplies, all efforts need to be focused on conserving current supplies while intensifying research on developing new energy sources.

Along with land and energy supplies, we take **water** supplies for granted and often forget that all vegetation requires and transpires massive amounts of water. For example, a corn crop that produces about 7,000 kg/ha of grain will take up and transpire about 4.2 million liters/ha of water during just one growing season (Leyton, 1983). To supply this much water to the crop, not only must 10 million liters (1,000 mm) of rain fall per hectare, but it must be evenly distributed during the year and especially during the growing season.

Of the total water currently used in the United States, 81% is used in agriculture while the remainder is needed for industry and for public use (USWRC, 1979). In the future, the rate of U.S. water consumption is projected to rise both because of population growth and because of greater per capita use (USWRC, 1979; CEQ, 1983). The rapid increase in water use already is stressing both our surface and groundwater resources. **Currently, groundwater overdraft is 25% higher than its replenishment rate** (USWRC, 1979) with the result that our mammoth groundwater aquifers are being mined at an alarming rate. In addition, both surface and groundwater pollution have become a serious problem in the United States, and concern about the future availability of pure water is justified (CEQ, 1980).

Threats to those Resources

Pollution is pervasive throughout our environment and degrades the quality and availability of resources like water, land, air, and biota. For example, when salts are leached from the land during irrigation (up to 18 tons of salts per hectare during the growing season) and deposited in rivers, the effectiveness of the river water for further irrigation is reduced (Pimentel et al., 1982).

Air pollution has a more pervasive impact than water pollution. In the United States, the estimated 21 million metric tons of sulfur dioxide from factories and cars that are released into the atmosphere annually cause serious environmental problems in both our natural and agricultural environments (EPA, 1986). For example, acid rain produced in part from sulfur dioxide is having major environmental impacts on aquatic life in streams and life in U.S. forests.

Further, a wide array of chemical pollutants are released to the air, water, and soil and already are adversely affecting the growth and survival of many of the 400,000 species of natural plants and animals that make up our natural environment. For example, each year about 500 million kg of toxic pesticides are applied to control pests, but all too often kill beneficial species as well. Some of these pesticides leach into groundwater and streams, damaging the valuable plants and animals that inhabit surface waters (Pimentel and Levitan, 1986; Pimentel et al., 1990).

In addition to toxic chemicals, the conversion of forests and other natural habitats to croplands, pastures, roads, and urban spread, in response to expanding population numbers is reducing biological diversity of plants and animals. These **natural biota are vital for the recycling of organic wastes, degrading chemical pollutants, and purifying water and soil** (Pimentel et al., 1980). Further, **they are the essential reservoirs of genetic material for agriculture and forestry**.

Transition from Fossil to Solar Energy

Instead of relying on the finite supplies of fossil energy, research must be focused on ways to convert solar energy into usable energy for society. Many solar energy technologies already exist, including solar thermal receivers, photovoltaics, solar ponds, hydropower, as well as burning biomass vegetation. Using some technologies, biomass can be converted into the liquid fuels, ethanol and methanol (ERAB, 1981, 1982).

As recently as 1850, the United States was 91% dependent on biomass wood or solar power for energy (Pimentel and Pimentel, 1979). Gradually that has changed until today we are 92% dependent on fossil energy while biomass energy makes up only 3% of the fuel we use (Pimentel et al., 1984).

Looking to the future, reliance on biomass energy use will grow and again become one of our dominant forms of solar energy (Pimentel et al., 1984). However, use of biomass has major limitations. Consider that the total amount of solar energy captured by vegetation each year in our country is about 13×10^{15} kcal (Pimentel et al., 1978). This includes all the solar energy captured by agricultural crops, forests, lawns, and natural plants. According to all estimates this yield cannot be increased to any great extent (ERAB, 1981).

Furthermore, the total solar energy captured by our agricultural crops and forest products is about 7×10^{15} kcal or slightly more than half the total solar energy captured (ERAB, 1981). Because this portion of biomass energy provides us with food, fiber, pulp, and lumber, it cannot be burned or converted into biomass energy.

Another factor to consider is that only 0.1% to 0.2% of the total solar energy per hectare can be harvested as biomass in the temperate region (Pimentel et al., 1984). This is because solar energy is captured by plants only during their brief growing season and for three-quarters of the year most plants are not growing (ERAB, 1981). To solve this problem will necessitate the use of relatively large land areas and large capital equipment investments for conversion of the energy into usable form.

This same biomass vegetation provides the food and shelter for a wide variety of important natural biota that help keep our natural environment healthy. Some species recycle wastes and nutrients, others help clean our air, soil, and water of pollutants. Without sufficient biomass these essential processes would stop.

Yet at our present population level, to sustain our lives and activities we are burning 40% more fossil energy than the total amount of solar energy captured by all plant biomass (ERAB, 1981). Clearly, our consumption of resources, especially nonrenewable fossil fuels, is out of balance with our supplies. The plain fact is that we are depleting these resources at an alarming rate and we now need to find and develop other energy sources.

Because almost three-quarters of the land area in the United States is devoted to agriculture and commercial forestry (USDA, 1987), only a relatively small percentage of our land area is available for harvesting biomass and other solar energy technologies to support a solar energy-based U.S. economy.

The inevitable conclusion is that **the availability of land will be the major constraint to the expanded use of solar energy systems** because land is needed for solar energy, and this need cannot encroach on that needed by agriculture, forestry, and natural biota in the ecosystem. Our expanding human population can be expected to put increasingly great pressure on land availability and use.

The amount of land required to provide solar-based electricity for a city of 100,000 people illustrates the land constraints. To provide the needed 1 billion kWh/yr from wood biomass would require maintaining 330,000 hectares of permanent forest (Table 3). Even hydropower is, in part, land based, because on average it requires 13,000 hectares of land for an adequate size reservoir. Then too, the land used for the reservoir is often good, productive agricultural land (Pimentel et al., 1984). Thus, solar energy and hydropower have serious land and environmental limitations. Note that nuclear and coal-fired power plants, including mining, require relatively small areas of land compared to biomass and hydropower production.

Table 3. Land resource requirements for construction of energy facilities that produce 1 billion kWh/yr of electricity for a city of 100,000 people (Pimentel et al., 1989).

Electrical Energy Technology	Land in hectares
Solar Thermal Central Receiver	800
Photovoltaics	600
Wind Power	2,700
Hydropower	13,000
Forest Biomass	330,000
Solar Ponds	9,000
Nuclear	68
Coal	90

Unfortunately, **the conversion of biomass like corn into energy such as liquid fuels requires enormous inputs of fossil energy**. For example, about 1.5 liters of oil equivalents are used to produce 1 liter of ethanol equivalents (ERAB, 1981; Pimentel et al., 1988). Thus, under optimal conditions only about one-third of the biomass can be converted into valuable liquid fuels (Pimentel et al., 1988). Even if we quadrupled the efficiency so that 1 kcal of fossil energy produced 2 kcal of ethanol, about 10 acres of corn land would be required to fuel one U.S. automobile per year (Pimentel et al., 1988).

If we make the optimistic assumption that the amount of solar energy used today could be increased about 3- to 10-fold without adversely affecting agriculture, forestry, or the environment, then from 3 to 10×10^{15} kcal of solar energy would be available (Pimentel et al., 1984; Ogden and Williams, 1989). This is one-fifth to one-half the current level of energy consumption in the United States, which is about 20×10^{15} kcal and averages 8,000 liters of oil equivalents per capita per year (USBC, 1988). One possibility is that fusion energy will eventually be developed and make up the shortfall. The odds for this happening in time are about 1 in 1,000 (Mataré, 1989), and further, the intense heat its production generates would have to be overcome.

Toward a Sustainable Agriculture

Analyzing the 1100 liters of oil we now use to produce food on one hectare of land suggests ways we might decrease that fossil-based energy expenditure. Both fertilizers and pesticides are lost or wasted in agricultural production. For instance, about $18 billion per year of fertilizer nutrients are lost as they are eroded along with soils (Pimentel, 1989). Further, livestock manures, which have 5 times the amount of fertilizer nutrients used each year, are underutilized, wasted, or allowed to erode along with soil. Much fossil energy could be saved if effective soil conservation methods were to be implemented and manures were used more extensively.

Another waste occurring in agriculture that affects energy use can be attributed to pesticides. **Since 1945 the use of synthetic pesticides in the United States has grown 33-fold, yet our crop losses continue to increase** (Pimentel et al., 1990). More pesticides have been used because agricultural technology has drastically changed. For example, crop rotations have been abandoned for many major crops. Now about 40% of our corn acreage is grown continuously as corn and this has resulted in an increased number of corn pests. Despite a 1,000-fold increase in use of pesticides on corn-on-corn, corn losses to insects have risen 4-fold.

Improved agricultural technology and a return to crop rotations would stem soil erosion, conserve fertile land, reduce water requirements for irrigation, decrease pesticide and fertilizer use and thereby save both fossil fuels and water quality. **The use of more land to produce food reduces the total energy inputs needed in crop production and would make agriculture more solar energy dependent and sustainable.** For example, instead of raising a given crop on one hectare with an energy input of about 1100 liters of oil, the use of two hectares for the same crop would make possible a reduction in energy inputs from 50% to 66% (Pimentel et al., 1988).

This of course assumes the availability of sufficient land, and a halving of yields per hectare. Some estimates suggest that if losses, waste, and mismanagement were eliminated, we would be able to produce present yields of food on the same amounts of land with one-half the energy outputs, and still have a more sustainable system (Pimentel et al., 1989). This should probably be considered an upper boundary. Since arable land cannot be much expanded, and since we have already hypothesized the diversion of some land to solar energy uses, **prudence would suggest that in planning any such shift to sustainable practices we anticipate lower yields and lower total production.** This, in turn, forces a choice between a smaller population, or a less well fed one.

Prosperity and Population

If the United States were to move to a solar energy-based economy and become self-sustainable, what would be our options and levels of prosperity? With a self-sustaining solar energy system replacing our current dependence on fossil energy, the energy availability would be one-fifth to one-half the current level. Then if the U.S. population remained at its present level of 246 million, a significant reduction in our current standard of living would follow. This would occur even if all the energy conservation measures known today were adopted.

If, however, the U.S. population wishes to continue its current high level of energy use and standard of living and prosperity, then its ideal population should be targeted at 40-100 million people. With sound energy conservation practices and a drastic reduction of energy use per capita to less than one-half current usage, it might be possible to support the current population. One projection suggests a significantly lower population level and the other a dramatic reduction in the standard of living. On the positive side, however, we do have sufficient fossil energy, especially coal, to help us make the needed transition in energy resources and population numbers over the next century, if we can manage the environmental impacts.

Conclusion

At present levels of fertility and migration, the U.S. population will rise one-third by 2080. A modest increase in fertility could drive it past a half billion. We could be heading eventually toward population densities like those in present-day China. Comparisons to China clearly emphasize why the United States will be unable to maintain its current level of prosperity and high standard of living, which is based on its available land, water, energy, and biological resources. We know that supplies of fossil energy, a nonrenewable resource, are being rapidly depleted. In just a few years, most U.S. oil resources will be consumed. Fortunately, natural gas reserves will last for nearly 50 years while coal reserves will carry us beyond the next century.

Therefore, we must start now to make the slow transition from our dependence on fossil fuels to development of solar energy power as our major energy resource. For the United States to be self-sustaining in solar energy, given our land, water, and biological resources, our population should be less than 100 million—significantly less than the current level of 246 million. However, with a drastic reduction in standard of living, the current population level might be sustained. With planning and determination, the United States could gradually reduce its numbers to more manageable levels.

The available supply of fossil fuels, especially coal, will provide the time we need to make the necessary adjustments involving new solar energy technologies and agricultural practices. Coupled with this, Americans will have time to change their behavior and respect for natural resources and the environment.

With a population of 40 to 100 million, the United States could become self-sustaining on solar energy while maintaining a quality environment, provided that sound energy conservation and environmental policies were in effect to preserve soil, water, air, and biological resources that sustain life. With these far-reaching changes, we feel confident that future generations of Americans would be able to enjoy prosperity and have a high standard of living. Starting to deal with the future before it reaches crisis level is the only way we will be able to avert real tragedy for our children's children. By education, fair population control, sound resource policies, the support of scientific research, and all people working together, Americans will be able to face the future with optimism and pride.

FOOTNOTES:
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