INTERNATIONAL JOURNAL OF DEVELOPMENT *ISSUES*

VOL. 4 • No. 2 **December 2005**

CONTENTS

International Journal of Development Issues
Vol. 4, No. 2 (2005) 1-20

Challenges of sustainable development under globalisation*

Jeffrey D. Sachs

Director, Earth Institute at Columbia University, USA
Director, United Nations Millennium Project
sachs@columbia.edu

Abstract

The paper asks a basic question: Is there any room for more growth on the globalising world that takes into account the budget constraints of ecosystems and the planet's scarce resources? Economists tend to be very complacent about sustainability issues on the planet because they have been a problem throughout human history. Yet technological change has always solved these problems. There is an element of truth to that, but there is probably a greater element of falsehood to it now. The element of truth is that, with sufficient science, we are able to make lots of progress in many areas; but the element of falsehood is that solving the problems of sustainability will become increasingly difficult.

1. Introduction

I would like to draw your attention to what we are doing at the Earth Institute, an interdisciplinary venture at Columbia University. The Earth Institute is organised around the theme of sustainable development. I want to talk about the challenge of sustainable development - not in enormously formal and technical terms, but mainly in policy and programmatic terms - and where we at the Earth Institute see the greatest challenges, and where we are trying to define our own approaches.

The Earth Institute is an interdisciplinary institute of earth process scientists, climatologists, seismologists, ecologists, environmental engineers, public

* This is an edited version of the lecture delivered on 14 October 2005 by the author at the School of Economics and Political Science, University of Sydney, New South Wales, Australia.

health specialists, economists and corporate policy experts. Sustainable development is the core component of our work together. We are trying to figure out a fairly basic question, which is whether there is such a thing as sustainable development. It is a contentious issue, and one that is far from settled. Indeed there are very serious minds on all sides of this important question. Another way of putting the question is to ask whether we can have development process on the planet in an environmentally sound way, or are we already reaching critical limits to environmental sustainability. I think there is much scientific uncertainty about a lot of the most critical issues.

Is there room for more growth on the planet? If we have run out of room, we have got a horrendous mess ahead, because there are so many poor people on the planet who believe it is their time to achieve economic growth and development, and there are a lot of rich countries who are absolutely committed to their own ongoing economic growth and development. If there is not a way for that growth to occur in a way that takes into account the budget constraints of ecosystems and scarce resources on the planet, the consequences are quite harrowing for global society.

2. Sustainable development: feasibility and constraints

What are the challenges and where are we likely to find constraints? I see the question of whether sustainable development is feasible as having three components. First of all, sustainable development means both development and sustainability. Some people use the term sustainable development to mean simply the environmental sustainability of economic activity. I think it is very important to start by taking note that sustainable development is first and foremost development, and development means rising material conditions for the planet, and especially rising material conditions for the planet's poor. The main point that I want to stress is that the expectation of economic growth is deeply embedded in the aspirations of the world's poor for development, which in turn has extensive implications for change on the planet in the decades ahead. Even if the rich countries stopped growing altogether right now, we could still expect a tremendous increase in economic activity around the planet, with many environmental consequences. Therefore, the right starting point for thinking about sustainable development is on the development side. Can poor countries in the international system expect to achieve economic progress? Of course progress is a loaded word, but when I use it I mean rising GNP per capita, on

a sustained basis - not sustained environmentally, but sustained so that economic growth can continue into the foreseeable future.

The second part of the development challenge, one that I'm engaged in most right now, is the question of whether economic development is feasible in the very poorest parts of the planet. We know that there is economic growth taking place in much of the world, but it is not taking place in many of the poorest parts of the world. One part of the development challenge that is really critical – where I currently place my own priority – is development at the very bottom of the income distribution, particularly in sub-Saharan Africa, where the situation is dire. The living standards in the poorest part of the world have been experiencing absolute declines over the last quarter of a century. This part of the development challenge is not concerned with the world average, but rather with the poorest of the poor.

The third piece of the puzzle is the sustainability challenge. If there is ongoing economic progress in India, China, and the rest of Asia - which is already two-thirds of the world's population – and if we add the economic development in Africa and the progress in Latin America, both of which are hoped for, we have to ask if the world can take all of this growth. Can it support it in terms of scarcity of finite resources, fragility of ecosystems, and the multiple pressures growth exerts on the biosphere? My answer is that we certainly do not know, and anyone who suggests that there is no problem does not know what he is talking about, because there surely is a very big problem in absorbing the growth ahead. Whether it is feasible or not is perhaps one of the two or three central research questions of the Earth Institute. Is there a way for development to be absorbed without doing irrevocable damage to critical life-supporting ecosystems? The punch line is that no one can be sure right now. I want to describe why that is the case.

The first question - whether development is feasible - is the easiest part of the puzzle to answer. There is a tremendous amount of development taking place on the planet, and as best we know essentially every inhabited part of the planet, including Africa, has experienced some significant increase in material conditions over the last two centuries. Before that, essentially all of human history has been flat in terms of measurable living standards over the last two thousand years, since the Neolithic Period. There was not much economic progress, people lived at subsistence levels, and the human population grew slowly. But there has been a take-off in the last two centuries, in what has been christened the era of modern economic growth.

The good news is that by now economic growth has gripped most of the planet, and development is proceeding in significant ways in most - although not all - areas. The most difficult aspect of development is that the poorest place on the planet at the start of the era of modern economic growth, Africa, is also the area that has had the least economic growth over the last 200 years. It thus remains at the very bottom of the world's income distribution, with a sharply expanding gap between income in Africa and income in the rest of the world, where economic growth has been achieved. The other most notable fact about development is of course Asia's explosive growth in the last fifty years, and China and India's particularly dramatic growth in the last quarter century.

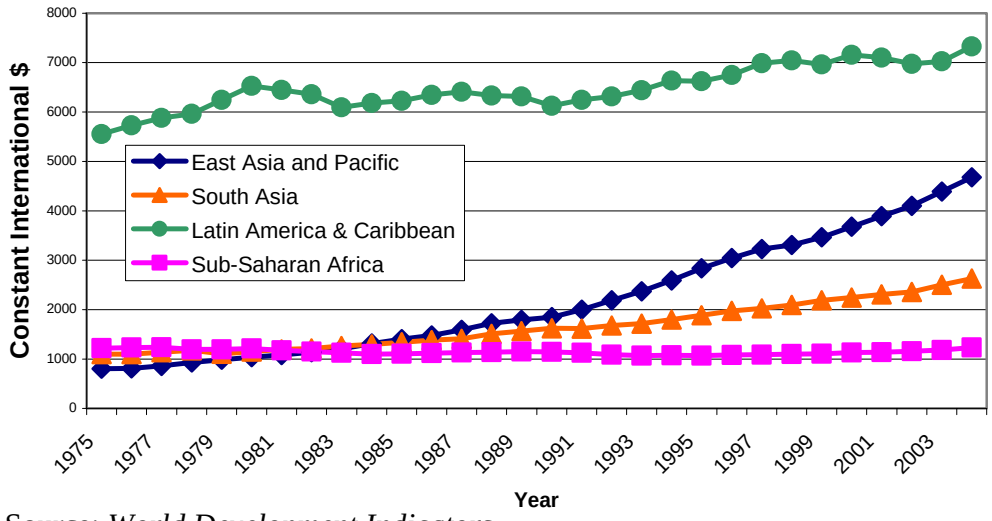
3. Economic development in regional contexts under globalisation

Economic development is a very powerful force, and it takes place in most parts of the world where there are sustained rises in per capita GNP (see Graph 1). There is a powerful– though not an all-powerful– tendency for poor countries not only to achieve economic growth, but to grow faster than the rich countries. So there are actually tendencies towards a narrowing of income inequalities across the globe. Contrary to the image of the world becoming increasingly unequal, I would say that countries actually tend to converge. This is of course a generalisation, but the reason it is true, in part, is that Asia, which was extremely poor on average a half- century ago, is now the fastest growing part of the world economy, and the poorest parts of Asia are among the fastest growers on the continent in per capita GNP.

The reason that the generalisation about convergence is not true is that there are poor places on the planet that aren't growing at all – Africa is the core challenge in that regard. In the debate that continues to rage about whether globalisation just makes the rich richer and the poor poorer, or whether it is the process that allows everyone to catch up in living standards, both sides are at once right and wrong. Certain very poor places are evidently trapped in poverty, and many other poor places with even larger populations are not trapped in poverty; they're experiencing very significant growth. Therefore the first conclusion is that development is possible, and it probably reaches about 80% of the world's population. But it has not yet reached Africa, and I think the critical question is whether it is possible to free places stuck in extreme poverty from an apparently relentless trap.

Graph 1

Per Capita GDP



Source: *World Development Indicators*

The World Bank's measure of extreme poverty is living under a dollar of income per day. That is certainly a poor measure of poverty, because extreme poverty should be measured in a multi-dimensional way. A person may earn one dollar per day, but there may be no clinic within 50 kilometres of her village, and no access to safe drinking water, so she is still in extreme poverty. Extreme poverty, in my view, is the lack of access to basic necessities. While that is related to the World Bank numbers, it is not the same thing by any means. But what this imperfect measure shows is the significant reduction of extreme poverty on the planet. Under certain conditions, it is possible to escape from extreme poverty.

In East Asia, by World Bank estimates, 58% of the population in 1981 was living below a dollar-a-day, or technically $1.08, since 1993 parity levels are the best current formal statistics used for the Millennium Development Goal objective of reducing dollar-a-day poverty. East Asian poverty has come down from about 60% of the population to about 15% in a matter of two decades. It is an astounding achievement, and quite a real achievement, in my view. It is not just a measure of GNP but also of actual economic well-being because it is correlated with rising nutritional intake, rising life expectancy, falling child mortality rates, and rising access to safe drinking

water and sanitation. There is something real, expansive, and rapid growth taking place in your part of the world. That counts on a global scale because it concerns about half of the world's population. In South Asia, it is a little bit less striking, but dramatic nevertheless. These numbers are being tested because there are people who argue the progress has been even greater than this. Here it is shown that the poverty rate in South Asia has gone down from a little over 50% of the population to a little over 30%. And estimates for India now place extreme poverty between 20-25% of the population, down from more than half of the population just 25 years ago. That is another case of tremendous progress, with evidence indicating that this trend is continuing quite rapidly.

Poverty levels have been stopped in Latin America at little or no growth in GNP for a quarter-century now. That is a puzzle. But for countries that are well above the extreme poverty line in general, GNP is usually at $2,000 or $3,000 per capita. In Latin America you see that the extreme poverty rate is estimated by the World Bank at about 10%, and it remains flat at about 10% over the past twenty years or so.

Sub-Saharan Africa is where the biggest mystery lies. In sub-Saharan Africa, extreme poverty measures are at about 40% of the population, which rises to about 46% of the population when very rapid population growth rates are taken into account. That means that the number of people living in extreme poverty is rising by the tens of millions. And I think these numbers probably underestimate what's happening in terms of duress, because they do not adequately capture the massive expansion of disease, falling food production per capita, and falling life expectancy in large parts of the continent.

4. Asian development and its implication for sub-Saharan African development

A lot of what we are doing at the Earth Institute is admiring progress in East and South Asia in terms of reductions in poverty, and spending a lot of time trying to understand what could be done about sub-Saharan African development. My understanding of the African situation, which my colleagues may disagree with, is optimistic about what's possible, in the face of a very pessimistic assessment of what's happened over the last quarter century. In broad terms, I view Africa, at least potentially, as being about

where Asia was forty years ago. And so sub-Saharan Africa, it seems to me, is in a position to follow the Asian experience of a break out of extreme poverty in the coming years. But that cannot happen without outside assistance.

If we look at how East Asia and South Asia went from overwhelming, extreme poverty to the current rapid decline in poverty rates, my interpretation is that the process really started about forty years ago, with the Green Revolution in the region. Until the mid-1960s, one would not have necessarily predicted that China and India would experience anything close to the growth they have experienced. The situation in both countries was one of income stagnation. In India, there was extreme political upheaval, and there was mass starvation in China during the Great Leap Forward, with no evidence of sustained progress in a situation of pervasive extreme poverty. My guess is that the situation in India in 1965 was not viewed much more optimistically than the situation in Africa is viewed today. That is good news, because it means that there is every possibility that we will be quite surprised by positive developments in sub-Saharan Africa.

My interpretation of the Asian development breakthrough is that it does not start with the manufacturing and service centre exports that are so famous, but that it starts with what came ten or twenty years earlier: a decisive increase in agricultural productivity that unlocked the region's poverty trap. Of course the story is now well known, but it is sometimes forgotten. In the mid-1960s improved seed varieties and improved farming techniques enabled a rapid doubling or tripling of farm yields in a chronically famine-ridden region. I think this was the major breakthrough that ended what had been an ongoing cycle of famine and political instability in much of the region. It was a technology-driven boost: improved seed varieties that Japan and the United States had developed for their own farm systems were diffused through the new institutional mechanism, funded by the Ford Foundation. It is a great example of how foreign aid works when properly designed and targeted; to use these improved seed varieties in East Asian rice growing regions and into the South Asian wheat growing regions. Food production soared from about 1965 to 1985, and my view is that this not only overcame the deepest hunger in impoverished farm communities in rural Southeast Asia, but it also freed up a great deal of the population to work in what were then the nascent manufacturing and service sectors, and triggered the famous Asian export-oriented growth in manufacturing and services.

Africa has not had that kind of productivity breakthrough in agriculture, and with all that is said and theorised about Africa's extreme poverty, addressing that should be the core focus of our work right now. There are many other high priority needs, but agricultural productivity is the most distinctive difference between the African and Asian experiences. While Asian agricultural productivity in cereal yields per hectare roughly tripled between 1965 and now, it rose by perhaps 30% in Africa. But since the African population has increased so dramatically, food production per capita in Africa has fallen sharply, while it has risen sharply in Asia. Sub-Saharan Africa is still plagued by famine, and most of Asia is far past that stage and has moved on to long term development.

Why didn't the Green Revolution come to Africa? In my view, it was easier to carry out in Asia, and attention was not paid to Africa's special characteristics. In Asia the technologies were developed for crops that were appropriate: wheat for India and rice for East Asia. That was a big advantage. Africa does not grow much wheat or rice, so the high-yield varieties of the early phase of the Green Revolution did not apply to most of the continent. It took another 20 years to obtain the right cultivators for Africa; the cross-breeding of African land grasses, sorghum, millet, teff, maize, cassava, banana, and others to get high yield varieties that could perform in the same way as the improved rice and wheat.

Two other factors were really important in the Asian context: irrigation and fertiliser, both of which were combined with the high yield crops. Asia has major advantages in getting fertiliser and irrigation to farmers. Irrigation comes in the great river plain systems of Asian agriculture. Asia is a river plain region, formed by the Himalayan Mountains, the Ganges, the Brahmaputra, the Mekong, the Yangtze, and the Yellow River, where hundreds of millions of farmers and their dependants live. It is very heavily irrigated, and in places where it is not irrigated, like the mountainous regions of Laos, Cambodia, or Myanmar, there was no Green Revolution and these regions lag far behind the irrigation-based agriculture of Asia's river plain systems.

Africa does not have river plains and it does not have irrigation. It is estimated that 96% of staple crop farmers in Africa depend upon rain, so the water control in African contexts is not comparable to water control in Asian contexts.

Finally, Asia - notably India and China - had transport systems which could get fertiliser to farmers. The main transport system in the Indian context was British rail, the rail system which had been built a century before and was really the key for carrying fertiliser to the Punjab and to the Ganges Plains. That kind of transport network does not exist in the African context. Africa did not have a great Green Revolution, because it did not have the right seeds, did not have irrigation and did not have transport. Yields have been flat, the population has been growing rapidly, hunger has been rising and land has become degraded, because as populations have expanded on these very low yield farms, even the traditional farm systems have broken down. Those farm systems were based on long land fallows to restore soil nutrients, but there is no longer any fallowing of land. There is only intensive non-fertiliser input and rain-fed agriculture on land now depleted of soil nutrients. Yields are going down as a result, and modern inputs are not being used in staple production in Africa.

The essence of my policy recommendations in Africa is to help make a Green Revolution in Africa and to combine it with public investment in other critical needs; health, education, and basic infrastructure. My argument is that Asia's Green Revolution can now be replicated in Africa, because the plant genetics have been done, the improved varieties exist, and small-scale water management techniques have been dramatically improved in the last 30 years, so that even if Africa does not have a vast river plain area, small-scale water management can be combined with improved varieties. The big problem is that impoverished farmers can't afford these inputs, and so this is why I constantly call for foreign assistance. I believe that we have to help subsidize the critical farm inputs for rural Africa for the next ten, fifteen, or even twenty years to help farmers in impoverished communities replenish soil nutrients, grow improved seed, and diversify agriculture. If this can be done - and I think the necessary agronomic science exists and the subsidies can be found - then it seems that one could see Africa following the Asian example of first getting out of famine, and then becoming competitive in non-traditional manufacturing and service sectors.

My rough answer to the question of whether it is possible to end extreme poverty is 'yes'. In most of sub-Saharan Africa, making the practical investments in food production and in the ancillary public goods – health, education, and infrastructure – is possible. The basic argument is that that

will not happen on its own, because there are hundreds of millions of people who are too poor to make the investments on their own. They are living below subsistence: there is no saving and there is no margin. In fact they are dissaving, because they are depleting soil nutrients and cutting down trees, and that dissaving is what's keeping them alive, but it is destroying the physical environment around them. Creating a situation of positive saving requires transfers from the rich countries to enable key investments to take place. I have spent the last couple of years trying to raise foreign assistance levels, not because I love to throw money at problems, but because I believe the magic of the market is a myth when there are no markets. When people are below subsistence, I do not believe that the kind of advice offered by the World Bank or the IMF is ever going to solve the problems. Those institutions were given a quarter-century to test their approach and it failed – the situation worsened. Of course, when they failed they blamed it on the poor countries, who were accused of not following the International Financial Institutions' advice properly.

5. Is global development sustainable?

It is time to give a different approach a chance. That is the essence of what we have been arguing in the U.N. Millennium Project. Therefore my view is that my field, development, is manageable, even in the poorest places on the planet. The question then is whether development is sustainable. Current world population is about six and a half billion people, and we have a combined world GNP of over 50 trillion US dollars. We are already doing quite a job of undermining world ecosystems. Now add in massive development in India and China over the coming decades, add in the success story that I envision for Africa, and let Latin America break out of its stagnation, which it looks like it is finally starting to do. Can we handle that growth?

The risk is exemplified by the recent collapse of the Newfoundland cod fishery. The entire cod fishery of the northeastern United States, and especially northeastern Canada, collapsed under the pressure of over-fishing. What is interesting about this collapse is that it was largely unanticipated, even by the scientific community. It illustrates the basic point about ecosystems, which is that they can be highly non-linear in their response and their degradation can be largely irreversible. The Newfoundland fishery had both of these properties. It was a not a *well* managed fishery, but it was still

managed, in that it was an allowable catch which was calculated based on estimates of the fishery's biomass yields. Of course what was permissible was always over-estimated, but there was an attempt to determine replenishable yields in the area. Yet all at once the fishery started to collapse. Fishing rights were withdrawn, and then the whole fishery collapsed and was finally eliminated entirely. It is now illegal to fish cod in those waters. That prohibition has been in place for a decade and the cod have not returned.

It is clear that there has been a cascade of changing marine biology conditions: there was a change in the composition of the prey, and the ecological niche in which the cod lived was apparently eliminated. And so the replenishment of the cod fishery has not come anywhere close to what a single standard, simplistic, or logistic function for fisheries regeneration would have predicted. This is because we live in a more complex environment with multi-dimensional, multi-species communities. Is that just the future of Newfoundland, or is it also the future of our planet? A lot of economists say no, because we have technological change. Malthus predicted similar phenomena, and he was wrong. They claim we will find a way out.

I use this scenario because I want to remind you that with all of the best reasoning, collapse really is possible. It is not just theoretical, it has occurred in many places on the planet; but this one was under the eye of the policy makers, the economists, and the fisheries experts. So, is the planet as a whole going to go that way? There is some good news, and some bad.

The good news is that one of the main hurdles to sustainability, and potentially one of the main drivers of ecosystem stress, is population growth. We know that the population growth, in proportionate terms, is falling sharply, even if just in the projections of the United Nations in terms of total fertility rates. They come down almost everywhere. Africa's is the opposite, with very poor people living in rural areas having lots of children for many reasons, but one reason is that children have, relatively speaking, many economic assets on impoverished farms. They collect fuel, they collect the water, and they offer so-called social security for their parents. And since so many children die in the African context, its poor households also have large families in part to compensate for the risk of child mortality. In other parts of the developing world fertility rates are nearing, or have even dropped below, the replacement rate.

The world is coming out of high fertility rates, such that even if the world fertility rate drops to replacement level, which is a little over two, there is still a massive increase in population for one more generation because of the big pyramid of poor girls who grow up to be mothers. Even if they just replace themselves, the pyramid of age structure becomes a chimney of age structure, and that chimney means a lot more people than the pyramid. That is called demographic momentum. We still have a lot of demographic momentum on the planet, and in some places total fertility rates are still significantly above replacement.

What this means is that population is still rising fairly quickly in absolute numbers. We are still adding 70 million people to the planet every year. As a growth rate this is now down to about 1.1%, from what had been a peak of over 2% growth in global population per year. According to the United Nations, something quite good for the planet is going to happen, and that is that the world population really could peak within the next half-century. Actually in the U.N. medium term forecast the global population stops rising in 2071, and then gently declines thereafter. The peak population in this century, if current trends continue, would be somewhere around 9 billion people. That is still far more people than we have today. It is another 50% increase of the global population, which is a lot of people. But considering it is a 50% increase that then levels off, compared to a quadrupling of world population in the 20th century, we have probably seen the end of population doubling. I think we are likely to see population stabilise, but with a continuing, significant increase in absolute numbers for at least the next forty or fifty years.

There is a lot of economic growth built into the world economy right now. If we are already stressing ecosystems, we are about to add – or we are in the process of adding – tremendous stress in the years ahead. Roughly speaking, what the economic growth model suggests is that poor countries, if not stuck in a poverty trap, have the potential to grow faster than the rich countries, and to narrow the proportionate gap. This is an illustration of one possible path in which the developed countries continue to achieve what has been their long-term trend of 1.6% per year of per capita economic growth, and the poor countries grow faster, so that the gap narrows. If that kind of catching up is applied, combing per capita growth and population growth, world GNP soars over the coming decades, and although this is probably not a serious scenario, if India and China continue their rapid growth and

narrowing of the income distribution, and if populations grow as the U.N. suggests, we have a four- or five- or six- fold increase in world GNP built in. That is assuming that poor countries achieve the catching up that they aspire to right now and the rich countries continue to achieve some economic progress. Even if the rich countries were to stop growing right now it would cause a lot of turmoil within our societies because of our own big gaps in income distribution. Abruptly stopping growth would not be so easy.

We probably have a three- or four-fold increase in GNP built into poor countries narrowing the gap with rich economies. We are already putting great stress on the physical capacity of world energy supplies, climates and so forth. We also have a lot built into population momentum and successful development, particularly in Asia, and in the hope and the potential for successful development in Africa. Now the question is whether the world could ever sustain this kind of increase. More specifically, are there physical resources available for this? The availability of energy resources is the big question right now, because fundamentally the economic growth that we have had for the last two hundred years and that we expect in the future is predicated on a massive expansion of non-biomass energy use – essentially fossil fuels and what ever we are able to get out of renewable energy sources. Since we are probably about to run out of oil and gas, then the answer for many is that we do not have enough energy.

My analysis, crudely speaking, is that energy resources are not likely to be the limiting factor, because Australia, the United States, China, India, and other economies have enough coal to keep this kind of economic growth going at quite a rapid rate for more than a century to come. May be in the 22nd century fossil fuels will start to be a limiting factor, but the key is that there are vast coal resource reserves around the world, and coal can be turned into anything: gas, liquid, or solid. That is probably the saving grace; while there is quite possibly a real squeeze on oil supplies, there will not be, or there need not be, a fundamental squeeze on capacity to provide the energy for worldwide economic development.

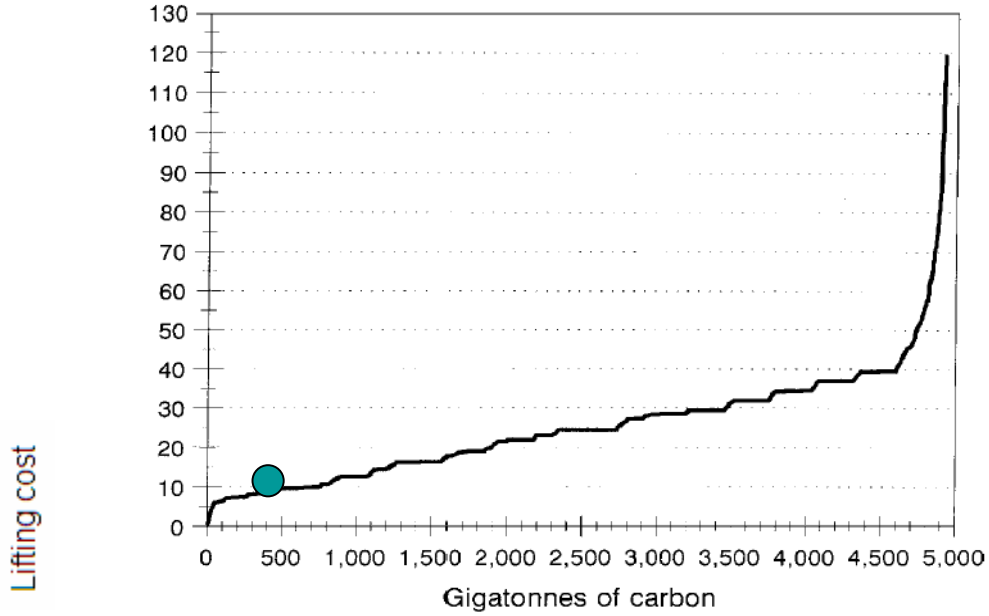
China is now investing massively in what are called coal to liquid plants, and what chemists call the Fischer-Tropsch process - taking coal and converting it into gasoline and other kinds of liquid fuels. This is a process that has been widely used in South Africa in recent decades. Sasol, the company that does this, is the partner with China in more than a billion dollars of investment right now to produce more than one million barrels per day of

gasoline out of coal. That investment is likely to rise significantly in the future.

There are probably more than two trillion tons of coal available in the world, so that there is possibly many centuries' worth of coal left, and certainly more than one century, even at an expanding rate. Of course it would require massive investments to use these resources properly, but energy per se is probably not the limiting factor, and Graph 2[1] below suggests that the cost of getting that coal is not so great. A picture of the long-term supply curve of energy reserves shows a long stretch of relatively inexpensive energy. The big dot on the graph indicates how much fossil fuel we have used cumulatively in the last two centuries – a little bit more than 300 gigatons of fossil fuel. The graph shows that we have many more times that amount of energy available to us at the relatively low current price of $60 a barrel. That is good news in terms of fuelling long-term economic development.

Graph 2

Carbon as low cost (1990 USD) energy per barrel of oil equivalent



But it is obviously very bad news in terms of the climate and the physical environment. It says we are not going to run out of resources and probably

[1] H.H. Rogner (1997), "An Assessment of World Hydrocarbon Resources," *Annu. Rev. Energy Environ.*, vol. 22, pp. 217–62

have enough resources to hang ourselves; because if we use all of this coal we will destroy the climate system and a great deal of the ecosystems that have developed around the climate we have had for thousands of years.

6. Global challenges of sustainable development

What is remarkable when looking at this closely - as several ecologists, led mainly by Peter Vitousek of Stanford, have - is that the amount of pressure exerted on the earth's ecosystems at current levels of GNP per capita is already phenomenal. Vitousek and his colleagues have measured this by trying to estimate the proportion of various aspects of the world's ecosystems that has already been appropriated for human use. Whether it is the fisheries, land-based photosynthesis, or fresh water resources, we are already – with 50 trillion dollars of world GNP - appropriating a surprisingly large fraction of current bio-mass creation and hydrological flows, in both terrestrial and marine ecosystems.

Vitousek and colleagues made a calculation of the amount of net primary photosynthesis on the planet that is appropriated for human use. There are several potential ways to measure this complicated question. The low estimate is that human society has already appropriated one third of all photosynthetic output on the planet at current levels. That is quite a phenomenal thing, because what this measures is human use of pastoral land and crop land, as a fraction of all photosynthesis on the terrestrial surface, including forests, undisturbed grasslands, etc. By the high estimate, the total human appropriation of photosynthesis is perhaps as much as 60%.

The first conclusion is that there is not a lot of land area or photosynthesis left to recuperate, and we are already placing phenomenal pressure on total, global-scale land use. A recent study tried to quantify this in terms of total area of planted pastoral land appropriated. The conclusion was that for pastoral land and crop land there is been a very strong correlation between income growth and appropriation of land for human use. When you apply the historic relations to this you find that massive destruction of the remaining rainforest areas and the few remaining undisturbed land areas on the planet is built in for the future.

The extent to which we have already tremendously deforested most of the planet has left us with few remaining heavily forested areas. The arboreal

forests in the very high altitudes can probably remain untouched because they're poorly suited to farming. Similarly, the remaining swamps in rainforest areas have been the last to be disturbed, partly because the soils under the Amazon and Congo basin are so poor that nobody ever saw fit to clear those areas – until now. The evidence suggests that they are now under dire threat. Not only insofar as they are being deforested right now, but improved farm practices now make it possible to grow a lot of food very productively in the Amazon basin by improving soils through better soil management and proper fertiliser input.

This scenario shows the implication of global economic growth. China has been a major net importer of soy beans in recent years, and we can expect a lot more of that in the future. Where are these soybeans coming from? Increasingly they're coming from Brazil, and specifically from the Amazon. We are seeing an acceleration of the de-forestation of the Amazon and, therefore, a large amount of land that is going to be appropriated as economic development takes place. I think the best guess is that without a massive change of land use regulation and land use patterns the deforestation process will only accelerate in the coming years. We have built in a tremendous amount of pressure on the remaining undisturbed areas. There are areas of massive water stress where already human populations are withdrawing over 40% or more of the fresh water resources within reach, with reach defined on a scale of kilometres. Many countries including Australia are responsible for a lot of water stress. If we use projections of water use we see a tremendous expansion in the share of the planet coming under extreme water stress.

Biodiversity destruction similarly follows the expansion of land use by humans. The greatest driver of extinctions is habitat destruction. Habitat destruction is taking place both terrestrially and in the marine environment. We know that the 14 main oceanic fisheries in the world are all under tremendous stress and biomass depletion and degradation of these oceanic fisheries is proceeding much faster than was first thought when the data was pulled together. The same thing is happening on land.

One final aspect of human impact is the rising frequency and rapid diffusion of zoonose diseases. As human society spreads out and interacts with animal habitats that were formerly separated from society, we are seeing a very large number of transfers of pathogens from animal reservoirs to human reservoirs. Avian flu is the most dramatic and recent of these. But that is

not an isolated and specific case – there have been dozens of these zoonose diseases where human populations have come into contact with animal reservoirs and there has been a transfer of genetic material from animal reservoirs to human reservoirs. That has been going on for thousands of years, but it is probably accelerating right now because of the massive spread of human population into every nook and cranny on the planet. We just learned last week that the 1918-1919 flu was itself a zoonose disease; in fact it was an avian flu, not a human one. There is some cause for concern for all of us, because it was one of the largest pandemics in recorded history, with 25 to 50 million deaths.

There have been many places where zoonose epidemics have occurred. Of course AIDS itself is an example and has been the most dramatic of these pandemic diseases. The best evidence is that AIDS passed from the chimpanzee population to the human population some time around 1930. What's interesting about that from a public policy point of view is that it was not detected. HIV was identified only about 50 years ago, after it became a human disease. That is because when Africans die, no one pays attention. AIDS was a disease in Africa for a long time. Africans were dying and no one was asking why, because there were so many diseases killing impoverished Africans. And the AIDS epidemic was only identified in San Francisco in 1981. That shows that we may be harbouring all sorts of equally serious conditions that we do not even know about, and in our globalized society, these diseases can become global pandemics before we know it.

Can we have successful sustainable development under these circumstances? The answer is that we do not yet have a clue as to whether it is feasible. The first great challenge that we face is protecting ourselves from pandemic disease, which really is a global threat. We do not have a global health system that is in place to carry out appropriate surveillance or appropriate preparations for immunisation. We have a terrible crisis in the vaccine industry, because we are not producing enough vaccines anymore. There are many legal, political, and cultural problems that need to be overcome.

The second challenge is the issues of climate change. To solve the climate change problem requires a fundamental solution to the energy conundrum. The only low-cost energy sources we have at scale are fossil fuel based, and of course there is also nuclear based energy, with all its unsolved problems for the planet, such as proliferation. We do not have any real scale

alternatives to this right now, so the energy conundrum boils down to finding a way to use fossil fuels safely.

Efficient energy use will not overcome this problem, because even if we continue to produce emissions at current levels, we will cause very dangerous anthropogenic interference with the climate. Add to that a six-fold increase in GNP, and even if we allow for a massive doubling of energy efficiency, we still face a three-fold emissions increase. There is a lot stored energy, as in China, which is becoming a massive emitter of carbon dioxide and will be the world's largest before long. The question then is whether there is a possible technological solution to this problem.

The best hope that we can see - the one we are working on the most - is to develop processes to capture and store the carbon dioxide emitted from the use of fossil fuels. These are the so-called carbon capture and sequestration technologies. The evidence is that these can be relatively inexpensive for large, fixed-use energy consumers: power plants, cement factories, steel mills, refineries, ammonia and hydrogen production plants. But there is not one working model in the world that proves this yet, and so we are trying to promote prototypes of carbon capture and sequestration technologies. I would like Australia to be one of those sites, because it is the largest exporter of coal and it has a strong interest in the generation of safe uses of coal. If we use up the world's coal supply under current technologies, the climate will be so radically transformed by next century that we will not recognise it, and we will be facing very profound risks long before then. Clean coal is the big hope for the next few decades. Solar energy is probably the greatest hope for energy management in the very long term, if we are able to lower its cost, or to discover the secret for using fusion energy. This remains a major puzzle, however.

At present we are not fully aware of the actual pressure we are putting on habitats all over the world: the destruction of forests, the appropriation of land for food production, the appropriation of clean water resources, and the destruction of the ocean fisheries. In my view, climate, land use, and fisheries use are the great unsolved puzzles of sustainability on the global scale. The solution in terms of food production is to intensify even more to achieve higher yields per hectare, but there is no evidence that this can be achieved. If intensification is not achieved, the destruction of more rainforests and habitats becomes highly likely. That is the course we are on now.

With respect to the oceans, we have already reached a plateau in terms of ocean catch. Virtually all of the world's main fisheries are now under stress. Deep-sea fishing, bottom trawling, and other continuing technological improvements in fishing mean that we are likely to essentially exhaust our oceans' resources in the coming two or three decades, unless we find a viable alternative. The most promising alternative would be environmentally safe aquaculture; to farm fish rather than hunt and gather fish. The problem with aquaculture so far is that most of the fish we like to eat are carnivorous fish, so we trawl the oceans for their feed. Farmed carnivorous fish need to eat three or four times their own mass, because that is how the trophic scales work. They need to eat several times their vital mass to stay alive and to grow. We are not saving the oceans through aquaculture for that simple reason.

Under current practices, aquaculture is also highly polluting, and we have not found the technologies that can protect the oceans. The exceptions would be if we learned to love herbivorous fish, such as tilapia, which is the herbivorous fish of choice right now. There is a very interesting set of experiments currently underway to make salmon vegan, and it turns out that they lack the pathway to process one crucial amino acid that prevents them from eating a vegan diet. There are scientists working to genetically modify salmon, in order to obtain salmon that can eat a vegan diet. That is one potential solution to the challenge of fisheries management.

7. Conclusion

Economists tend to be very complacent about sustainability issues on the planet because they have been a problem throughout human history. Yet technological change has always solved these problems. There is an element of truth to that, but there is probably a greater element of falsehood to it now. The element of truth is that, with sufficient science, we are able to make lots of progress in many areas, but the element of falsehood is that, assuming that economic development is successful, solving the problems of sustainability will become increasingly difficult. I regard the two challenges that I have discussed above, extreme poverty and sustainable development, as the most important challenges for the planet. They are vastly more important than the War on Terror, because they are true problems of scale. We are not directing much attention at these problems, and our efforts

certainly are not commensurate with the problem's magnitude. In the end we will need science, and we will need universities to be increasingly mobilised to address these challenges in an interdisciplinary setting, because none of these issues can be addressed by one sole discipline. The critical step is bringing together public policy with the ecological, earth, and health sciences.