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ENTROPY MAN

John Bryant

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Preface

The seeds for this book were sown in the 1970s, four decades ago, when I was then working as group economist for the engineering corporation Babcock International Plc. At that time the group employed about 30,000 people in subsidiaries spread all around the world, engaged in the design, manufacture and installation of capital plant for a variety of industries, including nuclear & conventional power generation, coal mining, gas, chemicals & petroleum, steel, automotive, cement, construction and environmental engineering. Prior to that, my formal university education had included a degree in engineering at University of Bath and a Masters in management science, allied to student sandwich experience with Amalgamated Power Engineering [*now a subsidiary of Rolls Royce*] and ASEA Brown Boveri, Switzerland, followed by working for SKF, the Swedish bearing manufacturer, often considered to be a bell-weather of world economic output.

From the 1980s onwards I worked as director of a consultancy, and subsequently also as an expert witness to the Courts, which roles I continue to the present day. These experiences have taught me to maintain an enquiring, dispassionate and impartial mind regarding the complex workings of human endeavour, the natural world and changes arising thereof.

My particular research interests in those early years concerned the parallels between the disciplines of economics and thermodynamics [*the science of energy & heat*] and how they relate to each other, as a result of which I published two peer-reviewed papers on the subject in *Energy Economics* [1979 & 1982]. Subsequent to these I gave presentations to international gatherings of government ministers, energy industry executives and academia.

Not being based at a university however, and with no research grant at my disposal, my main thrust had been to make a living from consultancy and therefore, until more recently, opportunities to spend time on research were few. Nevertheless, by the turn of the millennium I was able to find time to return to some research and published another peer-reviewed paper in the *International Journal of Exergy* [2007], followed up by several working papers on monetary aspects and energy models. Subsequently in 2009 I wrote a technical book on the subject, to bring together all the facets of the

work into a coherent whole: *‘Thermoeconomics – a thermodynamic approach to economics’*. The book was subsequently revised, corrected and added to, up to a third edition [2012], covering topics such as production and consumption processes, employment, money, interest rates and bonds, energy resources, climate change and sustainability, and including more up to date statistics. It has now been superseded by this book.

Whilst not being tied to a university, government agency, industrial enterprise or other organisation has disadvantages in terms of recognition and time available for research, it does nevertheless have the advantages of freedom to investigate and pursue a course of enquiry of one’s own choosing and of drawing conclusions independent of those that pay the piper or who may have pre-set agendas, however well-intentioned these may be.

The nature of the subject requires significant proof for economists and scientists to accept that similarities between thermodynamic and economic phenomena might imply more than just a passing analogy or isomorphism, and relations between the two disciplines have rarely been comfortable, with scientists sometimes having scant regard for the work of economists; and many economists believing that science has little to offer their discipline which, by its nature, can be thought of as anthropocentric rather than eco-centric. One eminent energy scientist advised me that he did not know of an economist who could follow a thermodynamic argument. Certainly a concept such as entropy means very little to most economists, still less to the man in the street – money is their language of communication. The latter is not, however, the language that Nature and the environment converse in.

This book is intended for a mixed readership of scientists, economists and those of an enquiring mind. It is a challenge therefore to convey the nub of the argument in terms that all can appreciate, with particular reference to the effects of potential problems such as ‘peak resources’, humankind’s effect on the ecosystem and the maelstrom that would ensue should resource failure or climate change ever come about to a significant degree.

While some chapters, notably chapters 4 through to 8, do contain some mathematical expressions, explanatory points are included to guide non-mathematicians onwards. Formal proofs and derivations have been relegated to the notes on each chapter.

Although economic man may currently have the ascendancy, he does not actually 'own' the Earth. He is there on sufferance, and the Earth would quickly forget him along the ecological timescale, should human civilisation fail or spoil the proceedings.

I am indebted to my wife Alison for all her support and for providing me with an atmosphere conducive to my research.

John Bryant

CHAPTER 10 RENEWABLE RESOURCES

In contrast to non-renewable resources, which involve once and for all use and a gradual reduction in reserves, renewable resources involve repeated use, up to a carrying capacity, but subject also to factors which might impact at different times to limit the size of that capacity. The chief resources that come within this description include the following:

- Humankind
- Water
- Land and soil
- Plant life
- Animate life
- Energy from sunlight and movements in wind and water

Not included in the above list are changes in the atmospheric climate of the Earth, which will be the subject of the next chapter.

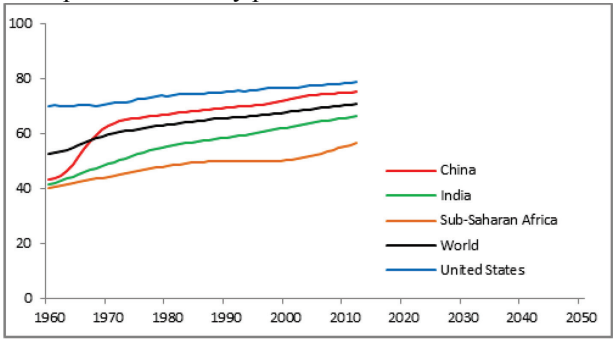
From the discussion at chapter 8, it is self-evident that some animate life, including humankind, would be regarded as predatory, being dependent upon prey and resources to sustain themselves, but that other animate life would be seen more as prey. However, even a cow could be regarded as predatory with regard to the grass and vegetation that it relies on for succour, and likewise, grass and vegetation in turn compete for water, soil and sunlight for their sustenance. Thus all living renewable resources operate via complex stocks, flows and interrelating chains and feedback mechanisms.

Humankind

We looked at the development of the human race in chapter 2, and here we add a bit more detail, in particular more recent trends which might indicate whether the world population is approaching a peak, is continuing to grow or may decline in the coming decades. Succeeding sections deal with some of the other resources with regard to the extent to which they might impact on the human population or, in reverse, their size and condition has been influenced by growth in human population and activities.

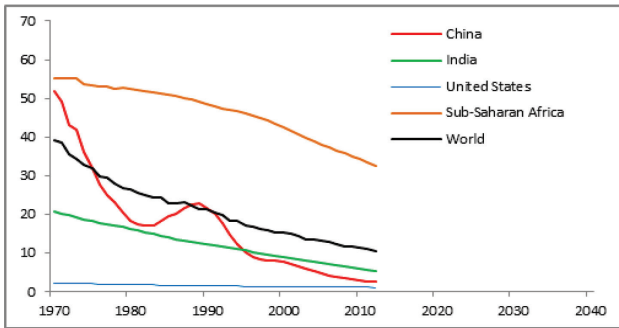
Comprehensive demographic statistics collected by the UN Department of Economic & Social Affairs indicate three very clear population trends. Figure 10.1 shows changes in longevity for selected economic areas, figure

10.2 incidence of deaths of children under five among all deaths and figure 10.3 the development of fertility per woman.



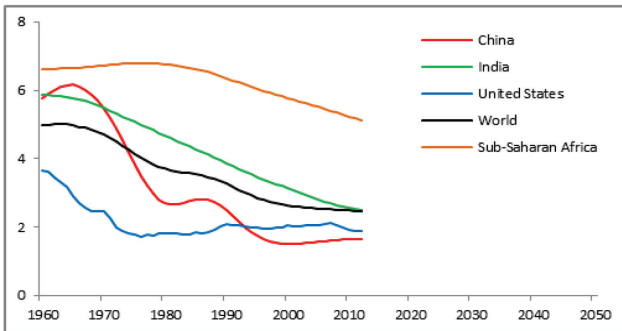
Source: UN

Figure 10.1 Life expectancy at birth (male & female) years.



Source: UN

Figure 10.2 % of deaths of children under 5 years to total deaths.

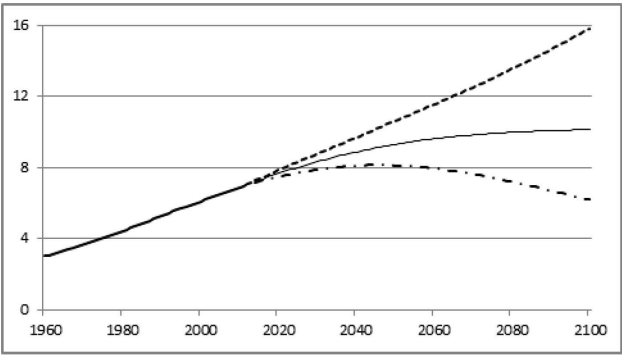


Source: UN

Figure 10.3 Fertility per woman aged 15-44 (number of children).

Life expectancy has risen in most countries over the last five decades, with an indication that this may continue for some time. Growth in economic wealth & well-being and the benefits of scientific advances are the likely forces at work, as a significant input to the trend has been the reduction in the death rate of young children. The latter in particular means that parents in most parts of the world currently do not need to plan for large families in order to propagate and sustain the species. A follow on from this trend has been a significant decline in fertility per woman, which appears likely to fall further, perhaps even to an average rate around 2 within two or three decades or so. Only in Africa is a rate above 2 likely by 2050, though even here a downward trend is evident.

A consequence of a continuing low fertility rate and a rise in longevity is that population will continue to rise for a few generations until the crude death and birth rates begin to meet each other. For a sufficiently low average fertility rate, perhaps a little over 2 for the world, population will begin to level off. For a very low fertility rate, eventually population will begin to decline. The United Nations have produced updated [2010] projections of world population, based on a number of scenarios, of which three are illustrated at figure 10.4. They assume that average world fertility rates per woman will eventually reach: low 1.5, medium 2.0, and high 2.5; with a resulting spread of population: from a peak and decline, to level or on to continued growth.



Source: UN Department of Economic & Social Affairs population division

Figure 10.4 World population prospects – the 2010 revision billions people.

Exactly what trajectory will eventually come to pass, however, will depend upon the unfolding forces at work and world events. Mass effects, such as

famine and recurrence of disease, or a restriction on resources, could curtail some of the benefits that humans have previously enjoyed, resulting perhaps in a step backwards in economic development.

Water

Water is an essential ingredient to sustenance of all life forms. Summaries by Shiklomanov [*IHP UNESCO 1998*] and Gleich & Palaniappan [*Proceedings National Academy of Sciences 2010*] indicate that the Earth contains a vast amount of it – 1,386 million km³ [cubic kilometres] – but of this, 97.5% is made up of saline water and only 2.5% fresh water. Of the latter small proportion, 68.7% is locked into the Arctic, Antarctic and mountainous regions in the shape of ice and permanent snow cover, and another 30% [10.5 million km³] appears as fresh groundwater around the world. Only a relatively small amount, 1.3%, appears in lakes, wetlands, rivers and clouds. Every year the Earth’s hydrological cycle turns over in the region of 577,000 km³ of water, 502,800 km³ evaporating from the Earth’s oceans and 74,200 km³ from the land; but in the other direction rather more of the turnover, 119,000 km³, falls as precipitation to the land, leaving 2,200 km³ to aquifer groundwater and in the region of 42,600 km³ per year as runoff to rivers, eventually to be returned to the oceans. These amounts alter slightly with the complex eco-cycles that the Earth moves through. Table 10.1 illustrates Shiklomanov’s estimate of world water resource flow by geographic area, along with updated data of human population for 1994.

1994	Human Population millions mid-year	Land Area millions km ²	Average Water Resources km ³ /year	Potential water availability per human m ³ /year
Europe *	729	10.5	2,900	3,980
North & Cent America	455	24.3	7,890	17,300
South America	317	17.9	12,030	37,900
Asia +	3,432	43.5	13,510	3,940
Oceania	29	9.0	2,404	82,900
Africa	699	30.1	4,050	5,790
World	5,661	135.3	42,784	7,560

Source: Shiklomanov World Water Resources IHP UNESCO 1998

* inc FSU

+ inc Siberia & far East Russia

Table 10.1 World water resources 1994.

While water is a renewable resource, it has variable cycles of renewal. Shiklomanov estimates that, compared to soil moisture, which has an annual cycle [according to seasonal fluctuations], by contrast groundwater is recharged slowly, over some 1400 years, with lakes in between at 17 years. Consequently, the two key water sources essential to land-based life are precipitation to the soil and river runoff. Groundwater becomes important to humans for areas of the Earth that are short of the main sources of water, and then only for the short term, because of its long recharge period. Fresh water, predominantly from rivers, is the key resource for human industrial activity and agricultural irrigation. The top fifty rivers of the world account for approaching half of total river water resources.

Compared to some energy and material resources, which may have some substitutability between each other, water cannot be substituted. It is its own substitute. Outside of river flow and local precipitation, it is expensive either to transport from other areas or to produce from ocean-water; the latter by desalination, requiring energy consumption to evaporate it as salt-free steam before condensing back to liquid for use.

Available data of renewable freshwater withdrawal and consumption are not standardised and are collected from a variety of sources [see *The World's Water - Gleich et al*], being either measured directly or modelled based on specific assumptions. Some data are recent and some many years old. Consequently care should be exercised when applying such data to derive conclusions. The writer does not profess to be an expert in these matters. Table 10.2 is a summary of more recent world water withdrawals by continent.

2006	Population millions mid-year	Total Water Withdrawals km ³ /year	Of which %			Withdrawals per head m ³ /year
			Municipal	Industrial	Agricultural	
Europe	732	333	22	56	22	455
N America	332	604	14	43	43	1,819
Cent & S America	566	225	22	12	66	398
Asia	3968	2507	9	10	81	632
Oceania	34	19	26	16	58	558
Africa	924	214	13	5	82	232
World	6556	3902	12	19	69	595

Source: UN World Water Development Report 2014 p178 indicator 6
 Table 10.2 World water withdrawals 2006.

These figures, alongside those of Shiklomanov [World Water Resources IHP UNESCO 1998], indicate that world water withdrawals are continuing to escalate, as shown in figure 10.5, yet average available water resources, as per table 10.1, remain about the same.

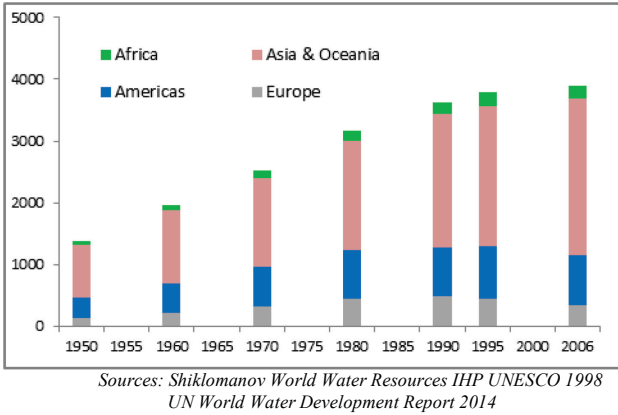


Figure 10.5 World water withdrawals km³/year.

The major area of increase in water withdrawals has been Asia, in particular, China and India.

Gleich and Palaniappan [The World's Water 2008-09] estimate that about one-third of the world's human population lives in countries with moderate to high water stress, defined by the United Nations to be water consumption that exceeds 10% of renewable freshwater resources. A working paper of Gasset, Reig et al [World Resources Institute, Dec 2013] ranks hydrological indicators of countries, river basins and most populous river basins, using the ratio of annual water withdrawals to annual renewable supply to measure baseline water stress. Countries high on the list include those in the Middle East, Mongolia, Pakistan, Spain and India. River basins with high water stress include Indus and Ganges [India] and Yongding He, Liao He and Huang He [China]. Gleich [The World's Water 2008-09] concludes that China in particular has developed a set of water quality and quantity problems as severe as any on the planet.

A paper by Wada, Ludovicus et al [Geophysical Research Letters Vol 27 L20402 (2010)] concludes that global depletion of groundwater resources has increased, from 126km³ [± 32 km³] in 1960 to 283km³ [± 40 km³] in 2000. At

2000, depletion per annum was equal to 39% of global annual groundwater abstraction. Particular hotspots included North-East China, North-East Pakistan, North-West India, some parts of the USA, Iran, Yemen and South-East Spain. Such depletion has run-off into rivers, ultimately to the oceans, giving rise to an increase in sea-level. Figures of the 4th edition of the UN World Water Development Report [figure 3.8 WWDR4] indicate that groundwater abstractions are growing rapidly.

Water stress and availability worldwide will likely pose a potential constraint in the future, engendering negative forces to limit or reduce output, with effects across national boundaries.

Land & Soil

Besides water, the states of land and soil resources are also key factors on which the carrying capacities of human, animal and plant life depend. Food-balance statistics for 2011 [FAOSTAT] indicate that, worldwide, average food supply per human per day was estimated to be 2,868 kcals, but of this only 34 kcals or 1¼% came from fish, seafood & aquatic products. Preserving cropland and maintaining soil fertility therefore should be of highest importance to human welfare. Table 10.3 summarises the distribution of world land by type of use.

Around Year 2000	Total Land M Ha	Of which %					
		Cultivated	Grassland Woodland Ecosystem	Forest	Sparsely vegetated & barren	Settlement & Infra-structure	Inland Water
Europe *	2243	13.5	32.8	44.4	6.7	1.0	1.6
N America	2090	11.0	32.2	29.1	21.6	0.7	5.4
Cent & S America	2036	8.4	37.6	46.5	5.3	0.7	1.5
Africa	2986	8.2	37.4	17.4	35.2	0.8	1.0
Asia	3096	18.2	25.7	17.3	35.4	2.4	1.0
Oceania	842	6.2	62.5	15.6	15.1	0.1	0.5
World	13293	11.7	34.7	28.1	22.5	1.1	1.9

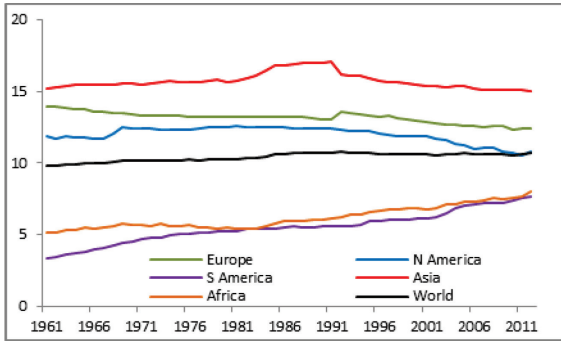
Source: FAO UN SOLAW Report 2 Table 1, GAEZ 2009.

*Inc Russia, Siberia

Table 10.3 Regional distribution of land use/cover - millions Ha.

Given that the total land surface of the Earth is approximately constant in size [barring changes in lake size and sea level], it is of interest to note

movements in it use, in particular, the share taken by arable land, as shown in figure 10.6.

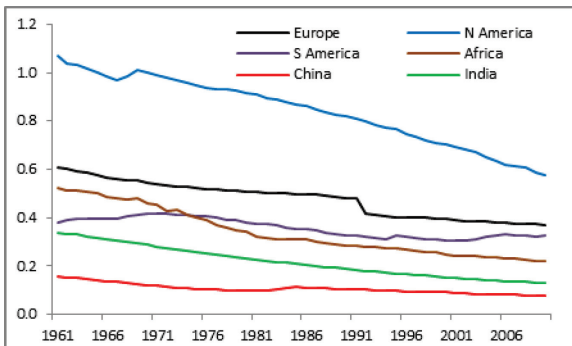


Source: FAOSTAT

Figure 10.6 Arable land as a percent of Total land.

Until about 1990, world arable land as a percent of the total had been rising, but thereafter it began to level off [the kinks in Asia/Europe likely arise from a switch in allocation of East Russia to the statistics]. However, the figures for 1990 onwards hide some underlying changes: first, a gradual decline in the proportions in Europe, North America and Asia, likely arising from land degradation, soil erosion and a switch to industry; and offsetting this, a rise in the proportions for Africa and South America. Second, alongside the latter, has been a reduction in the share of forest land to the total in these areas: South America from 54.1% down to 49.1%, and Africa from 25.3% down to 22.5%.

Given the rise in world human population over the last five decades, the amount of arable land *per capita*, on which crops can be grown to feed each human being, has fallen dramatically.



Source: FAOSTAT

Figure 10.7 Arable land per capita – Ha.

Currently the world figure is about 0.2Ha [equivalent to an area 40 x 50 metres per person] and appears set to decline further. While food for humans comes also from the oceans [fish] and grassland [animals], the chief source is still that that can be grown on arable land.

The main factors describing the states of land and soil worldwide are the extent and trends of land degradation, soil erosion and desertification. Land degradation measures the negative changes in the capacity of the ecosystem to provide goods and services. One might venture that the effect of this would impact on all living things and not just humans. Soil erosion has a narrower scope than land degradation and is concerned with absolute soil losses in terms of topsoil and nutrients, including soil carbon. Desertification refers to land degradation in arid, semi-arid and sub-humid lands that has become practically irretrievable.

Erosion occurs when soil is left exposed to raindrops or wind energy, with generally the finer more nutrient matter being flushed away, leaving less nutrient stuff behind. However, top-soil covered by plant biomass and/or trees, living or dead, is sheltered significantly from this effect. Pimental and Burgess [Agriculture 2013, 3] indicate that eroded soil contains three times as much nutrient per unit of weight than the remaining soil left behind. Crawford [World Economic Forum Dec 14, 201226] points out that just a handful of good topsoil literally contains billions of microorganisms which recycle organic material, and that moderately degraded soil will hold much less water than healthy soil. Lal [Food Sec. (2009) 1:45-57] concludes that soil degradation reduces crop yields. Thus preventing soil erosion is one of the keys to maintaining the productivity of agricultural land.

A key driver to land degradation is the activity of humans to change the world to their [short-term] benefit, though changes in climatic variations also have an input. Human activities cited by UNCCD [UN Convention to Combat Desertification] impacting on trends include deforestation, overgrazing, improper irrigation practices, poverty and political instability. According to UNCCD, severe land degradation now affects 168 countries across the world.

The UN has undertaken a number of initiatives to investigate and measure the problem. Oldeman, Hakkeling et al [ISRIC 1991] have collected data on some key indicators for national, regional and global areas. The method

employed to provide the data was by mapping individual small areas of the world and combining them together. Key indicators included types of degradation [*water, wind, chemical etc*], the degree and extent of degradation, and their causes, such as deforestation, overgrazing, agricultural and industrial activities, and over-exploitation of vegetation. About 15% of the Earth's land surface was found to be degraded in some way, and of this about 15% was at a strong/extreme level. Areas with high degradation included parts of Asia, Africa and Central America.

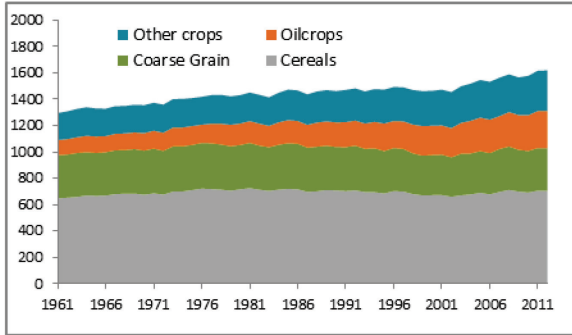
Nachtergaele, Biancalani and Petri [*Thematic report 3 SOLAW 2011*] state that land degradation processes are on-going over a large part of the land surface of the Earth. For less populated areas, most of the degradation was owing to soil erosion and biodiversity loss, whereas in most agricultural areas, soil depletion, pollution and water shortages were common. They concluded that 25% of global land degradation was at a high level, and that high land degradation was associated with a high level of poverty [*figures 6 and 7 of the report*].

A particular problem with land resources is that global time series data are hard to find in order to measure trends in degradation, and the extent to which matters may be improving or worsening. A recent UNCCD report [*Drylands Desertification*] states that 24% of global land was degraded between 1981 and 2003; though this was offset by 16% showing an improvement. An ISRIC report 2008/01 [*GLADA report 5*] indicates that land degradation is cumulative and that the 15% figure for the 1991 report referred earlier in this section has now risen to 24%.

Pimental and Burgess [*Agriculture 2013, 3*] estimate that about 10 million ha of cropland are lost each year, owing to soil erosion, and that the losses are highest in Asia, Africa and South America. Their figure implies a loss of cropland at an annual rate of about 0.6% p.a., which may not sound very much, but cumulatively over a number of years, can escalate to a very large reduction. Land resources are being degraded year by year, impacting on their ability to regenerate themselves, and thereby provide the basis on which to grow food to feed humans and other animate life. Thus what was a renewable resource is gradually being turned into a non-renewable one.

Figure 10.8 illustrates the development of the key harvested areas in the world: cereals [*wheat and rice*], coarse grains [*maize, barley, oats, sorghum*], oil crops [*soybeans, groundnuts, olives, rapeseed*] and other crops [*roots, tubers, pulses, tree-nuts, fibre crops, vegetables, fruit*]. World area harvested for cereals

has not risen above levels seen in the mid-70s, and that for coarse grain has declined by 5% over the same period. The areas for oil crops and other crops have expanded significantly, however, to take the overall area harvested to 1620 MHa, about 15% above that for the mid-70s.

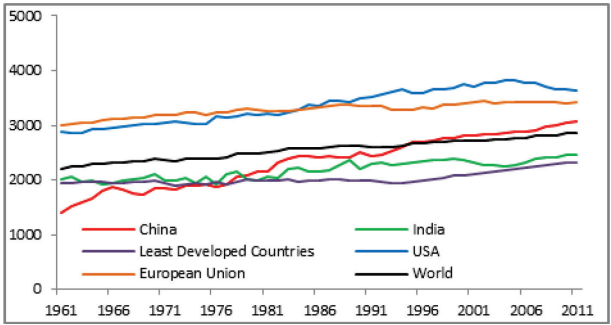


Source: FAOSTAT

Figure 10.8 World area harvested – M ha – by main crop type.

Human Dietary Trends

The UN FAO [Statistics Division report October 2008] sets out a recommended minimum dietary energy supply [DES] per human in the world of 2414 kcals/day [equivalent to about 2.8kWh]. The measure is derived from food balance sheets compiled by the FAO. This figure is not far removed from the value of 2600 kcals estimated by MacKay [Sustainable Energy – without the Hot Air, (2008)] for a moderately active person weighing 65kg. The FAO figure provides a base to calculate the relative level of human food deprivation around the world. Figure 10.9 illustrates trends since 1961 for some major countries and geographic areas.

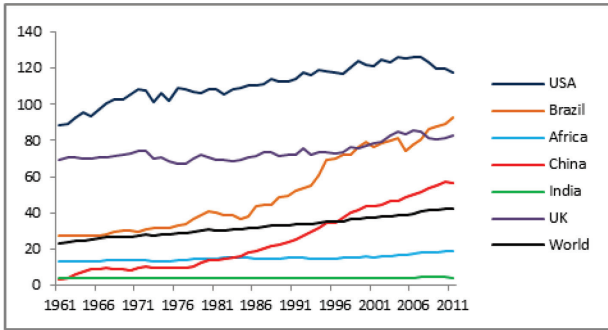


Source: FAOSTAT

Figure 10.9 Grand total food-supply per capita: – kcal/day.

In general, food supply per capita has gradually risen, with the average for the world reaching 2868 kcal/day by 2011, in excess of the minimum recommended daily dietary requirement. As might be expected, there is a wide distribution about the average, with the USA reaching 3,833 in 2005, though it has since declined a little since then. At the other end of the scale are the least developed countries averaging 2324 in 2011, with some much below this level. Of particular note is the rapid rise in food supply per capita achieved by China over the 50-year period. The World Health Organisation reports [fact sheet 311] that, worldwide, obesity has nearly doubled since 1980, with 1.4 billion adults being overweight and 0.5 billion being obese.

A trend that has become more prevalent is that of rising meat consumption, as illustrated by figure 10.10. It is well-known that energy input required to produce a given weight of food varies by type of food, from corn at about 1kWh per kg up to 70kWh for a kilogram of beef [Sources: McKay, Sustainable Energy – without the Hot Air (2008); Ghanta, The Oil Drum (2010)]. These figures do not include the power costs associated with farming machinery, fertilising, refrigerating and transporting food around the world. In addition, significant numbers of cattle and poultry are now fattened on corn and grain rather than reared on grass/pasture land.



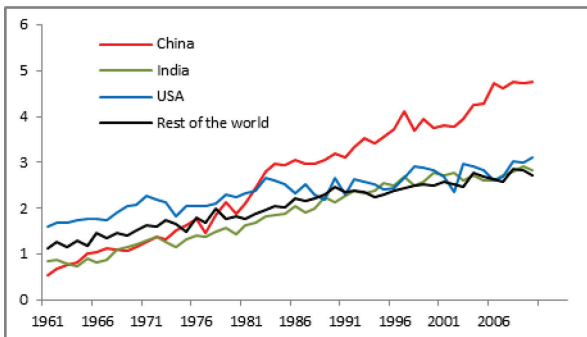
Source: FAOSTAT

Figure 10.10 Food supply meat per capita: – kg/year.

Thus the trend towards meat consumption has magnified the load on cultivated land significantly. An article of Worldwatch Institute [*Is meat sustainable? Vol 17 No. 4 (2004)*], concludes that meat-eating is becoming a problem for everyone on the planet.

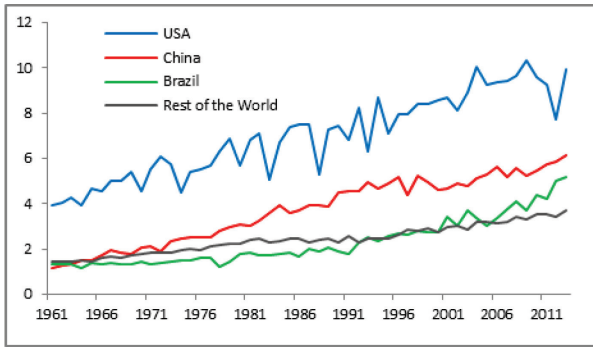
The Green Revolution and Yield

The 1960's saw a transfer of technology from the developed to the developing world concerning high yielding varieties of grain, and increasing use of irrigation, fertilisers and pesticides to improve crops yields, which has continued to the present day. Figures 10.11 and 10.12 show the inexorable rise in wheat and maize yields since 1961. Similar rises in yield have occurred in the world of rice.



Source: FAOSTAT

Figure 10.11 World wheat yield – tonnes/ha p.a.



Source: FAOSTAT

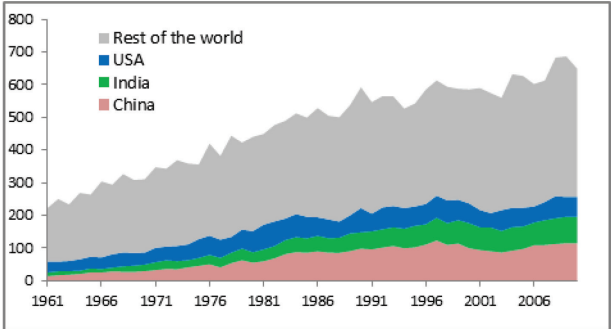
Figure 10.12 World maize yield – tonnes/ha p.a.

Many of the trends however do not exhibit exponential growth, but are more linear in shape, implying that as time goes on rises in production levels may slow down. Grassini, Kent et al [*Nature Communications Dec 2013*], after reviewing trends for all the main countries in each of the world’s continents, come to the same conclusion, and that there is also strong evidence of yield plateaus in some of the world’s most intensive cropping systems, though a number of years may be required before a plateau can be deemed to be statistically significant. Hypotheses cited that may be contributing to possible plateaus include: biophysical yield ceilings for specific crops, land degradation, shifts to regions with poorer soils and climate, policies on the use of fertilisers and pesticides, and poor R&D in agricultural research.

Time series of the UN FAO concerning fertiliser production [*nitrogen, phosphate and potash*] are not continuous, owing to a change in data methodology, and it is not possible therefore to deduce a long term trend. Production figures over the last decade however show a gradual rise from 152Mt p.a. up to 208Mt p.a. in 2012.

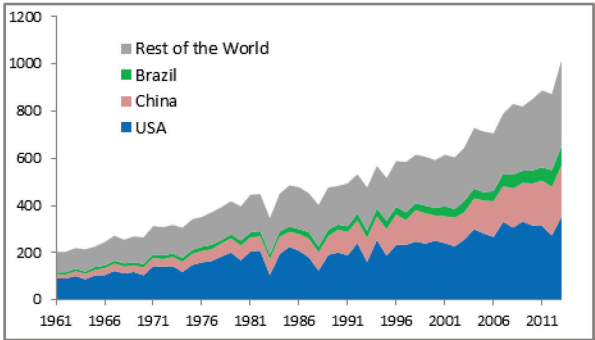
Cereal and Grain Production

Figures 10.13-10.14 illustrate key trends for world production of wheat and maize.



Source: FAOSTAT

Figure 10.13 World wheat production – M tonnes p.a.



Source: FAOSTAT

Figure 10.14 World maize production – M tonnes p.a.

In respect of wheat, at 2010 world area harvested had declined by more than 9% from a peak in 1981, with the decline being more marked for the USA [41% since 1981] and China [18% since 1986]. World yield per hectare continues to rise, though not exponentially. Chinese yield per acre has escalated dramatically. The net of these two trends appears to be for a continuing rise in production but at gradually reducing rates, with the possibility of peaking, perhaps in under two decades. World production per head of population peaked in 1990 at 111kg/hd, but is now down to 94kg/hd in 2010, a reduction of more than 15%.

World maize appears to be unstoppable, with area harvested, yield and production all escalating. However, the increase has been more than off-set by declines in other coarse grains, such as barley, oats, rye and millet.

World rice production, not illustrated, has shown significant growth, though not as fast as that of maize.

Meat

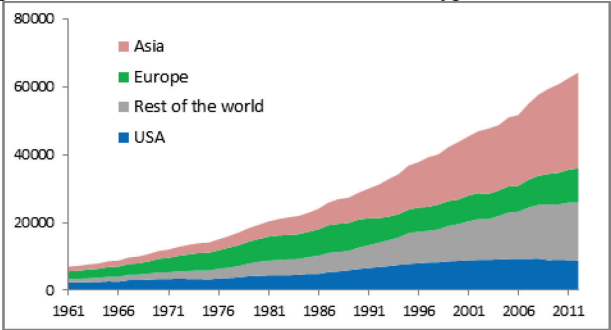
Turning now to meat, as noted at figure 10.9 earlier, meat consumption worldwide has been rising, particularly in China and Brazil, though none has reached the level sustained by USA. Table 10.4 summarises the world position between 1961 and 2012.

		Stock	Stock per Human	Slaughtered	Production	Production per Human
		Millions	No.	Millions p.a.	M Tonne p.a.	kg p.a.
Cattle & Buffalo	1961	1030.5	0.33	180.7	28.8	9.3
	2012	1676.8	0.24	321.2	66.9	9.5
Poultry & Birds	1961	4355.1	1.41	7014.6	8.9	2.9
	2012	23399.4	3.30	64135.7	105.6	14.9
Sheep & Goats	1961	1343.0	0.44	433.6	6.0	2.0
	2012	2160.0	0.31	975.8	13.8	1.9
Pigs	1961	406.2	0.13	376.4	24.7	8.0
	2012	969.9	0.14	1394.5	109.1	15.4

Source: FAOSTAT

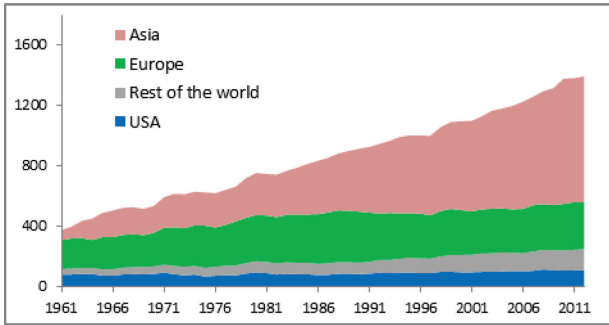
Table 10.4 World Livestock Production.

While all stocks have risen, that for chickens has expanded by more than 5-fold, with pig production also showing high growth. The short period for a chicken to come to maturity is a particular feature. Figures 10.15 and 10.16 illustrate production trends of these two livestock types in more detail.



Source: FAOSTAT

Figure 10.15 World chickens slaughtered – millions p.a.



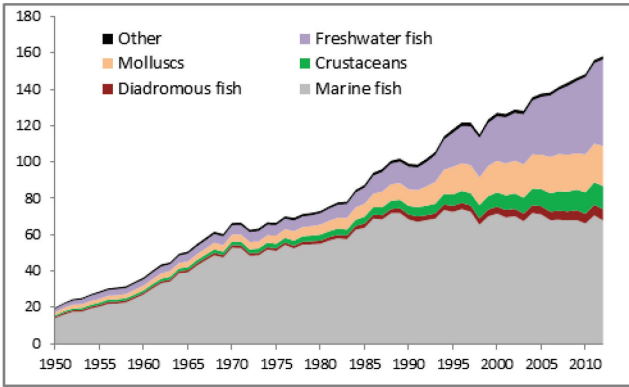
Source: FAOSTAT

Figure 10.16 World pigs slaughtered – millions p.a.

Livestock, of course, provide multiple benefits to humans besides being sources of meat – including milk, eggs, wool and skins. However, they are also significant emitters of greenhouse gases, methane and nitrous oxide,

Fish

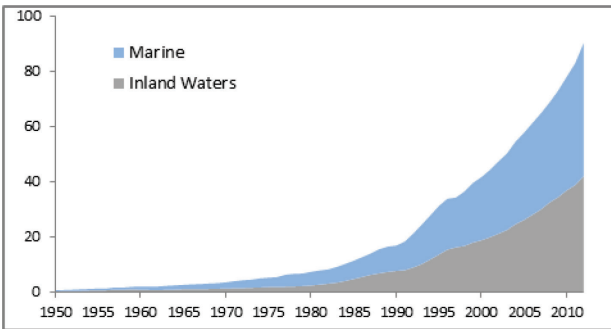
The world's fishing industry has long been the subject of debate with regard to fish stocks and the extent to which those in particular parts of the world have been over-exploited or depleted. A FAO newsroom summary of a UN FAO report [*Review of the State of World Marine Fisheries Resources 2012*], sets out, area by area, the degree to which each has been fished. Overall, 3% are regarded to be underexploited, 20% moderately exploited, 52% fully exploited, 17% overexploited, 7% depleted and 1% recovering from depletion. All of the oceans have areas where particular fish species have been over-fished and depleted through human activity. The result has entailed the introduction of fishing quotas and suspensions in order to allow stocks to replenish themselves over time. The net result of this has been to call a halt to expansion of marine capture production, as highlighted in figure 10.17, though offsetting the fall back in marine fishing, however, has been an increase in freshwater fishing.



Source: FAO FISHSTAT

Figure 10.17 World capture production – M tonnes p.a.

Bostock, McAndrew, et al [*Phil. Trans. R. Society 365 (2010)*] state that growth in aquaculture has been driven by favourable economics in intensive farming, with China being the largest producer. The majority of freshwater aquaculture is pond based requiring controlled eutrophication using fertilisers as well as feedstuffs from grain and other crops [*somewhat similar to the fattening of animals in meat production processes, again adding pressure to land-based agriculture*]. Figure 10.18 illustrates trends in world aquaculture.



Source: FAO FISHSTAT

Figure 10.18 World aquaculture production – M tonnes p.a.

Food Supply & Energy Consumption

According to the UN FAO [*Issue paper: Energy-Smart Food for People and Climate (2011)*], the food sector accounts for around 30% of the world’s energy consumption. For high GDP countries, the greater proportion of

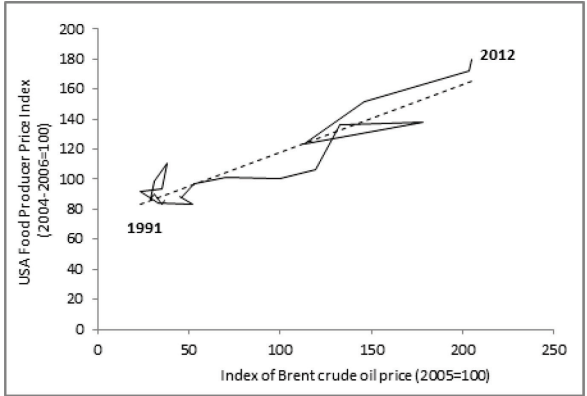
energy consumption is for processing and transport, whereas for low GDP countries, cooking consumes the higher share. Primary farming alone [*cropping, pastoral & intensive livestock, aquaculture & fishing*] accounts for about a fifth of food energy consumption. The rest occurs higher up the trading chain. One has only to think of the mechanical activities involved in tilling the land, sowing seed, irrigation, producing and adding fertiliser, harvesting crops, transporting to food centres [*often across oceans*], processing in factories and distributing to retailers, to see how energy consumption [*mostly non-renewable*] is accounted for.

It is of interest to compare the dietary energy supply/day per human obtainable from food [*see section on human dietary trends*] with primary energy consumption per capita, the latter providing the energy to power machines, provide human comfort and transport food, goods and commodities around the world. At standard conversion ratios, 2868 kcals/day of food is equivalent to about 3.33 kWh of energy intake, whereas, on average, each human in the world, as part of an economic system, effectively also consumes about 56.5 kWh of primary energy per day [*coal, gas, oil etc. Source primary energy data: BP Statistical yearbook 2013*]. The latter figure varies significantly by country. Primary energy consumption per capita for India, for example, is only 14.8 kWh, whereas that for USA is fifteen times higher at 225.6kWh. Nevertheless, taking the UN FAO world estimate of 30% of primary energy consumption for the food sector, then 30% of 56.5 kWh per head equates to 18.8 kWh, just to get 3.33 kWh of food value to each consumer in the world, a mark-up of more than 5½ times.

Clearly, without the availability of primary energy, many people in the world would have to find alternative, life-changing self-sufficient means of feeding themselves. Returning to home-grown food [*as per a war scenario*] in a city complex might be difficult. One is reminded of the resource ratio approach described at chapter 8, which concluded that the species that is able to survive at the lowest level of a limiting resource will be the best competitor for that resource.

Given that the production costs of food to the point of the consumer contain substantial energy costs and that a significant amount of that energy is related to oil [*to power farm machinery, transport across land and oceans etc*], it would not be surprising if food prices relate in some way to world energy

prices. The chart at figure 10.19 displays the USA food producer index set against Brent crude oil price index from 1991 to 2012.



Sources: BP Statistical Review, FAOSTAT

Figure 10.19 USA food price index v Brent crude oil price.

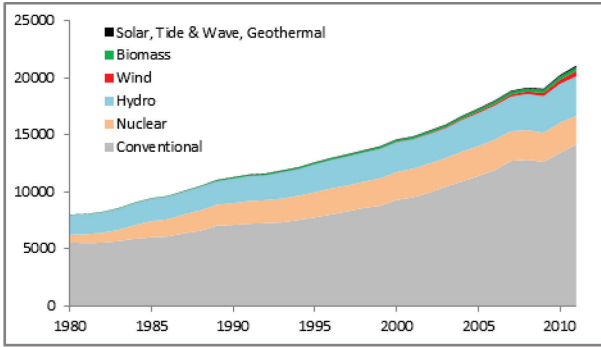
The author considers that there is a reasonable correlation between the two factors displayed [*correlation coefficient $R^2=0.87$*] for the time interval illustrated, though this might reduce if, for example, a relation between oil prices to European food prices is tried, or prices pertaining before 1991 [*a different time series*] are included in the data.

It follows from the above that trends in world energy, in particular oil, which is used to power ocean and land transport and farm machinery, will likely impact on the world food industry.

Renewable Energy

Renewable energy has been cited as providing a solution to the problem of carbon emissions arising from the burning of fossil fuels by humans. The chief renewable energy sources are: hydroelectric generators mostly sited at dams, wind turbines sited on exposed land or above shallow sea areas, solar energy converters [*PV (photo-voltaic) and CSP (concentrated solar power)*], biomass burning [*wood, agricultural and food waste*], geothermal power plants sited mostly over naturally occurring hot fissures to the Earth, and energy derived from tidal or wave movement. All of these energy sources are utilised to provide electrical energy. Figure 10.20 illustrates world annual electrical output so far set against the key non-renewal sources of

conventional power plant [coal, gas and oil] and current nuclear energy technology.



Source: EIA

Figure 10.20 World production of electricity by energy source –TWh p.a.

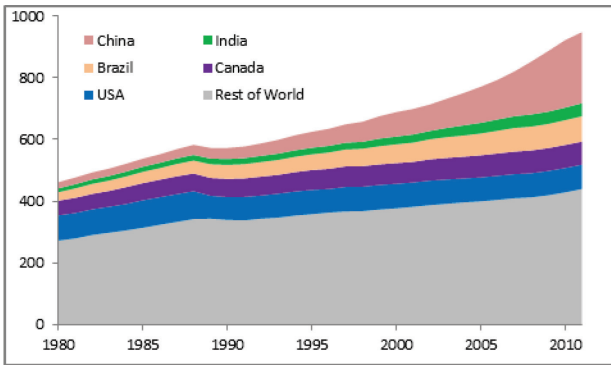
With the exception of hydro-electric power, non-renewable energy has yet to make a substantial impact on world markets, although clearly change is beginning to occur. At 2011 hydroelectric power provided 16.5% of world electrical generation, and the other renewables 4.5%, with the rest provided by nuclear and conventional plant.

Jacobson and Delucchi [*Energy Policy 39 (2011)*] have estimated the technology requirements at 2030 to convert a world of predominantly fossil-powered energy infrastructure to one involving renewables of wind, water and sunlight, including several million wind turbines, large numbers of CSPs, 1.7 billion rooftop PVs, along with additional hydro-electric and other technology capacity. Their world would be populated with battery-operated vehicles [BEVs] and would require the use of additional land for footprint and spacing for renewable power plant.

Hydro-electric Power

Of all the renewables, hydroelectric power generation offers an ideal solution to replacing fossil-fired plant. It has a high EROI [see section on EROI, chapter 9], its energy efficiency is very high, since no fuel is burnt, and it has no carbon emissions, other than those created from the input of engineering plant and construction materials. Hydro power can be ramped up and down quickly [around 1-2 minutes from nothing to full power] and it is

therefore ideal for meeting changing load requirements. Consequently it may not necessarily be used for continuous base load, as geothermal and nuclear plant are [their output is not easy to change up and down]. The main cost of hydro power is the capital cost, since it generally involves the building of a dam and the creation of a reservoir, which may involve disruption to and permanent submergence of upstream local eco-habitat. Figure 10.21 summarises installed capacity in the world.



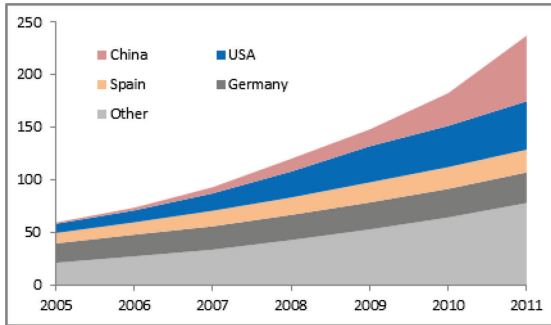
Source: EIA

Figure 10.21 World installed capacity hydroelectric power – GW.

While future growth of hydroelectric power may be limited by available and potential geological/landscape opportunities and considerations, it appears, nevertheless to be proceeding apace, with China leading the field in investment.

Wind

In terms of the provision of electrical power capacity, wind energy is a relatively recent entrant to the global market, though its growth rate has been quite high. Figure 10.22 illustrates the trend in capacity since 2005:



Source: EIA

Figure 10.22 World wind energy installed capacity to 2011 – GW.

World capacity growth has averaged about 25-30% since 2005, with China rapidly overtaking other key countries. The 2014 Global Wind Energy Council report indicates that by 2013 global installed capacity had risen to 318 GW; with China alone accounting for more than 91 GW, and USA 61 GW. A number of countries have achieved quite high levels of wind power penetration, such as Denmark, Portugal, Spain and Germany.

A particular problem with wind energy is that wind force cannot be guaranteed, being neither constant nor geographically evenly spread. Consequently load factors are low, at about 21-22% on average across the world.

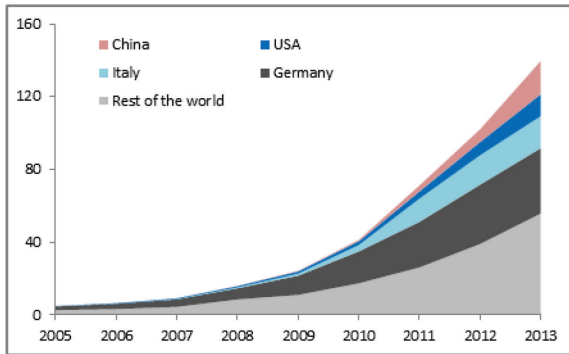
Wind turbines tend to be sited on open or high areas of land, or over shallow waters to maximise their efficacy. Denholm, Hand et al [*NREL (2009)*], report that land-based wind energy installations, on average, occupy about 0.3 HA per MW of capacity.

Solar

Besides hydroelectric and wind, solar energy is the other main contributor to the renewable energy sector. It is broadly split into two technology types; first, photovoltaic [*PV*] systems that convert sunlight directly into electricity, and second, concentrated solar power [*CSP*] systems that use lenses or mirrors allied to tracking systems to focus large areas of sunlight into a small beam, which is then used as a heat source in a power plant. PV systems are ideal for individual and medium-sized consumers, whereas CSP systems are suited to large scale complexes.

As with wind-powered systems, solar energy collectors have low load factors, arising first from the natural day/night cycle coupled to seasonal changes, and second the impact of cloud occlusion and latitude on the strength of sunlight falling on the receivers. Solar systems are more suited to countries having hot climates, but even then load factors only average at about 10%; meaning that for much of the time they are not providing energy output. To offset a low load factor, ideally electrical energy produced needs to be stored, so that it can be used also at times when the Sun has gone down. Technology to store power in car batteries is one such idea. Ong, Campbell et al [NREL (2013)] report that solar energy installations, on average, directly occupy about 3 HA of land per MW of capacity.

Figure 10.23 illustrates the rapid rise in solar power installations across the world. Germany is currently the largest producer of solar energy.



Source: BP

Figure 10.23 World solar PV energy installed capacity to 2013 – GW.

Other Renewable Energy

Space does not allow consideration of other sources of renewable energy, such as geothermal, biomass, and tide/wave movement. Compared to hydroelectric, wind and solar energy, however, they are currently relatively small in potential, or are specialised. Geothermal energy, for example, is currently produced in only a few countries, such as USA, Indonesia, Philippines, Mexico, Italy and Iceland, having particular geological features.