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Chapter 11
Energy

Teachers Note: This chapter has numerous helpful charts and graphs that could not be included due to software constraints. Readers are urged to find the book in the library if you would like to include them in your report.

We will soon run out of oil. Again. As *E magazine* wrote in July 2000:

> Here's the scenario: Sticker shock at the gas pumps, with prices nearly doubling overnight. Long lines at the few stations that are open. Crude cardboard signs reading "out of gas" blocking incoming traffic at the ones that are closed. Huge sales on "full-sized" vehicles. Long waiting lists for econoboxes. Nineteen seventy three? Nineteen seventy nine? How about 2007?[847]

We have heard it all before.[848] And we probably haven't heard it for the last time. But the argument seems not to be based on the facts. There are good reasons to believe that we will not have dramatic price increases, and that we will actually be able to handle our future energy needs.

We are a civilization built on energy

Each and every one of our actions demands energy. Our own body supplies energy equivalent to a 100 watt bulb,[849] but already early in history man attempted to gain control over more energy, primarily through the use of animals and slaves. Not long after we also learned through technical prowess to use nature's energy: sails for ships as well as wind and water mills. Nevertheless, it was only with Watts' invention of the steam engine in 1769 that it became possible for man to produce large amounts of energy on demand. The steam engine laid the foundation for the Industrial Revolution, which in England over the next hundred years changed production from being based almost exclusively on human labor to obtaining its primary energy input from fossil fuel.

But at the same time it became obvious that production was no longer able to rely on wood for energy supply. England was quickly becoming deforested. Increasingly coal was being used in both England and the US (Figure 62), partly because it was a better energy source than wood, partly because it was available in much larger quantity. This process repeated itself in all industrialized countries and cemented our dependence on energy and non-renewable resources. In this century coal has been replaced by oil, because it is easier to transport, store and use.

Coal, oil and natural gas are all the breakdown products of plants millions of years old. Consequently, they are collectively known as fossil fuels. Most of our coal is the remains of land plants that lived 300-400 million years ago and decomposed in vast swamps. First they were transformed into peat, then later into coal when sufficient pressure and temperature squeezed out the remaining water.[850] Oil and natural gas, however, are composed primarily of plankton which dropped to the seafloor some 2-140 million years ago. The ratio and quality of oil and gas depends on pressure and temperature - perhaps surprisingly most gas is produced where pressure is highest.[851] Crude oil consists of many different chemical elements, and it has to be refined before we can obtain products such as gasoline, diesel fuel, heating oil, and the substances used for asphalt.

Today, our civilization is heavily dependent on the adequate supply of energy. By the end of the nineteenth century human labor made up 94 percent of all industrial work in the US. Today, it constitutes only 8 percent.[853]

If we think for a moment of the energy we use in terms of "servants," each with the same work power as a human being, each person in Western Europe has access to 150 servants, in the US about 300, and even in India each person has 15 servants to help along.[854] It is indeed unpleasant to imagine what it would be like to live without these helpers.

Do we have enough energy to go on?

The main question is whether this dependency is sustainable. The surprising answer is that we will not run out of fossil fuel within the foreseeable future.

But what do we do in the long run? Our present-day energy supply is based on coal and oil, created over millions of years. Many have pointed out the apparent problem that - to uphold our civilization - we consume millions of years' resources in just a few hundred years Rather, we should use our resources sustain-ably, such that our consumption does not prevent future generations from also making use of these resources. But even if this argument sounds quite reasonable, it is impossible to use isolated, non-renewable resources such that future generations can also be assured of their use.[855] Even if the world used just one barrel of oil a year this would still imply that some future generation would be left with no oil at all.[856]

However, this way of framing the question is far too simple. According to the economics Nobel laureate Robert Solow, the question of how much we can allow ourselves to use of this or that resource is a "damagingly narrow way to pose the question."[857] The issue is not that we should secure all specific resources for all future generations - for this is indeed impossible - but that we should leave the future generations with knowledge and capital, such that they can obtain a quality of life at least as good as ours, *all in all.*

This is actually a surprisingly important insight. Let us look at it in connection with oil. Sooner or later it will no longer be profitable to use oil as the primary fuel for the world. The price of oil will eventually increase and/or the price the other energy sources will fall. But societies do not demand oil as such, only the energy this oil can supply. Consequently, the question is not whether we leave a society for the coming generations with more or less oil, but whether we leave a society in which energy can be produced cheaply or expensively.

Let us put this slightly more simplistically. If our society - while it has been using up the coal and oil - simultaneously has developed an amazing amount of technical goods, knowledge and capital, such that this society now can use other energy sources more cheaply, then this is a better society than if it had left the fossil fuel in the ground but also neglected to develop the society.

Asking whether we will run out of oil in the long run is actually a strange question. Of course, in the long run we will undoubtedly rely on other energy sources. The reason why the question nevertheless makes us shudder is because it conjures images of energy crises and economic depression. However, in this chapter (as well as the next on raw materials) we will see that there are sufficient resources for the long-term future and that there are good reasons to expect that when the transition happens it will happen because it actually makes us even better off.

As Sheik Yamani, Saudi Arabia's former oil minister and a founding architect of OPEC, has pointed out: "the Stone Age came to an end not for a lack of stones, and the oil age will end, but not for a lack of oil."[858] We stopped using stone because bronze and iron were superior materials, and likewise we will stop using oil, when other energy technologies provide superior benefits,[859]

The oil crisis

What actually happened to the oil crisis? We were told over and over that oil was getting scarcer and that *now* it would run dry. But it didn't happen. The oil crisis happened because the OPEC countries during the 1970s and the beginning of the 1980s were able to cut back on production and squeeze up prices. But it was never an indication of an actual scarcity. There was - and still is - oil enough.[860] Nevertheless, ever since we started depending on fuel we have been worried about running out. For many, the first oil crisis in 1973 was exactly proof of the scarcity of resources.

One year earlier a book had been published that was to prove both immensely popular and influential - *Limits* to Growth. Using the new concepts of systems analysis and computer simulation, the book served as a focal point for analyses of our overconsumption and our course towards disaster in the 1970s. From seemingly endless scrolls of computer output the book showed us a variety of scenarios leading to catastrophe and breakdown. The book was based on two simple and basic arguments, that even today often seem to be the starting point for most resource discussions. Both points refer back to Malthus and questions of agricultural production, but they can be formulated quite generally. The first point supposes that many processes in social expansion grow; the second assumes that there are limits to this growth.

When you place a single bacterium in a jar with lots of nutrients it will quickly multiply. Suppose it can double each hour. After one hour the glass contains 2 bacteria, after two hours 4 bacteria, then 8,16, 32, etc. This is an example of exponential growth. A doubling takes place for each time interval. This exponential growth constitutes the first assumption. Many human phenomena seem to have this character. Draw a graph of the number of people on Earth over time, and it will seem exponential. Money in the bank with a 5 percent interest rate will grow exponentially, doubling every fourteenth year. Actually *everything* that has stable growth rates constitutes exponential growth. The economy, the GDP, society's capital, the demand for goods, etc.

Limits constitute the second assumption. That Earth only contains a limited amount of resources is really just an obvious consequence of the fact that Earth is a sphere. This is why this idea is so enchanting. There is simply a limit to what the Earth can contain. If we use some of the resources there will be less left over for the next year, and sooner or later we will run out. There are, indeed, limits to consumption.

With the assumptions of exponential growth and limited resources we can easily make a doomsday prophecy. Exponential growth means that demand goes up and up, faster and faster, while limited resources set a sharp upper limit for the cumulative supply. And a doomsday prophecy was exactly what we got from *Limits to Growth.* Along with numerous other resources, *Limits to Growth* showed us that we would have run out of oil before 1992.[861] As we know, that did not happen. Ehrlich told us in 1987 that the oil crisis would return in the 1990s.[862] That did not happen either.

One might have thought that history would have made us wiser. But 1992 saw the publication *of Beyond the Limits,* the revised edition of limits *to Growth.* Here, once again, we were told that our resources would soon run out.[863] Perhaps the first edition had been somewhat mistaken in the exact prediction of the year of resource exhaustion, but *now* we would soon see the problems cropping up. *Beyond the Limits* predicts once again that we will run out of oil (2031) and gas (2050). We might be able to postpone the pain somewhat, but gas consumption grows by 3.5 percent a year, i.e. consumption doubles every 20 years.[864] Thus, every twentieth year we have to find as much new gas as our entire cumulated consumption up till now. "Thus is the nature of exponential growth," as the book puts it.

How much oil left?

Throughout most of history petroleum has been scorned as a sticky, foul-smelling material. Among the few known uses was the fabled Tower of Babel, built to a height of 90 meters with bricks cemented with the petroleum product bitumen.[865] Tar was used to waterproof boats like Noah's Ark.

Until the middle of the nineteenth century the demand for lubricants and illuminants was serviced by vegetable and animal oils, especially whale oil. But through the invention of various distillation processes oil suddenly became an interesting commodity. During the next 50 years the commercial production of oil expanded rapidly, and since the first large discoveries in the Middle East at the beginning of the twentieth century there has been a virtual explosion in production after World War II (Figure 63).

Constituting 1.6 percent of global GDP, oil is today the most important and most valuable commodity of international trade.[866] Oil can be found all around the world, but the largest resources by far are to be found in the Middle East - it is estimated that somewhere between 50 and 65 percent of the global reserves are found here.[867] Consequently, it is also imperative for our future energy supply that this region remains reasonably peaceful.[868]

Oil is the most versatile of the three primary fossil fuels. Oil has high-energy content, it is relatively compact, and it is easy to transport. Conversely, coal is heavier, more bulky and pollutes more. Gas is clean, but very bulky and requires pipelines for transportation.[869] This is reflected in the relative prices as seen in Figure 64, where oil is the most expensive per energy unit, and coal the cheapest. That gas has become more expensive than coal over time is precisely due to the fact that many nations have installed pipelines to exploit this cleaner energy source.

We have long been told that we were running out of oil. In 1914 the US Bureau of Mines estimated that there would be oil left over for only ten years' consumption. In 1939 the Department of the Interior projected that oil would last only 13 more years, and again in 1951 it was again projected that oil would run out 13 years later.[870] As Professor Frank Notestein of Princeton said in his later years: "We've been running out of oil ever since I've been a boy."[871]

How should scarcity be measured? Even if we were to run out of oil, this would not mean that oil was unavailable, only that it would be very, very expensive. If we want to examine whether oil is getting more and more scarce we have to look at whether oil is getting more and more expensive.[872] Figure 65 shows that the price of oil has not had any long-term upward trend.

The oil price hike from 1973 to the mid-80s was caused by an artificial scarcity, as OPEC achieved a consistent restraint to production.[873] Likewise, the present high oil price is caused by sustained adherence to OPEC agreed production cutbacks in the late 1990s.[874] Thus, it is also expected that the oil price will once again decline from $27 to the low $20s until 2020.[875] This prediction lies well in the middle of the $17-$30 stemming from eight other recent international forecasts.[876]

The reason why it is unlikely that the long term trend will deviate much from this price is that high real prices deter consumption and encourage the development of other sources of oil and non-oil energy supplies. Likewise, persistently low prices will have the opposite effects.[877]

In fact, if we look at the real price of gas at the pump (the consumer price) excluding tax, it stands at $1.10, on a par with the lowest prices before the oil crisis (Figure 64). This is because most of the gas price consists of refining and transportation, both of which have experienced huge efficiency increases.[879]

At the same time Figure 66 demonstrates that we have more reserves than ever before. This is truly astounding. Common sense would tell us that if we have 35 years' consumption left in 1955, then we should have 34 years' supply left the year after.[880] Yes, actually we should probably rather have 33 years' worth left because we consumed more oil in 1956 than in 1955. But Figure 66 shows that in 1956 - contrary to what common sense would indicate - there were *more* years of reserves even at a *higher* annual consumption.[881] Nor when we look at remaining years of supply does oil seem to be getting scarcer.

Notice how Figure 65 seems to indicate that oil consumption steadily increases (with the exception of the 1970s) just as predicted by the doomsayers: consumption is headed towards a breakdown. But look at Figure 67, where demand is depicted in the same diagram as the collected, known reserves. Here it is clear that the development in reserves by far outpaces development in demand.

Optimists and pessimists arguing

Why is it that we continuously believe oil will run out, when it is not happening?

In 1865 Stanley Jevons, who was one of Europe's most highly esteemed scientists, wrote a book on England's coal use. In his analysis, the Industrial Revolution saw a relentless increase in the demand for coal, which inevitably would cause the exhaustion of England's coal reserves and grind its industry to a halt. "It will appear that there is no reasonable prospect of any release from future want of the main agent of industry."[882] His arguments were not unlike those expounded in the *Limits* to Growth. But what he did not realize was that when the price of coal increased it would also increase the incentive to search for more effective ways to use coal, to search for new coal reserves, to find cheaper ways of transporting coal, and to search for other energy sources such as oil.[883] Jevons' crisis never took place.

That we can both use resources better and find more and more could be subsumed under the idea of human ingenuity. True, Earth is spherical and limited, but this is not necessarily a relevant objection. The problem is rather how large are the deposits that are actually accessible for exploitation. These deposits can seem limited, but if *price* increases this will increase the incentive to find more deposits and develop better techniques for extracting these deposits. Consequently, the price increase actually increases our total reserves, causing the price to fall again.

Actually, the question of whether resources are becoming more scarce or more abundant is staked on these two approaches: doomsayers claiming that resources are physically limited and consequently must grow scarcer and cornucopians focusing on human ingenuity and the empirical evidence of the data. Whether the one or the other is right is in truth an empirical question.[884]

Ever more oil available

Looking at Figure 65 it is clear that the price of oil has not had any long term increase and that oil has not been getting scarcer. Looking at Figure 66, it is clear that we have more and more oil left, not less and less. But it still seems odd. How can we have used ever more and still have even more left?

The answers to this question point to the three central arguments against the limited resources approach.

1. "Known resources" is not a finite entity. It is not that we know all the places with oil, and now just need to pump it up. We explore new areas and find new oil. But since searching costs money, new searches will not be initiated too far in advance of production. Consequently, new oil fields will be continuously added as demand rises. This is part of the reason why we see years of consumption increasing and not decreasing.

Actually, it is rather odd that anyone could have thought that known resources pretty much represent what is left, and therefore predict dire problems when these have run out. It is a little bit akin to glancing into my refrigerator and saying: "Oh, you've only got food for three days. In four days you will die of starvation." No, in two days I will go to the supermarket and buy some more food. The point is that oil will come not only from the sources we already know but also from many other sources which we still do not know.[885] US Geological Surveys have regularly been making assessments of the total undiscovered resources of oil and gas, and writing in March 2000 they state: "Since 1981, each of the last four of these assessments has shown a slight increase in the combined volume of identified reserves and undiscovered resources."[886]

2. We become better at exploiting resources. We use new technology to be able to extract more oil from known oil fields, we become better at finding new oil fields, and we can start exploiting oil fields that previously were too expensive and/or difficult to exploit. An initial drilling typically exploits only 20 percent of the oil in the reservoir. Even with present-day, advanced techniques, using water, steam or chemical flooding to squeeze out extra oil, more than half the resource commonly remains in the ground unexploited. It is estimated that the ten largest oil fields in the United States will still contain 63 percent of their original oil when production closes down.[887] Consequently, there is still much to be reaped in this area. In the latest US Geological Survey assessment, such technical improvement is expected to yield more than a 50 percent increase of identified reserves.[888]

At the same time we have become better at exploiting each liter of oil. The average US car has improved its mileage by 60 percent since 1973.[889] Likewise, home heating in Europe and the US has improved by 24-43 percent.[890] Many appliances have become much more efficient - the dishwasher and the washing machine have cut about 50 percent of their energy use.[891]

Still, efficiency has much potential to be increased. It is estimated that 43 percent of American energy use is wasted.[892] The US Department of Energy estimates that we could save anywhere from 50 percent to 94 percent of our home energy consumption.[893] We know today that it is possible to produce safe cars getting more than 50-100 km per liter (120-240 mpg).[894] Of course, while such efficiency gains have often been documented, the reason why they have not all been utilized is simply because it does not pay at the current energy price and level of technology.[895]

Most nations actually exploit energy better and better: we use less and less energy to produce each dollar, euro or yen in our national product. Figure 68 shows how the US has produced ever more goods with the same amount of energy since 1800, and this holds true for the UK since 1880 and the EU and Japan from 1973.[897] For the world at large, almost twice the amount of wealth was produced in 1992 per energy unit compared to 1971.[898] Over the same period Denmark actually went even further and "delinked" the connection between a higher GDP and higher energy consumption: in total Denmark used *less* energy in 1989 than in 1970 despite the GDP growing by 48 percent during that time.[899]

3. We can substitute. We do not demand oil as such but rather the services it can provide. Most often we want heating, energy or fuel, and this we can obtain from other sources. Therefore we can swap to other energy sources if they show themselves to be better or cheaper. In England around the year 1600 wood became increasingly expensive (because of local deforestation and bad infrastructure) and this prompted a gradual switch over to coal, a similar movement to the one in the US, depicted in Figure 62.[900] During the latter part of the nineteenth century a similar substitution took place from coal to oil.

In the short run, it would be most obvious to substitute oil with the other commonly known fossil fuels such as gas and coal. In the longer run, however, it is quite possible that we will cover a large part of our energy consumption using nuclear power, wind and solar power, biomass and shale oil.

Other fossil energy sources

Gas is a clean and cheap energy source, requiring, however, a large pipeline distribution system. Gas has had the largest growth of all the fossil energy sources since World War II - production has increased more than 12-fold since 1950 as is evident in Figure 69. While gas only constituted about 10 percent of the global energy in 1950, today it constitutes 23 percent.[901] Gas releases much less carbon dioxide per energy unit than the other fossil fuels, where coal in particular is the big culprit.[902]

Despite the dramatic increase in production, gas has become *more* abundant over time, just like oil. But given the arguments above, this should not surprise us. Today, our gas reserves have more than doubled since 1973. Despite using ever more gas each year the gas reserves will last ever more years. In 1973 we had enough gas for the next 47 years given 1973 consumption. In 1999 we had gas for 60 years, despite consumption having shot up more than 90 percent.[904]

Historically, coal has been the most important fossil fuel, but in the post-war period it has been partially displaced by oil. Only with the energy crisis in the 1970s did coal again become an interesting energy source, although it is heavy and bulky and consequently costly to transport.[905] Therefore most coal is consumed close to its source - only 10 percent of all coal is exported compared to 60 percent of all oil.[906] In Denmark, coal replaced a large part of our oil consumption after the initial 1973 oil shock, and only slowly has gas begun to replace coal. This tendency has been widespread throughout Europe since gas is cleaner and because local coal in Germany and England has become too expensive.[907]

Typically, coal pollutes quite a lot, but in developed economies switches to low-sulfur coal, scrubbers and other air-pollution control devices have today removed the vast part of sulfur dioxide and nitrogen dioxide emissions.[908] Coal, however, is still a cause of considerable pollution globally, and it is estimated that many more than 10,000 people die each year because of coal, partly from pollution and partly because coal extraction even today is quite dangerous.[909]

But coal can supply us with energy for a long time to come. As with oil and gas, coal reserves have increased with time. Since 1975 the total coal reserves have grown by 38 percent. In 1975 we had sufficient coal to cover the next 218 years at 1975 levels, but despite a 31 percent increase in consumption since then, we had in 1999 coal reserves sufficient for the next 230 years. The main reason why years-of-consumption have not been increasing more is due to reduced prices.[910]

The total coal resources are estimated to be much larger - it is presumed that there is sufficient coal for well beyond the next 1,500 years.[911] Production has increased almost tenfold over the last hundred years, but, as can be seen in Figure 70, this has not led to any permanent increase in price (beyond the oil crisis price hike). Actually, the price of coal in 1999 was close to the previous low of 1969.

At the same time there are several other discoveries that have expanded the fossil fuel resources considerably. First, we have now begun to be able to exploit methane gas in coal beds. Earlier, miners would fear seeping methane gas that could cause explosions and make the mine collapse. Today, this gas can be exploited. The precise recoverable amounts of coal bed methane are not known, but are estimated to exceed the current reserves of natural gas and could be double the size.[912] This discovery alone gives us gas for at least another 60 years.

An increasing amount of attention has been given to tar sands and shale oil. Both contain oil which unfortunately is much harder to extract and consequently more expensive to exploit. In Canada, oil has been extracted from tar sands since 1978 and here the costs have dropped from $28 per barrel to just $11.[914] For comparison the price of a barrel of oil was $27 in 2000.

The US Energy Information Agency estimates that today it will be possible to produce about 550 billion barrels of oil from tar sands and shale oil at a price below $30, i.e. that it is possible to increase the present global oil reserves by 50 percent.[915] And it is estimated that within 25 years we can commercially exploit twice as much in oil reserves as the world's present oil reserves. Should the oil price increase to $40 per barrel we will probably be able to exploit about five times the present reserves.

The total size of shale oil resources is quite numbing. It is estimated that globally there is about 242 times *more* shale oil than the conventional petroleum resources. There is more than eight times more energy in shale oil than in all other energy resources combined - oil, gas, coal, peat and tar sands.[916] This stunning amount of energy is the equivalent of our present total energy consumption for more than 5,000 years.[917]

Consequently, there is no need for any immediate worry about running out of fossil fuels. A proportion of the fossil fuels, however, is probably only accessible at a higher price. Still, there is good reason to believe that the total energy share of our budget - even if we continue to depend solely on fossil fuels - will be dropping. Today the global price for energy constitutes less than 2 percent of the global GDP, and yet if we assume only a moderate continued growth in GDP this share will in all likelihood continue to drop. Even assuming truly dramatic price increases on energy of 100 percent, by the year 2030 the share of income spent on energy will have dropped slightly.[918]

Nuclear energy

Nuclear energy constitutes 6 percent of global energy production and 20 percent in the countries that have nuclear power.[919] Despite growth in Asia, the prospects for this sector spell stagnation until 2010 and a minor recession after that. This recession is mainly caused by perceived problems of security as stressed by the accidents at Three Mile Island and Chernobyl which undermined many people's confidence in this energy source.[920]

Ordinary nuclear power exploits the energy of fission by cleaving the molecules of ura-nium-235 and reaping the heat energy. The energy of one gram of uranium-235 is equivalent to almost three tons of coal.[921] Nuclear power is also a very clean energy source which, during normal operation, almost does not pollute. It produces no carbon dioxide and radioactive emissions are actually *lower* than the radioactivity caused by coal-fueled power plants.[922]

At the same time nuclear power also produces waste materials that remain radioactive for many years to come (some beyond 100,000 years). This has given rise to great political debates on waste deposit placement and the reasonableness of leaving future generations such an inheritance. Additionally, waste from civilian nuclear reactors can be used to produce plutonium for nuclear weapons. Consequently, the use of nuclear power in many countries also poses a potential security problem.

For the moment there is enough uranium-235 for about 100 years.[923] However, a special type of reactor - the so-called *fast-breeder reactor* - can use the much more common ura-nium-238 which constitutes over 99 percent of all uranium. The idea is that while uranium-

238 cannot be used directly in energy production it can be placed in the same reactor core with uranium-235. The uranium-235 produces energy as in ordinary reactors, while the radiation transforms uranium-238 to plutonium-

239 which can then be used as new fuel for the reactor.[924] It sounds a bit like magic, but fast-breeder reactors can actually produce more fuel than they consume. Thus it is estimated that with these reactors there will be sufficient uranium for up to 14,000 years.[925] Unfortunately these reactors are more technologically vulnerable and they produce large amounts of plutonium that can be used for nuclear weapons production, thus adding to the security concerns.[926]

Nuclear power, however, has barely been efficient in the production of energy and this is probably the major reason why its use has not been more widespread.[927] It is difficult to find unequivocal estimates of the total costs since there are so many different variables that can affect the calculations, but typically the price hovers around 11-13 cents for one kilowatt-hour (kWh) in 1999 prices.[928] This should be compared with an average energy price for fossil fuels of 6.23 cents.[929]

In the longer run, the primary focus is no longer on fission energy but rather on fusion energy. This technology aims at fusing two hydrogen atoms into a single atom of helium. A single gram of fuel can develop the same energy as 45 barrels of oil.[930] Fuel comes basically from ordinary sea water and thus supply is virtually infinite. Moreover, there will be very little radioactive waste or emissions. However, fusion demands astronomical temperatures and despite investments above $20 billion we have still only managed to achieve 10 percent of the laser power necessary for producing energy.[931] Consequently it is supposed that fusion energy will be commercially available only after 2030 or perhaps only well into the twenty-second century.[932]

Renewable energy

Renewable energy sources, unlike fossil fuels, can be used without ever being used up.[933] These are typically sources such as sun, wind, water and Earth's internal heat. Up until a few years ago these energy sources were considered somewhat "alternative" - pet projects for "bearded vegetarians in sandals" as *The Economist* puts it.[934] But this picture is changing.

There are great advantages in using renewable energy. It pollutes less, makes a country less dependent on imported fuel, requires less foreign currency, and has almost no carbon dioxide emission.[935] Moreover many of the technologies are cheap, easy to repair and easy to transport, ideally suited for developing countries and remote regions.

Looking at Figure 71 it is clear that renewable energy sources constitute only 13.6 percent of the global energy production. Here, the two important constituents are hydroelectric power and traditional fuels. Water power makes up 6.6 percent of global energy production. The traditional fuels consist of fuel wood, charcoal, bagasse (fibrous cane residue left over from sugar production), and animal and vegetal wastes. These make up 6.4 percent of the world's energy production and constitute more than 25 percent of the energy consumption in the developing countries.[936]

The other, more well-known renewable energy sources such as biomass, geothermal energy, wind and solar power make up the last 0.6 percent of global energy production, or the top, thin slice in Figure 71. Of this slice, the greater part is made up by the 0.4 percent of biomass - burning wood and agricultural waste for energy, but also energy production from municipal waste incineration.[937] The rest consists mainly of 0.12 percent from geothermal energy, made with the heat from the earth's interior.

The best-known renewables, wind and solar power, supplied in 1998 just 0.05 percent of all energy produced, wind dominating with almost 0.04 percent and solar energy putting in a mere 0.009 percent.[938] Even for electricity alone, wind power makes up just 0.09 percent and solar energy 0.02 percent.[939] In the progressive EU only 5.6 percent of the consumed energy is renewable, with most being supplied from biomass (3.7 percent) and hydropower (1.8 percent), whereas wind makes just 0.04 percent and solar 0.02 percent.[940]

Virtually every year, Lester Brown makes much of the fact that the use of renewable energy sources grows much faster than that of oil:

> In earlier years, the discussion on energy centered on what the new economy would look like. Now we can actually see it emerging. It can be seen in the solar cell rooftops of Japan and Germany, in the wind farms of Spain and Iowa, and in the widely varying growth rates of the various energy sources. While wind use was expanding at 22 percent a year from 1990 to 1998 and photovoltaics at 16 percent per year, the use of oil was growing at less than 2 percent and that of coal was not increasing at all.[942]

But such growth rate comparisons are misleading because, with wind making up just 0.05 percent, double-digit growth rates are not all that hard to achieve. In 1998, the amount of energy in the 2 percent oil increase was still 323 times bigger than the 22 percent increase in wind energy.[943] Even in the unlikely event that the wind power growth rate could continue, it would take 46 consecutive years of 22 percent growth for wind to outgrow oil.[944]

Put simply, this low share of renewable sources in global energy production is simply a consequence of the sources not yet being competitive compared to fossil fuels.[945] Up till now most renewable energy projects have been completed with public funding and tax rebates.[946] But as is clear from Figure 72, price has been rapidly declining, and it is expected that this decline will continue.

Hydroelectric power is important for many nations - it supplies more than 50 percent of the electricity production in 63 countries and at least 90 percent in 23 countries.[947] Hydropower has been competitive for quite some time but it is also quite well developed and there are few substantial opportunities for expansion in Europe.[948] Moreover, hydro-power also has several downsides: partly because it often has negative consequences for the environment,[949] and partly because most dams silt up within 20 to 50 years. It is expected that Egypt's Aswan High Dam. will be at least half silted by 2025.[950]

Geothermal energy from tapping the Earth's internal heat can also be competitive, but only a few places in the world are just right, for example locations in the Philippines and Indonesia.[951]

Presently the most competitive renewable energy source with a wide applicability is wind power. The price today is around 5-6.4 cents per kWh, and although this is more than ten times cheaper than the price 20 years ago, it is still somewhat more expensive than energy derived from fossil fuels.[953] Though the price is expected to decline further, it is expected still to be about 50 percent higher than the cheapest electricity production from gas-fired generating plants in 2005, and some 20 percent higher in 2020,[954]

Many people are often surprised that renewable energy is not cheaper than fossil energy. After all, the fuel is free. True, but there are several reasons why this is not the main issue. First, the price of the actual fuel only makes up a fairly small part of the total energy cost - in 1995 the fossil fuel price accounted only for 16 percent of the total cost of electricity.[955] Second, fossil fuels have a solid lead in research and development, since they have been around much longer and have had much larger shares of the national research budgets. Finally, the use of fossil fuels also gets much more efficient over time. New research has made capital costs fall by 2.5 percent with each doubling of new capacity. Concurrently more competition and better management mean that coal-fired power plants needing 250 people in 1982 could make do with just 200 people in 1995. Gas-fired power plants have experienced even larger efficiency gains, with a drop in the required man-power of 28 percent in the same period.[956] Deregulation of the oil and gas market as well as electricity has also made energy from non-renewable fuels cheaper.[957]

Nevertheless, it is important to focus on the fact that the difference in cost between traditional fossil fuels and some of the cheapest renewable energy sources is so relatively slight. Moreover, these economic costs do not include the negative social cost of fossil fuel use on the environment. Energy from a coal-fired power plant may still be 20-50 percent cheaper than the energy produced by a windmill, but if the effects on environment and humans from coal pollution and waste products exceed the price difference then society ought to choose wind energy.[958]

Recently, one European and two American large-scale projects have attempted to examine all costs associated with electricity production, all the way from the mortal risks of mining coal, the traffic hazards of transportation and occupational hazards of production including consequences of acid rain, particles, sulfur dioxide, nitrogen oxides and ozone on lakes, crops, buildings, children and old people and up to the consequences of tax codes and occupation plus a long, long list of similar considerations and costs.[959] Altogether these studies find that the extra social cost of new coal-fired power plants is around 0.16-0.59 cents per kWh.[960] None of the three studies, however, quantifies the costs of carbon dioxide which probably means an additional 0.64 cents per kWh (cf. the chapter on global warming).[961]

Consequently renewable energy actually has to drop somewhat in price before it will be competitive, even including social costs. Nevertheless, it is estimated that the price of renewable energy will fall faster than the price for conventional energy. It should however also be added that there is still quite a bit of uncertainty about the predictions of such prices, not the least because early predictions in hindsight have seemed rather optimistic -in 1991 the Union of Concerned Scientists predicted that solar power today would drop below 10 cents per kWh, but unfortunately it has still only dropped to about 50 cents per kWh.[962]

Thus, it is unclear whether it is necessary to support renewable energy with subsidies and tax exemptions. In Denmark this subsidy is as much as 5 cents per kWh for wind energy,[963] and in the US, subsidy for wind power is estimated at about 1.5 cents per kWh.[964] It would still be much more effective to tax energy such that its actual price would adequately reflect the social costs in production and emissions.

The underlying argument is often that we should support renewable energy because the market will discover only too late that we are running out of fossil fuels. But as we have seen above there is no risk of running out of fossil fuels anytime soon, even if some sources might be getting more expensive. Consequently, the assumption should still be that the market will invest the optimal amount of renewable energy if taxes reflect social costs.[965] However, in the chapter on global warming, we will look at whether society might prefer to invest more heavily in *research* into making renewable energy cheaper more quickly.

Nevertheless, the most important point in this section on energy is to stress not only that there are ample reserves of fossil fuels but also that the potentially unlimited renewable energy resources definitely are within economic reach.

Solar energy

By far the largest part of the energy on Earth comes from the sun. Only a small part comes from radioactive processes within the Earth itself. The sun gives off so much energy that it is equivalent to a 180-watt bulb perpetually lighting up every single square meter on Earth. Of course energy is not distributed equally - the tropics receive more than 250 watts whereas the polar regions get only about 100 watts.[966]

The solar energy influx is equivalent to about 7,000 times our present global energy consumption.[967] The scale of these relationships is depicted in Figure 73, where it is also clearly illustrated that the yearly solar energy by far exceeds any other energy resource. Or put in a different way: even with our relatively ineffective solar cells, a square area in the tropics 469 km (291 miles) on each side - 0.15 percent of Earth's land mass - could supply all our current energy requirements.[968] In principle this area could be placed in the Sahara Desert (of which it would take up 2.6 percent) or at sea.[969] In reality, of course, one would not build a single, central power plant, but the example underscores partly how little space really is necessary to cover our energy needs, partly that the area can be placed somewhere of little or no biological or commercial value.

The cheapest photovoltaic cells have become three times as effective since 1978, and prices have dropped by a factor of 50 since the early 1970s.[970] Solar cells are not quite competitive yet, but it is predicted that the price will drop further and it is expected that by 2030 it will drop to 5.1

cents per kWh. Particularly in areas that are far from cities and established grids, solar cells are already now commercially viable.

The remote Indonesian village of Sukatani was changed literally overnight when solar cells were installed in 1989. The equatorial nights, which last 12 hours all year round, previously left little to do. But today, children can do their homework after supper, the village sports a new motorized well pump providing a steady supply of water for better sanitation, and now some of the local *waning* (shops) are open after sunset and television sets provide entertainment and a window on the wider world.[971]

Solar energy can also be exploited directly through heating and indirectly by growing plants, later to be burnt (biomass). In Denmark it is estimated that direct solar energy can provide about 10-12 percent of our energy.[973] In the US also, biomass is predicted to have substantial growth. The trouble is, the green plants only poorly exploit sunlight, as is evident from Figure 73. It is unlikely that biomass will be able to provide a major part of global energy consumption - the total agricultural biomass production from stalks and straw, making up half the world's harvests in mass, only constitutes about 65 EJ or about 16 percent of the current consumption.[974] Green plants exploit on average 1-3 percent of solar energy, compared to solar cells' 15-20 percent energy efficiency.[975] Thus, solar cells only use one-thirtieth of the area required by plants -and they need not use good agricultural soil.[976] At the same time biomass gives rise to a slew of other pollution problems, e.g. suspended particles, sulfur, nickel, cadmium and lead.[977] Although biomass today still is not competitive it is cheaper than solar cells.[978]

For many developing countries biomass would also have to compete with food production for access to agricultural land. For some places in the world, however, growing biomass may turn out to be sensible, since production can take place on poor soils, help prevent erosion, and even help recreate more productive soil.[979]

The US Energy Information Agency estimates that solar energy could cover the entire American energy requirements more than 3.5 times over.[980] But for this to become reality a lot of ingenuity is required.

Japan has started integrating solar cells in building materials, letting them become part of roofs and walls.[981] Others have produced watertight thin-film ceramic solar cells to replace typical roofing materials. In Wales an experimental center open to visitors has chosen solar cells not only to supply the building with electricity, but also because it can save costs for traditional roofing.[982]

Wind energy

Wind energy has been exploited through millennia. Long before the Current Era, ancient civilizations in China, India and Persia used wind to pump up water and to mill grain.[983] Already in early medieval times windmills were a known technology throughout Europe, and the windmill remained the primary energy source till the arrival of the steam engine. In countries such as Denmark that did not have their own coal supply, the windmill continued to have a central position. In 1916 alone Denmark built more than 1,300 new windmills.

The oil crisis spurred a new research interest in windmills and since then fantastic results and progress have been achieved. Since 1975 prices have dropped by a whopping 94 percent, and productivity has increased by 5 percent every year since 1980.[984] Globally it is estimated that windmills *can* cover upwards of half of all energy consumption, but this would require in the region of 100 million windmills.[985] Being the world leader in wind power, windmills in Denmark still produced only about 9 percent of all Danish electricity in 1998.[986] In the US, windmills produced just 0.1 percent of the total electricity production in 1998.[987]

But problems will arise if a significant part of a nation's electricity requirements are to be met by wind power. Close to inhabited areas windmill noise can be a nuisance. Moreover, to be effective, windmills need to be placed in open environments, and here they easily mar the scenery. The only long-term solution is placing windmills far out to sea. Not only will there be few if any esthetic problems but windmills are typically 50 percent more effective here.[988]

Critics of windmills often point out that they are still not profitable, that they require much energy to produce, and that they kill birds.[989] As we saw above, windmills are still not fully competitive, although they are probably no more than 30-50 percent more expensive, and even less when including the social and environmental costs of continued use of fossil fuels. In the longer run, they will undoubtedly be competitive or even cheaper.

It is also objected that windmills themselves demand quite a bit of energy to be produced: the steel has to be mined, smelted and rolled, and the windmill itself has to be transported and in the end disposed of. However, going over the extended energy account, it turns out that a modern windmill can produce the energy used for its own production within just three months.[990]

It is true that windmills kill birds, although the problem will be much smaller at sea. In Denmark it is estimated that about 30,000 birds die in collisions with windmills each year.[991] In the US, the number is about 70.000.[992] While this may seem a large number, it is fairly trivial compared to the loss of birds elsewhere.[993] In Danish traffic alone it is estimated that far more than 1 million birds die each year, and in Holland about 2-8 million.[994] In the US, cars are estimated to kill about 57 million birds every year, and more than 97.5 million birds die colliding with plate glass.[995] In Britain, it is estimated that domestic cats annually kill some 200 million mammals, 55 million birds and 10 million reptiles and amphibians.[996]

Storage and mobile consumption

Both solar power and wind energy have a timing problem: the sun does not necessarily shine and the wind does not necessarily blow when humans need energy the most. Thus it is necessary to be able to store energy.

If the power grid is hooked to dams, these can be used for storage. Essentially, we use wind power when the wind blows, and store water power by letting water accumulate behind the dams. When there's no wind, water power can produce the necessary electricity.

However, this implies that both wind power and water power require a sizeable excess capacity, since both need to be able to meet peak demand. The solution also depends on relatively easy access to large amounts of hydroelectric power.

Generally speaking it is therefore necessary to secure a larger diversification of production. Biomass and geothermal energy can be used at all times. Moreover energy can be stored in hydrogen by catalyzing water.[997] The hydrogen can later be used in electricity production or as a general substitute for petrol in cars.[998] Costs here are still about twice those of ordinary gas, but hydrogen would be an exceedingly environmentally friendly fuel, since its combustion only leaves behind water.

Conclusion

The evidence clearly shows that we are *not* headed for a major energy crisis. There is plenty of energy.

We have seen that although we use more and more fossil energy we have found even more. Our reserves - even measured in years of consumption - of oil, coal and gas have increased. Today we have oil for at least 40 years at present consumption, at least 60 years' worth of gas, and 230 years' worth of coal.

At $40 a barrel (less than one-third above the current world price), shale oil can supply oil for the next 250 years at current consumption. And all in all there is oil enough to cover our total energy consumption for the next 5,000 years. There is uranium for the next 14,000 years. Our current energy costs make up less than 2 percent of the global GDP, so even if we were to see large price increases it would still not have significant welfare impact - in all likelihood the budget share for energy would still be falling.

Moreover there are many options using renewable energy sources. Today, they make up a vanishingly small part of the global energy production, but this can and probably will change. The cost of both solar energy and wind energy has dropped by 94-98 percent over the last 20 years such that they have come much closer to being strictly profitable. Renewable energy resources are almost incomprehensibly large. The sun leaves us with about 7,000 times our own energy consumption - for example, covering just 2.6 percent of the Sahara Desert with solar cells could supply our entire global energy consumption. It is estimated that wind energy realistically could cover upwards of half of our total energy consumption.

Notice that all of these facts do not contest that fossil fuels which today supply most of our energy are non-renewable - if technology remained constant and we kept on using just fossil fuels, we would some day run out of energy. But the point is that technology does not remain constant and fossil fuels are not our only or main long-term energy source. First, the historical evidence shows that we have become constantly better able to find, extract and utilize fossil fuels, outpacing even our increased consumption. Second, we know that the available solar energy far exceeds our energy needs and it will probably be available at competitive prices within 50 years.
Consequently, it is surprising that over and over again we hear the stories that *now* we will run out of energy. The data show us that this is not plausible. As the US Energy Information Agency wrote in the *International Energy Outlook 1999:* "bleak pictures painted of the world's remaining oil resource potential are based on current estimates of proven reserves and their decline in a [typical, theoretical] manner. When undiscovered oil, efficiency improvements, and the exploitation of unconventional crude oil resources are taken into account, it is difficult not to be optimistic about the long-term prospects for oil as a viable energy source well into the future."[999]

In the longer run, it is likely that we will change our energy needs from fossil fuels towards other and cheaper energy sources -maybe renewables, maybe fusion, maybe some as-of-now unimagined technology. Thus, just as the stone age did not end for lack of stone, the oil age will eventually end but not for lack of oil. Rather, it will end because of the eventual availability of superior alternatives.

Endnotes

813. Nigeria has lost 85-90 percent, Madagascar 60-85 percent (WCMC 1998). Reference to Central America from Williams 1990:191-2.

814. Notice, that Brazil's Atlantic rainforest has been reduced by some 88 percent, almost all of which was cleared before the end of the nineteenth century (Brown and Brown 1992:122).

815. Cunningham and Saigo 1997:297-8. See a general criticism of the many erroneous guesstimates in Glantz *et al.* 1997.

816. As several researchers have pointed out, the figure of 13 percent could mean that much more forest has been disturbed, as the forest next door to a cleared area is also affected - a so-called edge effect - (Botkin and Keller 1998:283). The original article by Skole and Tucker (1993) showed that 6 percent clearance of the Amazon led to an edge-effect of 15 percent. The problem is that the edge-effect is simply assumed to be one kilometer (also because of satellite resolution); had the edge-effect only been 100 m, the area concerned would not have been much larger than the 6 percent.

817. More than 100.000 km^2 has returned to forest since 1960 (Faminow 1997). See also Fearnside 1991:93.

818. 70 percent (Brown and Brown 1992:122). 25 million ha (WWF.http://www.panda.org/forests41ife/news/allirel.htm).

819. Quote from WWF chief executive officer Mohamed El-Ashry, cited in Anon. 2000b. Note equivalent quotes: from an academic text dealing with how to teach our children about the environmental problems: "We need to protect the forests, the precious 'lungs' of the Earth, that are being destroyed at a growing pace to obtain wood, agricultural land, mineral resources" (Camino and Calcagno 1995). Greaves and Stanisstreet (1993) state that 42 percent of all children incorrectly believe and voluntarily expressed this story.

820. Broecker 1970.

821. Broecker 1970:1,538; Ehrlich and Ehrlich 1987:138.

822. WI 1998d.

823. Bailey 1995:180. The world uses I,55e9 m^3 of wood for timber and paper (WRI 1996a:220); forest such as that in Denmark has a net growth rate of approx. 7.5 m^3/ha (ERA 1995:474). At this rate of growth, total world demand would call for 2E8 ha, or about 4.95 percent of the Earth's forest cover of 4.168E9 ha.

824. WI 1998a:23; WWF 1998a:6.
825. Myers 1991:54.
826. FAO 1997c:13, table 2.
827. WWF1998a:6.
828. "Only about 3 percent of the world's forests are forest plantations" (FAO 1999a:l). Compare, however, to a FAO estimate in 1997: Plantations in the industrialized world total some 80-100 Mha, in the developing world 81.2 Mha out of a total forest area of 3,454 Mha, i.e. 5.2 percent (FAO 1997c:10,14).
829. Estimate of fire, health and tourism costs of US$ 3.8 billion, EEPSEA/WWF 1998; of an annual GDP of US$ 198 billion, WRI 1998a:237.
830. WWF 1997b, title and p.l.
831. WWF 1997b, 1997d, 1998c.
832. WWF 1997b:7.
833. WWF 1997b:7; Woodard 1998; UNEP 1999a:8.
834. UNEP (1999a:40) reports 4.56 Mha burnt, of which 28.58 percent is forests and timber areas.
835. Goldammer is a scientist at the Max Planck Chemistry Institute and a participant in the Biomass Burning project with the National Center for Atmospheric Research, the US Forest Service NASA. http://asd-www.larc.nasa.gov/biomass_burn/ biomass_burn.html. Personal communication and Woodard 1998.
836. WWF 1997b:17. They also tell us several times that "thousands of fires are burning across 10,000 miles of the Amazon rainforest," although 10,000 miles stretches around more than one-third of the globe (WWF 1997b:4,17).
837. WWF1997b:18.
838. WWF 1997b:18; LaFranchi 1997; IPAM 1998.
839. UNEP 1999a:40; Golddammer 1991:84; Levine *et al.* 1995. In May alone more than 4.7 Mha burned (Cahoon *et al.* 1991:66).
840. UNEP1999a:4.
841. Conard and Ivanova 1997:308.
842. Indonesia has 109 Mha of forest (FAO 1997c:183). This is in accordance with the UNEP estimate (1999a:41) of 4.58 percent protected areas of forests, or about 208,000 ha.
843. Andreae 1991:5, 7; WWF 1997b:18.
844. Andreae 1991:4.
845. Levine 1991 :xxviii.
846. The WWF itself is involved in a certification process of this kind (Sedjo and Clawson 1995:343). Obviously, since so small a share of the world's forests are actually used in wood and paper production, this practice is not enough in itself.
847. Motavalli 2000.
848. See e.g. CNN from 1996, Mattingly 1996.
849. Craig et al. 1996:103.
850. Craig et al. 1996:111-14.
851. Craig et al. 1996:125-8.
852. The year 2000 is estimated from its first ten months. There is a discontinuity in the wood figures between 1945 and 1949 (1949 being 22 percent higher than 1945) due to changes in definitions. Data through 1945 are for fuelwood only, while thereafter include wood-derived fuel and wood byproducts burned as fuel, such as cord wood, limb wood, spent pulping liquor, pulp waste, wood sludge, hogged fuel, peat, railroad ties, sawdust, wood chips, bark, forest residues, and charcoal, E1A 2000d:349.
853. Barry eta!. 1993:131.
854. Craigetal 1996:103.
855. Unless we also include a certain probability that the civilization dies out.
856. "One barrel" should be taken as a metaphor for a tiny fraction of the present day oil consumption. Since oil is created on a million-year time scale, we can actually use a small amount each year (the oil that was created during this period), and still leave the coming generations with their own supply. A back-of-an-envelope calculation would seem to indicate that this amount is less than 50,000 barrels per year or what is equivalent to one minute of today's oil consumption.
857. Solow 1986:142.
858. Greider 2000, although, as with all popular phrases, more people seem to claim ownership. Anon. 1999g, 2001a.

859. Likewise, when *The Economist* asked in early 2001: "Will The Oil Run Out?" their answer was: "Eventually, yes; but by then it might no longer matter" (Anon. 2001 a).

860. Even Ehrlich agrees on this: Ehrlich and Ehrlich 1991:46-7.

861. Meadows *et al.* 1972:58.

862. Ehrlich and Ehrlich 1987:222.

863. Meadows *etal.* 1992:74 *et passim.*

864. Meadows *et al.* 1992:74.

865. Craiget a!. 1996:123.

866. Craig *et al* 1996:135. In 1996 the total oil production was 64 million barrels a day (EIA 1997b:table 11.5), each valued at about $20 (BP 1998). All in all $467 billion, or 1.58 percent of the global GDP of $29,609 billion (IMF 1997:147).

867. EIA 1997b:table 11.3.

868. One of the background reasons for the Gulf War (CRS 1995b).

869. Barry eta!. 1993:135-6.

870. Simon 1996:165.

871. Simon etal. 1994:325.

872. Simon 1996:24ff.

873. Greene 1997. Although it is often claimed that OPEC is a monopoly, oligopoly or a cartel, there is actually obvious evidence against this - 1) OPEC lacks the clout since non-OPEC production constitutes the majority of the world output, 2) only since 1983 has OPEC attempted to set production quotas and it has never agreed on price, and 3) OPEC has no mechanism for punishing members for defecting from any OPEC agreement. Instead, empirical evidence seems to point to Saudi Arabia as the dominant producer, with its production *negatively* correlated to the rest of OPEC, allowing the price to increase beyond the competitive price (Alhajji and Huettner 2000).

874. IEA2000b:25.

875. EIA2000e:58.

876. EIA2000e:102.

877. EIA2000b:26.

878. Price of unleaded spliced with price of leaded from 1950s to 1970s; tax information for the 1950s from http://www.eia.doe.gov/oiaf/issues98/ gastax.html.

879. Adelman 1995:287; cf. EIA 1997b:table 3.3, when measured in real prices, table Dl.

880. This argument is used in, e.g., Ehrlich and Ehrlich 1974:48.

881. Be aware that part of the increase in the reserve estimates for the OPEC countries in the late 1980s could be caused by the fact that these figures are also used in negotiations for OPEC quotas. This is suggested by CRS (1995b) and Ivanhoe (1995:82). Nevertheless, it is generally estimated that reserves did go up, also in the 1980s (USGS 1997a).

882. Quoted in Simon 1996:165.

883. Simon 1996:164-5.

884. E.g. Nordhaus 1992b:16.

885. It should be added that more advanced models like the Hubbert curve try to predict future discoveries, but although these models have been successful with countries like the US, using up its resources early, it is not at all clear whether these models will work with the much bigger and more important oilfields. It is still possible that the low rates of new discoveries primarily are reflections of low prices and very high oil reserves. See Campbell 1997 and Ivanhoe 1995.

886. USGS2000b.

887. Craig et a!. 1996:134. In Denmark it was estimated that less than 20 percent of the oil is exploited *JyllandsPosten,* 15 May 1998:E5.

888. USGS2000b.

889. From 13.4 mpg to 21.4 (EIA 2000c:17).

890. Europe uses 24 percent less energy per square meter in 1992 than in 1973; the US uses 43 percent less (Schipper *et al.* 1996:184).

891. Schipper *et al.* 1996:187. In Denmark electric home appliances have become 20-45 percent more effective over the last ten years (NERI 1998a:238).

892. "Unnecessarily" meaning that the waste could have been avoided. A further 41 percent is wasted in transforming fossil fuels to electricity, and this waste is not (easily) avoidable (Miller 1998:398).

893. Cunningham and Saigo 1997:494-5.

894. Miller 1998:404. See also *Time* 1997:48-9.

895. See the discussion in Wirl 2000, but this is a protracted debate, which we will discuss in chapter 24.

896. There are data for Japan and the EU back to 1960 (which is where the World Bank 1999b data start) and it shows a slight U-curve. However, this is misleading, since this does not take into account the use of non-traded energy and that the energy efficiency of Japan improves dramatically before 1960 (Grubler *et al.* 1996:245; cf. CIA 1997, http://www.odci.gOV/cia/publications/hies97/f/figl8. jpg). For similar reasons, the UK energy efficiency is not extended back before 1880, since non-traded energy is not estimated (unlike for the US) but becomes ever more important when going back in time.

897. That Japan and the EU can produce more with the same amount of energy is strongly related to higher average energy prices than in the US (Moisan *et al.* 1996:54-5).

898. World Bank 1994:171; see also EU 2000a:36.

899. Turner *et al.* 1994:45-6. This also holds true for the time span 1970 to 1994 per capita (Statistics Denmark 1997a:128). Jespersen and Brendstrup note, however, that part of this effect is due to better insulation, which is pretty much a one-time gain; consequently they estimate the true energy efficiency to have increased by 22 percent rather than 33 percent (1994:66).

900. Hausman 1995.

901. WRI1996b.

902. 40 percent less CO_2 than coal (NERI 1998A.-169).

903. Other reserve years from a graph of reserves for 1973-98 (BP 1999; http://www.bpamoco.com/worldenergy/naturalgas/page_01.htm#).

904. Measured at the current rate of consumption for each quoted year. Gas reserves have increased to 252 percent (BP 1999).

905. WRI 1996a:276; Botkin and Keller 1998:336.

906. HargreavesetaZ. 1994:373.

907. EIA1997c:67.

908. Jespersen and Brendstrup 1994:58-9; NERI 1998A.-169.

909. Cohen 1995:579. In the US more than 50 miners die each year in coal extraction related accidents (Craig *et al* 1996:119). The total death toll seems to be very uncertain, as we will see in the chapters on pollution: Cunningham and Saigo (1997:468-9) estimate excess deaths in the US to be close to 5,000; Miller (1998:441) suggests 65,000-200,000 extra annual deaths. In comparison, the World Bank estimates an annual 300,000-700,000 extra deaths in the developing world, where pollution is much higher (with 1.3 billion people, this estimate is much lower than Miller) (World Bank 1992:52).

910. WEC 2000:chapter 1.

911. Craig et al. (1996:159) estimate global resources at 7.8el2 tons. EIA (1995a:8) estimate that the US resources alone are approximately 4el2 tons.

912. Methane gas reserves are estimated by the US Geological Survey to be somewhere between 85 and 262el2 m^3, compared to natural gas at 119el2 m^3 (Craig *et al.* 1996:150; USGS 1997d).

913. Additional resource data from *International Energy Annuals,* personal communication, Harriet McLaine, EIA. Price of Bituminous Coal FOB Mines.

914. Notice, though, that this is also due to production facilities having been written off (EIA 1997c:37).

915. EIA 1997c:37. See also USGS 1997b.

916. Craig *et al.* 1996:159. Notice that this is from a resource and not a reserve view - coal resources are here estimated at around 7.8e9 tons, or more than 1,700 years at present consumption.

917. The total energy in shale oil is estimated at 2.11e24J, while we consumed 4e20J in 1999 (see Figure 63).

918. World's yearly non-renewable energy consumption of 3.25e20J in 1993, or about 3.09el7 BTU, at a 1996 average price of $1.85 per million BTU (EIA 1997b:table 3.1), or approximately $570 billion, or 1.9 percent of the global GDP at $29.609 billion (IMF 1997:147). With an annual growth of 2.7 percent from 1998 to 2030 (IFPRI's assumption to the year 2020,1997:10), global GDP will have grown to about 2.35 times the present size. If the price of energy is doubled in real terms, this will imply an energy share in 2030 of 1.6 percent. Historically, this share has been declining too (Simon 1996:31).

919. EIA1997c:75.

920. 30 percent of all new nuclear reactors are placed in Asia (EIA 1997d:13). Stagnation (EIA 1997d:5). From 1975 to 1986 the attitude in the US changed from 65 percent in favor to just 20 percent, whereas opposition exploded from 19 percent to 78 percent (Cunningham and Saigo 1997:482; Craig *el a\.* 1996:172-3).

921. Craig *etal* 1996:164.

922. Because coal has trace amounts of radioactive materials, released during combustion (Chiras 1998:266; Cunningham and Saigo 1997:467; USGS 1997c).

923. This is very dependent on the price of uranium (WEC 2000:chapter 6). Nuclear power produced 2.266el2 kWh (EIA 2000a:93) or 8.16el8J. It is assumed that with conventional U-235 about 8e20J is producible, i.e. 100 years (Craig *etal.* 1996:181).

924. See e.g. Craig *et al.* 1996:170.

925. All in all about 1140e20J (Craig *et al.* 1996:181).

926. Cunningham and Saigo 1997:477-9.

927. Miller 1998:452.

928. The median price in the year 2000 is 7.7* in 1987 prices (=10.99<t) cited by a pro-nuclear writer (Cohen 1995:table 29.2), while it is 13.54: cited by an opponent (Miller 1998:452).

929. Average price is 6.63<t in 1999 in 1999$ (EIA 2000c:128). In the commercial price is included the price of distribution, which should be subtracted before comparing with the nuclear power price -typically around 0.4<t (EIA 1996:108).

930. Using the two isotopes of hydrogen - deuterium and tritium. Deuterium can be extracted economically from ocean water, and tritium from reactions with lithium in the fusion process (Botkin and Keller 1998:371).

931. Cunningham and Saigo 1997:484.

932. Miller 1998:454.

933. CRS1998.

934. Anon. 1998d.

935. EIA 1993:1.

936. WRI 1996a:286; Botkin and Keller 1998:264.

937. Biomass is the extraction of energy from wood, wood waste, wood liquors, peat, railroad ties, wood sludge, spent sulfite liquors, agricultural waste, straw, tires, fish oils, tall oil, sludge waste, waste alcohol, municipal solid waste, landfill gases, other waste, and ethanol blended into motor gasoline (EIA 1999a:249, see also EIA 1998c).

938. This can also be estimated independently. The global sold wind power is estimated at 10,153 MW (http://www.windpower.dk/stat/tabl 9.htm, accessed 23 April 2000) yielding an annual, maximal production of 8.9elO kWh. In California with 20 percent of all wind power, it is estimated that the actual power production is about 21 percent of the maximal figure (26 percent for windmills after 1985, CEC 1995:12) because the wind does not always blow. With 26 percent efficiency, the global production is maximally 2.3elO kWh, or about 83.3 PJ. The global energy production in 1998 was about 400 EJ, and with wind counting in fossil-fuels-avoided of a factor 3, this makes about 0.062 percent. The total, shipped solar cell capacity is 960.7 MW (WI 1999a:55), which is a maximum estimate of installed capacity. If these solar cells operate at 100 percent efficiency 12 hours a day, this is equivalent to 15.2 PJ annually, or 0.011 percent of the total energy production.

939. The global electricity production is 48 EJ (or about 144 EJ in fossil-fuel-avoided, EIA 2000a:93), where wind makes up 0.045 EJ and solar 0.01 EJ.

940. From 1997 in actual energy and not on fossil-fuel-avoided basis, EU 2000a:21, 64.

941. Data broken down into net electricity generation from biomass, geothermal, solar and wind electric power in 1998 provided by Michael Grillot, EIA, personal correspondence, from Energy Information Administration, International Energy Database, December 1999. Data for nuclear, hydro, biomass, geothermal, solar and wind electric power is measured by fossil-fuel-avoided energy. Since 1 kWh produced would take about three times that energy in, say, oil to produce, these are about three times higher than their direct energy production (65.6 percent in USA, EIA 1997b:diagram 5). Outside the US, only energy from biomass, geothermal, solar and wind used for electricity generation is counted. Data for traditional fuels are from 1995, projected on past increases to 1998. The total generated electricity from geothermal, solar and wind is 56.8 TWh, which compares well with the IEA estimate of 57.6 TWh (IEA 1999:11, 18. Notice, when WRI finds geothermal energy ten times bigger (2000:292), it is because they assume not only the 10 percent electrical energy is exploited but also the other 90 percent heat, p347).

942. WI 1999b:16-17, cf. p. 48, 54; 1997b:54; 2000a:17.

943. 22 percent of 0.045 EJ versus 2 percent of 159.7 EJ.

944. .045EJ*1.22^{A}45.7=159.7EJ*1.02^{A}45.7.

945. EIA1997c:85.

946. In the US, subsidy for wind power is about 1.5 t/kWh (CRS 1998), and in Denmark the Center for Biomass Technology under the Department of Agriculture states quite honestly: "When the Centre for Biomass Technology hosts foreign visit groups a major question is always: how can you have so many plants and techniques in your small country? The answer is: it pays off! And the reason that it pays off is the subsidies for investment and subsidies for electricity production, which improve the situation for biomass, and the taxes on fossil fuels, which make these more expensive" (CBT 2000).

947. WEC 2000:chapter 7.

948. EIA1997c:88.

949. Hille 1995:193.

950. Craiget ol. 1996:191.

951. DOE 1997:3-lff.

952. Primary figures and estimates are summarized in DOE 1997:7-3. For wind energy (at 5.8 m/s wind) also: EIA 1997c:85; 1993:11; 1996:55. For solar thermal generation EIA 1993:11; Ahmed 1994:39. For photovoltaic systems, Ahmed 1994:77. A number of other sources give somewhat non-comparable prices, among these DOE 1995:9; WI 1991:27; 1995:70; EU 1994b; DOE 1996:11; Andersen 1998; Greenpeace (http://www.greenpeace.org/~comms/ no.nukes/nenstcc.html); Cunningham and Saigo 1997:496.

953. DOE 1997:7-3.

954. EIA (2000e:75) estimates that wind power will cost 6 <t/kWh in 2005 and 4.5 <t/kWh in 2020, still more expensive than power from coal (4.3 and 4.2 <t/kWh) and gas-fired combined cycle (4.2 and 3.8 <t/kW). Notice, that due to very different ways of calculating total cost, including different capital recovery time spans, it is difficult to compare prices across studies.

955. EIA 1996:108.

956. EIA1997a:53.

957. McVeigh 2000:237-8.

958. Hohmeyer 1993. Of course, we should also include any social costs from wind mills in the calculation, but these will probably be small.

959. Krupnick and Burtraw 1996. The three studies are: US Department of Energy (Oak Ridge National Laboratories/Resources for the Future, Lee *et al* 1995), EU (DG XII 1995) and Empire State Electric and NY State Energy Research and Development Authority (1995).

960. Krupnick and Burtraw 1996:24. It is here relevant to disregard the EU estimate for $S0_2$, since we want a cost estimate on the *present* social price (i.e. what it costs with the present technology to replace a part of the present electricity consumption). EU's own estimate is 1.56 <f/kWh.

961. Krupnick and Burtraw 1996:38. Taking into account not only the detrimental effects of CO_2 but also the benevolent consequences on employment and tax revenues, coal turns out to be *better* than gas, for example, and has a *positive* social value.

962. Cunningham and Saigo 1997:496; cf. McVeigh *et al* 2000.

963. This is the result of a direct subsidy of 10 and 17 orer (8 orer to the cent), and an indirect subsidy through tax exemption of somewhere between 12.2 and 22 0rer per kWh (Ministries of Finance *et al.* 1995:35, 51).

964. CRS 1998.

965. This also means that it is problematic when people like Levins (in Miller 1998:426-7) argue that we should conserve energy, since much energy is used for "bad energy." Lovins finds that we should not use electricity to heat and cool buildings, because this is very expensive - we should rather insulate more, use superwindows, plant trees, etc. But the point is that if the consumer - after including social cost - still would prefer to use electricity instead of extra-thick windows, then it is dangerous to argue that the social planner would know better than the consumer what would give the highest mix of utilities. See discussion in Wirl 2000.

966. Craiget a!. 1996:183.

967. 180 W/m^2 on the Earth's 5.1e8 km^2 gives an annual energy of 2,895e24 J or 6,951 times the energy consumption in 1997.

968. With an average influx of 300 W/m^2 and an efficiency at 20 percent, 21,9961 km^2 would exactly produce an annual 416 EJ. 21,9961 km^2 is 0.147 percent of the Earth's land area of 1.495e8 km^2.

969. The Sahara Desert takes up about 8.6e6 km^2, "Sahara," *Encyclopedia Britannica Online,* http://www. britannica.eom/bcom/eb/article/5/0,5 716, 66425+l+64749,OO.html?query=sahara.

970. EIA 1993:13; Ahmed 1994:80.

971. Cunningham and Saigo 1997:487-8.

972. For alternative estimates, see IPCC 2000a:134, 136. Here 'recoverable with technological progress' is estimated for oil to be 9ZJ, gas 20ZJ, coal 80ZJ, and nuclear >11ZJ. For renewables, annual 'long-term technical potentials' are estimated at >130EJ for hydro, >130EJ for wind, >2,600E] for solar, and >1,300 forbiomass.

973. Donmarks Energifremtider 1995:137.

974. Smill999.

975. Ahmed 1994:10-11.

976. 20 percent efficiency at 100 W/m^2 on 27,746 ha gives an annual energy production of 175 PJ.

977. Radetzki 1997:552-3.

978. DOE 1997:7-3 estimates 8.7 <t/kWh for bio-mass and 49.1 <t/kWh for solar cells.

979. Miller 1998:420.

980. EIA 1993:3.

981. IEA/OECD 1996.

982. IEA/OECD 1998.

983. The following is based on Andersen 1998.

984. http: || www.windpower.dk / present / produke. pdf.

985. Hille 1995:195-6.

986. http:|/www.windpower.dk/stat/tabl4.htm, accessed 26 April 2000; cf. Windpower Note 1998a:7

987. EIA2000a:211.

988. 51 percent more efficient (Windpower Note 1997:11). Price is estimated at 49 ore (about 7 cents)/kWh (http://www.caddet-re.org/html/article2 .htm).

989. E.g. Bradley 1997.

990. Windpower Note 1997:8 estimates that a windmill earns the energy used to produce it 80 times through its 20 years of service, meaning that its own energy is paid back after 91 average days.

991. Andersen 1998 (calculating with 4,000 turbines, where the correct number for 1997 is 4,700 [Windpower Note 1998a:7]).

992. The average Danish turbine has a nameplate capacity of 276 kWh (Windpower Note 1998a). Assuming approximately similar setup for the US, with total nameplate capacity of 2,500 MWh (AWEA 2000b), and using 30,000 birds per 4,000 turbines (Andersen 1998), gives 67,000 birds annually. Notice, that when AWEA (2000a:2) claim only 500 birds lost in California, this is incorrect - the 500 refers only to raptors, not all birds (Kenetech 1994:3).

993. NERI1995.

994. Andersen 1998; NWCC 1994:appendix 2.

995. Kenetech 1994:3; AWEA 2000a.

996. The total number of domestic cats are estimated at 9 million (the survey did not measure the kills of the approximately 800,000 stay cats), making each cat catch some 30 animals per year, Mammal Society 2001a&b, Wark 2001.

997. See e.g. DOE 1997:appendix 1.

998. Miller 1998:423ff.

999. EIA1999d:23.

1000. Meadows *et al.* 1972:56ff.

1001. The calculated years of consumption are primarily based on present production divided by reserve base.

1002. Simon 1996:35-6.

1003. WRI1996a:170

1004. Leon and Soto 1995:16 (index from 1900-92) finds that 15 out of 24 products have declined in price, six have remained stable and only three have become more expensive.

1005. This is calculated with prices and quantities for 93 raw materials from US Geological Survey the first 24 listed in Table 2. It is equivalent to the 1.2 percent, mentioned in Goeller and Zucker 1984:457. Since parts of the raw materials listed overlap, this is undoubtedly a maximal estimate.

1006. Anon. 2000c. The industrials price index consists of Metals and Nfas (non-food agricultural commodities), each weighted with the following percentages, now based on the value of world imports in 1994-96. Metals: Aluminum 47.0 Copper 32.4 Nickel 8.2 Zinc 6.7 Tin 2.9 Lead 2.8. Nfas: Cotton 30.7 Timber 19.4 Hides 15.4 Rubber 15.4 Wool 64s 6.5 Wool 48s 6.5 Palm oil 2.9 Coconut oil 1.5.

1007. Surprisingly, previous analyses have focused on weight of the raw materials, a decision which does not seem quite obvious (Agerup 1998:83; Simon 1996:48; Kahn et al. 1976:101ff).

1008. Notice that this assumes the entire world paying the American price for Portland cement, which is definitely a maximal assumption.
1009. Craig *et al* 1996:339.
1010. Craig *et al.* 1996:340; Hille 1995:299.
1011. WRI 1998a:344.
1012. Craig *et al.* 1996:232ff.
1013. Craig et *al.* 1996:43.
1014. Measured in 1999 reserve base/world production of bauxite.
1015. Craig *et* al. 1996:212.
1016. Craig *et al* 1996:221.