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Global Trends and Patterns in Carbon Mitigation

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Dedicated to the memory of:

Jane Elizabeth Haworth (Cawthorne)

1956–2013

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Preface

I intend that this book will have the following purposes. It will provide an up-to-date coverage of carbon emissions and mitigations throughout the world. It attunes the mind of a reader not previously specialising in such matters to such things as carbon-neutral fuels. And it will have its place in university courses in energy matters. A reader might think that the calculations throughout the book on carbon release and mitigation are starting, by about half way through the text, to become a little repetitive. This is intentional for two reasons. One cannot argue the points made without such calculations, and to a reader previously inexperienced in such matters they will provide helpful exercises.

This is the sixth in my series of books published by Ventus. Given the subject matter, I can imagine that there will be scope for a revised edition after about five years. This, subject to the approval of Ventus, I shall be happy to undertake.

J.C. Jones

Aberdeen, June 2013.

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1 Introduction

1.1 The seminal application of physics to global warming: Arrhenius 1896

The name 'Arrhenius' is known to chemistry graduates everywhere; his method of expressing the temperature dependence of the rate of a chemical reaction features at latest in second year of any university degree course in chemistry. It was proposed by Svante Arrhenius (1859–1927) and is very simple. As a participant in such matters over a period exceeding 30 years (e.g. [1]) the author has often thought it remarkable that the Arrhenius expression has persisted almost to the complete exclusion of alternatives not only with well characterised chemical compounds but also with substances such as coals, for which kinetic analysis is often 'rough and ready' because of compositional uncertainties.

Arrhenius is however also noted for having been amongst the first to express the view that products of combustion of fuels from industrial processes when they enter the atmosphere can lead to warming. Arrhenius, who lived in Sweden for his entire life, first expressed this hypothesis in 1896 [2], by which time coal and oil usage worldwide were both major. In fact Arrhenius' utterance on the effect of the burning of fossil fuels coincided almost exactly with the centenary of coal mining in Sweden, which began at Höganäs in the south of the country in 1797. Arrhenius published his work as a major article [3] comments on which follow.

1.2 Some concepts from Arrhenius' treatise

Physicists before Arrhenius had performed analyses showing that had absorption of radiation by certain components of the atmosphere not taken place the temperature of the earth would have dropped to a value much too low to sustain life. Arrhenius points out that at the moon's surface it is the absence of an atmosphere capable of absorption of radiation that leads to diurnal temperature fluctuations there which so hugely exceed those on the earth. So the *natural and indispensable* role of radiative absorption by the atmosphere is made clear to a reader of the earliest parts of [3], a perspective which has not always had its due place in much more recent discussions in which absorptive gases have featured as if they were mere contaminants.

Stefan's law is drawn on in [3], and instead of the emissivity (ϵ) the term $(1 - \nu)$ is used, where ν is the albedo, meaning whiteness. Clearly $(1 - \nu)$ is the emissivity in the visible region of the spectrum. Thermal radiation in the non-visible parts is termed in [3] 'dark heat'; equivalently, heat from a body having a low albedo is 'dark'. The contrast is emphasised by Arrhenius in the following way. He performs calculations on the entry of light from a body at 15°C, representing the earth's surface, into the atmosphere. This he calls 'dark heat': emission in the visible region is nil at such temperatures. He goes on to make comparisons with measurements of solar radiation in independent work which he cites, describing this as 'quite different from dark heat'. 'Quite different' means not in intrinsic nature but in absorption behaviour, and that there *is* atmospheric absorption at wavelengths in the solar radiation absent from the notional terrestrial radiation in the calculations is clear from the field work from which he argues, which had been performed in Colorado in 1882.

On the matter of heat balance at the surface of the earth, Arrhenius argues that temperature changes due to atmospheric effects are at the 'upper layers of the earth's crust' only and that the temperature profile at greater depths is not affected. His paper is concerned with radiation, but what later became called convection is referred to as 'atmospheric currents' and given a qualitative place in the discussion. On the basis of radiation effects only, Arrhenius gives temperature variations due to carbon dioxide in the atmosphere as a function of three factors: the carbon dioxide concentration, the latitude and the time of year. It is the first of these which is the most influential, and at the highest value used by Arrhenius in his calculations temperature effects in the range 7 to 9°C are calculated across the latitudes and seasons. The value of the carbon dioxide concentration in this set of calculations is actually 3 gram per cubic metres, corresponding to 1700 p.p.m. molar or volume basis, which well exceeds actual levels then (as Arrhenius was aware) or now. The range of carbon dioxide concentrations in the calculations does not take in such levels. Arrhenius' work is often quoted as predicting temperature rises of 5 to 6°C, and these are from his calculations using a carbon dioxide level of 2 gram per cubic metre, still well in excess of actual values.

1.3 Enter Kyoto

At the time of Arrhenius' work the level of carbon dioxide in the atmosphere was in fact approaching 300 p.p.m. By 1990 it had increased to about 350 p.p.m. The year 1990 is in fact the baseline one for the Kyoto Protocol, which was not formally put forward until December 1997. In other words, nations ratifying the Protocol undertook to reduce their carbon dioxide emissions to an agreed margin below the 1990 levels. Very many countries have accepted obligations under the Kyoto Protocol.

1.4 References

[1] Gray B.F., Jones J.C. 'Critical behaviour in chemically reacting systems IV Layered media in the Semenov approximation' Combustion and Flame **40** 37–45 (1981).

[2] http://www.lenntech.com/greenhouse-effect/global-warming-history.htm

[3] Arrhenius S 'On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground' Philosophical Magazine and Journal of Science Series 5, Volume 41, April 1896, pages 237–276, accessible online on:

http://www.rsc.org/images/Arrhenius1896_tcm18-173546.pdf

and on

http://www.math.umn.edu/~mcgehee/Seminars/ClimateChange/references/Arrhenius1896-ocr.pdf

2 The United Kingdom

2.1 Preamble

The 1990 release of carbon dioxide in the UK was 590 million tonnes: the 2010 release was 496 million tonnes [1]. The UK Kyoto target for 2010 was 12.5% below the 1990 level, whereas in fact it was almost 16% below it. The most important reduction was in the energy production sector, from 242 million tonnes in 1990 to 196 million tonnes in 2010, a decrease of 19%. This will be semi-quantitatively analysed in the next section.

2.2 Electricity production in 2010

The total amount of electricity generated in the UK in 2010 was 381772 GWh (gigawatt hours) [2]. This is equivalent to:

$$381722 \times 10^9 \text{ J s}^{-1} \times 3600 \text{ s} = 1.4 \times 10^{18} \text{ J}$$

Imagine that this had been generated entirely by steam turbines operating on a Rankine cycle with 35% efficiency and with natural gas (approximated to pure methane) as fuel. The release of carbon dioxide would have been:

$$[(1.4 \times 10^{18}\text{J}/889 \times 10^{3}\ \text{J mol}^{-1})/0.35] \times 0.044\ \text{kg mol}^{-1} \times 10^{-3}\ \text{tonne kg}^{-1} = 198\ \text{million tonnes}$$

which is in remarkable agreement with the actual figure, but thermal generation of electricity uses largely fuel which emits more carbon dioxide than natural gas does, other things being equal. A heavy fuel oil will have a calorific value of about 42 MJ kg^{-1} and will approximate to the empirical formula CH_2. The corresponding calculation for that is then:

$$[(1.4 \times 10^{18}\text{J}/42 \times 10^{6}\text{J kg}^{-1})/0.35] \times (12/14) \times (44/12) \times 10^{-3}\ \text{tonne kg}^{-1}$$
$$= 299\ \text{million tonnes}$$

Imagine now that the power was raised with coal of carbon content 80% and calorific value as fired 20 MJ kg^{-1}. The calculation becomes:

$$[(1.4 \times 10^{18}\text{J}/20 \times 10^{6}\text{J kg}^{-1})/0.35] \times 0.8 \times (44/12) \times 10^{-3}\ \text{tonne kg}^{-1}$$
$$= 587\ \text{million tonnes}$$

All three classes of fuel considered in the above calculation are used in the UK, and the effect of the mitigating measures such as carbon-neutral fuels and wind farms, to be discussed more fully below, can be expressed as the carbon dioxide emissions if one or other of the above fuels had been used. A reader should note the very high sensitivity of the carbon dioxide emissions to choice of fuel: a factor of almost exactly three between natural gas and coal of the specification given. In the table below some electricity producing utilities in the UK are described with details of the fuels used. Notwithstanding the large amounts of natural gas in the UK sector of the North Sea (and import into the UK of some gas from the Norwegian sector: the UK is currently a net importer of natural gas) power generation from this fuel in the UK is not as high as might be expected, a situation which might be exacerbated by the extremely limited discovery of shale gas in the UK to date (although there is plenty of coal bed methane if the infrastructure were installed to collect it). There are proposals to build more gas fired power stations between now and 2030 to replace coal-fired ones [3]. The calculations above show the benefits of this in carbon dioxide emission terms. The justification for the policy of more gas-powered plants is that many of the coal-fired ones are elderly, an important point but not really having any bearing on carbon dioxide emissions. Obsolescent coal plants might well be unfavourable in terms of other emissions including sulphur dioxide and particulate. In relation to the calculations above we note that equivalence is expected if a conventional gas turbine, working on a Brayton cycle, is used instead of a steam turbine. Efficiencies are about the same for each and there are close parallels in their respective thermodynamic cycles.

Examples of selected thermal power stations in the UK are in the table below. Comments follow the table.

Location	Details
Connah's Quay, Wales.	Operated by E.ON. Natural gas fuel from Liverpool Bay. Nameplate capacity 1420 MW of electricity with gas turbines.
Drax, Yorkshire. Plate 2.1	Capacity 4000 MW. Formerly entirely coal-fired, now co-firing coal with biomass. Detailed analysis follows.
Sutton Bridge, Lincolnshire.	North Sea natural gas used as fuel for generation with gas turbines. Nameplate capacity 819 MW.
Cottam, Notts.	2000 MW coal-fired facility using steam turbines. Some biomass usage.
Steven's Croft, Lockerbie, Scotland.	Operated by E.ON. 44 MW of electricity using wood fuel only [5].

Table 2.1 Selected UK thermal power stations.

The gas field at Liverpool Bay is sometimes considered to be an extension of the Morecambe Bay field, which has been producing since the 1970s and is of course at the opposite side of the UK landmass from the North Sea. It is reported in [4] that at one of its turbines Drax (second row) is producing 500 MW of electricity by co-firing 12.5% biomass, balance coal. This is examined in the shaded area below.

500 MW of electricity from say (500/0.35) = 1425 MW of heat.

Let the coal supply rate be α kg per second and the calorific values of the coal and the biomass as fired be respectively 25 and 17 MJ kg^{-1}

↓

$$(\alpha \text{ kg s}^{-1} \times 25\text{MJ kg}^{-1}) + [(12.5/87.5)\ \alpha \text{ kg s}^{-1} \times 17\text{MJ kg}^{-1}] = 1425 \text{ MW}$$

↓

Plate 2.1. Drax power station. Reproduced with permission.
Illustration: http://www.google.co.uk/search?q=drax+power+station&hl=en&tbo=u&rlz=1T4ADFA_enGB466GB470&tbm=isch&source=univ&sa=X&ei=Y0kBUZe6KurD0QWQt4HgDA&ved=0CHwQsAQ&biw=1061&bih=613

$\alpha = 52$ kg s^{-1}

52 kg s^{-1} of coal and 7.4 kg s^{-1} of biomass

Coal of that calorific value would be expected to have about 80% carbon, so the rate of production of carbon dioxide is:

52 kg s^{-1} × 0.8 × (44/12) = 153 kg s^{-1}

The carbon dioxide from the biomass combustion is non fossil fuel carbon dioxide, and is simply being put back where it came from when the biomass is burnt. It need not therefore be added to the above figure. Carbon dioxide production from a day's operation of the turbine is therefore:

153 kg s^{-1} × 3600 s hour^{-1} × 24 hour day^{-1} × 10^{-3} tonne kg^{-1} = **13200** tonne per day.

If that amount of electricity had been produced by the coal only without biomass the rate of burning of the coal would have been:

(1425 MW/25 MJ kg^{-1}) = 57 kg s^{-1} giving over a day's operation:

0.8 × 57 kg s^{-1} × (44/12) × 3600 s hour^{-1} × 24 hour day^{-1} × 10^{-3} tonne kg^{-1} = **14446** tonne of CO_2.

The reduction due to the co-firing with biomass is therefore **9%.**

The reduction of carbon dioxide emissions due to co-firing with biomass is clearly demonstrated by the above figures relating to Drax. As noted, carbon dioxide in the biomass was in the fairly recent past in the atmosphere having been converted to cellulose, so when the biomass is burnt it is being returned to where it came from and does not add to the carbon dioxide level of the atmosphere.

The Sutton Bridge facility (row 3) has been in service since 1999, and it is expected that decommissioning will occur in about 2029, that is, it will have had a 30 year life span. Its nameplate capacity given in the table can be checked against the figure given on the operator's web site of 5.6 TWh annual production:

$$5.6 \times 10^{12}\ \text{W h}/(365 \times 24)\ \text{h} = 639\ \text{MW}$$

which is 21% below the nameplate capacity.

At Steven's Croft (row 5) the fuel is wood only and is sourced from sawmills, wood product manufacture and (to an extent of about 20%) from short rotation coppices. These can be blended to give a fuel with reasonable homogeneity and 480000 tonnes of such fuel are used annually, giving 44 MW of electrical power as stated in the table. Calculations in the shaded area below examine how these figures hang together, noting also that the rate of heat production is given as 126 MW.

The efficiency is 44/126 = 0.35, a typical value.

Using the 'boiler-as-calorimeter' method, the calorific value of the fuel is:

$$[126 \times 10^6 \text{ J s}^{-1}/(480000000 \text{ kg})] \times 365 \times 24 \times 3600 \text{ s} = 8.3 \text{ MJ kg}^{-1}$$

This is about half the calorific value of seasoned wood, indicating quite simply that the wood has a higher moisture content than it would have had there been time for moisture equilibration with the atmosphere. This is often true of wood fuels in electricity generation.

The quantity of coal of say 20 MJ kg^{-1} calorific value and 75% carbon as fired required to produce the same daily amount of heat would have been just under 200000 tonnes, releasing:

$$(200000 \times 0.75 \times 44/12) \text{ tonnes of } CO_2 = 550000 \text{ tonnes of } CO_2$$

so this is an estimate of the carbon dioxide benefit from the plant, given on the E.ON web site as 140000 tonnes which the present author takes to refer to the *carbon*: this would scale to ≈ 515000 tonnes of carbon *dioxide*.

The table gives examples of three ways in which carbon emissions can be reduced in the thermal generation of electricity: use of natural gas, coal-biomass co-firing and use of biomass only. In 2010 nuclear fuels contributed 61.4 TWh – 61400 GWh – to UK's electricity or 16% of the total and this of course entails carbon dioxide reductions.

In analysis of the response to the need for carbon release mitigation non-thermal (strictly, isothermal) means of producing electricity must be factored in, and this follows.

'Isothermal generation' includes hydroelectric power, which of course dates from the nineteenth century and was important long before the worldwide campaign to reduce carbon emissions. The UK is not heavily capitalised with hydroelectricity, having a capacity in 2010 [6] of 1650 MW round-the-clock use of which at full load would realise:

$$1650 \times 10^{-3} \times 24 \times 365 \text{ GWh} = 14454 \text{ GWh}$$

which is less than 4% of the total of 381772 GWh and, in any case, full load is seldom if ever achieved and the contribution made by hydroelectricity to the UK's power demand in 2010 probably did not exceed 2%. Wind farms are very much a growth industry, and one observes newly installed wind turbines at on- and off shore locations continually. The Guardian newspaper on 25th September 2012 reported that wind farms had contributed 7TWh – 7000 GWh – to the electricity demand of the UK in 2010, or about 2% of the total. This is not insignificant and is expected to rise, but it and hydroelectricity jointly cannot start to account for the attainment of the target carbon dioxide emission targets for 2010. Solar devices including photovoltaic cells are not worth incorporating into the discussion at their current levels (although they feature in later chapters of the book). These comments are not a disparagement, and it is emphasised again that wind turbines in particular are expected to increase in importance. The point being made is that realisation of the 2010 figure for carbon dioxide emissions was just about entirely by judicious *thermal* generation of electricity. That is why calculations of the genre of those in the previous sections of this chapter feature centrally in energy planning and will continue to.

2.3 Transport

Carbon dioxide release from transport fuels was almost the same in 2010 as in 1990: respectively 121 million tonnes and 119 million tonnes [1]. There were just under 22 million registered vehicles (private and commercial) in the UK in 1990 and about 34 million in 2010 [7]. The carbon dioxide emissions have therefore remained the same in spite of an extra 12 million vehicles. Reasons for this will be sought in the analysis which follows.

The 1990 figure equates to 5.5 tonnes per vehicle for that year, and the 2010 figure to 3.5 tonnes per vehicle. Now an automotive fuel from crude oil will, like a fuel oil for power generation (see Section 2.2), approximate in composition to a compound of empirical formula CH_2. The 2010 figure of 3.5 tonnes of carbon dioxide per vehicle therefore corresponds to:

(3.5 × 14/44) tonnes per year of fuel = 1.1 tonnes per year of fuel, equivalent to about 275 Imperial gallons per year.

Over the twelve month 'obligation period' for 2010–2011, UK usage of biodiesels as automotive fuels was of about 185 million gallons [8], thermally equivalent (when the different calorific values are factored in) to about 160 million gallons of mineral diesel. In the same year UK usage of ethanol fuel was of the order of 130 million gallons, thermally equivalent to about 90 million gallons of mineral gasoline. This converts to 250 million gallons substitution of conventional by carbon-neutral fuels in the period under discussion, sufficient for about one million vehicles, yet the effects on carbon emissions of an increase of 12 million vehicles had been offset. The contribution of carbon-neutral fuels to the stability of the emission figures is therefore only of the order of 10%.

The role of carbon-neutral fuels in meeting emission targets is therefore minor without being insignificant, and a reader might welcome information on the source of the biodiesel and ethanol for the UK which feature in the previous paragraph, both domestic and imported. Most is in the latter category [9]. The UK imports biodiesel derived from Soybeans from countries including the US [10]; there is also biodiesel from palm oil imported from Asian countries including Malaysia and Indonesia [11]. Brazil has always been pre-eminent as a producer of ethanol as automotive fuel, and at present exports to the EU as well as to the US and certain Middle East countries. The destination of some of the imported ethanol will be conventional refineries for blending with gasoline. Blending in such a way that the proportion of ethanol, the octane number and the Reid Vapour Pressure of the gasoline-ethanol mix all have the required values is challenging. Details of some domestic production of carbon-neutral fuels are given in the table below.

Location	Details
South Humberside [12]. Currently being commissioned.	Plant to be operated by Vireol Bio-Industries for production of ethanol from wheat straw. 200 million litres per year of ethanol. Mass balance below.
Liverpool (Plate 2.2), South Wales and Southampton.	A facility at each location, operated by Agri Energy (a division of Irish Food Processors and recently renamed Olleco), for the recovery of useful products including biodiesel from used cooking oil by conventional refining.
Motherwell, Scotland.	Up to 50 million litres per year of biodiesel from animal fat by Argent Energy.

Table 2.2. Examples of carbon-neutral fuel production in the UK.

Production of ethanol from wheat straw (row 1) or similar agricultural waste involves first breaking down polysaccharides by hydrolysis to sugar units which can be fermented. Such sugar will not be entirely fermented: some will be respired and form carbon dioxide which is of course a saleable by-product being usable for example as a shielding gas in welding. The part of the wheat straw which was not broken down in the hydrolysis, which contains cereal proteins as well as carbohydrates, is suitable for use as animal feed. In fact reference [12] gives sufficient information for a mass balance on the process and this is attempted in the shaded area. All figures are on an annual basis.

Reactants:

Wheat straw: 500000 tonnes

Products:

Ethanol production 200 million litres = 157800 tonnes

Animal feed production 177000 tonnes

Carbon dioxide production 127000 tonnes

Total products 461800 tonne

The difference is 8%, just about the value expected for the moisture content of the wheat straw. The mass balance is therefore quite precise, and very informative. The Vireol facility is in fact one of three independently operated plants for the production of ethanol from wheat straw currently being commissioned in that part of England. Some animal feed is currently imported from South America: less will need to be imported if the ethanol-from-polysaccharides industry expands.

Agri Energy (second row of the table) offers a regularised form of the 'grease car' concept, the use of spent cooking oil to power compression ignition engines. Agri Energy treats at the three locations mentioned the waste it collects, some of which after processing becomes cooking oil for re-use whilst some as noted becomes automotive fuel. Its biodiesel products are of the highest quality, complying with the standard ISO 14064 which specifies quantitatively the carbon saving which must accrue from use of unit amount of a fuel to which the standard is applied. Agri Energy also make available to customers blends of its biodiesel with mineral diesel. Plate 2.2. shows the Agri Energy plant at Liverpool. Note the refining towers.

Agri Energy (Olleco) deal both in vegetable products only, although some animal fat might of course be present from previous use of the substance in cooking. By contrast Argent Energy in Motherwell are concerned solely with spent cooking fat, slaughter house waste and meat having gone beyond its use by date [13]. From such starting materials it produces biodiesel complying with the standard EN 14214 2008 which specifies *inter alia* a minimum cetane number of 51. We note as a point of interest that the US standard ASTM D 6751-07b, also for biodiesels, sets the less stringent value of 47. The products of Argent Energy are in the composition range from biodiesel alone to 7% biodiesel in mineral diesel. There has been a very successful supply arrangement of the pure biodiesel product with a local bus operator.

Plate 2.2. Agri Energy plant at Bootle, Merseyside for the recovery of useful products from used cooking oil.
Reproduced with the permission of Olleco (formerly Agri).
Illustration: http://www.letsrecycle.com/news/latest-news/energy/uk2019s-2018largest2019-biodiesel-plant-opens-in-liverpool

It has been shown in this section how carbon-neutral fuels have made their contribution to the control of carbon dioxide emissions in the UK, and it is expected that this will continue to increase in importance. As already pointed out, other factors have to be invoked to account for the absence of change in carbon dioxide release from vehicular sources over a 20 year period in spite of the increase in number of vehicles, and this follows.

A 1955 Cadillac Series 62 had a fuel consumption [14] of 18.2 litres of gasoline per 100km travelled, which converts to 15.5 miles per Imperial gallon. A related calculation follows.

1 Imperial gallon = 0.00455 cubic metres or about 3.6 kg (depending on the density of the gasoline: a typical value of 800 kg m^{-3} has been used.)

Gasoline consumption per mile = 3.6/15.5 kg = 0.23 kg

Carbon dioxide footprint = (230 × 44/14) g per mile = 722 g per mile

A motorist in the US in 1955 might have regretted the expense of running such a car, in which case a gas guzzler like a Cadillac was a strange choice in the first place. He or she would not however have given a thought to the carbon footprint. Nowadays the carbon footprint is an important selling point for a new car, and manufacturers are deeply preoccupied with it. The table below shows figures for the carbon footprint of selected petrol engine cars currently widely sold in the UK.

Make and model	Carbon footprint/g $mile^{-1}$
Volkswagen Golf 1.6 litre	165 [15,16]
Vauxhall Corsa 1.2 litre	200 [15,17]
Toyota Avensis 1.8 litre	248 [15]
Mazda MX5 2 litre	303 [15]
Aston Martin DB9	593 [15]
Average for all new cars sold in the UK in 2011	223 [18]

Table 2.3. Carbon footprints of petrol engine cars sold in the UK.

Under 'extra-urban' conditions, that is at speeds around 40 m.p.h., the Volkswagen Golf (row 1) has a fuel consumption of 3.5 litre per 100 km which equates to 81 miles per gallon. By a calculation along the lines of that above for the Cadillac this gives a carbon footprint for the Golf of 140 g per mile, and the somewhat higher figure quoted in the table reflects the urban component of average usage. In contrasting the figures for the Golf and the Corsa one row below we note that many factors influence the carbon footprint. These are no doubt amenable to formal multivariate analysis, but for the purposes of a coverage such as this identification of one or two obvious factors and their tentative linkage with the carbon footprint figure is the best approach. The Corsa has an extra-urban fuel consumption of 64.2 m.p.g. [17].

If one multiplies the carbon footprint by the fuel consumption one obtains a quantity composed of:

$$\text{g } CO_2 \text{ mile}^{-1} \times \text{mile gallon}^{-1} = \text{g } CO_2 \text{ gallon}^{-1}$$

and a constant value of this signifies inverse proportionality between one quantity and the other. Intuitively this is reasonable and the interested reader can easily confirm that it applies to the figures given above for the Golf and the Corsa. In general terms however one has to consider the Otto cycle itself to confirm or refute this hypothesis. In the fuel initially the energy is entirely chemical and that is converted to heat at ignition. Some of the heat is converted to work whilst some remains as heat, and the proportion depends on the efficiency of the engine which depends in turn on design and operating features.

The later rows of the table show the increasing carbon footprint for high-performance cars. Such figures are of course incorporated into calculation of the tax payable annually for particular cars, there being a scale ('bands') of levy according to carbon release.

2.4 Household energy

Discussion in this section will exclude such energy supplied as electricity, considered earlier in this chapter but will consider fuels used in heating and cooking, by far the most important of which is of course natural gas. The carbon dioxide from households due to such fuels was 87 million tonnes in 2010, up on the 79 million tonnes for 1990 [1]. This figure fluctuates across the period covered because of weather variations and how severe the winter in a particular year was.

Coal, whilst continuing to have an important role on the industrial scale, has all but vanished as a domestic fuel. This is good news in terms of carbon emissions. Fuel oil and natural gas are now the only household fuels in major use in the UK, the latter well exceeding the former [19]. True, there are local schemes to press wood and other biomass into service as residential fuels but the contribution of these to the total is extremely small. There is no carbon-neutral alternative to natural gas available in major quantities (although methane in carbon-neutral form does exist: see sections 3.4 and 13.1) There are alternatives to fuel oil. Bio-ethanol has been discussed as an automotive fuel and its use as a domestic fuel is 'on the agenda'. Whereas ethanol would be expected to be a substitute for a distillate fuel oil, biodiesels are likely to be more suitable to replace residual fuel oil. Again the potential for carbon dioxide mitigation is clear, but implementation will depend on availability of the respective carbon-neutral fuels and meanwhile the extent of usage remains very small.

2.5 Carbon dioxide sequestration

This is as yet limited to R&D level, such activity including the 'White Rose Project' at Drax power station (see Table 2.1). If this becomes a reality, carbon dioxide from Drax will be converted to liquid before being passed by pipeline to the North Sea where it will be permanently stored in porous rock. The suitability of particular rock formations, in terms not only of their porosities quantitatively expressed and their permeabilities but also of their chemical compositions, is one aspect of the R&D. R&D is, if promising, followed by 'demonstration', and the White Rose Project is moving towards that. Oxidant for the coal in the 'demonstration' at Drax will be supercritical oxygen, and some background physical chemistry is requisite. The critical temperature of oxygen, above which it cannot be made into a liquid by increase of pressure, is -118.6°C and the equilibrium vapour pressure at that temperature is 50.4 bar. Under circumstances such that pressure and temperature are both above their critical values only one phase exists, termed the supercritical state, and this is neither liquid nor vapour but a distinct phase. By the phase rule there are two degrees of freedom so a supercritical substance will exist across a region of a P-T phase diagram. The principles summarised for oxygen are of course true of gases more widely, and supercritical fluids including carbon dioxide are an important technology being used, for example, in extraction processes.

In the Drax project, oxygen in this condition will be used to burn the coal and the same principles of physical chemistry will be used in treating the (initially gaseous, obviously) carbon dioxide product. The critical temperature of carbon dioxide is 31.1 °C, at which the equilibrium vapour pressure is 74 bar. Returning in our minds to a phase diagram, the carbon dioxide will be taken to an equilibrium state in the vapour-liquid co-existence region and, in that state, transferred by pipeline for sequestration.

The North Sea is, if the 'demonstrations' currently under way go further, set to become a major scene of carbon dioxide storage, featuring (as we have seen) in the White Rose Project and also in many other such projects. A particular formation in the UK sector of the North Sea – the Bunter formation, composed of sandstone – is being evaluated for carbon dioxide sequestration capacity [20,21]. This is off the east coast of England, and some of the carbon sequestration potential is in sandstone of high porosity (up to 22%), currently occupied by salt water which can be displaced by carbon dioxide. The estimate set on the total amount of carbon dioxide which could be taken up in this way by the sandstone formation is 2811 million tonnes and this figure is examined in the shaded area below.

$2811 \times 10^6 \times 10^3$ kg = 2.811×10^{12} kg from $2.811 \times 10^{12} \times 12/(44 \times 0.8)$ kg of coal of 80% carbon content

= 10^{12} kg of the coal releasing on burning ≈ 2×10^{19} J of heat or 7×10^{18} J of electrical energy

Now a 500 MW turbine will produce this amount of electricity in about 450 years. Alternatively, the formation could take the carbon dioxide from 100 such turbines for 4 to 5 years.

It is clear that time of the order of years or decades is provided for when such a sequestration site is functional. Additionally, there are gas-producing fields within the Bunter geological formation which as they deplete can hold carbon dioxide in space vacated by methane. Another way of putting that is that any carbon sequestration at those sites will be *depletion driven*.

In the White Rose Project use of oxygen, in a supercritical state, as an oxidant eliminates the need for carbon dioxide capture. There is of course a need for capture when a fuel is burnt conventionally in air, in which case the dominant constituent of the flue gas will be elemental nitrogen. 'Capture' will obviously have to precede sequestration. Accordingly R&D into materials suitable for carbon capture is taking place widely, and some examples of this in the UK are given in the table below.

Material and references.	Details
Calcium oxide [22]	$CaO + CO_2 \rightarrow CaCO_3$ $\downarrow$ heat $CaO + CO_2 \leftarrow$ 'captured' Conditioning of CaO by heating before use. ($Ca(OH)_2$) ('portlandite') found to be more effective than CaO.
Structure containing indium and carboxylate ligands [23,24]	Carbon dioxide capture in spaces in the nanopore size range, with a high degree of selectivity.
Aqueous amine solutions [25]	Amine solutions have long been used to remove carbon dioxide from natural gas and refinery streams.
Solvents other than amines [26]	Carbon dioxide once captured regenerated as the pure compound for subsequent sequestration.

Table 2.4. Substances for carbon capture.

The chemical principles in the first row of the table could hardly be more elementary! The ready availability of calcium-containing minerals obviously adds to the attractiveness of this approach. The substance in the second row is clearly a 'co-ordination compound' in the terminology of inorganic and structural chemistry. It is referred to as NOTT-202a. The challenge facing the researchers and developers into capture by amine solutions (next row) is the rise in scale from the current applications to power generation.

Carbon capture is at the demonstration stage at the power station at Aberthaw in Wales. There 50 tonne of carbon dioxide a day are captured, about 0.2% of the total, at a pilot scale capture device [27]. Aberthaw power station, which has been in service for over 40 years, uses locally sourced higher rank coal as fuel.

2.6 Tree planting

Without doubt the most important means of carbon sequestration is the natural one provided by trees. A tree absorbs ≈ 0.025 tonne of carbon dioxide in a year, so the 2010 release of 496 million tonnes would require for sequestration by this means:

$$(496 \times 10^6/0.025) \text{ trees} = 2 \times 10^{10} \text{ trees (20 billion)}$$

In fact the number of trees in the UK is of the order of 2 billion, meaning that this carbon sequestration resource can handle about 10% of the carbon dioxide released. Over the 20th Century the ratio of trees to persons worldwide declined dramatically: it is currently about 60, and is believed to have been at least ten times that in 1900. 'Tree planting projects' and the like deserve the support of communities and afforestation/reforestation are always part of the approach of a particular country to controlling amounts of carbon dioxide.

2.7 References.

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3 Other European Union countries

3.1 Introduction

Member countries vary widely in population and in standards of prosperity. This chapter will begin with two of the original members of the predecessor organisation the 'Common Market' – France and the Netherlands – and will later discuss some of the newer members which are former communist states. The UK is of course in the EU.

3.2 France

France, population 65.4 millions, had a CO_2 emissions figure for 2010 of 395 million tonnes. An alert reader will have noticed that whereas the UK and France have remarkably close populations (about 63 millions for the UK, 65 millions for France) the carbon dioxide emissions of the latter are appreciably lower. This is of course largely because of the extensive use of nuclear plants to make electricity for France. In 2011 nuclear reactors provided 421 billion kWh, 78% of the total [1]. A related calculation follows.

421 billion kWh = 421 × 10^{12} J s^{-1} × 3600 s = 1.5 × 10^{18} J or electricity.

Efficiencies of generation do not depend on whether nuclear and or chemical fuels were used, so the electricity above must have been obtained from about:

(1.5 × 10^{18}/0.35) J of heat = 4.3 × 10^{18} J of heat

If this had been raised from natural gas, the carbon dioxide release would have been:

[4.3 × 10^{18} J/(889 × 10^3 J mol^{-1})] × 0.044 kg mol^{-1} × 10^{-3} tonne kg^{-1} = 212 million tonnes

The benefits to carbon dioxide emission reduction from electricity from nuclear sources is clear. To this can be added the fact that France also has hydroelectricity. The original motive for development of nuclear fuels for electricity in France was lack of oil. In any one year up to about 12% of the electricity generated in France is exported. In a typical month the UK will itself import of the order of one terawatt hour from France: the transmission cable goes along the Eurotunnel.

Transport contributes 35% of the total carbon dioxide in France. Ethanol-gasoline blends, most notably E10, are widely available in France [2]. E10 means of course 10% ethanol balance gasoline weight basis although (a point touched on in the previous chapter) some variation from the nominal percentage of ethanol might be necessitated to meet octane number and Reid Vapour Pressure requirements. Whether such variations occur and if so to what degree depends on the gasoline: gasoline fractions differ widely from each other in such properties according to the nature of the crudes from which they were obtained.

The automotive fuel E10 provides a suitable context for illustration of carbon balance for a fuel partly carbon-neutral. Carbon dioxide from the carbon-neutral part is being put back where it came from before being used in photosynthesis and does not contribute to rises in the atmospheric level when such a fuel is burnt. The working in the shaded area below is concerned with this.

Heat released on the burning of 1 kg of gasoline = 45 MJ, releasing:

(44/14) kg CO_2 = 3.14 kg

Taking E10 to be 10% by weight of ethanol (calorific value 29.7 MJ kg^{-1}), balance gasoline, its calorific value is

[(0.9 × 45) + (0.1 × 29.7)] MJ kg^{-1} = 43.5 MJ kg^{-1}

So 45 MJ are released by (45/43.5) kg = 1.03 kg

Fossil fuel derived CO_2 = (1.03 × 0.9 × 44/14) kg = 2.91 kg

Using the stoichiometry: $C_2H_5OH + 3O_2 + (11.3\ N_2) \rightarrow 2CO_2 + 3H_2O + (11.3\ N_2)$

Non fossil fuel derived CO_2 = (1.03 × 0.1 × 44/23) kg = 0.20 kg

A drop in the fossil fuel derived CO_2 of (3.14 – 2.91) kg = 0.23 kg or 7%.

Reduction of fossil fuel derived carbon dioxide is shown above. It is possible with such fuels for the total carbon dioxide per unit heat released to be higher than in the absence of the carbon-neutral component, and this is always so with coal-biomass firing such as is described in the previous chapter. It is the fossil fuel derived carbon dioxide only that is relevant for the reason explained.

France is by far the most abundant producer of bioethanol in the EU, with an annual output of 1250 million litres [3], thermally equivalent to:

$$1250 \times 10^{6} \times 10^{-3}\ m^{3} \times 0.159\ bbl\ m^{-3} \times (29.7/44)\ \text{barrels of oil} = 0.13\ \text{million barrels of oil.}$$

One would expect its financial worth to be greater than that of the amount of oil calculated because of the advantage of ethanol over refined oil products of carbon neutrality.

Sugar beet and cereal are common feedstocks for ethanol production in France. At the Lillebonne plant (plate 3.2) wheat is used, the starch being first converted to fermentable sugars. Current figures for Lillebonne [4] are 300 million litres of ethanol annually from 820000 tonnes of grain, with 300000 tonnes of animal feedstock by-product. Failure (which a reader can confirm, using a density of 789 kg m^{-3} for ethanol) of a mass balance on this to close is due to high moisture contents both of the wheat and the solid by-product, influenced by water loss or uptake in the processing. The general point can be made that carbohydrates ranging from simple sugars immediately fermentable to long-chain polysaccharides needing quite vigorous breakdown can all be used to make bioethanol [5].

In 2010 France produced 1.9 million tonnes of biodiesel [6]. Being commissioned at the time of writing for commencement of operations in mid 2013 is the biodiesel plant at Le Havre [7,8]. Like the plant at Motherwell mentioned in the previous chapter, that

Plate 3.1. Lillebonne ethanol plant in Normandy. The river in the background is the Seine.
Illustration: http://www.tereos-syral.com/web/syral_web.nsf/Page/U1D5T0Q0/Manufacturing_sites?opendocument

at Le Havre will take animal fats as feedstock and like those operated by Agri Energy it will take spent cooking oil for refining. The output of the plant will eventually be 75000 tonnes per year of biodiesel. Assigning this a calorific value of 37 MJ kg^{-1}, the amount of fossil fuel derived carbon dioxide eliminated by its use in preference to mineral diesel will be:

$$\{[75000 \times 10^3 \text{ kg} \times 37 \times 10^6 \text{ J kg}^{-1}/(44 \times 10^6 \text{ J kg}^{-1})] \times 44/14\} \times 10^{-3} \text{ tonnes}$$
$$= 0.2 \text{ million tonnes}$$

Such projects are of interest and value, providing a use for wastes and a supplement to the carbon-neutral fuels supply. Most of the biodiesel in France is however more conventionally produced. France is in fact the EU's largest rapeseed grower. Not all of the oil so produced, of course, is put to fuel use: some is diverted to the food industry. As mentioned later in the chapter, there is limited import of biodiesel into France from Belgium.

3.3 The Netherlands

The Netherlands (population 16.7 millions) produced 114734 GWh (4.1×10^{17} J) of electricity in 2010. It is well known that the Netherlands has abundant sources of natural gas, both onshore and in the Dutch sector of the North Sea, and one intuitively expects this to be the primary fuel for electricity. In 2010, 71310 million kWh (equivalent to the same number of GWh) of electricity were generated in the Netherlands from natural gas [9], representing (by comparison with the figure in the first sentence of the paragraph) 62% of the total. The carbon footprint of this is easily calculated as:

$$\{[(71310 \times 10^{6}\ \text{kJ s}^{-1} \times 3600\ \text{s}/889\ \text{kJ mol}^{-1})]/0.35\} \times 0.044\ \text{kg mol}^{-1} \times 10^{-3}\ \text{tonne kg}^{-1}$$
$$= 36\ \text{million tonnes of } CO_2$$

and there is also major (>20%) production of power from Rhineland coal, adding to the above. There is however major interest in the Netherlands in electricity from the combustion of biomass. For example, there are plans for the Hemweg power plant in Amsterdam, currently using coal, to start using up to 15% biomass. The announcement of this [10] informs a reader that this will require up to 360000 tonne per year of wood pellets, a figure which is examined below.

The nameplate capacity of the plant is 650 MW of electricity. If we take it that this is to remain the capacity when biomass is introduced, 97.5 MW will be produced from that or 280 MW of heat for 35% efficiency. Wood *pellets*, having in manufacture experienced air drying and compression, are of calorific value about 18 MJ kg^{-1}, higher than that of newly harvested timber or forest thinnings. The required amount in a year will therefore be:

$$[(280 \times 10^{6}\ \text{J s}^{-1} \times 3600 \times 24 \times 365\ \text{s})/18 \times 10^{6}\ \text{J kg}^{-1})] \times 10^{-3}\ \text{tonnes} = 490000\ \text{tonnes approx.}$$

and the discrepancy of about 35% is no doubt due to the fact that the power station will not be operating round the clock at nameplate capacity.

The Port of Amsterdam currently handles 1.5 million tonnes per year (several times the requirement of the Hemweg power station) of wood fuel and is to be set up to handle more. Wood in pelletised form is imported from Georgia, USA. Wood waste is used in the Netherlands to the degree that it is available in a way which makes for viable use, reducing the dependence on imports.

On the bioethanol front, the Netherlands at its largest plant for the production of this substance uses cereal feedstock [11]. This plant, at Rotterdam, produces 127 million gallons of ethanol (0.46 million tonnes) annually as well as animal feed and carbon dioxide by-products. A great deal of ethanol is made in the Netherlands and fuel (nominally: see note section 2.3) as high in ethanol as 85% is available from some filling stations, this being known of course as E85. Its calorific value will be:

$$[(0.85 \times 29.7) + (0.15 \times 45)] \text{ MJ kg-1} = 32 \text{ MJ kg}^{-1}$$

We saw in the previous section how one kilogramme of conventional gasoline releases on burning 3.14 kg of fossil fuel derived CO_2. A thermally equivalent amount of E85 would release:

$$[(45/32) \times 0.15 \times 44/14] \text{ kg} = 0.66 \text{ kg}$$

which represents a reduction of almost 80%. The octane number of E85 is typically 100 to 105.

In 2010 biodiesel consumption in the Netherlands was 2000 barrels per day. A great deal of rapeseed is grown in the Netherlands. This was true long before the move towards carbon-neutral fuels, when plant oils were produced solely as ingredients of margarines, cooking oils and the like. There is a biodiesel manufacturing plant at Emmen in the north east of the country where biodiesel is produced entirely from rapeseed oil. Commencing operations in 2005, this plant has an eventual target production of 200000 tonnes per year. The major Dutch manufacturer of heavy vehicles Daf have a very positive attitude towards biodiesels [12]. We saw in the previous chapter how Argent Energy in the UK invoke the standard EN 14214 2008 in the quality of their products, and the very same standard is cited by Daf [12].

The Netherlands has shown itself progressive in the matter of electricity from wind turbines, having a nameplate capacity in late 2011 of 2328 MW. The usual way of assessing carbon mitigation by a wind farm is to assume that its operation will be equivalent to nameplate capacity for 2500 hours in the year, so the amount of electricity raised is in the Netherlands is:

$$2.328 \text{ GW} \times 2500 \text{ hours} = 6\text{TWh approximately}$$

or equivalently

$$2328 \times 10^6 \text{ J s}^{-1} \times (2500 \times 3600) \text{ s} = 2 \times 10^{16} \text{ J}$$

The carbon dioxide raised in a year from this generation rate thermally with natural gas at 35% efficiency would be:

$$[(2 \times 10^{16} \text{ J}/889 \times 10^3 \text{ J mol}^{-1})/0.35] \times 0.044 \text{ kg mol}^{-1}$$

$$\downarrow$$

3 million tonnes

The Dutch government plans to raise its nameplate wind power capacity to 6000 MW by 2020 in spite of concerns about noise and a moratorium on the erection of new wind turbines in the province of North Holland on the grounds of their visual impact. Many of the assemblies of wind turbines in the Netherlands are offshore. Accordingly a wind farm fourteen miles out to sea from the coast of the Netherlands with a capacity of 129 MW is proposed, construction to begin in mid 2014 with Mitsubishi as a participant [13]. One would not regard an enterprise generating half a megawatt of ‘ green electricity’ as making a major contribution, yet generation on that scale at and for Rotterdam Central Station, which receives over 100000 rail travellers per day, deserves a mention. This is by photovoltaic (PV) cells installed across the roof. PV projects for particular buildings and structures are common, and in the earlier part of this chapter which was focused on France it might have been pointed out that a contribution to the electricity requirements of the Eiffel tower is made by PV cells. PV cells feature in subsequent chapters.

3.4 Germany

Germany was also (as West Germany) one of the founding members of the Common Market. The current population is 82 millions. Germany has fulfilled its commitments under Kyoto [14]: emissions of carbon dioxide in 2012 were 21% lower than in 1990. Power generation in 2011 was 615 billion kWh (2.2×10^{18} J) [15]. The sector diagram from [15] is reproduced below, and discussions follow.

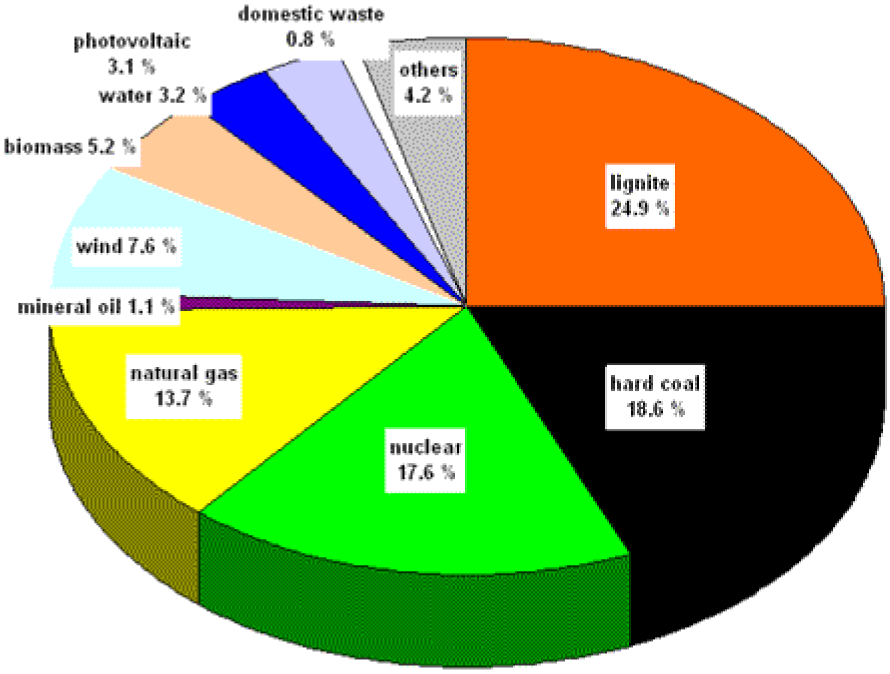

Figure 3.1 Electricity generation in Germany in 2012.
Taken from [15]

We note that lignite, a.k.a. brown coal, accounts for a quarter of the electricity in Germany. (Other parts of the world where brown coal is used in power generation include Victoria, Australia, North Dakota USA and Greece). Lignite is wet when in the ground and partly dried before and during admittance to a boiler furnace at a power facility. The carbon content of raw lignite will be about 30%, rising to about 70% due to the partial drying preceding burning. Its calorific value in the dried condition will be around 20 MJ kg^{-1}. The annual carbon dioxide emission from this route to electricity, from these rough figures and from the more precise figures which precede them, will be:

$$0.249 \times [(2.2 \times 10^{18}/0.35)\ J/(20 \times 10^{6})\ J\ kg^{-1}] \times 0.7 \times (44/12) \times 10^{-3}\ \text{tonnes}$$
$$= 200\ \text{million tonnes}$$

It is sometimes seen as surprising that in spite of her opposition to carbon dioxide emissions in principle and her commitments under Kyoto Germany still produces so much electricity from lignite. Assigning the 'hard coal' (meaning black coal: brown coal when in the bed-moist state is soft) a carbon content of 85% and a calorific value of 25 MJ kg^{-1}, the emission of carbon dioxide from its contribution to the electricity will be:

$$0.186 \times [(2.2 \times 10^{18}/0.35)\ J/(25 \times 10^{6})\ J\ kg^{-1}] \times 0.85 \times (44/12) \times 10^{-3}\ \text{tonnes}$$
$$= 145\ \text{million tonnes}$$

The emissions from the gas-fired generating plants will be:

$$0.137 \times [(2.2 \times 10^{18}/0.35)\ \text{J}/(889000\ \text{J mol}^{-1})] \times 0.044\ \text{kg mol}^{-1} \times 10^{-3}\ \text{tonnes}$$
$$= 43\ \text{million tonnes}$$

so the three fossil fuels in used in electricity generation release between them just under 400 million tonnes annually of carbon dioxide.

As in the UK there are carbon storage sites under development in Germany. The onshore one at Ketzin received 53000 tonnes of carbon dioxide over the first 39 months of its trial operation [16]. The formation there is sandstone. It has the legal status of a trial only, and admittance beyond a total of 100000 tonnes will not be permitted without revision of terms. A German analogue of England's White Rose Project is the Schwarze Pumpe power plant in northern Germany [17], where on a pilot scale of 30 MW lignite is burnt in oxygen alone. The carbon dioxide after capture is injected into a disused gas field. If lignite is to continue to provide such a large share of Germany's electricity, sequestration will become increasingly important.

Natural gas is a major fuel in electricity generation and also of course in the heating of domestic and commercial buildings. The consumption of natural gas in Germany in 2010 was 97329 million cubic metres [18], releasing:

$$97329 \times 10^{6}\ \text{m}^{3} \times 40\ \text{mol m}^{-3} \times 0.044\ \text{kg mol}^{-1} \times 10^{-3}\ \text{tonne kg}^{-1}\ \text{of}\ CO_2$$
$$\downarrow$$
$$170\ \text{million tonnes of carbon dioxide}$$

Ethanol production from sugar beet in Germany was 253866 tonnes [19]. There is also ethanol production from cereal feedstocks, in particular rye. A great deal of the ethanol produced in Germany is used to make E5, nominally 5% of ethanol in gasoline, and a government decision to replace E5 with E10 was reversed when representations were made to the effect that a significant number of cars were not suitable for use with E10. In 2010 total ethanol production in Germany was 752 million litres which, if diverted entirely to fuel use, would eliminate about a million tonnes of fossil fuel derived carbon dioxide (a calculation which an interested reader can easily confirm). Biodiesel manufacture is also very buoyant in Germany, there being a number of plants for making it including those described in the table below.

Location	Details
Regensburg [20]	Commencement of operations in 2007. 60000 tonnes per year from rapeseed oil, sunflower oil and spent cooking oil. Conformity of products with EN14214.
Grimmen [20]	Commencement of operations in 2006. 33000 tonnes per year from rapeseed oil, sunflower oil and spent cooking oil. Conformity of products with EN14214.
Tangermünde [20]	Commencement of operations in 2006. 33000 tonnes per year from rapeseed oil, sunflower oil and spent cooking oil. Conformity of products with EN14214.
Hamburg [21]	Rapeseed and soybeans processed for the food industry as well as for fuel production.
Brunsbüttel [22]	250000 metric tonnes of biodiesel production annually from different starting materials.
Neubrandenburg [23]	Recently reopened 40000 tonne per year facility making biodiesel from rapeseed oil.

Table 3.1. Biodiesel production facilities in Germany.

At the Regensburg facility as at many other state-of-the-art biodiesel production sites, the glycerol by-product ($C_3H_8O_3$) is used in the manufacture of *biogas* which is of course itself carbon-neutral. This is also true of the glycerol produced at Grimmen and at Tangermünde (second and third rows of the table): the Regensburg, Grimmen and Tangermünde facilities were all built by Energie GmbH. The facility at Neubrandenburg (last row of the table) has resumed operations after temporary closure through reductions in government subsidies of biodiesel over the triennium 2005–2008.

The major German car manufacturers have ambitious research programmes into carbon-neutral fuels, and they include eco-gas (a.k.a. e-gas) which is supported by Audi [24,25]. This will take electricity from an offshore wind farm in the North Sea to produce hydrogen which will be reacted with carbon dioxide to make methane for engines. For the present the carbon dioxide so used will come from a nearby biogas plant, where it is a by-product. Its methanation by electrolytically obtained hydrogen will produce methane which will be reticulated to forecourts. That methane is a good fuel for spark ignition engines is already well known, there being compressed natural gas and (less widely) liquefied natural gas usage in vehicles in many countries. It is stated in [25] that in the e-gas project 1000 tonnes of methane manufactured annually will 'bind' 2800 tonnes of carbon dioxide, and these figures can be examined.

The methanation process is:

Produced by electrolysis with power from a wind farm

↓

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

↑

By-product from a biogas plant

and from the stoichiometry 44 g of carbon dioxide will be 'bound' by 16 g of methane, giving a ratio of 2.8 which corresponds to that in the paragraph above.

This is quite viable, and delivery can be expected. Less so are the related 'petrol from air' projects of which one reads. These aim to take carbon dioxide from the atmosphere for methanation.

A reader will have noted with interest the datum in the sector diagram that photovoltaic cells contribute over 3% to Germany's electricity, and Germany is in fact a leader in PV usage. The broad aspiration is that PV will increase and nuclear will decrease. Subsidies for biodiesels, and the closure of one biodiesels plant because of their withdrawal, were mentioned above. Similarly the future of electricity PV cells depends on their ability or otherwise to attain grid parity, that is, to supply at a cost no greater than that from the grid without any sort of subsidy or privileged treatment. A 2012 report [26] indicated progress towards grid parity for PV in Germany, without which its expansion will be precluded. It has been asserted that grid parity for PV is quite impossible under the different electricity supply circumstances of the UK. Belgium (following section) has over 2GW of PV installations at Flanders.

3.5 Belgium

One of the smaller states of the EU (population 11 millions), Belgium more than fulfilled her obligation under Kyoto by reducing her carbon dioxide emission by 8% between 2010 and 2011 [27]. The 2011 figure was 127 million tonnes. Her electricity consumption annually is of the order of 80 terawatt hours (equivalent units to billion kWh) a small proportion (about 2%) of which she imports. About half of her electricity production is nuclear (the precise figure for 2012 was 48.2%) and natural gas and oil jointly contribute most of the balance. All natural gas is imported, the 2010 amount being 20826 million cubic metres. This will leave carbon footprint of:

$$20826 \times 10^6\ m^3 \times 40\ mol\ m^{-3} \times 0.044\ kg\ mol^{-1} \times 10^{-3}\ tonne\ kg^{-1} = 37\ million\ tonnes\ of\ CO_2$$

Oil imports into Belgium are about 1 million barrels per day, for which there are refining facilities. Total's Raffinaderij refinery at Antwerp, capacity 360000 barrels per day, is one of the most progressive refineries in Europe. Other refineries include the Esso refinery, also at Antwerp, which came in to service 60 years ago.

Coal production is very limited in Belgium and did for a period cease altogether. Accordingly some former coal-fired power stations remain in service having been adapted to biomass as the fuel. An example is the Rodenhuize Power Station at Ghent [28] which produces 180 MW of electricity from solid biomass. This is obtained as wood pellets, partly from a supplier in British Columbia. The national generator Electrabel has a total of 341 MW installed capacity for electricity from solid biomass, necessitating a quantity of biomass annually of:

$$[(341 \times 10^6\ J\ s^{-1}/0.35)/(18 \times 10^6\ J\ kg^{-1})] \times (365 \times 24 \times 3600)\ s\ year^{-1} \times 10^{-3}\ tonne\ kg^{-1}$$

$$\downarrow$$

$$1.7\ million\ tonne\ per\ year$$

Ten to fifteen per cent of this is obtained from the supplier in BC referred to. Like all responsible biomass fuel users worldwide, Electrabel ensures that the wood it receives is from suppliers with Forest Stewardship Council (FSC) recognition for sustainability. Such suppliers are monitored by the FSC for replacement of trees felled with new plantings.

The bioethanol plant at Wanze, Belgium (Plate 3.2) commenced production in 2009 and can produce up to 300000 cubic metres of ethanol per year, thermally equivalent to 1.6 million barrels of oil. It receives feedstock from diverse sources, making for flexibility. These include syrup from Wanze Sugar Refinery, who are in fact the owner of the bioethanol plant, so one might see this as an example of 'integration'. Other bioethanol plants in Belgium include that at Ghent which uses cereal as feedstock, the construction and commissioning of which were largely by Siemens. This operates under the name Alco Bio Fuel and, like many other such plants, supplies animal feed by-products. A great deal of the primary product of Alco Bio Fuel goes into automotive fuel blends ranging from E25 to E85, the company having received a large share of the bioethanol quota imposed by the government. The quota is of course part of Belgium's strategy to comply with greenhouse gas targets. That the acceptability of such quotas under EU law has been challenged [29] merits no more than a passing mention.

Biodiesels have been available at filling stations in Belgium since 2006. Production in 2010 was just over 8000 barrels per day. The current biodiesel quota in Belgium is 4%, that is, any supplier of diesel for Belgium must ensure that 4% by volume of its products are composed of biodiesel. Whether the biodiesel is domestic or imported is irrelevant in formal application of the quota. Belgium's leading manufacturer of biodiesels is Oleon, whose HQ is near Ghent, which has factories in Belgium and elsewhere making plant oil products for the food industry. It also supplies biodiesel to companies including Total to enable them to satisfy the quota. At its production facility in Ghent, Oleon produces 100000 tonnes per year of biodiesel conforming to EN 14214, some of which is exported to France. It receives as starting material rapeseed oil as well as used vegetable oils. Belgium is capitalised with wind turbines to a generating capacity of 1078 MW [30]. That is a little more than half that of the Netherlands, a figure exceeding the ratio of the respective populations therefore reflecting major activity in Belgium.

Plate 3.2. Bioethanol plant at Wanze. (Reproduced with permission of CropEnergies AG)
Illustration: http://www.cropenergies.com/en/Unternehmen/Standorte/Wanze/

This is a convenient place at which to consider briefly wind turbines *per se* and in the calculation below we examine a particular Belgian wind farm.

Estinnes wind farm near Brussels [31] has five turbines each with a nameplate output of 6MW of electricity. The turbine blade diameter (symbol d) is 127 m.

The efficiency of conversion of mechanical power to electrical at a wind turbine is 30 to 35%, so the figure above of 6MW converts to about 20 MW mechanical power. Assigning this the symbol *W* (units watts):

$$W = 0.5mc^2$$

where m = flow rate of air through the turbine (kg s^{-1}) and c the entry speed of air at the turbine blade, that is, the wind speed.

Now $m = \rho c A$ where ρ = density of the air (kg m^{-3}) and A = area swept out by the blades on rotation (m^2) = $\pi d^2/4$

$$\downarrow$$

$$W = 0.5\rho \times (\pi d^2/4) \times c^3 \text{ W}$$

Using a value of 1.16 kg m^{-3} for ρ, from the above a turbine at Estinnes will, when working at nameplate capacity, require a wind speed of:

14 m s^{-1} or 31 m.p.h.

Reference [32] gives graphical records of wind speeds at the Estinnes facility for a particular February, and they equal or exceed the value calculated for part of the time whilst sometimes being below 10 m.p.h. In general however a wind farm will not operate at nameplate capacity for anywhere near all of the time, a point made earlier when an operational criterion of 2500 hours per year at nameplate capacity was applied. The figure in [31] for the annual electricity output of Estinnes is 165GWh, whereas round-the-clock operation at nameplate capacity would be:

$$30 \times 10^{-3}\ \text{GW} \times 365 \times 24\ \text{h} = 263\ \text{GWh}$$

3.6 Spain

Spain, population 47 millions, has been in the EU since 1986. Her 2010 carbon dioxide release was 316 million tonnes and in the same year she consumed 259 TWh of electricity. Just under half of the electricity in Spain is generated from the three traditional staple fuels coal, oil and natural gas. There is also significant nuclear generation. There is no shortage of local biomass, and this includes olive stones of which Spain's olive industry produces 4 million tonnes per year. At Huelva in southern Spain there is currently electricity generation from biomass fuel at 50 MW [33]. It will use both biomass waste and forest products, in a total quantity of 400000 tonnes annually, a figure which is examined in the shaded area below.

50 MW of electricity from (50/0.35) MW of heat = 140 MW of heat

Using (again) the 'boiler-as-calorimeter' method, the calorific value of the fuel is:

$$[140 \times 10^{6}\ \text{J s}^{-1}/(400000000)\ \text{kg})] \times 365 \times 24 \times 3600\ \text{s} = 11\ \text{MJ kg}^{-1}$$

The quantity of heavy fuel oil of calorific value 43 MJ kg^{-1}
which would have raised an equivalent amount of heat is:

$$(11/43) \times 400000\ \text{tonnes, producing:}$$

$$[(11/43) \times 400000 \times 44/14]\ \text{tonnes of } CO_2 = 321595\ \text{tonnes of } CO_2$$

It is stated in [33] that the facility at Huelva 'captures' 312500 tons (316530 tonnes) of carbon dioxide annually, so agreement is remarkably close. It makes a significant difference to the calculation whether oil, coal or natural gas is taken to be the alternative to the biomass, so it appears that the figure in [33] is on the basis of oil.

The bioethanol plant at Babilafuente in western Spain [34] uses cereal feedstock, and the ethanol is used in gasoline blends. It produces 200 million litres of ethanol a year, thermally equivalent to 0.85 million barrels of oil. The Valencia region of Spain is a major producer of citrus fruits, and there are proposals [35] to make ethanol from citrus peel which contains amongst other constituents cellulose. Breakdown of those to sugars and their fermentation will yield the required product. One stakeholder in the project is Ford Spain, whose involvement is linked to their manufacture of flexible fuel vehicles (FFV). In a number of countries including the US, poplar trees are seen as being a good basis for ethanol production from cellulose. That poplars are abundant in Spain has been noted, and investigative work on ethanol production by this route is on the agenda as Spain's ethanol production continues to increase annually. Biodiesel production in Spain in 2011 was 604000 tonnes, thermally equivalent to about 3 million barrels of oil [36]. The biggest manufacturing facility for biodiesel in Spain is at Bilbao [37], where the projected production figure is 200000 tonnes per year with soya, rapeseed and palm as the feedstock. (It will not re-process previously used oils.) Also producing at about 200000 tonnes per year is the biodiesel facility at Cartagena, which unlike that at Bilbao uses animal fat feedstock additionally to plant oil.

In 2011 wind power accounted for 21% of Spain's electricity generation, producing of the order of 50000 GWh from a total installed capacity (for round-the-clock operation) of about three-and-a-half times that. Such over-capitalisation is usual with electricity generation from wind. Spain is in fact a leader in the EU in wind power generation. Details of a few wind farms in Spain are therefore given in tabular form below.

Name and location.	Details.
Agreda wind farm, Castile region.	Newly commissioned at the time of going to press. 48 GWh annually expected [38].
A Capelada II wind farm, Galicia.	Commissioned in 1997, nameplate capacity 15 MW. Forty-five turbines with blades of 30 m diameter [39].
La Solana wind farm, Comunidad Valenciana.	Nameplate capacity 44 MW. Fifty-two turbines of diameter 58 m [39].
Vilobí wind farm, Cataluna.	Nameplate capacity 41 MW. 27 turbines of diameter 77 m [39].
Zorreras wind farm, Andalucía	Nameplate capacity 41 MW. 10 turbines of diameter 70 m [39].

Table 3.2. Selected wind farms in Spain.

With reference to the A Capelada II wind farm (second row of the table) we note that its commencement of operations was over 15 years ago, and that 30 m is a small turbine blade width by current standards. It is taken to operate at an equivalent of 2500 hours at nameplate capacity annually (see section 3.3), giving:

$$15 \times 10^{-3} \text{ GW} \times 2500 \text{ hours} = 37.5 \text{ GWh}$$

From the treatment of wind turbines in a previous section it might be expected that the power per turbine would be in proportion to the square of the turbine diameter. This is tested below for the A Capelada II (row 2) and La Solana (row 3) wind farms:

$$(15/45 \times 30^2/(44/52 \times 58^2) = 1.5$$

and that exact proportionality is not demonstrated is an indication of the extent to which like is not being compared with like in the calculation. We simply record that the fairly sedate speed of 31 m.p.h. calculated previously for Estinnes can be exceeded by a factor of three, and that the origin of the departure from unity of the ratio above is believed to be average wind speeds at the two sites. The wind speed appears to power 3 in the expression for generation rate so the ratio of speeds required to give the factor of 1.5 in the turbine powers is:

$$1.5^{1/3} = 1.14$$

In Comunidad Valenciana there has been destruction of wind farm plant by excessive wind speeds [40].

3.7 Portugal

Portugal, population 10.6 millions, has been a member of the EU since 1986. Her electricity production for 2009 was 46.5 billion kWh [41]. That figure is *approximately* two thirds fossil fuel and one third hydroelectric: there is no nuclear component.

Portugal produces no natural gas, but imports about 5000 million cubic metres per year. A great deal of it comes by pipeline across the Spanish border, having been imported into Spain as liquefied natural gas (LNG). There are some significant power-from-biomass installations including that at Mortágua [42] where forest residues are burnt once natural gas has been used in start-up. Figures given for 2005 [42] are 91882 ton of forest residues, 800×10^3 m^3 of natural gas. Assigning the forest residue a calorific value of 10 MJ kg^{-1} the ratio of heat from the two is:

heat from the gas/ heat from the forest residue

$$= (800 \times 10^3\ m^3 \times 37 \times 10^6\ MJ\ m^{-3})/(10 \times 10^6\ MJ\ kg^{-1} \times 91882000\ kg)$$

$$= 0.032 \text{ or } 3\%$$

consistently with the role of gas in start-up only. We are also told that 51389 MWh of electricity were produced, giving an efficiency of:

$$51389 \times 10^6\ J\ s^{-1} \times 3600\ s/(10 \times 10^6\ J\ kg^{-1} \times 91882000\ kg) = 20\%$$

Most interestingly of all we are given in [42] a value for the carbon dioxide release of 1729 tons. Equating tons to tonnes and having regard to the fact that unit molar amount of methane goes to unit molar amount of carbon dioxide, we can estimate the natural gas used as:

$$(1729000\ kg/0.044\ kg\ mol^{-1})/40\ mol\ m^{-3} = 980 \times 10^3\ m^3$$

which is just over 20% higher than the usage figure given. The carbon dioxide from the biomass will of course enormously exceed that from the natural gas, but it is not 'fossil fuel derived carbon dioxide' which in the plant at Mortágua arises from start-up only and is fairly negligible.

No ethanol fuel is produced in Portugal, but some E10 fuel is imported. In 2012, 0.33 million tonnes of biodiesel were produced in Portugal and a quantity equivalent to about one per cent of that imported from within the EU. The biodiesel is blended with mineral diesel at 7%. At Sines, a coastal location within Portugal, biodiesel conforming to EN14214 is produced from animal fats and used cooking oil. In 2011 installed the wind power capacity for Portugal was 9616 MW [43]. On the usual measure of full load for 2500 hours in the year, this gives:

$$9616000 \text{ kW} \times 2500 \text{ hour} = 24 \text{ billion kWh (TWh) per year}$$

which is a very substantial proportion of the country's usage. Portugal's first offshore wind production was in 2011 with a single-turbine unit in 50 m of water four miles from the coast [44]. Of 5 MW nameplate capacity, it has a floating support and is illustrated below.

Plate 3.3. WindFloat Agucadoura, offshore Portugal.
Illustration: http://www.offshorewind.biz/2012/08/15/portugal-abs-certifies-first-windfloat-facility/

The above measures, in particular wind power, have enabled Portugal to fulfil its obligations under Kyoto. Portugal is an example of a country which is allowed restricted *growth* in CO_2, and a 2008-2012 target of 27% above the 1990 level was set and complied with.

3.8 Newer members of the EU

The countries selected for coverage previously in this chapter were all in the EU before Perestroika when, for example, for Poland to seek admission to the EU would have been an utter impossibility. Many of the former communist states have, since the 1989 collapse of Communism, one by one joined the EU and effects of this on the demographics of western European countries including the UK have been far-reaching. Some of the new members are discussed from the point of view of energy and greenhouse gas emissions in the table below.

Country	Details
Poland. Population 38.5 millions. Joined the EU in 2004.	Electricity production annually 150 TWh [44]. ≈ 90% of the electricity from coal (lignite and black coal) Total annual CO_2 emissions ≈ 325 million tonnes.
Czech Republic. Population 10.6 millions. Joined the EU in 2004.	85 TWh of generation in 2010, a considerable part of which was exported [45]. 60–65% from coal sources, also significant hydroelectric and nuclear.
Romania. Population 21.5 millions. Joined the EU in 2007.	61 TWh of electricity generated in 2010 predominantly from fossil fuels, also nuclear and hydro. Suspension from Kyoto in 2011 [46].
Cyprus. Population 0.8 millions. Joined the EU in 2004.	About 1 GW of electricity generation using imported fuel oil. 2008 emission of carbon dioxide 10 million tonnes.
Hungary. Population 10 millions. Joined the EU in 2004.	Annual carbon dioxide emissions ≈ 55 million tonnes. 36 TWh of electricity generated in 2011.
Bulgaria. Population 7.6 millions. Joined the EU in 2007.	About 35TWh of electricity in 2012. ≈56 million tonnes of carbon dioxide.
Lithuania. Population 3.3 millions. Joined the EU in 2004.	About 12 TWh of electricity in 2012. Previously major nuclear generation, now none at all.
Slovenia. Population 2 millions. Joined the EU in 2004.	About 2TWh of electricity generated in 2010. ≈ 17 million tonnes of carbon dioxide. Significant hydroelectric activity.

Poland is amongst the countries still have a heavy reliance on lignite, and the following point can be made in relation to lignites generally, irrespective of their country of use (such countries include Australia).

A lignite when dry will contain something like 65% carbon and something like 20% oxygen. In 1 kg there will be (650/12) mol of carbon = 54 mol of carbon, of which (200/32) mol = 6 mol will be required for devolatilisation of the oxygen as CO_2. The CO_2 will therefore be composed of:

6 mol of CO_2 from the coal's own decomposition

48 mol from combustion of the carbon content when burnt in air

----

Total 54 mol

The figures are for dry lignite, and it will not be fired perfectly dry.
This however does not affect the mass balance above.

The Czech republic (second row) produces, imports and exports bioethanol, and automotive fuels as high in ethanol as E95 are available there. The ethanol plant at Vrdy in central Bohemia receives 150000 tonnes of cereal annually as feedstock for ethanol manufacture. Sugar beet is increasing in importance as the starting material for ethanol produced in the Czech Republic. Biodiesels are also a growth industry, and 2010 usage was 88121 tons. Equating tons to tonnes, this gives a carbon dioxide mitigation of:

(88121 × (37/44) × (44/14) tonnes = 0.23 million tonnes.

In considering wind power for the Czech Republic we have to bear in mind that the country is landlocked, so no offshore wind farms are in existence. Wind farms are very much 'on the drawing board', and rises of at least 10 MW in wind power per year are planned in the Czech Republic between the present time and 2020. This involves a raised nameplate capacity of approximately 35MW.

In Romania (following row) there was unease and dissatisfaction at the reporting of carbon dioxide emission and the country was suspended from trading in 'carbon emission surpluses'. (At almost exactly the same time, the Ukraine was also so suspended.) Ethanol fuel production in Romania is very low at present but expansion is under way: at Remetea in central Romania EU funding has been provided for a plant producing ethanol from feedstocks including cereal ('Black Sea grain') and sugar beet. Romania produces a modest 1000 barrels per day of biodiesel. There is scope for expansion, and areas of land suitable for rapeseed production in the future have been identified and evaluated [47]. Romania has a considerable wind power capacity and it includes the wind farm at Fantanele-Cogealac in the Romanian Province of Dobruja, which is in fact the largest onshore wind farm in Europe. Its proximity to the Black Sea (about 10 miles) enhances the wind speeds it experiences, so although it is onshore it would be correct to describe it as 'coastal'. The wind turbines there vary in diameter, but most are 99 m with a nameplate capacity of 2.5 MW of electricity. A calculation similar to that performed above for the wind farm at Estinnes reveals that attainment of nameplate capacity requires a wind speed of 26 m.p.h.

Cyprus (fourth row of the table) is a diminutive member of the EU, perhaps too small in population and activity for a critical mass in terms of analysis of energy and emissions. Her self-sufficiency in electricity (though with imported fuel) is noted in the table. The carbon dioxide emission annually from this will be of the order of:

$$(10^9\ \text{J s}^{-1}/0.35)/(42 \times 10^6\ \text{J kg}^{-1}) \times (44/14) \times 3600 \times 365 \times 24\ \text{s} \times 10^{-3}\ \text{tonnes} = 6.7\ \text{million tonnes}$$

which is actually an upper bound as it assumes round-the-clock operation at full load. A major contributor to carbon dioxide emissions in Cyprus, accounting for a substantial proportion of the total figure given in the table, is transport. One reason for this is the number of elderly cars on the roads of Cyprus. The widespread practice of export from other EU countries of second-hand cars to Cyprus has been the topic of a legal dispute in taxation terms: should a second-hand car imported into Cyprus attract import duty when such duty was paid on its arrival as a new car in the selling country [48]? More important to a reader of this book than such fiscal arguments is the fact that vehicular carbon mitigation in Cyprus is a long way from being state-of-the-art.

Hungary's electricity (following row) comes from oil and gas (largely imported) as well as from local coal. However, nuclear power stations contribute over 40%, which is very favourable in greenhouse gas terms. There are four nuclear power electricity generating stations in Hungary each with a capacity of 470 MW [49]. In Bulgaria (sixth row of the table) there is 2.6 GW of installed hydroelectric power also significant nuclear capacity. Wind power is as yet modest but plans for expansion are in place with a target of 3GW by 2020. The Vetrocom wind farm, 125 miles from Sophia, came into service in 2012 [50]. Supplying 210 GWh to the grid, it has 25 turbines of collective nameplate capacity 73MW, indicating an effective time at full capacity of:

$$210 \times 10^3 \text{ MWh}/73 \text{ MW hours} = 2876 \text{ hours}$$

and a reader will recall that a value of 2500 hours has, in previous calculations in this book, been taken to be the time over which a wind farm is for annual rating purposes operating at full capacity. The 15% creep reflects more judicious choice of site for the wind farms.

In 2009 (the most recent year for which the author has been able to obtain data) Lithuania (following row) generated 0.7 TWh from sources not involving fossil fuel derived carbon dioxide, and these included solid biomass combustion. The plant at Siauliai in northern Lithuania uses wood chips to produce just under 10 MW of electricity in a combined heat and power (CHP) set-up, meaning that heating for homes is also provided.

3.9 Concluding remarks

We can expect even better compliance of EU countries with Kyoto targets as this second decade of the twenty-first century continues. In order to provide balance and due contrast as the book unfolds, this chapter will be followed by one on a region of the world where there is no such positivity.

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4 China

4.1 Introduction

China (population 1.3 billion) is seen by some as the birthplace of civilisation and by others as a contemporary mess and muddle, there being some truth in both views. China has a very bad record of industrial safety and hygiene. China has ratified the Kyoto Protocol [1] but has not been set targets in terms of carbon dioxide emissions because of the impossibility of realising them in the decadent and moribund conditions which prevail. 2012 release of fossil fuel derived carbon dioxide in China is put at 35.6 billion tonnes [2]. China is highly varied in its terrain and in the nature of its heavily populated places, and clearly the Special Administrative Region of Hong Kong requires separate discussion which will conclude this chapter. The national capital Beijing will however be covered in the next section. A big plus for China was the success of the Beijing Olympics in 2008.

4.2 Beijing

This city of 20.2 millions has appreciable gas fired electricity capacity but is 'proactive' at electricity from renewable sources. Power for the Olympics was provided partly by the Beijing Guanting Wind Power Project [3] which has 49.5 MW of installed generating capacity. Biodiesel automotive fuel is produced in Beijing at plants including those operated by Gushan Environmental Energy, which is China's largest energy producer being active for example in Shanghai as well as in Beijing. Feedstocks include used cooking oil and animal fat as well as rapeseed. Some of the ethanol finding fuel use in Beijing is derived from Cassava, by breakdown of its high starch content and fermentation. All of the means of reducing carbon dioxide emissions which one would expect to find in a progressive city have their due place in Beijing.

4.3 Regional China

Some of the other parts of China will be discussed in terms of their energy production. East China, population 384 millions, takes in Shanghai, population 23 millions (bigger than Beijing) and Nanjing, population 7 millions. The Donghai Bridge Offshore Wind Farm (see illustration) is close to Shanghai and has an installed capacity of 102 MW. There are 28 turbines of diameter 116 m. A calculation similar to that for the Estinnes wind farm in Chapter 2 follows.

$$W = 0.5mc^2$$

with symbols as used previously

and

$m = \rho cA$ where ρ = density of the air (kg m^{-3}) and A = area swept out by the blades on rotation (m^2) = $\pi d^2/4$

↓

$$W = 0.5\rho \times (\pi d^2/4) \times c^3 \text{ W}$$

Using a value of 1.16 kg m^{-3} for ρ, a turbine at the Donghai Bridge Offshore Wind Farm will, when working at nameplate capacity, require a wind speed of:

8 m s^{-1} or 18 m.p.h.

Plate 4.1. Wind turbines at the Donghai Bridge Offshore Wind Farm
Illustration from: http://www.google.co.uk/search?q=Donghai+Bridge+Offshore+Wind+Farm&hl=en&tbo=u&rlz=1T4ADFA_enGB466GB470&tbm=isch&source=univ&sa=X&ei=JV0bUcjBLOLB0gXPx4DIBg&ved=0CEEQsAQ&biw=1244&bih=641

There are ambitious plans for ethanol manufacture in Nanjing, but it is from starting materials derived from coal and so will be 'non carbon neutral by paternity'. At Pukuo in Nanjing a wind farm is being planned which will eventually provide 200MW so again, urban China is observably in the business of carbon mitigation. Further evidence is use of the same methods – supercritical oxygen and carbon dioxide sequestration – at the Waigaoqiao coal-fired power station in Shanghai that are being developed at Drax. Over 80% of China's electricity comes from coal, and notwithstanding ventures like Waigaoqiao there are many dated power stations awaiting removal from service or modernisation. The Yangshupu power station in Shanghai has been in service since 1882 and has always used coal as fuel. It produces 1.8 TWh annually, and there have been some concessions to present-day emission standards including new turbines built and installed by Siemens, giving greater efficiencies than those which they replaced. In fact many coal-fired power stations in China have been so upgraded by Siemens [4], including that at Ninghai south of Shanghai, where 4.4 GW can be raised.

It is clear that in what might be called the conurbations China has retained coal but attempted to reduce carbon dioxide emissions by improved turbines and new power stations using coal are continually being built in China (approaching a hundred a year [5]). China needs more and more energy for social reform and will have to continue to get it largely from fossil fuels, which is why assignment of a Kyoto target is not possible. The rural sector of electricity in China, using infrastructure put in place over the second half of the twentieth century, is less advanced in terms of carbon mitigation than the urban. China is active in nuclear powered generation but again aspirations are modest. A figure of 58 GW is aimed for by 2020.

4.4 The Hong Kong Special Administrative Region (SAR)

In November 2012 Hong Kong consumed 11518 TJ of electricity [6], converting to a notional generation rate of:

$$[11518 \times 10^{12}/(30 \times 24 \times 3600)] \times 10^{-9}\ \text{GW} = 4.4\ \text{GW}$$

The Black Point Power Station in Hong Kong began generation in 1996 and has been expanded since. It uses natural gas and its maximum capacity is 2500 MW, giving an estimated carbon footprint of:

$$\{[(2500 \times 10^{6}\ \text{J s}^{-1})/0.35]/889000\ \text{J mol}^{-1}\} \times 0.044\ \text{g mol}^{-1}$$

$$= 353\ \text{kg s}^{-1}\ \text{or 11 million tonnes per year.}$$

Hong Kong's Lamma Power Station, commencing operations in 1982, uses coal in its eight turbines the largest of which produces at 350 MW. An extension to the Lamma facility uses gas. Close to the power station is a solitary wind turbine which produces at about 100 kW. On an altogether grander scale is the wind farm offshore Hong Kong being built and expected to start producing in 2015 [7]. It nameplate capacity will be 100 MW. Comparing that with the 'notional' generation rate for the entire territory calculated above gives a percentage:

$$(0.1\text{GW}/4.4\ \text{GW}) \times 100\% = 2.3\%$$

and we are told in [7] that 1 to 2% of the total electricity needs of the SAR could be supplied by the wind farm so the calculations hang together.

No fuel ethanol is made in the SAR, and only very modest amounts imported. There is more activity in biodiesel, including the ASB biodiesel factory expected to begin production before the end of 2013 [8]. It will take feedstocks including waste cooking oil and animal fat, producing at about 100000 tonnes per year of biodiesel conforming to EN 14214. The author notes from [8] that refinery waste will also be amongst the starting materials. That of course will lead to a product which is not 100% carbon-neutral.

In *Macau*, also a Special Administrative Region, there is major import of electricity from mainland China, just under 3GWh (≈ 10 TJ) in 2010. Such local production as there is at present uses imported diesel. The intention for the longer term is that Macau will use natural gas from China to generate electricity and this awaits the laying of a pipeline.

4.5 Concluding remarks

China, so populous, so socially diverse and in many ways so politically troubled, needs its own coverage in a tome like this one which addresses a major issue region by region. There will be other Asian countries to be considered including Japan, which in spite of its isolation from Europe and America became industrialised in the Nineteenth Century. Industrialised usually also means militarised, and Americans in the 1920s warning of threats from Japan to its Pacific territories were voices crying in the wilderness. China and Japan cannot be considered alongside each other in a synthesis such as this one, and Japan will have its due place separately. The chapter immediately following will however return to the Western Hemisphere by considering the US.

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5 North America

5.1 Introduction

Carbon dioxide emissions in the USA (population approx. 312 millions) in 2012 were 5.9 billion tonnes [1]. Oil usage is about 19 million barrels per day, which would be expected to lead to 3.5 billion tonnes of carbon dioxide annually. We examine some parts of the USA on a place by place basis below.

5.2 Selected locations in the USA examined for carbon dioxide emissions and mitigation.

Comments follow the information in the respective rows of the table.

Area.	Details.
New York City (NYC).	54 million tonnes of CO_2 in 2010 [2]. Several large gas and oil dual-fuelled power stations including Astoria in Queens, nameplate capacity 1296 MW. No coal-fired electricity generation in NYC, considerable such generation at other places within the State.
Central New Mexico.	NM assessed as having high wind resource potential. The New Mexico Wind Energy Center has 136 turbines with a combined capacity of 200 MW [5].
Juliette GA.	Scene of what is said to be the most severely CO_2-emitting power plant in the US: 25.3 million tons annually. Four 880 MW turbines powered with coal from Wyoming.
Los Angeles CA.	18.6 million tonnes of CO_2 released annually [7]. 2.5 million registered vehicles in the City of LA (see comments below).
Nuclear generating plants of the entire USA.	104 such plants. 821 billion kWh of electricity in 2011.
Midwest.	81% of the US total of 57 million gallons of biodiesel production in December 2012 [8]. Soybean the feedstock most used, followed by corn oil. Also major ethanol production.
McDonald's restaurants across the US.	Spent cooking oil passed on for re-use including biodiesel production. McDonald's in some other countries more proactive in this regard (see comments below).
Houston TX.	The scene of much oil business. 18.6 million tonnes of CO_2 released annually. Extensive LNG usage in transport.
JFK Airport NY.	Resurfacing of runways and closer scheduling of departing planes. 5 million gallons of fuel saved, 48000 tonnes CO_2 mitigated [11].
Alta Wind Energy Center, CA.	Completed in phases: current total capacity 1.55 GW. About 600 turbines of Danish manufacture.

Table 5.1 Selected scenes of CO_2 activity (production or mitigation) in the US.

In 2012 the electricity production rate of NYC (row 1) was 9466 MW [3], entirely by conventional thermal means. The power requirements of the entire State are about 40000 MW, and a degree of carbon mitigation is realised by nuclear facilities including that at the India Point Energy Centre in Buchanan NY, 38 miles north of Manhattan [4]. Some of 2000 MW of electrical power which it currently produced from it goes to NYC.

At the NM Wind Energy Center (row 2) the expectation is 594000 MW hours per year from the 136 turbines each with 1.5 MW capability. The proportion of the maximum possible is then:

$$[594000/(136 \times 1.5 \times 365 \times 24)] = 0.33 \text{ (one third exactly)}$$

At Juliette (row 3) no mitigation measures such as co-firing (as occurs at Drax in the UK) are as yet in place. At Dublin GA there is a new power facility which uses biomass only as fuel and generates 56 MW [6]. It uses only such biomass as can be 'scratched' locally by way of bark and chips in a quantity of 1.2 million tonnes annually. This in the rough-and-ready state in which it is used will have a calorific value of around 12 MJ kg^{-1}.

Turning our attention to LA (row 4), 2.5 million vehicles each with a carbon footprint of 100 g per mile and doing an annual mileage of 12000 would create:

$$2.5 \times 10^{6} \times 0.1 \text{ kg mile}^{-1} \times 12000 \text{ mile} \times 10^{-3} \text{ tonne kg}^{-1} = 3 \text{ million tonnes.}$$

The footprint figure of 100 g per mile is low as inspection of Table 2.3 will reveal, and this is intentional so as to make a rough allowance for the gasoline-ethanol blends and the like used by drivers in LA. A hypothesis that vehicles account for ≈ 15% of the carbon dioxide released in the city is therefore supported. At present E10 is widely used in California and oil companies are opposing the introduction of blends richer in ethanol.

The 2011 figure for electricity from nuclear plants in the US is given in the following row. The carbon dioxide from an equivalent amount of electricity raised from natural gas would have been:

$$[(821 \times 10^{12} \text{ J s}^{-1} \times 3600 \text{ s})/(889000 \text{ J mol}^{-1})] \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 146 \text{ million tonnes.}$$

which is about 2.5% of the total annual carbon dioxide production of the US. In the following row the point is made that biodiesel production is concentrated in the part of the country known as the Midwest. This applies to biodiesel from quality feedstock. A reader is however aware that biodiesel can be made from such things as spent cooking oil, to which the agricultural milieu of the Midwest is irrelevant. This is addressed in the following row, where it is emphasised that although the McDonald's chain does produce fuel from spent cooking oil in the US, its country of origin, it does so to a greater extent in other countries. These include the UK where some of the company's own heavy vehicles are powered with biodiesel made from cooking oil previously used at the restaurants [9].

From the following row a reader will deduce that amounts of carbon dioxide released are the same in Houston as in LA. It was shown in section 2.2. of this book that methane, though not carbon neutral, releases less carbon dioxide per unit amount of energy from combustion. This makes LNG a good choice for public transport vehicles in cities including Aberdeen and Houston. They are paired for the purpose of this discussion for the obvious reason of proximity of the first to the North Sea and of the second to the Gulf of Mexico. Natural gas has a good octane number and a poor cetane number, making it good for spark ignition engines and bad for compression ignition engines. The problem with CI engines is easily overcome by inclusion of diesel (dual fuel) which will prevent the ignition delay represented by the low cetane number, and LNG consequently *is* used in CI engines. Some of the buses in Houston have been changed from diesel to LNG and back [10]!

The two numerical figures in the next row appertaining to practices at JFK Airport can be checked for consistency. Using the fact that 1 cubic metre is 0.0038 US gallons and a density of 800 kg m^{-3} for the density of the fuel:

$$5 \text{ million US gallons} = 19000 \text{ m}^3 \text{ or } 19000 \times 800 \times 10^{-3} \text{ tonne}$$

$$\downarrow$$

15200 tonne of fuel giving:

$$(15200 \times 44/14) \text{ tonne } CO_2 = 47771 \text{ tonnes } CO_2$$

5.3 CCS in the USA

One of the most important such facilities is the Century Plant in Texas, with an aimed for capacity of 8.4 million tonnes of carbon dioxide. The interested reader can easily show that this is the amount released on the burning of 4.5 to 5 billion cubic metres of natural gas. Removal of CO_2 from the post-combustion gas is by the solvent Selexol™.

Expecting to become fully operational in mid 2013 is the CCS plant at Decatur, Illinois [12]. Initial use was in 2012, and about 1000 tonnes per day of carbon dioxide were being disposed of at the plant by the end of that year. The carbon dioxide in supercritical state is injected into sandstone ('Mount Simon Sandstone') and it is noted that carbon dioxide can exist in the supercritical state at pressures well below those at which the sandstone will fracture.

The storage carbon dioxide in oil reservoirs might simply be in a reservoir having become too depleted to be worth continued operation or it might, as in the diagram below, be to the end of enhanced oil recovery (EOR) through the CO_2 injection. Not within the scope of this text is EOR with CO_2 either manufactured or from natural reservoirs of it, which exist at sites strategic for use with oilfields in TX or NM. Over a billion barrels of oil have been recovered in the US by this means since the mid 1980s. Described in [14] as the 'poster child' for EOR by carbon dioxide sequestration is the facility which crosses the border between ND and Saskatchewan Canada; it has already been discussed at length by the present author [15]. Plans set out in [14] are a quantity of 410 to 530 million tonnes annually of carbon dioxide to be used in EOR in the whole of the US, yielding 3 to 3.6 million barrels per day. At the ND/Canada enterprise referred to the cumulative yield is 130 million barrels of oil from 18 million tonnes of CO_2, or about 7 barrels per tonne of CO_2. The mid-range numbers from [14] give a value of 2.6 barrels per tonne of CO_2.

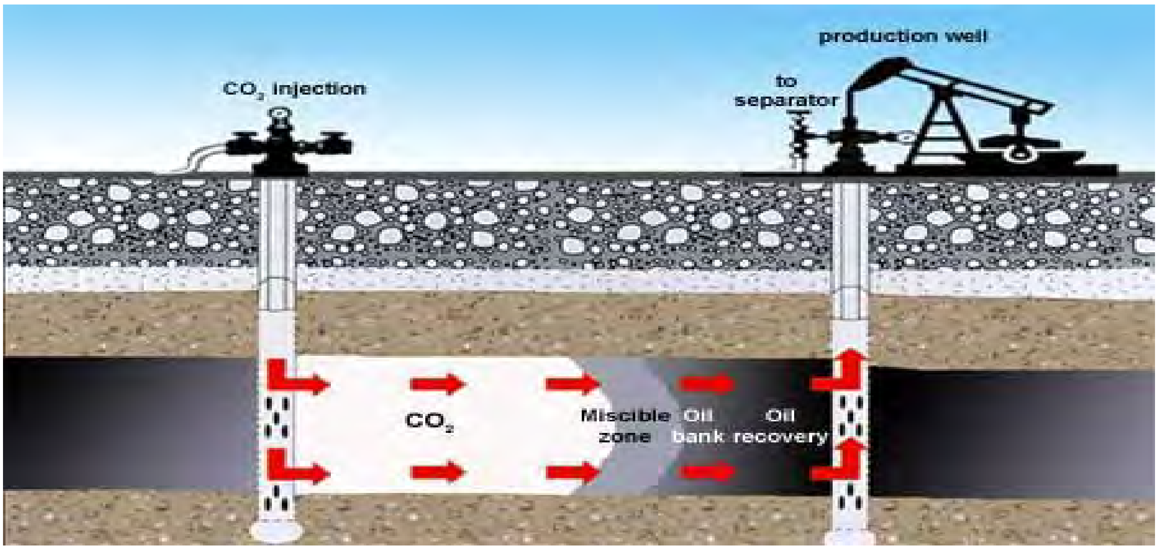

Figure 5.1. Schematic showing EOR by carbon dioxide at an oil well. Taken from [13].

5.4 Tree planting in the US

Tree planting activity in the US is wide and ranges in scale from local voluntary schemes to major Federal programs. A report to Congress in May 2009 [16] makes the usual distinction between reforestation (replacement of trees where there has been stripping of them, or loss by fire) and afforestation (the planting of trees on land not having previously, or for a very long period, been occupied by trees) and gives different estimates for the carbon sequestration potential of reforested and afforested land: 1.1 to 7.7 tonnes per acre per year for the former and 2.2 to 9.5 in the same units for the latter. An aimed for annual increase in sequestration of one billion tonnes per year would, at a sequestration rate of 5 million tonnes per acre per year, require an area of:

$$10^9 \text{ tonne year}^{-1}/(5 \text{ tonnes acre}^{-1} \text{ year}^{-1}) = 200 \text{ million acres } (\approx 6000 \text{ square miles})$$

to be afforested/reforested. Note that one billion tonnes per year represents about 16% of the total annual carbon dioxide release for the US.

5.5 The situation in Canada

Though headed 'North America', this chapter has been concerned up to this point with the USA and a supplementary few paragraphs on Canada are appropriate. Carbon dioxide release in Canada in 2011 was 553 million tonnes [17]. Electricity production in 2011 was 592 TWh [18]. Nuclear and hydroelectric are both prevalent, making the contribution to carbon dioxide from the electricity industry much lower than it would otherwise have been. In fact steam turbines operating on a Rankine cycle account for only about 16% of the total [18]. Five per cent of the electricity is made from natural gas either at a steam turbine or at a gas turbine [19], and the carbon footprint from this is estimated as:

$$[592 \times 10^{12}\ \mathrm{J\ s^{-1}} \times 3600\ \mathrm{s} \times 0.05\ /0.35 \times (889000\ \mathrm{J\ mol^{-1}})] \times 0.044\ \mathrm{kg\ mol^{-1}} \times 10^{-3}\ \mathrm{tonne\ kg^{-1}}$$

$$= 14 \text{ million tonnes}$$

One must remember that Canada is a major oil producing country, both conventional oil and, in the West, oil from tar sands. Fuel oil therefore features in electricity production and, as explained previously, this leaves a bigger carbon footprint than does natural gas. Oil is exported from Canada to the US and this includes oil derived from tar sands.

Biodiesel production in Canada has been slower than in some other advanced countries [20]. Since 2011 the national government has required that diesel fuels have a minimum of 2% biodiesel, and blends up to 5% are obtainable in some filling stations but not all. In Alberta where conventional fuels abound because of the tar sands there is no biodiesel plant, so enough to comply with the 2% requirement has to be brought from elsewhere. Similarly ethanol at 5% level is required nationally for fuels for spark ignition engines, or there might be a higher content of ethanol imposed by law in certain provinces. E85 is not routinely available anywhere in Canada.

5.6 Concluding remarks

There is no OPEC country in North America. Two are in South America: Venezuela (one of the founding members in 1960) and Ecuador. Nor is there an OPEC country in Europe, or in Asia since Indonesia left OPEC in 2008. Yet OPEC countries produce between them about 35% of the world's oil, and apart from the three exceptions referred to these countries are concentrated in the Middle East and Africa. It is probably logical to consider OPEC countries in some degree jointly in this text, but before that is attempted another enormously important region of the world having no OPEC affiliation must feature. This is the Far East, taking in countries including Malaysia and Singapore where there is enormous hydrocarbon activity: Malaysia is the world's largest producer of LNG having fairly recently 'overtaken' Indonesia. This group of countries will be considered in the following chapter and OPEC countries in the following one.

5.7 References

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6 The Far East

6.1 Introduction

The nations of this region vary widely in wealth and in political regime, and examples chosen for discussion and analysis of carbon mitigation will be representative.

6.2 Carbon dioxide emissions

In Table 6.1 below carbon dioxide emissions of selected Far East countries are given.

Country.	**CO_2 emissions 2010/million tonnes [1].**
Malaysia, population 28.9 millions.	182
Singapore, population 5.2 millions.	172
Japan, population 128 millions.	1164
Philippines, population 95 millions.	86
Thailand, population 69.5 millions.	279
South Korea, population 49 millions	579
Taiwan, population 23 millions.	305
Cambodia, population 14.3 millions.	3.6
Vietnam, population 87.8 millions.	113
Myanmar (a.k.a. Burma), population 55.4 millions.	12.8

Malaysia (row 1) is a major hydrocarbon producer as noted, and as well as making domestic electricity it exports it to Singapore and to Thailand. Tenaga Nasional Berhad, the largest electricity supply company in Malaysia, is in the business both of thermal and hydroelectric generation. The former is at 7200 MW, the latter just over a quarter of that. The thermal generation is at four power stations owned by the organisation all of which use coal as fuel. This is imported from Australia, from Indonesia and from South Africa. Annual import is 16.5 megatonnes which, for coal of 80% carbon, would leave a footprint:

$$16.5 \times 10^6 \times 0.8 \times (44/12) \text{ tonnes} = 48 \text{ million tonnes}$$

which is over a quarter of the annual release of the entire country, an example of high CO_2 emissions from coal. There is as yet no carbon sequestration at these coal-fired plants in Malaysia, although its introduction is expected. Natural gas is also used to generate electricity in Malaysia, with gas from offshore platforms operated by Petronas.

The carbon dioxide figure for Singapore (second row) is disproportionately high and in 2012 was much higher still, about 210 million tonnes. Consumption of petroleum products in Singapore is approximately 1.1 million barrels per day, leading to:

$$\times 10^{6} \text{ bbl day}^{-1} \times 0.159 \text{ m}^{3} \text{ bbl}^{-1} \times 900 \text{ kg m}^{-3} \times (44/14) \times 365 \text{ day year}^{-1} \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 180 \text{ million tonne per year of carbon dioxide, or 85\% of the 2012 total.}$$

Singapore has 9800 MW of electricity generating capacity but more commonly operates at about 6500 MW [2]. Import of some electricity from Malaysia was mentioned above: *vice versa* was the case for part of 2011 when because of interruptions at the platforms offshore Malaysia there was a drop in natural gas supply to power stations. A supply of 6500 MW round the clock from natural gas, disregarding for the purposes of the calculation the minor contributions from 'renewables', would leave an annual carbon footprint:

$$[6500 \times 10^{6} \text{ J s}^{-1}/(889000 \text{ J mol}^{-1}) \times 0.35] \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1} \times 365 \times 24 \times 3600 \text{ tonnes}$$
$$= 30 \text{ million tonnes}$$

which is about 15% of the 2012 total, making this figure and the one from the previous calculation add up to 100% exactly and reliably establishing that petroleum is by far the major source of carbon dioxide. In 2010 about 80% of Singapore's electricity generation was from natural gas. Correction for higher emissions for the oil and coal which contributed the remaining 20% would not make a *major* numerical difference to the mass/energy balances.

Unlike Malaysia and Singapore which rose to being major business centres in the second half of the twentieth century, Japan (row 3) has, as pointed out in section 4.5, been an industrialised nation for almost as long as the US and (for example) Germany have. There is considerable hydroelectricity and use of nuclear fuels to make electricity , but well over half comes from power stations using conventional fuels. Total generation in 2011 was 1058 billion kWh [3]. Hiroshima has not quite passed out of living memory, and this causes there to be an emotive side to the use of nuclear fuels in Japan. All of the conventional fuels used in the Japanese power industry are imported, and this includes a huge amount of LNG of which Japan is the world's biggest importer. Her own coal reserves, which are large, are no longer drawn on and coal is imported from Indonesia and from Australia. Japan has so to speak a dutiful proportion of electricity from renewables, and wind turbines have the particular advantage that if destabilised by an earthquake they will not release anything flammable or toxic. The Shin Izumo wind farm in Honshu, commissioned in 2009, is one of the largest in Japan. It has 26 turbines and the performance is 195 GWh annually for 2500 hours of service at nameplate capacity.

Interestingly enough, biodiesel usage originated in Japan. That was at the time of WWII, when there was insufficient bunker fuel for the Japanese Navy, and fuels based on plant oils were developed to supplement such petroleum fuel as Japan *could* get from the then Dutch East Indies, her only source after Pearl Harbour. Carbon neutrality was not of course an issue then: the (very effective) Japanese R&D into fuels from plant oil at that time was motivated purely by the paucity of petroleum. Biodiesel production in Japan at the present time is modest: about 5 million litres per year [4]. Assigning a value of 875 kg m^{-3} to the density and 37 MJ kg^{-1} to the calorific value, this provides a carbon dioxide mitigation of:

$$5 \times 10^3 \text{ m}^3 \times 875 \text{ kg m}^{-3} \times (37/43) \times 44/14 \times 10^{-3} \text{ tonne} = 10 \text{ million tonnes}$$

which is hardly significant.

Having regard to the fact that Japan almost dominates the world in car manufacture, we expect leadership in the matter of carbon-neutral fuels for spark ignition engines and gasoline-ethanol blends are indeed currently in use there and growing in importance [5]. The ethanol is largely imported, from countries including Thailand.

The Philippines (following row) is a 'recently industrialised country', prosperity having been engendered since the end of the sad regime under Ferdinand Marcos. By no means every urban householder in the Philippines has electricity laid on, and even by 2017 only about 90% of such householders will have this benefit [6]. Electricity generation in 2009 was 6192 GWh, and conventional fuels provided about 65% of the electricity with hydroelectric providing most of the remainder. Below is an image of the Sual coal-fired power station, which has a capacity of 1200 MW and is one of nine major coal-fired power stations in the Philippines [7]. There is no co-firing with biomass at any of them.

Plate 6.1. Sual coal-fired power station, the Philippines, sourced from [8].

There is some local production of coal in the Philippines, but most is imported from Indonesia and (in minuscule amounts) from Vietnam. Figures for 2011 [9] are 7.61 million tonnes of domestic coal and 10.96 million tonnes of imported coal. In that year 10.58 million tonnes of bituminous coal were used for power generation, leaving a carbon footprint of about:

$$10.58 \times 10^6 \times 0.8 \times 44/12 \text{ tonnes} = 31 \text{ million tonnes of } CO_2$$

or roughly 35% of the total CO_2. Long-term planning is for coal to continue as the prevalent fuel for power generation as electrification expands. Even so, consistently with the responsibility of any country to reduce greenhouse gas emissions, expansion of wind farms is planned. The Bangui Bay II wind farm is an example; commissioned in 2009, it currently has five turbines and a total nameplate capacity of 8.25 MW. A wind farm of nameplate capacity 87 MW will commence operations at Ilocos Norte in the north west of the country in 2014. On the usual criterion of 2500 hours per year at full capacity this will realise a carbon mitigation of:

$$(87 \times 10^6 \text{ J s}^{-1}/0.35 \times 25 \times 10^6 \text{ J kg}^{-1}) \times 0.8 \times 2500 \times 3600 \times 44/12 \times 10^{-3} \text{ tonnes of CO}_2$$
$$\approx 0.3 \text{ million tonnes}$$

where a value of 25 MJ kg^{-1} has been used for the calorific value of the coal which the wind is notionally replacing.

Coconuts are an important part of the primary produce of the Philippines [10], and coconut oil is a very good basis for making biodiesel. The country has a 1 to 2% mandatory biodiesel content of fuels for vehicles with compression ignition engines, and annual production is of the order of a million barrels. There is a strong move to get E10 into petrol tanks, and from a previously negligible ethanol production the Philippines built up its annual amount to about 0.8 million barrels in 2010 [11]. As in China (section 4.2), Cassava is amongst the feedstocks.

The following row of the table is concerned with the turbulent nation of Thailand, not noted for its social and political stability. Thailand both imports and exports electricity. Generation in 2012 was 139 TWh and consumption 131.6 TWh, making Thailand a net *ex*porter of electricity. Countries having received electricity from Thailand include Laos. About 70% of the electricity is raised from natural gas, the resulting CO_2 being:

$$[0.7 \times 139 \times 10^{12} \text{ J s}^{-1} \times 3600 \text{ s}/(0.35 \times 889000 \text{ J mol}^{-1})] \times (0.044) \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 49 \text{ million tonnes}$$

There are of the order of 11 million vehicles in Thailand. If each emits say 150 g of carbon dioxide per mile and does and annual mileage of 12000 the carbon dioxide from this source is:

$$11 \times 10^6 \times 0.1 \text{ kg mile}^{-1} \times 12000 \text{ mile} \times 10^{-3} \text{ tonne kg}^{-1} = 13 \text{ million tonnes.}$$

so one can conclude that automotive fuels contribute about a quarter as much carbon dioxide as the natural gas used in power generation. Ethanol blends for spark ignition engines are in fact available in Thailand. Biodiesel is made in Thailand from palm oil, and a reduced crop caused a decrease in biodiesel production in 2012 to 1.5 million tonnes from 1.8 million tonnes in 2011 [12]. There are ambitious plans for expansion of biodiesel production by 2020.

In the table Japan and South Korea, two highly important countries on the world business scene, have been separated by two which are less so not least because their internal organisation does not make for full reliability. In spite of its huge manufacturing base South Korea was classified as a 'developing country' when it became a Kyoto signatory. South Korea generated 459.5 TWh of electricity in 2012, roughly two thirds with conventional fuels and a third with nuclear fuels. Hydroelectricity makes a very small contribution (< 1%). Of the order of 100 TWh is made from natural gas imported as LNG. There are 22 GW of installed coal-fired electricity generation in South Korea, distributed between five power stations all currently functioning. There is interest in co-firing of coal with wood pellets, and producers of such pellets from Canada are seeking supply arrangements with South Korea. Appropriately for a country with major coal usage, South Korea is active in R&D into CCS and its KIERSOL method [13] is being evaluated by Hyundai and Kia. It is a variant on the widely practiced use of potassium carbonate in carbon dioxide removal.

South Korea's major producer of biodiesels is Eco Solutions. It and other Korean manufacturers use *inter alia* coconut oil from the Philippines. The government of Korea requires at least 2% of biodiesel to be blended with conventional diesel and this is expected to rise to 4%. Vehicular use of diesel in South Korea in 2009 was 13925 kilotonnes [14]. Replacement of 4% of this with biodiesel would realise a carbon mitigation of approximately:

$$[0.04 \times 13925 \times 10^6 \text{ kg} \times 44/14 \times 10^{-3}] \text{ tonnes} \approx 2 \text{ million tonnes}$$

Over the period 1910 to 1945 major area of forests in Korea was stripped by the Japanese to provide fuel and timber [15], and systematic reforestation began in 1967. There are now said the be 6 million hectares of forest in South Korea. 'Trees per hectare' for forests internationally is in the range 1000 to 2500, so taking the middle of the range and applying to the South Korean forests gives 10^{10} trees. On the rough basis that a tree takes up a tonne of carbon dioxide every 40 years, or 0.025 tonne per year, the sequestration potential is:

$$10^{10} \times 0.025 \text{ tonnes} = 250 \text{ million tonnes}$$

Noting the total figure in the table for the annual amount of carbon dioxide released in South Korea we observe that the above figure for sequestration by trees is 43% of it. For the sequestration potential of the trees in an industrialised country to be a third to a half of the release is typical. It is consistent with the need to husband this resource for its carbon sequestration value that, as noted earlier, the power industry is expecting to import wood fuel for co-firing with coal.

Taiwan features in the next row, and its electricity generation in 2012 was 229 TWh [16]. About 70% is from conventional fuels, 20–25% from nuclear and a few per cent from hydro. The 4 GW Taichung power station in west Taiwan uses coal has been identified [17] as the *world's* biggest emitter of carbon dioxide, releasing in excess of 50 million tonnes per year (figures reported vary widely). The coal is imported from countries including Australia, the US and Indonesia. The statistic of being the biggest emitter in the world is being addressed by proposed CCS programmes, and there is a pilot process under way whereby by 2014 about 10000 tonnes of carbon dioxide from Taichung will have been removed from the flue gases and sequestrated at the nearby seabed. A quantity of electricity equivalent to about three quarters of that from coal is raised by natural gas in Taiwan, and this of course has a less severe carbon footprint.

Taiwan produces oil without being self-sufficient in it, and daily consumption is about 0.9 million barrels per day, entailing a carbon footprint of:

$$0.9 \times 10^6 \text{ bbl} \times 0.159 \text{ m}^3 \text{ bbl}^{-1} \times 900 \text{ kg m}^{-3} \times (44/14) \times 365 \times 10^{-3} \text{ tonne per year}$$
$$= 150 \text{ million tonnes per year}$$

which is about half of the total.

There are of the order of 2 million hectares of forest in Taiwan, and a calculation like the one above for South Korea gives a carbon sequestration potential of around 90 million tonnes per year. This is 30% of the emissions which, as far as can be judged from such rough calculations, indicates nothing amiss or deficient in Taiwan in regard to her care and development of forests. One of the countries most noted for illegal felling of trees is Cambodia (following row), which itself has a very small carbon dioxide emission rate. Its electricity production in 2009 was of the order of 1 TWh [18], some of it from hydro. The loss of trees in Cambodia has been noted with concern by the International Tropical Timber Organisation [19]. Its legal timber industry is far exceeded in magnitude by illegal felling and export of trees for timber exported to or via Thailand. Plate 6.2 below shows the immediate visual consequences of the corrupt activity referred to.

Plate 6.2. The scene of illegal felling of trees in a Cambodian forest. Sourced from [20].

Loss of Cambodian forests began with the Vietnam war, and it is believed that since then about 1.5 million hectares of forest in Cambodia have been lost. Nations address carbon dioxide control in their own way but in co-ordination with each other via such things as the Kyoto Protocol, in recognition that the matter is one without frontiers. To destroy 1.5 million hectares of forest is therefore to rob the *planet* of carbon sequestration capacity of the order of:

$$1.5 \times 10^6 \times 1750 \times 0.025 \text{ tonnes per year} = 65 \text{ million tonnes per year}$$

which is sufficient to cause an annual rise of 0.01 p.p.m. in the carbon dioxide level of the entire atmosphere. Add to that the illegal felling of trees in neighbouring Vietnam (following row), even severer than such felling in Cambodia, and the seriousness of the denuding of forests in this region is clear.

Vietnam is a major oil producer, yielding 305000 barrels per day in 2011 [21]. About 70% of this is exported, but an amount roughly equivalent to that exported is imported. The carbon footprint of refining is of the order of 50 kg of CO_2 per barrel of oil processed. There are two oil refineries in Vietnam with a combined throughput of 350000 barrels per day. The carbon dioxide release from these is then:

$$350000 \text{ bbl day}^{-1} \times 50 \text{ kg bbl}^{-1} \times 10^{-3} \text{ tonne kg}^{-1} \times 365 \text{ day year}^{-1} = 6.4 \text{ million tonnes per year}$$

or 5 to 6 per cent of the total.

Myanmar/Burma (final row of the table) is traditionally very much an 'oil country', entering the oil industry before the USA did. Current production is modest, but that supplemented with imports gives a consumption of circa 40000 barrels per day, leading to carbon dioxide in a quantity:

$$40000 \text{ bbl day}^{-1} \times 0.159 \text{ m}^3 \text{ bbl}^{-1} \times 900 \text{ kg m}^{-3} \times (44/14) \times 365 \text{ day year}^{-1} \times 10^{-3} \text{ tonnes} = 6.6 \text{ million tonnes per year}$$

which is half the total. Myanmar consumes about 0.9 million tonnes of domestic coal per year and much of it is below bituminous in rank, being sub-bituminous or lignite. Whereas a figure of 80% has typically been used previously in this book for the carbon content of coals, an averaged figure of 70% is probably more suitable for analysis of coal usage in Myanmar. The carbon dioxide expected from coal usage annually is therefore:

$$0.7 \times 0.9 \times 10^6 \text{ tonnes} \times (44/12) = 2.3 \text{ million tonnes per year}$$

or 40% of that from oil. Annual natural gas consumption in Myanmar is 3.25 billion cubic metres, with carbon footprint:

$$3.25 \times 10^9 \text{ m}^3 \times 40 \text{ mol m}^{-3} \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1} = 5.7 \text{ million tonnes of } CO_2.$$

Addition of the three contributions gives:

$$(6.6 + 2.3 + 5.7) \text{ million tonnes of } CO_2 = 14.6 \text{ million tonnes}$$

which is 14% higher than the figure in the table and reflects the very reasonable accuracy of calculations of the type throughout the book. Refinement might be possible by obtaining more detailed information but whether that would add value of a book of this genre is doubtful.

6.3 Further remarks

Ten countries in the 'Far East' ranging vary widely in their economies and political regimes have featured in this chapter. Hong Kong was discussed in Chapter 4. Indonesia will be discussed in the next chapter, which is concerned with OPEC countries (even though it left OPEC in 2008), and Papua New Guinea in the chapter on Australasia.

6.4 References

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7 The OPEC Countries

7.1 Introduction

The *raison d'etre* of OPEC when it was set up over 50 years ago was assertion of countries in which the US had major production capacity to negotiate prices for their own oil instead of receiving fixed payment for it from the US companies who then traded it on world markets on their own terms.

7.2 Member countries and their CO_2 emissions

Table 7.1 below lists the OPEC countries as of March 2013, with their CO_2 emissions taken from [1].

Country and OPEC membership details.	Carbon dioxide emissions 2010/ million tonnes [1].
Indonesia, OPEC member from 1962 to 2008.	389.4
United Arab Emirates (UAE), OPEC member since 1967.	199.4
Saudi Arabia, OPEC member since 1960.	478.4
Kuwait, OPEC member since 1960.	81.3
Qatar, member of OPEC since 1961.	64.7
Libya, member of OPEC since 1962.	60.6
Iran, member of OPEC since 1960.	560.3
Ecuador, joined OPEC in 1973, withdrew in 1992 and re-entered in 2007.	24.4
Venezuela, joined OPEC 1960.	158.4
Angola, joined OPEC 2007.	24.2
Algeria, joined OPEC 1969.	110.9
Nigeria, joined OPEC 1971.	80.5
Iraq, joined OPEC 1960.	118.3

Table 7.1. OPEC countries.

Indonesia (first row) left OPEC on ceasing to be a net exporter of oil. This was due to heavy internal demand in this country of population 242 millions. Her annual oil consumption is 1.3 million barrels per day [2] and her gas consumption 40.5 billion cubic metres annually (2011 reckoning). These figures are processed below:

CO_2 footprint from the oil:

$$\times 10^{6}\ \text{bbl} \times 0.159\ \text{m}^{3}\text{bbl}^{-1} \times 900\ \text{kg m}^{-3} \times (44/14) \times 365\ \text{day year}^{-1} \times 10^{-3}\ \text{tonne per year} = 213\ \text{million tonnes per year}$$

CO_2 footprint from the gas:

$$40.5 \times 10^{9}\ \text{m}^{3}\ \text{year}^{-1} \times 40\ \text{mol m}^{-3} \times 0.044\ \text{kg mol}^{-1} \times 10^{-3}\ \text{tonne kg}^{-1} = 71\ \text{million tonnes}$$

That oil and gas jointly account for about three quarters of the carbon dioxide release is clear and part of the remainder is accounted for by condensate. We have seen that Indonesia is a major coal producer, and it is remarkable that although Indonesia only entered the coal mining business in 1983 she was one of the world's leading exporters of coal by the early 2000s.

There are wind farms Indonesia and they include that in Sukabumi, West Java which is rated 30 MW and therefore eliminates in a year usage of a quantity of natural gas:

$$(30 \times 10^{6}\ \text{J s}^{-1}/0.35) \times (2500 \times 3600\ \text{s}/889000\ \text{J mol}^{-1} \times 40\ \text{mol m}^{-3}) = 0.022\ \text{billion cubic metres}$$

Indonesia is the world's largest producer of palm oil, producing 28 million tonnes (about 200 million barrels) in 2012. Ethanol production there is currently negligible.

The United Arab Emirates (population 4.6 millions), which follows Indonesia in the table, is a major user of condensate both domestic and imported from Iran. The UAE imported about 12 million gallons (45600 m^3) of ethanol in 2011. Its motor gasoline usage in the same year was about 4000 kilotonnes. The ratio of ethanol to gasoline was therefore

$$45600\ m^3 \times 789\ kg\ m^{-3} \times 10^{-3}\ tonne\ kg^{-1}/(4000000\ tonne) = 0.009$$

This low value reflects the fact that in the UAE ethanol is added to gasoline not to make it carbon neutral – amounts are too small for that – but as an oxygenate, reducing carbon *mon*oxide emissions and possibly raising the octane number. Such usage of ethanol in quantities too low to be of any value in greenhouse gas reductions takes place extensively in other countries including the US. Electricity generation in the UAE is 90 TWh (2009 figure). A quantity of 'renewables' thermally equivalent to 16.9 million tonnes of oil was used in the UAE (also in 2009) for electricity generation, providing a carbon mitigation of:

$$16.9\ \text{million tonnes} \times 44/14 = 53\ \text{million tonnes}$$

which is about a quarter of the total. The refining capacity of the UAE is 0.67 million barrels per day [3], which, using information from the previous chapter, will lead to an annual CO_2 emission of:

$$0.67 \times 10^6\ bbl\ day^{-1} \times 0.05\ tonne\ bbl^{-1} \times 365\ day\ year^{-1} = 12\ \text{million tonnes}$$

The UAE have been innovative in the matter of use of solar energy to make electricity, at their Shams facility 75 miles from Abu Dhabi. It does not comprise photovoltaic cells: it concentrates heat from the sun to heat oil which is then heat exchanged with water for conventional electricity generation. Clearly the curvature and configuration of the surface receiving solar flux is important to performance, and at Shams this takes the form of a 'parabolic trough'. A photograph is shown as plate 7.1.

Plate 7.1. Concentrated solar power plant at Shams in the UAE Photo from [4]

The performance specification of the facility is 1934 kWh of electricity per m^2 of area of receptor per year and expected production is 100 MW. Some tentative calculations which seek to link and clarify these quantities are below.

100 MW round-the-clock for a year is 3×10^{15} J

1934 kWh of electricity per m^2 per year is 7×10^9 J per m^2 of receptor

area = 3×10^{15} J/(7×10^9 J m^{-2}) = 4×10^5 m^2

which can be seen as the effective area of the parabolic trough assembly.

Very pleasingly, we can claim order-of-magnitude agreement (or better) for the above calculation with published specs. : reference [5] amongst other sources gives 627840 m^2 (6×10^5 m^2 to one significant figure) for the 'mirror aperture'. Some of the 'other sources' referred to call this the 'solar field aperture area'. Either way it corresponds conceptually with the 'effective area' calculated. The heat generated by the solar concentration converts water to steam in a totally orthodox way as previously mentioned. Shams came into operation, after a lengthy construction programme, just as this was being written and expansion there is planned.

Saudi Arabia, population 26.5 millions, features in the next row. It is the world's largest oil producer (2012 average 11.6 million barrels per day). Some contributors to the carbon dioxide release are examined in the table below.

Source.	Extent.	Carbon footprint.
Electricity	≈ 190 TWh per year	If originating entirely from oil: $[(190 \times 10^{12} \times 3600/0.35)/(43 \times 10^6 \text{ J kg}^{-1})] \times 44/14$ kg = 143 million tonnes of CO_2
Vehicles	≈ 9 million vehicles in Saudi Arabia	$9 \times 10^6 \times 0.1$ kg $\text{mile}^{-1} \times 12000$ mile = 11 million tonnes of CO_2
Refining	Refining capacity 3.5 million barrels per day	3.5×10^6 bbl $\text{day}^{-1} \times 0.05$ tonne $\text{bbl}^{-1} \times 365$ day year^{-1} = 64 million tonnes of CO_2
Flaring of associated gas	3.8 billion cubic metres flared annually	3.8×10^9 $m^3 \times 40$ mol $m^{-3} \times 0.044$ kg mol^{-1} ↓ 6.7 million tonnes of CO_2

Table 7.2. CO_2 releasers in Saudi Arabia.

Saudi Arabia, like many other oil producing nations, has reduced its flaring of associated gas in recent years because of concerns about the carbon dioxide. The gas which would in former days have been flared is diverted to petrochemical manufacture. More generally, apart from the need to reduce flaring, use of natural gas as a feedstock for organic chemical manufacture is on the increase. Examining the above table we find that refining causes much more CO_2 than flaring does, which carries the positive suggestion that flaring has been brought under control in Saudi Arabia.

During the Prohibition years in the US alcohol for fuel use was not exempted, in spite of lobbying by people as influential as Henry Ford. In Islamic countries there is the same difficulty, which is why the future of ethanol as a carbon-neutral fuel in Saudi Arabia remains uncertain.

Kuwait (next row), which has a population of less than three millions, consumes 0.35 million barrels of oil per day and 0.9 billion cubic feet of gas (25 million cubic metres) per day [6]. Kuwait is in fact a net *im*porter of natural gas. Carbon dioxide releases from the two are estimated as:

$$0.35 \times 10^6 \text{ bbl day}^{-1} \times 0.159 \text{ m}^3 \text{ bbl}^{-1} \times 900 \text{ kg m}^{-3} \times (44/14) \times 10^{-3} \text{ tonne kg}^{-1} \times 365 \text{ day year}^{-1}$$
$$= 57 \text{ million tonnes of } CO_2 \text{ per year from the oil}$$

and

$$25 \times 10^6 \text{ m}^3 \text{ day}^{-1} \times 40 \text{ mol m}^{-3} \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1} \times 365 \text{ day year}^{-1}$$
$$= 16 \text{ million tonnes of } CO_2 \text{ per year from the gas}$$

and therefore a total of 73 million tonnes per year from the two. This is within 10% of the total for the country given in Table 7.1. Factoring in associated gas flaring of the order of one billion cubic metres per year, a calculation like the one for Saudi Arabia in Table 7.2 gives about 2 million cubic metres per year of carbon dioxide from such flaring. This raises the total to 75 million tonnes per year which is within about 8% of the CO_2 emission figure for Kuwait given in Table 7.1. Amongst countries producing oil – OPEC and non-OPEC – the reduction of gas flaring has been seen as having an important role in carbon mitigation during the first part of the 21st Century.

Qatar (row five of the table), population just under 2 millions, has received international commendation for its reduction in associated gas flaring [7]. It relates to two particular facilities. One is an LNG reception terminal where gas from 'boil off' – evaporation of the LNG – is retained and either used as a gaseous fuel or converted back to LNG instead of being flared. The amount of methane recovered in one way or the other by this facility (known as the 'Jetty Boil-Off Gas Recovery Project') is 0.6 million tonnes per year, eliminating an amount of CO_2:

$$(0.6 \times 44/16) \text{ million tonnes per year} = 1.7 \text{ million tonnes per year}$$

which would have been produced had the gas been flared. The other scene of major flaring reduction in Qatar is the Al Shaheen oil field, an offshore field producing about 300000 barrels of oil per day [8]. Gas previously flared is being used to make electricity in situ for the platform although such usage is not total, that is, there is still some flaring of gas at Al Shaheen. The refining capability of Qatar is 0.34 million barrels per day, producing carbon dioxide to an extent of:

$$0.34 \times 10^6 \text{ bbl day}^{-1} \times 0.05 \text{ tonne bbl}^{-1} \times 365 \text{ day year}^{-1} = 6 \text{ million tonnes per year}$$

There tends to be more carbon dioxide per unit weight of LNG production from the gas than per unit weight of crude oil refined, partly because the gas being liquefied often contains some carbon dioxide. Qatar has an LNG production capacity of 42 million tonnes per year and this doubtless contributes significantly to the national carbon dioxide emissions. There are no nuclear or hydroelectric power generation facilities in Qatar: all electricity is from conventional fuels. Electricity for household use is not charged for in Qatar and this leads to profligacy in use, one factor in the high carbon dioxide emissions in Qatar in relation to the population. There is no CCS in the electricity industry although there is major R&D into the suitability of the local geological formation for carbon dioxide storage [9] with a view to CCS by not later than 2020.

A few days prior to the writing of this, a 'Tree day' was held in Qatar during which over 2000 mango trees were planted in Ras Laffan in the north east of the country. They were added to an existing mango plantation at Ras Laffan, and the initiator of the project was Qatar Petroleum. In a different tree-planting enterprise [10], species of tree suited to the climate of Qatar have been identified with the help of arboriculturalists in Norway.

Libya (population 6.48 millions) occupies the next row of Table 7.1. Its oil production before the internal difficulties of about two years ago was 1.6 million barrels per day. Much repair and reconstruction work involving overseas companies has been necessary to restore it. The refining capacity of Libya is major, five refineries with a combined capacity of 0.38 million barrels per day. The carbon footprint of this would, using calculations similar to those performed previously in the text, will be:

$$0.38 \times 10^6 \text{ bbl day}^{-1} \times 365 \text{ day year}^{-1} \times 0.05 \text{ tonne bbl}^{-1} = 7 \text{ million tonnes per year of } CO_2$$

or a little over 10% of the total. Electricity production in Libya in 2012 was 27 TWh [11], all of it generated from oil or from natural gas: no nuclear, no hydroelectric and no renewables. Libya has an indifferent track record for flaring associated gas. The 2010 figure for natural gas flaring in Libya is of the order of 120 billion cubic feet [12]. The carbon footprint from this is:

$$120 \times 10^9 \text{ ft}^3 \times 0.028 \text{ m}^3\text{ft}^{-3} \times 40 \text{ mol m}^{-3} \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 6 \text{ million tonnes}$$

More positively, there is reinjection of associated gas into reservoirs in Libya. The primary motivation for this is enhanced oil recovery but it does also provide for carbon mitigation and, of course, enables the gas to be raised up the well again when there is a better market for it.

There are 1.8 million motor vehicles in Libya, and on the previous criterion of 12000 miles per year with 100 g carbon dioxide per mile this gives:

$$1.8 \times 10^6 \times 12000 \times 0.1 \times 10^{-3} \text{ tonnes} = 2 \text{ million tonnes}$$

There is no ethanol usage in automotive fuels in Libya, and biodiesels are only at the stage where 'consultancies' are taking place. There is token involvement in wind power, one wind farm with a nameplate capacity of 20 MW.

Iran (population 75 millions) features in the seventh row of the table. It is widely known that oil production there goes well back into the period when the country was called Persia (as it sometimes still is) and was one of the reasons for a high expatriate population at that time. Its oil production in 2013 is of the order of 2.5 million barrels per day. Its electricity production is about 210 TWh annually almost all from oil and gas; there is a nominal hydroelectric contribution. Clearly, in that very populous country electricity accounts for a significant amount of the very high carbon dioxide emissions. The country has been sharply criticised for its tardiness in introducing wind farms [13].

A quantity of oil of 2.5 million barrels per day would be expected to entail large volumes of associated gas and Iran is one of the major 'flarers' of such gas to the disadvantage, obviously, of its carbon mitigation endeavours. A World Bank estimate [14] is that the amount of gas flared in Iran is 10 to 20 billion cubic metres annually. Taking the middle of the range, the carbon footprint will be:

$$15 \times 10^9 \text{ m}^3 \times 40 \text{ mol m}^{-3} \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1} = 26 \text{ million tonnes}$$

Plate 7.2 below shows two gas flares at the Gachsaran oil field, in the south west of the country. This field is in the world's 'top five', producing 0.61 million barrels of oil per day, and is 70 km in length.

Plate 7.2. Gas flares at the Gachsaran oil field, Iran.
Photo sourced from http://www.flickr.com/photos/adam_jones/7424756274/

Iran has not however been totally unresponsive to the matter of carbon dioxide from flaring. Extinguishment of some of the flares at four oil fields in Iran has led to a reduction of about 3 million cubic metres annually of gas flared. Such gas can be collected for use or reinjected. As touched on in a previous part of this text, these are inter-related. When gas prices are low associated gas can be stored in the reservoir, and brought out again when prices rise.

There is significant ethanol production in Iran and substances for fermentation include dates. Installations for such production have a combined capacity of 10^8 litres (0.6 million barrels) per year although production at this level has not yet been attained [15]. Some of the ethanol is exported, whilst some ethanol is imported into Iran. There is only one biodiesel manufacturing unit in Iran; it is on Qeshm Island and has been in business only since 2009. Its products conform to ASTM D6751.

Ecuador, population 15.2 millions, is next in the table. This South American country produces half a million barrels per day of oil and consumes about 0.17 million barrels per day, leaving a carbon footprint:

$$0.17 \times 10^6 \text{ bbl} \times 0.159 \text{ m}^3\text{bbl}^{-1} \times 900 \text{ kg m}^{-3} \times (44/14) \times 0.001 \text{ tonne kg}^{-1} \times 365 \text{ day year}^{-1}$$
$$\approx 28 \text{ million tonnes of carbon dioxide.}$$

Gas consumption will add to that and the combined sum will exceed to 2010 total figure given in the table. For a smaller country these figures are very finely balanced, and such an anomaly can easily arise when numerical values used as input are from periods separated by a couple of years or so. We note that Ecuador uses negligible coal.

There is a small wind farm – nameplate capacity 15MW – under construction at Loja in southern Ecuador. In fact two of the proposed eleven turbines are already producing. In 2010 the government of Ecuador introduced a scheme for E5 usage in petrol engines, which was not implemented because ethanol production fell well short of the target. Ecuador makes some biodiesel from palm oil, a moiety of which is exported.

Venezuela, population 28 millions, is the next OPEC country to be listed in the table. The country has a coastline with the Caribbean Sea. She produces 2.9 million barrels of crude oil per day. Some of it is very viscous and has to be blended with a distillate for pipeline transfer. Electricity production in 2011 was 123 TWh, and the breakdown into sources is interesting: approximately a third fossil fuel and the remainder (that is, approximately two thirds) hydro. On the basis that the amount from hydro would otherwise have been produced from natural gas, the carbon mitigation is then:

$$(123 \times 10^{12}\ \text{J s}^{-1} \times 3600\ \text{s})/(0.35 \times 889000\ \text{J mol}^{-1}) \times 0.044\ \text{kg mol}^{-1} \times 10^{-3}\ \text{tonne kg}^{-1}$$
$$= 63\ \text{million tonnes of } CO_2.$$

Wind farms in Venezuela are at the 'announcement' stage! Associated gas flaring in Venezuela is lower than in Iran but sufficient for there to have been admonitions to the country to improve in this regard. The matter of import of ethanol into Venezuela is a sensitive one, as Brazil are claiming that under the terms of a cartel they and not the US should supply ethanol to Venezuela. According to a BBC report [16] this issue 'dominated' an energy summit in South America in 2007. This matter is not merely political: ethanol exported from the US is made from corn and is more expensive than that exported from Brazil which is made from sugar. A final note on Venezuela follows. She has huge refining capacity but much of it is in poor condition, meaning that some refined products are having to be imported.

Angola, population 19.6 millions, is the most recent member of OPEC (although its admission predates by a few months Ecuador's *re*admission: each was in 2007) and features in the next row of the table. Oil production, largely offshore, is 2 million barrels per day. Consumption is 74000 barrels per day and that of natural gas 2 million cubic metres per day. Carbon footprints from these are estimated below.

CO_2 footprint from the oil:

$$74000\ \text{bbl} \times 0.159\ \text{m}^3\text{bbl}^{-1} \times 900\ \text{kg m}^{-3} \times (44/14) \times 365\ \text{day year}^{-1} \times 10^{-3}\ \text{tonne per year}$$
$$= 12\ \text{million tonnes}$$

CO_2 footprint from the gas:

$$2 \times 10^6 \times 365\ \text{m}^3\ \text{year}^{-1} \times 40\ \text{mol m}^{-3} \times 0.044\ \text{kg mol}^{-1} \times 10^{-3}\ \text{tonne kg}^{-1}$$
$$= 1\ \text{million tonnes}$$

These jointly account for just over half of the emission of CO_2, and a quantity of natural gas slightly higher than that used is flared. In previous calculations of this type in the text emissions from LPG have not been considered, and it is instructive to do so in one case. Angola uses about 5000 barrels of LPG per day. Approximating this to pure propane (which has the same molar mass as carbon dioxide) a density of about 500 kg m^{-3} applies, so 5000 barrels per day becomes:

$$(5000 \text{ bbl day}^{-1} \times 0.159 \text{ m}^3\text{bbl}^{-1} \times 500 \text{ kg m}^{-3}/0.044 \text{ kg mol}^{-1}) \times 365 \text{ day year}^{-1}$$
$$= 3.3 \times 10^9 \text{ moles of propane}$$
$$\downarrow$$
$$10^{10} \text{ moles of } CO_2 \text{ or } 0.4 \text{ million tonnes}$$

In gleaning data for LPG amounts from web sources it is impossible to tell whether LPG has been included with the oil figures. Of course, some LPG comes from natural gas in an LNG train although this is unlikely to be so for Angola where the LNG industry is only incipient.

Wind farms are only at the planning stage in Angola, and even those 'planned' will only provide about 100 MW. There is ethanol production at Cacuso, in the north of the country. Sugar is grown there, from which the ethanol is made. The enterprise is expanding and it is expected that about over half a million barrels of ethanol annually will be produced at the facility when it is fully developed. The cellulosic residue from the sugar cane ('bagasse') can itself be used as a fuel and is of course carbon-neutral. At Cacuso it is used to make electricity, a very significant bonus. Angola does not yet produce biodiesel, but has evaluated her land for future growth of palm oil for this purpose. In [17] it is reported that, without deforestation, enough land is available to produce annually palm oil capable of yielding 6 exajoules (6 $\times 10^{18}$ J), thermally equivalent to:

$$[(6 \times 10^{18} \text{ J}/43 \times 10^6 \text{ J kg}^{-1})/(900 \text{ kg m}^{-3} \times 0.159 \text{ m}^3 \text{ bbl}^{-1})]$$
$$= 10^9 \text{ barrels of oil}$$

This is a startling result, but so much is involved in even starting to implement it. Reference [17] realistically gives a date of around 2050 for such implementation.

Algeria, antepenultimate row of the table, has a population of 37 millions, produces 1.27 million barrels of oil per day (2011 reckoning) and consumes about 0.3 million barrels per day. She produces 85 billion cubic metres of gas per year and there is major LNG production. There is as yet no significant electricity production from wind. Algeria imports some ethanol from the US. She also imports soybean oil for processing into carbon-neutral fuels.

Nigeria is in the penultimate row. Its population is 162 millions and its oil production of the order of 2.5 million barrels per day. Its oil consumption is 0.28 million barrels per day, and her gas consumption about 7 billion cubic metres per year (20 million cubic metres per day). In spite of major reductions in natural gas flaring in Nigeria over the last decade, the country is still high on the 'bad boys list' in this regard. A 2009 report in 'Business Today' [18] identifies companies which flare gas in Nigeria, and these details are given in Table 7.3. below. The carbon footprint has been calculated as previously in this text, for example in the last row of Table 7.2.

Company	Gas flaring in Nigerian operations/ million cubic meters per *half* year [18]	Carbon footprint/millions of tonnes per year
Chevron	1.67	5.9
ExxonMobil	1.58	5.6
Shell	0.94	3.3
'Other Joint Venture Companies'	0.92	3.2
Production sharing contract, involving the NNPC* and many outside oil companies including Mobil and Conoco [19]	0.92	3.2
Service contract companies	0.14	0.5
Indigenous companies and marginal fields	0.06	0.2

*Nigerian National Petroleum Corporation.

Table 7.3. Associated gas flaring in Nigeria.

NNPC (see above) is seeking to initiate ethanol production in Nigeria. Plans are to grow sugar as a feedstock and Brazil is being looked to for a lead. In that region of Africa there are abundant supplies of palm oil, which was being exported as a food ingredient long before biodiesel became the 'in thing'. There is no significant biodiesel production in Nigeria as yet. There is a small wind farm (< 1MW) at Katsina in northern Nigeria. Nigeria's annual electricity consumption is about 18 TWh annually, ≈ 60% from oil and gas and the balance hydroelectric. The carbon mitigation of the hydroelectricity is therefore appreciable.

The cliché 'last but not least' can validly be applied to Iraq (population 33 millions) which is the last OPEC country to be discussed in the table. Oil production in Iraq dropped to a level whereby its OPEC quota had to be put on hold for a period after the war there, but the country is now delivering > 3 million barrels per day. She flares 10 billion cubic meters of associated gas per year, leaving a carbon footprint of 17.5 million tonnes of CO_2. As with so many of the countries discussed in this chapter, wind farms are no further than feasibility studies, yet because the conventional power generation plant in the country is, in general, in such poor condition wind farms could benefit Iraq for reasons other than carbon mitigation. This is said to apply in particular to those parts of Iraq inhabited by the Kurdish people.

7.3 Further considerations

It has long been the expressed view of the author that producers and processors of conventional oil are positive and co-operative in their attitude to renewables. Good examples are Jurong Island in Singapore and the Rijnmond region of the Netherlands. Each is a major hub in hydrocarbon distribution yet has positively led in application of carbon-neutral technologies. Neither Singapore nor the Netherlands is an OPEC country (although, of course, oil from OPEC countries is received at Jurong Island and in the Rijnmond). On reading the summary herein on the OPEC countries one might wonder whether, collectively, they merit a similar commendation.

An interesting point on which to conclude this chapter is estimation of the contribution made by the OPEC countries to the rise in carbon dioxide level of the atmosphere. This follows.

Summing the emissions in Table 7.1 for the current OPEC countries (that is, excluding Indonesia) the 2010 aggregate figure is 1961.4 million tonnes of CO_2.

The mass of the atmosphere is approximately 5.1×10^{18} kg.

p.p.m. rise (molar basis) = $(1961.4 \times 10^9/5.1 \times 10^{18}) \times 10^6 \times (28.8/44) = 0.25$ p.p.m.

Average rises over the period 2003–2012 were 2.1 p.p.m. per year, indicating that OPEC countries are responsible for 12% of the total rise. In Table 7.4 below are the land areas of the respective OPEC countries.

Country	Land area/million km^2
Kuwait	0.018
Qatar	0.001
Libya	1.76
Venezuela	0.92
Nigeria	0.92
Algeria	2.38
Ecuador	0.28
Iraq	0.44
Iran	1.65
Saudi Arabia	2.15
UAE	0.08
Angola	1.25

Table 7.4. Land areas of OPEC countries.

The total is 11.8 million square kilometres. The total *land* surface area of the earth is 148.3 km^2, so the OPEC countries whist occupying:

$$(11.8/148.3) \times 100\% = 8\%$$

of the land are releasing 12% of the carbon dioxide, an indication that there is more than proportionate CO_2 release from these countries.

7.4 Concluding remarks

In 2007, Angola was the first new member of OPEC since Nigeria 36 years earlier. A century ago the major oil producers were the US, Mexico and Russia, with Venezuela just starting up. The first country of the Middle East to produce oil was Bahrain in 1933, and this is not an OPEC country. The only OPEC country which features in the above brief historical sketch is Venezuela. He or she would be a bold petroleum analyst who predicted with any degree of confidence which country will be the next to join OPEC. The present author's conjecture, for what very little it is worth, is that it will be Brazil. The fact that whilst being a major oil producer (2.3 million barrels per day) Brazil has for a very long time been pre-eminent in ethanol production, which will surely enhance its eligibility for OPEC.

7.5 References

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[19] http://www.nipc.gov.ng/contract.html

8 The Indian subcontinent

8.1 Preamble

The Indian subcontinent takes in India (population 1.24 billions), also Pakistan (population 176 millions) and Bangladesh (population 150 millions) which were until the late 1940s one country. Against the wishes of Mahatma Ghandi two Islamic pockets were separated to form Pakistan, which comprised West Pakistan and East Pakistan. When East Pakistan became Bangladesh, West Pakistan became simply Pakistan.

8.2 Some relevant details on India

These are in tabular form below.

Carbon dioxide release (2010)	1695.62 million tonnes
Oil production	0.95 million bbl per day [1]
Oil consumption	3.2 million bbl per day [2]
Coal consumption	509 million tonnes per year [3]
Electricity generation (2009)	899 TWh
Natural gas production	30.6 billion cubic metres (2008) [4]
LNG imports	10.79 billion cubic metres once regasified (2008) [4]
LNG exports	Nil
Wind power	17352 MW of installed capacity [5]
Ethanol production	Major. See comments in the main text.
Biodiesel production	'Commercially insignificant as yet' [6]
Photovoltaic	India has the world's largest photovoltaic generating facility, the **Gujarat Solar Park**.

Table 8.1. Data for India.

We note from rows one and two that oil consumption exceeds production by more than a factor of three. Whilst being therefore a net importer of oil India does export some, notably to Pakistan and in refined form. Countries having exported oil to India include Iran and, to a greater extent, Saudi Arabia. Coal (row 4) has featured relatively infrequently in this text, so it is helpful to estimate the carbon footprint of the colossal amount of coal used in India annually. We first note that in the year in which 509 million tonnes was the total coal production, 35 million tonnes were used not in combustion but in coking to make metallurgical reductant. Coals of various rank are used, from lignite to bituminous, having respectively about 60% and 80% carbon when dry. They are not however dry when mined and assignment of a carbon content to this calculation is the most uncertain part, especially as there is also the ash content to be considered. Making the carbon content 65% gives:

$$(509 - 35) \times 10^9 \text{ kg} \times 0.65 \times (44/12) \times 10^{-3} \text{ tonne per year of } CO_2$$
$$= 1130 \text{ million tonnes per year}$$

or 66.6% (two thirds) of the total. This result is a little 'elastic' because of the approximations explained, but is sufficiently rigorous to support the view that *more than half* of the CO_2 released in India comes from coal. We note as a point of historical interest that in 'Imperial India' coal was very important, for its own sake and for the sake of the chemicals such as disinfectants that could be made from it. The electricity production is 2.4 times that in the UK, although this of course is nowhere near to being in proportion to the populations. India has not been totally inactive in the matter of coal-biomass co-firing, and agricultural wastes are taken to power stations for such use, though certainly on a limited scale at present.

Plate 8.2 below shows one of the major coal-fired power stations in India, the Guru Hargobind Thermal Plant in the Punjab. It has a capacity of 920 MW between the four turbines. There has been considerable difficulty locally from the emission of particulate.

Plate 8.1. Guru Hargobind Thermal Plant, India. Source: http://www.treehugger.com/living/

Moving to LNG (next three rows of the table) we first note that much of the imported gas comes from Qatar. The total used for 2008 – domestic and imported – was the sum of the figures in the table, that is 41.4 billion cubic metres, and 37% of this was used to make electricity. This is a carbon mitigation measure: the same amount of electricity from oil or (even more so) from coal would have produced significantly more carbon dioxide. The carbon footprint from the electricity from gas is:

$$(41.4 \times 10^9 \text{ m}^3 \times 0.37 \times 40 \text{ mol m}^{-3} \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1}) = 27 \text{ million tonnes}$$

or 1.6% of the total. The power generated would have been:

$$41.4 \times 10^9 \text{ m}^3 \times 0.37 \times 40 \text{ mol m}^{-3} \times 889000 \text{ J mol}^{-1} \times 0.35 = 2 \times 10^{17} \text{ J or } 53 \text{ TWh}$$

equivalent to 6% of the total. India has always been proactive in wind power matters, having had some capacity in the mid 1980s. Using the usual measure of 2500 hours annually at nameplate capacity, the current total installation figure in the ninth row of the table gives:

$$17352 \text{ MW} \times 2500 \text{ hours} \times 10^{-6} \text{ TWh} = 43 \text{ TWh}$$

(only 30% lower than the amount of electricity from natural gas)

Carbon mitigation in the production of electricity in India is also aided by there being a number of nuclear power stations, notably in Madras.

In moving on to ethanol (following row) we first note that India is the largest producer of sugar in the world, and that 55% of its annual yield goes to ethanol production. The country is moving towards E5 for all petrol engine cars. Production of ethanol in 2012 was about 2 billion litres (12.6 million barrels), enough to make about 250 million barrels (9 billion Imperial gallons) of E5 by blending with gasoline. There are about 0.1 billion cars in India, so if each does 12000 miles a year at 35 miles per gallon of E5 the fuel requirement is:

$$(0.1 \times 10^{9} \times 12000 \text{ miles}/35 \text{ miles gallon}^{-1} = 34 \text{ billion gallons}$$

so there is as yet a significant shortfall in the amount of ethanol required for E5 to be used nationwide. Biodiesel occupies the next row of the table, and Jatropha is seen as the most promising source for development. There is some local use of plant oils as fuel in regions of India distant from supplies of conventional fuel.

The Gujarat Solar Park (final row) produces at 600 MW and occupies a total area of 2000 hectares not all of which is absorptive. Photovoltaic cells usually convert about 12% of the solar energy they receive to electricity. Using a value of 900 W m^{-2} for the solar flux, the area which is receptive is:

$$(600 \times 10^{6} \text{ W})/0.12 \times 900 \text{ W m}^{-2}) = 5.6 \times 10^{6} \text{ m}^{2} \text{ or } 560 \text{ hectares}$$

Numerous legitimate modifications to the above approximate calculation are possible, and the nominal and calculated areas become the same if one makes the approximation that the periodicity of sunlight is such that a value of 250 W m^{-2} can be taken to apply all day. This is 17% of the 'solar constant'.

8.3 Pakistan

This nation of population 177 millions produced in 2010 a quantity of 151.65 million tonnes of carbon dioxide. Electricity generation there has been unreliable in recent years and the capacity which could be depended upon has been at most two thirds of the nominal. Reform is in hand and projected annual amounts between the present and about 2020 are 135.5 TWh. The largest power station in Pakistan is Kot Addu [7], which has 10 gas turbines and 5 steam turbines. Fuels used are natural gas, distillate fuel oil and residual fuel oil; the nameplate capacity is 1600 MW. On the 'mitigation' side there is not inconsiderable hydroelectric capacity in Pakistan and a very limited degree of nuclear generation.

Pakistan produces only about 65000 barrels per day of oil. Some of that which she imports from India is already refined, as noted above. Total consumption is in fact of the order of 0.4 million barrels per day, a significant proportion of which is used for electricity. Like India (of which it was once a part) Pakistan has major coal reserves and 3.2 million tonnes of coal (actually quite a small amount, a tenth of the UK annual production) was mined in 2011. Unfavourably from the 'carbon' point of view, there might need to be a swing from oil to coal in power generation over the next few years. Burners for fuel oil can easily be adapted to suspensions of fine particles of coal (< 30μm diameter) in water, and this seems to the author to be a highly probable course of events in Pakistan. Such adaptation was widespread in countries including the US before the carbon dioxide emission issue became so dominant. Ethanol is made in Pakistan from sugar and there are major exports of it. The gasoline/alcohol blend routinely available at filling stations is E10. Biodiesel production from Jatropha is expanding towards government target of 10% biodiesel ('B10') in all fuels for diesel engines. One advantage of Jatropha oil is that it has a satisfactory cetane number (≈ 50) without transesterification. (The same is sometimes true of Soybean oil.) The Jhimpir Wind Power Plant, about 100 miles from Karachi, is the first such plant in Pakistan. At present it has five turbines with total nameplate capacity 6 MW.

Pakistan then is certainly not dormant on the carbon mitigation front. There are in Pakistan a number of 'Clean Development Mechanism' (CDM) projects. These were brought into existence under the Kyoto Protocol and enable an advanced foreign country to implement in a developing country a carbon-reducing initiative and for the developing country to sell any carbon credits accruing. CDM projects in Pakistan include expansion of its hydroelectricity.

8.4 Bangladesh

This country (population 150 millions) released 56.74 million tonnes of carbon dioxide in 2010 and consumes about 100000 barrels per day of oil, leaving an annual footprint:

$$10^5 \text{bbl day}^{-1} \times 0.159\ \text{m}^3\text{bbl}^{-1} \times 900\ \text{kg m}^{-3} \times (44/14) \times 365\ \text{day year}^{-1} \times 10^{-3}\ \text{tonne kg}^{-1}$$
$$= 16 \text{ million tonnes per year.}$$

An annual natural gas consumption of 20 billion cubic metres per year adds 35 million tonnes to that, and the gap between the sum of those and the total can be attributed to the coal consumption, for which no precise figure appears to be in the public domain at the time of writing. The energy ratio of gas to oil in Bangladesh is:

$$(20 \times 10^9/365)\ \text{m}^3\ \text{day}^{-1} \times 37\ \text{MJ m}^{-3}/(10^5\text{bbl day}^{-1} \times 0.159\ \text{m}^3\text{bbl}^{-1} \times 900\ \text{kg m}^{-3} \times 43\ \text{MJ kg}^{-1}) = 3.3$$

and the preponderance of gas by a third of an order of magnitude is of course favourable in carbon dioxide emission terms. It is also good in economic terms, as unit heat from gas is usually only about a fifth the cost of unit heat from oil. Electricity production (2009) was 20.9TWh, 94% from oil and gas and the balance from hydro. Prospects for ethanol production are not good. Many Bangladeshis are subsistence level farmers and cannot spare land to grow corn for the market. It was mentioned in an earlier part of this chapter that biodiesel is used locally in India at places distant from supplies of petroleum fuels. Karanja oil is so used in parts of India; the Karanja plant is grown in Bangladesh and development work on making biodiesel from it is under way. There are ambitious plans for electricity from wind turbines, but negligible generation by this means at present.

8.5 Sri Lanka

This island nation of population 21 millions released 14.1 million tonnes of carbon dioxide into the atmosphere in 2010. Her oil consumption is a little over 90000 barrels per day and natural gas is not available at all. Proposals to import LNG have not yet come to fruition, and a supposed 'find' of natural gas offshore Sri Lanka in 2011 would require for collection more infrastructure than could be justified by its size or by the projected demand for gas. Wood is a common domestic fuel in Sri Lanka and this of course is carbon-neutral.

8.6 Conclusion

The countries having featured in the chapter are so diverse and their domestic affairs so complex that unifying 'concluding remarks' are impossible to make. By way of conclusion then a calculation similar to that for the OPEC countries in aggregate will be done, that is, the carbon dioxide emissions of India, Pakistan, Bangladesh and Sri Lanka will be summed, and the sum appraised. The sum is:

$$(1695.62 + 151.65 + 56.74 + 14.1) \text{ million tonnes per year} = 1920 \text{ million tonnes per year}$$

adding annually to the atmosphere:

$$(1920 \times 10^9 \text{ kg}/5.1 \times 10^{18} \text{ kg}) \times 10^6 \times 28.8/44 \text{ p.p.m. molar basis} = 0.25 \text{ p.p.m.}$$

The accuracy of these particular calculations is not in doubt: they depend only on figures for CO_2 production for the respective countries. That the Indian sub-continent and the OPEC countries collectively contribute the same amount of carbon dioxide is noteworthy. The former is pretty well a landmass whilst the latter are widely distributed across the globe.

8.7 References

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9 Australia, New Zealand and the South Pacific

9.1 Introduction

The title of this chapter takes in two former British dominions together with small island nations including Fiji, Tonga and the Solomons. There is also Papua New Guinea (PNG) to be considered.

9.2 The current milieu in Australia

Australia, population 22.6 millions, is a country with a high 'standard of living' which a generation ago more than now was due to export of primary produce. Her major scenes of hydrocarbons include the Bass Strait, off the coast of south east Australia, which was in fact seen as a 'wildcat' at the exploration stage. Almost as far from the landmass of Australia from the Bass Strait as one could imagine is the North West Shelf, which since the 1980s has grown and grown as a scene of natural gas production. Current oil production is of the order of half a million barrels per day. Current gas production is 45 billion cubic metres, a considerable part of it destined for conversion to LNG and shipment.

In 2009 Australia produced 261 TWh of electricity, and the expected demand for 2020 is 325 TWh. Table 9.1 below gives a summary of how the '100% renewable energy' aspiration [1] for that year is being approached.

Method of generating.	Comments.
Hydroelectric	All of the states and territories on the mainland except South Australia and the Northern Territory have hydroelectricity, as has the island state of Tasmania. 8186 MW of installed capacity (2011 figure) [2].
Wind farms	About fifteen sizeable wind farms in Australia. Total nameplate capacity 1.9 GW.
Nuclear	No generation from nuclear fuels.
Co-firing of coal with biomass	Less activity than in the US and the EU, but on the increase.

Table 9.2 Carbon mitigating methods of power generation in Australia.

The performance of hydroelectric installations does of course depend on rainfall, and hydroelectric generation in state of Victoria has fallen short of expectation because of lower than expected rainfall in recent years. This has to some extent frustrated the efforts by the Victorian government to reduce electricity production from brown coal (lignite). The figure for hydroelectric capacity given in the table would at *hypothetical* full output yield 70 TWh annually.

Using the criterion applied previously for wind farms, those in Australia will produce:

$$1.9 \text{ GW} \times 2500 \text{ hours} = 4.75 \text{ TWh}$$

This gives a capacity factor of:

$$[4.75/(1.9 \times 365 \times 24 \times 10^{-3})] \times 100\% = 29\%$$

whereas capacity factors of 35% are in fact being claimed, in which case the annual yield would be 5.7 TWh. Though lacking hydroelectricity, South Australia (capital Adelaide) leads the country in wind powered electricity generation.

There is no nuclear powered generation of electricity in Australia, as noted. A 2011 report [3] proposes 3% (energy basis) of co-firing of biomass with coal for electricity in Queensland. The largest coal-fired power station in Queensland is the Gladstone Power Station with a nameplate capacity of 1680 MW. We perform a calculation on this similar to the one for Drax earlier in the book.

Assigning the coal a calorific value of 25 MJ kg^{-1}, the requirement for 1680 MW is:

$$[1680 \times 10^6 \text{ J s}^{-1}/(25 \times 10^6 \text{ J kg}^{-1} \times 0.35)] \times (365 \times 3600 \times 24) \text{ s year}^{-1} \times 10^{-3} \text{ tonne kg}^{-1} = 6.055 \text{ million tonnes per year}$$

Now the heat from 3% of that is to be replaced by heat from biomass. The amount of biomass required is then:

$$(0.182 \times 25/17) \text{ million tonnes per year} = 0.27 \text{ million tonnes per year}$$

This is a very small amount of biomass, and scaled up for coal fired electricity generation in the whole of Australia would represent only a small proportion of the amount burnt to no purpose or disposed of at landfills annually. Turning from electricity to transport, there are three plants for ethanol production for automotive use in Australia. The most recent to enter service is that at Nowra, New South Wales, and plate 9.1 shows this.

Plate 9.1. Ethanol plant at Nowra NSW. Illustration from http://www.manildra.com.au/our_products/article/ethanol/

At the plant in Nowra ethanol is made from starch (as at Lillebonne – see section 3.2). There are also two ethanol plants in Queensland, both much smaller than the one at Nowra. Annual production of ethanol on Australia stands at 440 million litres, thermally equivalent to about 1.8 million barrels of oil and realising a carbon mitigation, if put to automotive use, of:

$$1.8 \times 10^6 \text{ bbl} \times 0.159 \text{ m}^3 \text{ bbl}^{-1} \times 900 \text{ kg m}^{-3} \times (44/14) \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 0.8 \text{ million tonnes of } CO_2.$$

E10 is widely used in Australia, and blends up to E85 are available in some parts of the country. On the biodiesel front, B5 to B20 are available for vehicular use in Australia. Annual production of biodiesel in Australia is 51 million litres and an additional quantity is imported. The domestic amount brings about a carbon mitigation equivalent to the release by:

$$[(37/44) \times 51 \times 10^3/0.159] \text{ barrels of oil} = 0.27 \text{ million barrels of oil.}$$

9.3 The current milieu in New Zealand

New Zealand (population 4.4 millions) released 39.58 million tonnes of CO_2 in 2010. The country has little oil and a significant but not enormous quantity of natural gas, including that at the Maui field off Taranaki. The electricity consumption is 0.039 TWh annually. Hydroelectricity accounts for over half of this and natural gas about a quarter. There is a relatively small contribution (≈ 7%) from coal. One's impression on examining the carbon-neutral methods of generating electricity is that there are numerous very small facilities where consolidation might have been better. Wind accounts for 2% of the electricity; there are 17 wind farms with a combined nameplate capacity of only 622 MW [4]. 'Biogas' made from organic waste, is used for electricity at a number of organisations usually themselves manufacturing it, and nationally this sums to a mere 37 MW.

The NZ government has limited the amount of ethanol that can be blended with gasoline to 10%. Ethanol made in NZ is from the fermentation of lactose, obtained from the dairy industry. This is insufficient for demand, and there are imports of ethanol from the US, Australia, Brazil and the EU. Biodiesel is available in the range B20 to B100. Materials from which it is made include tallow, used cooking oil and rapeseed.

9.4 PNG

Papua New Guinea, population 7 million, released 5.31 million tonnes of carbon dioxide into the atmosphere in 2010. The electricity production is about 3 TWh. She neither imports nor exports it: all generation is for domestic use. The generation 'mix' is 54% fossil fuel, balance hydroelectric. There is natural gas in plenty, about 130 million cubic metres per annum being produced. LNG trains are being constructed and export from PNG of LNG is expected to begin in 2014. Not lacking cultivable land, PNG is with help from international companies developing ethanol production from Cassava plantations. For future biodiesel production on a major scale, coconut oil is the favoured starting material.

9.5 The Pacific Islands

These communities will be considered in turn in Table 9.3 below. They are not preoccupied with carbon mitigation in the way that more populous countries heavily capitalised with industrial plant are, and when for example wood is used as a fuel in one of the island (or multi-island) nations under discussion it is because it is available, not because it is carbon-neutral. PNG is of course a 'Pacific island country', but different in size and in importance from those in the list below. Until 1975 PNG belonged to Australia.

Country and population.	Details.
Fiji, 0.87 millions.	Electricity production 0.1 TWh annually, > 80% from hydro.
Tonga, 0.1 millions.	Electricity production 0.04 TWh annually all from imported diesel.
Solomon Islands, 0.55 millions.	Electricity production 0.08 TWh annually all from imported diesel.
Vanuatu, 0.25 millions.	Electricity production 0.04 TWh annually all from imported diesel.
Pitcairn Islands, 67	Generation of electricity using diesel. Available only for parts of the day.

Table 9.3 Selected Pacific island nations.

There are three thermal power stations in Fiji which supply electricity additional to that from hydro. The largest of these is the Kinoya power plant near the national capital Suva, which using imported diesel as fuel can generate at 30 MW. Despite its small size and economic unimportance, Fiji is 'playing the game' by trialling diesel-coconut oil blends in thermal generation of electricity. Fiji is of course noted for sugar production and exports some of it, but there is no ethanol production in Fiji. Her first wind farm at Butoni on Viti Levu has a nameplate capacity of 10 MW. This seems negligible at first consideration but must be viewed on the scale of a country of population less than one million: it is a third the capacity of the country's largest thermal power station.

The annual carbon footprint from electricity generation in Tonga will be:

$$[0.04 \times 10^{12} \text{ J s}^{-1} \times 3600 \text{ s}/(44 \times 10^{6} \text{ J kg}^{-1})] \times (44/14) \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 10000 \text{ tonnes approx.}$$

which, using a calculation similar to those in sections 7.3 and 8.6, can be shown to add one part per *million million* (10^{12}) to the CO_2 level of the atmosphere! Like Tonga the Solomons (next row) rely entirely on imported diesel for electricity generation. Use of a fuel which is not only imported but already refined obviously makes for expensive electricity. Palm oil is exported from the Solomons although this has been jeopardised in recent times by the internal conflicts of the country. In Vanuatu (next row) as in Fiji coconut oil is being examined as a means of reducing the reliance on diesel. With something of a tongue-in-cheek attitude, the author included the Pitcairn Islands – a 'nano nation' – in the table. There are quarterly visits by chartered vessels bringing goods to the islands, including cylinders of natural gas. There has been a swing towards this from biomass fuel in the Pitcairns.

9.6 Concluding remarks

Obviously by far the most important of the countries covered in this chapter has been Australia which has ratified the Kyoto Protocol and is conspicuously proactive in carbon mitigation measures.

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10 South America

10.1 Introduction

Venezuela and Ecuador have already been discussed under OPEC countries and Brazil has also featured. Other South American countries will be discussed in this chapter.

10.2 Miscellaneous South American countries

This section will have the format used in some previous parts of this book whereby a table is followed by discussion.

Country and population.	Comments.
Argentina, 40.7 millions.	2010 oil production 0.63 million barrels per day. Both exports and imports oil and in any one year might by a small margin be a net exporter or a net importer. 169.83 million tonnes of CO_2 produced in 2010.
Chile, 17.3 millions.	2010 oil production 0.011 million barrels per day. Oil imports about 30 times amount this from Argentina, Brazil, Angola, and Nigeria. 68.76 million tonnes of CO_2 produced in 2010.
Uruguay, 3.4 millions.	Oil consumption 45000 barrels per day. 7.27 million tonnes of CO_2 produced in 2010.
Bolivia, 10 millions.	≈ 0.05 million barrels of produced oil per day. 13.29 million tonnes of CO_2 produced in 2010.
Peru, 29.4 millions.	0.16 million barrels of oil produced per day. 41.88 million tonnes of CO_2 produced in 2010.
Guyana, 0.76 millions.	1.52 million tonnes of CO_2 produced in 2010. See calculation in main text.

Argentina produces of the order of 120 TWh per year of electricity, about 40% of it by hydroelectricity. The nuclear component is small, and nearly all of that not produced by hydro is from natural gas. The country both exports (e.g. to Uraguay and to Brazil) and imports (from Paraguay) electricity in amounts >10TWh. There is 167 MW installed capacity of wind turbines, capable of producing in a year:

$$167 \times 10^{-6} \text{ TW} \times 2500 \text{ hours} = 0.4 \text{ TWh.}$$

Argentina is a major producer of corn (20 to 30 million tonnes annually), some of which is exported for ethanol manufacture in other countries. Argentina herself produced 260 million tonnes of ethanol in 2012, and is expected to produce 3 billion litres (19 million barrels) of biodiesel in 2013 [1], a huge quantity. The amount of biodiesel exported from Argentina in 2012 was 11 million barrels. The carbon mitigation due to the expected 2013 production will be:

$$(37/44) \times 3 \times 106 \text{ m}^3 \times 900 \text{ kg m}^{-3} \times (44/14) \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 7 \text{ million tonnes of } CO_2.$$

In considering Chile (next row) it is interesting to note that there are oil imports from two of the African OPEC countries. The country has 10.7 GW of installed electricity generation, approaching a half from hydro. Also favourable from the emissions point of view is that natural gas is widely used in thermal generation; the gas is imported from Argentina. There are 190 MW (nameplate) of wind turbine capacity in Chile. Ethanol is not yet used in automotive fuels but land suitable for growing sugar is being evaluated to that end. There is however rapeseed production – one million tonnes of rapeseed oil (about 7 million barrels) in 2012 – and this has enabled the government to impose a B2 requirement on vehicles powered by diesel. Jatropha is being grown in pilot schemes.

Uruguay, in the next row, is a small country in population terms. She produces about 60% of the oil consumption and imports the balance. There are 70 million litres per year of ethanol production capacity using cereal feedstock. There is domestic biodiesel, sufficient for a B5 policy that is not yet law. A biodiesel production facility near Montevideo is expanding towards a production in the near future of 0.4 million barrels per year [2]. There is limited export of electricity from Uruguay. A remarkable 99% of the electricity in Uruguay is hydroelectricity and below we attempt a rough analysis of the Salto Grande Dam, the nameplate output of which is 1890 MW from fourteen water turbines.

Nameplate capacity is sustained for nowhere near the whole of the time, and the annual output of the dam is 6.7 TWh giving a rating of:

$$6.7 \times 10^6 \text{ MWh}/(24 \times 365 \text{ hour}) = 764 \text{ MW}$$

The total water flow rate is about 5 tonnes per second [3], and the efficiency of a water turbine is as high as 90%, so the mechanical power needed will be ≈ 850 MW. At turbine exit the speed of water flow can be taken to be negligible, and the potential energy is also zero as the turbine depth is the level at which the vertical co-ordinate (symbol z) is zero, therefore all of the energy is 'pressure energy'. Letting the pressure at this point be P N m^{-2} and using the symbol σ for the density:

$$(P/\sigma) = \sigma z g/\sigma = zg \text{ m}^2 \text{ s}^{-2} \text{ (equivalent to J kg}^{-1}\text{)}$$

The turbine depth is then:

$$850 \times 10^6 \text{ J s}^{-1}/(5000000 \text{ kg s}^{-1} \times 9.81 \text{ m s}^{-2}) = 17 \text{ m}$$

This is a perfectly sensible answer. The author has not been unable to verify it from published information.

Bolivia (next row) operates on a small scale in hydrocarbon terms, and imports a modest 17000 barrels of oil per day and exports 5000 barrels per day. These can be judged against the production figure give in the table. Bolivia produces about 13 billion cubic metres of dry (condensate-free) gas per year and significant amounts of condensate. As well as being a small nation Bolivia is a poor one, and such things as wind farms have lacked initiation through paucity of capital. Even so in 2012 there was about 20 MW of wind farm capacity in Bolivia [4]. More importantly there is hydroelectricity with about 40% of the country's power consumption coming from that. Some sugar cane growth takes place in Bolivia, and indigenous trees capable of yielding oil suitable for biodiesel have been identified. Here again everything depends on investment.

Peru (next row) is a significant oil producer and exports about 73000 barrels per day. She has hydroelectricity to an installed capacity of 8GW. Total annual production is 39 TWh, with fossil fuels making up the 15% gap approximately between the hydroelectric capacity and the demand. The hydro at full capacity would yield:

$$8 \times 10^{-3} \times 365 \times 24 \text{ TWh} = 70 \text{ TWh}$$

whereas actual delivery is just about half of that (as can easily be deduced from the figures immediately above). There is no significant wind generated electricity in Peru although turbines are being obtained and sites for them developed with a view to some such generation within the next year or so. There is a new ethanol production facility at Piura, in the north east of the country. Over the period March to November 2012 it yielded 11.5 million gallons (≈ 0.07 million barrels) of ethanol for fuel use from sugar cane. The bagasse is used in power generation. Peru's first biodiesel plant in Lima uses vegetable oil and animal fat as starting material and target production is 5000 to 6000 barrels per day. In Peru blends of gasoline-ethanol and diesel-biodiesel are mandatory for SI and CI engines respectively.

Guyana (following row) uses 10000 barrels of oil per day, leaving a carbon footprint of:

$$10^4 \text{ bbl day}^{-1} \times 0.159 \text{ m}^3\text{bbl}^{-1} \times 900 \text{ kg m}^{-3} \times (44/14) \times 10^{-3} \text{ tonne kg}^{-1} \times 365 \text{ day year}^{-1}$$

$$= 1.6 \text{ million tonnes of } CO_2 \text{ per year.}$$

which to within the accuracy of calculations at this level matches the total. There is no natural gas usage in Guyana. Wind power has not got beyond anemometric measurements at selected sites!

10.3 Further remarks

Other countries could have been considered in this chapter, but most of those selected are shown to be rather negligible in their carbon mitigation activity and the extend the list would not be productive. Trinidad and Tobago (T&T), though a Caribbean country, is also sometimes classified as a South American one. (From the capital Port of Spain it is possible to see across to the Venezuelan coastline.) T&T has become a hydrocarbon producer by reason of its immense natural gas resources and much of this is made into methanol. This is of no relevance to carbon mitigation: the natural gas is obviously not carbon neutral therefore neither is anything made from it. Import of ethanol from Brazil to T&T has, in recent years, been more prevalent than local production, and T&T has become less of a sugar producer since she entered the hydrocarbon business.

10.4 References

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11 The Former Soviet Union

11.1 Introduction

These countries [1] will be discussed in turn, and a reader should be aware that Russia was one of the first producers of oil. There was a period of year or so in the early 20th century when the Russian oil production exceeded US. Russia is of course one if the countries of the Former Soviet Union, having a population of 142 millions. It will be the first of the countries to be discussed in this chapter.

11.2 Russia

2011 oil production in Russia was 9.8 million barrels per day [2], over a tenth the world total. Natural gas production is 600 billion cubic metres per day, and Russia also holds the world's largest natural gas reserves. There is a great deal of coal (see below). Annual carbon dioxide emissions in Russia are 1700 million tonnes, capable of causing a rise:

$$[1700 \times 10^9 \text{ kg}/(5.1 \times 10^{18} \text{ kg})] \times 10^6 \times 0.0288/0.044 \text{ p.p.m. molar basis}$$
$$= 0.2 \text{ p.p.m. molar basis.}$$

in the carbon dioxide level of the atmosphere. Electricity production in Russia is approaching 1000 TWh (1PWh) per year. The mix is thermal with conventional fuels 68%, thermonuclear 16%, hydro 16%. For calculation purposes treating the 'conventional fuels' as entirely natural gas only, the carbon footprint would be:

$$[0.68 \times 1 \times 10^{15} \text{ J s}^{-1} \times 3600 \text{ s}/(889000 \text{ J mol}^{-1})] \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 120 \text{ million tonnes.}$$

There are 36.8 million cars in Russia, and many are older and not as well maintained as those in (for example) the UK. The figure of 100 g CO_2 per mile can probably reasonably be doubled for Russia, giving a footprint (retaining the annual mileage of 12000) of:

$$36.8 \times 10^6 \times 0.2 \text{ kg mile}^{-1} \times 1200 \text{ miles} \times 10^{-3} \text{ tonnes kg}^{-1} = 9 \text{ million tonnes.}$$

An operation not previously considered in this book is steel manufacture. This once involved coke oven gas and producer gas, and the former is still used as it is obtained from the manufacture of the coke which is used to obtain iron from its ore. However, natural gas (possibly supplied as LNG) and liquefied petroleum gas (LPG) are also used in present day steelworks, and the carbon footprint of steel manufacture is on the order of a tonne of carbon dioxide per tonne of final product steel [3]! This is at first a little startling, and a perspective can be put on it be considering how much CO_2 unit amount of LPG would produce on burning.

Treating the LPG as propane, the stoichiometry is:

$$\begin{array}{ccc} C_3H_8 & \rightarrow & 3CO_2 \\ (0.044\ \text{kg}) & & (0.132\ \text{kg}) \end{array}$$

so 1 tonne of CO_2 is produced from 0.33 tonne of propane (LPG).
The density of liquid propane at its boiling point is 493 kg m^{-3}, so 0.33 tonne will have a volume of:

$$0.33 \times 10^3\ \text{kg}/493\ \text{kg m}^{-3} = 0.67\ \text{m}^3 \text{ or } 670 \text{ litres}$$

Russia produces of the order of 70 million tonnes of steel in a year with a carbon footprint of about the same, that is, a tonne of CO_2 per tonne of steel. Summing power, cars and steel manufacture:

$$(120 + 9 + 70) \text{ million tonnes} = 200 \text{ million tonnes}$$

which is a long way short of the total given above. Some closure of the gap can be achieved by noting that Russia uses ≈ 225 million tonnes of coal in a year (2009 figure). It varies from higher rank to lower rank (lignite) and a rough average figure of the carbon content of the coal of 70% will be used in estimating the carbon footprint:

$$0.7 \times 225 \times 10^9\ \text{kg} \times (44/12) \times 10^{-3}\ \text{tonne kg}^{-1} = 578 \text{ million tonnes of } CO_2$$

Russia has not developed far with wind farms, and a 2013 release on the matter [4] states that the contribution made by wind to the power requirements of the country is negligible. There are proposals for installation, but even by 2020 the capacity is expected to be less than half a gigawatt. Russia produces ethanol but exports it all, and also exports grain as feedstock for ethanol production in other countries. There is no biodiesel production in Russia at the present time [5]. So 25 years after Glasnost Russia has still not become attuned to world trends in spite of her massive resources of oil and gas.

11.3 Ukraine

This country of population about 46 millions produces 82000 barrels of oil per day and imports a much larger amount primarily from Russia, whence she also obtains natural gas. Electricity production in the Ukraine is 173 TWh, about half from conventional thermal production. Nuclear and hydro account for the balance, with wind power making a nominal contribution which is nevertheless expected to increase. There are fifteen nuclear reactors for power generation in the Ukraine, providing nearly a half of the country's electricity. Uranium nuclear fuel used is domestic, not imported.

In the province of motoring, the Ukraine is operating ethanol pants and is intending to make E5 mandatory for petrol engine cars in the near future. There have until recently been biodiesel imports from Belarus.

11.4 Kazakhstan

This country of population 16.9 millions produces 1.6 million barrels of oil per day, exports 1.4 million barrels per day and imports about 94000 barrels per day. It is therefore a strong net exporter. Domestic oil consumed and that imported add up to:

$$(0.2 + 0.094) \text{ million bbl per day} \approx 0.3 \text{ million bbl per day}$$

leaving an annual carbon footprint of:

$$0.3 \times 10^6 \text{ bbl day}^{-1} \times 0.159 \text{ m}^3\text{bbl}^{-1} \times 900 \text{ kg m}^{-3} \times (44/14) \times 10^{-3} \text{ tonne kg}^{-1} \times 365 \text{ day year}^{-1}$$
$$= 50 \text{ million tonnes of CO}_2$$

which is a little under third of the total. Gas consumption in Kazakhstan is about 10 billion cubic metres per year, adding another 18 million tonnes of CO_2. Most electricity (>80%) is produced from coal and the balance from hydro. Kazakhstan produced 117 million tonnes of coal in 2011 [6]. There is no nuclear generation of electricity in Kazakhstan.

The country has not been inactive in relation to carbon-neutral automotive fuels. Kazakhstan produces biodiesel from rapeseed, and exports some of it. Production in 2011 was over a million tonnes. There is also major ethanol production, for example at the plant in Taiynsha in northern Kazakhstan were ethanol is made from wheat.

11.5 The Baltic states

These are Latvia, Estonia and Lithuania. They are considered in the Table 11.1 below.

Country and population.	Details.
Latvia, 2.3 millions.	9.07 million tonnes of CO_2 released (2010) 3.6 TWh of electricity generated annually [7]
Estonia, 1.3 millions.	20.56 million tonnes of CO_2 released (2010) 13TWh of electricity generated annually [8]
Lithuania, 3.4 millions.	15.98 million tonnes of CO_2 released (2010) 14 TWh of electricity generated annually [9]

Table 11.1. Information on the Baltic States.

In Latvia electricity is over 70% hydroelectric in origin, balance gas and oil imported from Russia. Coal is also imported from Russia. There are four operating wind farms in Latvia, with a combined nameplate capacity of just under 35 MW, mitigating an amount of CO_2

$$(35 \times 10^6 \text{ J s}^{-1}/889000 \text{ J mol}^{-1}) \times 2500 \times 3600 \text{ s} \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 0.016 \text{ million tonnes of } CO_2$$

on the basis that the power would otherwise have been generated from natural gas.

Estonia, in spite of its small size, is noted internationally as a producer of oil from shale. About 90% of Estonia's electricity is made from shale oil which is not, of course, carbon neutral. That is why the CO_2 emissions, when considered alongside population, are out of line with those for Lithuania and Latvia. Electricity from shale oil is a growth industry in Estonia in spite of being a long established one, and to date 550 TWh of electricity have been generated by this means, or 42 times the current annual amount. There are exports of electricity from Estonia to countries including Finland. Lithuania used to have a very strong (>75%) nuclear component to her electricity production but this ceased in 2009. The capacity so surrendered was largely covered by gas imported from Russia.

In 2009 production began at the biodiesel facility at Ventspils, Latvia, and its products conform to EN14214 (see Table 3.1). The primary feedstock is rapeseed, some of it locally produced and some of it imported from the other Baltic States and from the Ukraine. A small amount (about 1.5%) of the biodiesel from Ventspils will be exported to Norway. Estonia produced no biodiesel at all in 2011, whilst Lithuania produced an impressive 79000 tonnes [10]. Lithuania produces of the order of 1000 barrels per day of fuel ethanol and also imports some. Blends from E5 upwards are available to motorists.

11.6 Selected further Former Soviet Union countries

The coverage is in tabulated form and comments follow Table 11.2

Country and population.	Details.
Armenia, 3.3 millions.	A moribund energy regime, including wide use of gas manufactured from coal. All oil and natural gas is imported. A wind farm ('Lori 1') of 2.6 MW nameplate capacity. Ethanol production developing (see comments following table).
Turkmenistan, 5.1 millions.	A significant oil producer (about 0.2 million bbl per day) and gas producer (>40 billion cubic metres per year). >95% of electricity production from oil, gas and coal.
Uzbekistan, 29.6 millions.	A moderate (87000 bbl per day) oil producer, a more abundant producer of gas (59 billion cubic metres per year). Significant (about 12% of the total) hydroelectric production (see discussion following table).
Azerbaijan, 9.2 millions.	One million barrels per day of oil produced. Some hydroelectricity. Wind power for one major business only (see discussion following table).
Georgia, 4.5 millions.	Very modest producer of oil (about 2000 bbl per day). Major hydroelectricity (see discussion following table).
Belarus, 9.5 millions.	Major CO_2 emissions for the electricity industry.
Tajikstan, 7.6 million	Largely an agricultural milieu. Significant hydroelectricity some of which is exported.

Table 11.2. Countries of the FSU.

The Lori 1 wind farm is set to expand, as a joint Armenian-Iranian utility, to 90MW nameplate capacity. Ethanol production on a significant scale is just starting in Armenia. Only in the north of the country is the climate at all suitable for growing corn as feedstock, and such cultivation is in fact taking place. It is planned that by as soon as 2014 a quantity of 14000 tonnes annually of ethanol will be made in Armenia so that E5 can become the norm at filling stations. Turkmenistan differs from Armenia in being a major oil producer, and at any one time a large number of personnel from 'western' oil companies and oil field services companies will be there conducting various tasks and commissions. Georgia imports oil from Azerbaijan. On the plus side, the country generates 80% of her electricity hydroelectrically.

The hydroelectric sector in Uzbekistan is expanding. Existing ones include the Charvak hydroelectric facility 70 km from the national capital Tashkent. It has four equivalent water turbines, with a combined capacity of 600 MW. Plate 11.1 shows the Charvak utility.

Plate 11.1. Charvak hydroelectric facility in Uzbekistan. Illustration from [11]. Reproduced with permission.

Like many hydroelectric plants, Charvak uses *pumped storage*. Drawing on electricity during low-demand periods when it is cheaper, water is pumped to a particular altitude and released for water turbine passage at high demand. The altitude to which the water is raised at Charvak is 148 m (measured from the turbine axis) which can descend at 500 $m^3\ s^{-1}$ through the turbines when released. The rate of conversion of potential energy to energy at the turbine blades is then:

$$500\ m^3\ s^{-1} \times 1000\ kg\ m^{-3} \times 9.81\ m\ s^{-2} \times 148\ m = 725\ MW$$

Division of that into the nameplate capacity of 600 MW gives an efficiency of 83%, which is typical.

Azerbaijan is a major oil producer, and takes in some of the offshore fields in the Caspian Sea. BP are very active there. About 10% of the country's electricity generation is hydroelectric. Wind power is just coming into being in Azerbaijan and the current installed capacity of 2 MW is entirely for the the use of Caspian Fisheries (which specialises in caviar!). It has four turbines, imported from Spain.

Georgia imports some oil from Azerbaijan to supplement her own rather meagre production. On the positive side, about 80% of her electricity is hydroelectrically produced. By far the largest of the ten hydro facilities in Georgia is the Inguri Dam (below).

Plate 11.2. Inguri Dam in Georgia. Image sourced from [12].

The installed capacity of the Inguri Dam is 1320 MW from five equivalent water turbines and it is this which makes Georgia a net exporter of electricity. Wind power is as yet negligible in Georgia (of the order of kW), but a 'wind atlas' enabling the most suitable sites for future activity has been compiled by experts. Belarus (next row) produces, imports and exports oil. Electricity production there is almost entirely by oil, gas and coal: other means of production are negligible. In fact total production for 2011 was 32.00 TWh, all of which was thermal from conventional fuels except for 0.04 TWh from hydro [13]. Wind farms are being built in Belarus, with a target nameplate capacity of 1500 MW by 2015. The hydroelectric capacity in Tajikstan (following row) is recently installed with help from Russia.

For Moldova (population 3.6 millions, and a large importer of oil, coal and natural gas from Russia) and Kyrgyzstan (population 5.5 millions, and an importer of gas from Uzbekistan) to have been added to table would have the chapter comprehensive in the sense that all the FSU countries had featured.

11.7 Concluding remarks

What is evident is that hydroelectricity is keeping down the CO_2 emissions in many parts of the FSU. Sakhalin, part of Russia, is one of the world's major scenes of hydrocarbon resource development at the present time. Flaring of natural gas is carefully controlled and a 2012 report [14] describes how ALARP – as low as reasonably practical – principles are applied to flaring.

11.8 References

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12 Some selected African countries

12.1 Introduction

This chapter will of course exclude the African OPEC countries – Libya, Egypt, Algeria, Angola and Nigeria – which as such have featured in Chapter 7. South Africa is a former British Dominion and as such might have featured naturally alongside Australia and NZ which are also former dominions. South Africa will in any case feature first in this chapter.

12.2 South Africa

This country of population 50.5 millions imports about half a million barrels of oil a day, largely through the import terminal at Richards Bay near Durban. Five per cent of its electricity is nuclear, there being two reactors, and expansion of nuclear capacity is envisaged for South Africa's future. There is also major hydroelectricity, at ten facilities one of which is just coming into operation. This is the Ingula Pumped Storage Scheme in Orange Free State [1] with a capacity of 1.33 GW. South Africa's projected power needs by 2025 are 40000MW and Ingula is part of the plan for this.

Coal-fired power stations include the Arnot station in the Transvaal, which has an installed capacity of 2100 MW via six turbines. There have been discussions of coal-biomass co-firing at Arnot [2] and trials, but it is probable that what was learnt from these will be applied the Kriel Power Station east of Johannesburg. The Lethabo Power Station in the Orange Free State is also coal fired but with a photovoltaic facility. This will provide 1.25 million kWh of electricity annually, providing a carbon mitigation of:

$$[1.25 \times 10^{9} \text{ J s}^{-1} \times 3600 \text{ s}/(25 \times 10^{6}) \text{ J kg}^{-1}] \times 0.8 \times (44/12) \times 10^{-3} \text{ tonne kg}^{-1}$$

$$= 500 \text{ tonnes approx.}$$

on the basis that the power would otherwise have come from coal
of 80% carbon content and 25 MJ kg^{-1} calorific value.

The Sere wind farm in the Western Cape [3] is being constructed and expected to start to deliver by the end of 2013, with a nameplate capacity of 100 MW. These are all evidence of South Africa's commitment to greenhouse gas reductions in power generation, but there is a long way to go. The neglected infrastructure during the apartheid regime is still having an effect on reliability of electricity supply and equally on emissions. Like Pakistan (see section 8.3) South Africa is implementing Clean Development Mechanism projects under the Kyoto Protocol.

On the automotive fuels front, biodiesels are just coming into availability, there being a newly set up enterprise for biodiesel from waste cooking oil with a target annual production of 50000 tonnes per annum [4], providing a carbon mitigation of:

$$(37/43) \times 50000 \times 10^{3}\ \text{kg} \times (44/14) \times 10^{-3}\ \text{tonne kg}^{-1} = 0.13\ \text{million tonnes of}\ CO_2$$

Other sources of biodiesel for South Africa are being followed up with a view to a norm of B2 in the near future. Jatropha is believed to be amongst the existing plant life of Natal, and its cultivation as a basis for biodiesel is an obvious option. There are organisations in South Africa which make ethanol for fuel use and they include SASOL. Previously SASOL made liquid hydrocarbons from coal via synthesis gas when oil imports were restricted by trade sanctions against South Africa.

12.3 Lesotho

This landlocked country of population 2.1 millions which once bought electricity from South Africa has more recently moved towards self-sufficiency. South Africa has however had a holding in the Lesotho Highlands Water Project, which supplies almost the entire electricity requirement of Lesotho. The nameplate installation is 200 MW. The country is primitive and few homes are supplied with electricity, so a capacity of this order is sufficient to maintain the status quo. Lesotho has no known oil or gas and no refineries, so any petroleum products have to be imported in fully processed form. Being mountainous the country has potential for wind power, and a wind farm of 30 MW – a large capacity for Lesotho – is a little beyond the drawing board [5].

12.4 Botswana

This country of two millions contrasts with Lesotho in electricity terms: all of Lesotho's electricity is from hydro and therefore produces no CO_2, whilst all of Botswana's is from fossil fuels. The annual amount for Botswana is however only of the order of 0.6 TWh [6]. Most of the oil used in Botswana is imported from South Africa without, of course, originating there. This need for intermediate countries in oil supply in Africa is expected to be reduced by pipeline capacity from Angola, a factor in Angola's admittance to OPEC. A quantity of 0.6TWh of electricity from oil will leave a carbon footprint of:

$$[0.6 \times 10^{12}\ \mathrm{J\ s^{-1}} \times 3600\ \mathrm{s}/(43 \times 10^{6}\ \mathrm{J\ kg^{-1}})] \times (44/14) \times 10^{-3}\ \mathrm{tonne\ kg^{-1}}$$
$$= 0.16 \text{ million tonnes of carbon dioxide.}$$

In countries lacking advanced amenities biomass fuels are used, as previously pointed out, not because they are carbon neutral but because they are there. Whilst this is so of Botswana there is the anomaly that most of the wood fuel used there is imported, largely as wood waste such as sawdust, from South Africa and Zimbabwe. This is because the government of Botswana has a very protective attitude towards its own forests and when it does grant a licence for felling it is for certain species only [7]. One might note that Botswana is one of the many countries to which Eucalypts have been introduced.

Biodiesel production is taking place in Botswana, using waste cooking oil with a current output only a little above pilot scale, being of the order of hundreds of barrels a month. Several indigenous plants are being investigated for potential production of suitable plant oil, and these include Sclerocarya birrea the seeds of which are known to be rich in oleic, palmitic and stearic acids.

12.5 Cameroon

This country (population 19 millions) has a border to the north west with Nigeria (an OPEC country) and a coast with the Gulf of Guinea. Oil production is 65000 barrels per day and there are both exports and imports of oil. The installed electricity capacity 817 megawatts MW of which 88% is hydroelectric [8]. There are no operating wind farms at present and extension of hydroelectricity is seen as being more promising. Biodiesel production from palm oil is 'on the agenda' but yield from the current number of palm trees would not suffice to influence the energy supply regime of the country in a big way. Jatropha trees are receiving attention along similar lines, but that there are many processes between planting a Jatropha tree and producing a quality biodiesel is widely realised and a great deal will depend on the willingness of financiers to provide infrastructure. For the Cameroon's domestic requirements import of palm oil is an obvious alternative.

12.6 Kenya

This east African country of population 41 millions is the scene of oil exploration with very positive results, and an *eventual* export pipeline to the country's Indian Ocean coastline is envisaged. 'Eventual' has been put in emphasis because as yet production is of the order of hundreds of barrels per day, hardly worth noting! The Kenya Electricity Generating company has an installed hydro capacity of >765MW, representing 65% of the company's total capacity. The company is noted for its advances in geothermal activity and an analysis of this follows.

In geothermal production of electricity a conventional steam turbine is used, but the steam is not 'raised' by application of heat but comes from a natural subterranean source and is brought up wells. Using the Olkaria I Power Station in Kenya [9] as an example, the steam is at 5 bar pressure and 152°C. Consultation of steam tables confirms that the steam is therefore saturated and it will be taken to be dry – having a minuscule proportion in the vapour phase, but enough to make the fluid two-phase for the purposes of applying the phase rule – on turbine entry.

The specific enthalpy of vapour (only) at 5 bar pressure, 152°C is, from tables, 2749 kJ kg^{-1}.

If the steam condenses to liquid water at 25°C the specific enthalpy (from steam tables) is 105 kJ kg^{-1}

The efficiency (work out/heat in) of a steam turbine is about 35%,
so the work done per kg of steam passing through the turbine is:

$$(2749 - 105) \times 0.35 \text{ kJ} = 925 \text{ kJ per kg steam}$$

The nameplate capacity is 45 MW, so the rate of steam passage

$$[45 \times 10^6 \text{ J s}^{-1}/(925000 \text{ J kg}^{-1})] = 50 \text{ kg s}^{-1} \text{ (4000 tonne per day)}.$$

This is quite consistent with performance figures for the plant which are in the public domain.

12.7 Madagascar

This island nation of population 22 millions generates annually about 1TWh of electricity, two thirds of it by hydroelectricity. All of that generated is for domestic use: none is exported, nor is there import of electricity into Madagascar. Madagascar imports about 16000 barrels of oil per day; exploration schemes for oil within Madagascar are under way and showing promise. Unusually, R&D into production of ethanol as a household rather than as an automotive fuel is under way. There is also an incipient biodiesels industry. Three thousand hectares of land currently in eroded condition and depleted of nutriment have been identified for reconditioning and use in the cultivation of Jatropha for processing into biodiesel which will find application in vehicles, in farm machinery and in power generation. It is intended entirely for internal use, no export.

12.8 Mauritius

This Indian Ocean island of 1.3 millions has no known oil reserves, but does have refining capacity for imported crude oil. Electricity production annually is about 2TWh, roughly 10% from hydro (this varying seasonally) and the remainder thermal some of it with biomass fuel. This is at the Mount Sugar Power Plant which produces about 7.5 GWh annually with, of course, no fossil fuel carbon dioxide. There is also co-firing of (imported) coal with biomass in the 'electricity mix' of Mauritius, entirely analogous to Drax on a scientific basis but on a much smaller scale and in a totally different economic milieu. Wind farms are being built in a small way in Mauritius, one of the most recent being at Plaine Sophie in south west Mauritius having a nameplate capacity of 30 MW between the 14 turbines [10]. The national goal is 8% of the total electricity from wind by 2025.

12.9 Other selected African nations

These are discussed in 12.1 below, with comments following the table.

Country and population	Comments.
Ethiopia, 91 millions	6.74 million tonnes of CO_2 released in 2010. >97% of electricity from hydro. Tree planting major (see comments following table).
Djibouti, 0.8 millions	0.3 TWh of electricity generated annually entirely from fossil fuels.
Somalia, 9.6 millions	0.3TWh of electricity from imported diesel.
Eritrea, 5.9 millions.	No domestic oil. ≈ 4000 bbl per day of imported oil. 0.3 TWh of electricity produced from imported diesel.
Morocco, 35 millions.	4000 bbl of oil per day produced. About six times as much imported. ≈ 20 TWh of electricity
Democratic Republic of Congo, population 68 millions.	Major production of palm oil, not as yet for fuel use. Also abundant sugar. Major hydroelectricity (see comments following table).

The remarkable extent of hydroelectric generation in Ethiopia has a carbon mitigation effect calculable as follows. The country's annual production is about 3.7 TWh which raised from natural gas would have left a footprint:

$$[(3.7 \times 10^{12}\ \text{J s}^{-1} \times 3600\ \text{s}/0.35)/889000\ \text{J mol}^{-1}] \times 0.044\ \text{kg} \times 10^{-3}\ \text{tonne kg}^{-1}$$
$$= 1.9\ \text{million tonnes}$$

There are only of the order of a quarter of a million privately owned cars in Ethiopia, which will release less than a million tonnes of carbon dioxide annually. The rail system there is poised for reform, the current reliance on diesel and coal ceasing as lines become electrified [11]. There is a Kyoto 'Clean Development Mechanism' (CDM) project under way in Ethiopia [12] whereby 2700 hectares of land will be afforested. At a typical value of 2500 trees per hectare of forest this will introduce of the order of 7 million trees, each with the capacity to take up 0.025 tonne per year of carbon dioxide, giving a total mitigation of 175000 tonnes of carbon dioxide[1] or, more consistently with the aims and philosophies of CDM, carbon credits to a degree sales of which will advance development of Ethiopia in other ways. The World Bank have agreed to purchase a specific proportion of these credits.

There is a 784 km railway (not in heavy use at the present time) between the Ethiopian capital Addis Ababa and the Port of Djibouti. In other words the countries are close and there is the anomaly that one is almost entirely hydroelectric and the other 100% fossil fuels in its power generation. There are two orders of magnitude difference in populations. A transmission line is being constructed which will enable hydro power from Ethiopia to be exported to Kenya at an *eventual* rate, following expansion of hydroelectricity in Ethiopia, of about 400 MW. Somalia generates electricity from fossil fuels at a rate equivalent to that at Djibouti in spite of the much smaller population of the latter. The reason obviously is the energy requirement of the Port of Djibouti.

The figure of 0.3 TWh annually occurs for three successive entries in the table. Such a figure would require a quantity of petroleum fuel equivalent to:

$$[(0.3 \times 10^{12}\ \text{J s}^{-1} \times 3600\ \text{s})/(0.35 \times 7 \times 10^{9}\ \text{J bbl}^{-1})]/365\ \text{bbl day}^{-1} = 1200\ \text{bbl per day}$$

where a calorific value of 7 GJ per barrel has been used for the calorific value of the diesel. On the hypothesis that all of the diesel from crude imported was used for electricity this would give a yield (1200/4000) = 0.3 (30%), which is in the right 'ball park', possibly a little high.

Descent of the table in going from Eritrea to Morocco involves such a contrast! We first note that the domestic oil production is entirely 'conventional': there is no commercial shale oil production in Morocco at the present time even though in the minds of many fuel technologists Morocco is linked with 'shale'. Morocco imports of the order of 3 million tonnes of coal annually, from the US, Colombia and South Africa. Morocco's largest power plants are those at Mohammedia and Jorf Lasfar each of which uses coal entirely. The Mohammedia Power Station (below). The installed capacity at Mohammedia has four 150 MW turbines, giving an installed capacity of 600 MW. Because of recent expansion that at Jorf Lasfar is more than twice that at Mohammedia. Coal-biomass co-firing is not on the agenda at either at the present time.

Plate 12.1. Mohammedia Power Station in Morocco. Reproduced with permission.
Image sourced from http://www.industcards.com/cc-morocco.htm

Like more than one of the other countries featuring in this volume, Morocco has a Clean Development Mechanism (CDM) project in hand. This is at Tetouan in northern Morocco [13] where a wind farm is being developed. There are other wind farms in Morocco and a target of 2GW of wind power has been set for 2016. This will provide, using the usual approximation of full capacity for 2500 hours in the year, a quantity:

$$2 \times 10^{-3}\ \text{TW} \times 2500\ \text{hour} = 5\ \text{TWh}$$

which is a quarter the current production. There are 1.5 million cars in Morocco leaving an expected carbon footprint:

$$1.5 \times 10^{6} \times 0.1\ \text{kg mile}^{-1} \times 12000\ \text{mile} \times 10^{-3}\ \text{tonne kg}^{-1} = 1.8\ \text{million tonnes of } CO_2.$$

Ten thousand hectares of land have been identified for possible plantation of Jatropha trees. However, neither biodiesel nor ethanol is a contributor to carbon mitigation in Morocco at this time. One must not however overlook the hydroelectricity production in Morocco, about 1TWh annually having been produced from the eight hydroelectric power stations of Morocco over the last five or so years. This obviously represents substantial carbon dioxide emission reduction. There are no nuclear power stations in Morocco.

In the Democratic Republic of Congo 185000 tonnes of palm oil was produced in 2012, and this country has a history of palm oil production for use in the manufacture of foodstuffs. The country also grows sugar, so would seem to be in a strong position to become a major centre for carbon neutral fuel production. Land availability for expansion either of palm oil or of sugar will of course be a decisive factor in any policies of the government or of overseas investors. There is the obvious point that clearance of trees to free up land for growth of palm or sugar seems at first consideration to be 'robbing Peter to pay Paul'. Where this has in fact happened, for example in Indonesia, this criticism has been made.

The information below on electricity generation in the DR of Congo is taken from [14].

2008 figures: 7.45 TWh total production >98% from hydro.
Installed capacity 2475 MW

Comparison of actual production and hypothetical production at full capacity round the clock suggests over-capitalisation with generating plant, but such a trend is not unusual when hydroelectricity dominates, as it assuredly does in the DR of Congo! The actual amount if generated from fuel oil would have left a carbon footprint of:

$$[(7.45 \times 10^{12}\ \text{J s}^{-1}/0.35) \times 3600\ \text{s}]/(43 \times 10^{6}\ \text{J kg}^{-1}) \times (44/14) \times 10^{-3}\ \text{tonne kg}^{-1}$$
$$= 5.6\ \text{million tonnes of } CO_2.$$

another example of how in an African country hydroelectricity is providing carbon mitigation. In the capital Kinshasa, charcoal is used widely as a domestic fuel. This is of course carbon-neutral, but its production on a large scale involves deforestation.

12.10 Concluding remarks

Hydroelectricity has featured strongly in this chapter. The possibility that, for example, the DR of Congo might become a major supplier of plant oil and of ethanol has been raised and a time might come when countries able to supply these in large quantities acquire wealth in so doing, analogously to the fiscal growth of the conventional oil and producers in earlier generations. One expects intuitively that land availability will be on the side of Africa in competition for a share of the world markets in biodiesel and ethanol as the demand for these products increases.

12.11 References

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13 Large cities across the world

13.1 Introduction and selection of cities

The book thus far has dealt with continents and regions. There are interesting points to be made from study of carbon mitigation in places of particularly high concentrations of human inhabitants and such a study is attempted in this chapter. Commuting is a feature of large cities: the population of a city centre is not stable but increases sharply on weekday mornings and drops sharply on weekday evenings as people go to and from work. We therefore expect public transport to be a major factor in carbon dioxide emissions. The selected cities are listed in the table below, and a discussion follows the table.

City and population.	Details.
London, 8 millions.	Hybrid buses in increasing use since 2006. Of the order of 1TWh of electricity annually consumed by the London Underground.
Jakarta, 10 millions.	Increasing use of biodiesels in buses. 5 GW consumption of electricity in the city during peak hours.
Tehran, 12 millions.	Fairly nominal hydro contribution to local electricity generation. A nuclear station distant from Tehran providing electricity for the national grid.
Tokyo, 13 millions.	Nuclear generation of electricity by TEPCO[3] at stations distant from Tokyo.
Shanghai, 9 millions.	Considerable activity in wind power (see comments following table).
Istanbul, 13.5 millions.	Some use of landfill gas (LFG).
Seoul, 10.6 millions.	Hybrid buses, manufactured by Hyundai. No automotive fuel use of ethanol. Biodiesel available.
Karachi, 21 millions.	CNG for buses, a proposal jeopardised by financial constraints and civil unrest (see comments following table).
Mumbai (formerly Bombay), 12.5 millions.	Biodiesel for buses.
Mexico City, population 8.9 millions.	8 hybrid buses in service.

Table 1. Cities selected for discussion[2].

This is a convenient place at which to outline how a hybrid vehicle works. As is well known, such a vehicle contains an internal combustion engine and an electrical power unit. Energy from braking, lost as heat in a traditional design, is used to recharge the battery for the electrical power unit. In thermodynamic terms this means that kinetic energy is being converted to electrical: that is of course also true of a wind turbine. Depending on design and construction, the electrical component might at certain periods propel the vehicle, or it might only 'take over' when the vehicle is idling. Either way there is a fuel economy bonus and therefore a carbon mitigation bonus.

Transport of London (formerly London Transport) has made available the following information on the hybrid buses it uses [1]. On such a bus the electric power available, via a 'pack' of batteries, is 120 kW (161 h.p.). The conventional engine is powered by diesel and is 1.9 litre, a much smaller engine than could be used in a vehicle of the same size with sole reliance on diesel. It is stated in [1] that carbon dioxide emissions are 38% lower than those of a bus of the same passenger carrying capacity powered by diesel only. A reader can put a perspective on this by noting that a 'diesel only' bus emits typically 1295g of carbon dioxide per kilometre travelled. Indonesia has featured intermittently throughout this book, and its capital Jakarta has its due place in the Table above. One of the major bus companies in Jakarta is Transjakarta, which commenced operations in 2004. It carries a quarter of a million passengers per day on buses using blends of conventional diesel and biodiesel, typically B20. A recently introduced member of the Transjakarta fleet is shown as plate 13.1 below. The viability of Transjakarta is ensured by two privileges granted by the government: the exclusive right to use certain traffic lanes at particular times of day and fare subsidies. There are two large power stations in Jakarta amongst the many in Indonesia. One, at Tanjung Priok in northern Jakarta, produces at 900 MW and the other, at Muara Karang also on the north side of 'town', produces at 750 MW. Each uses natural gas, of which there is plenty in Indonesia, which as previously noted is more favourable than coal or oil in carbon dioxide emission terms.

Plate 13.1 Transjakarta bus, which uses diesel-biodiesel blends as fuel.
Image taken from http://www.google.co.uk/search?q=transjakarta+buses&rlz

The annual production of the Tehran Province Regional Electricity Company [2] is of the order of 10 TWh, corresponding to an actual (not nameplate) capacity of:

$$[10 \times 10^{12} \text{ J s}^{-1} \times 1 \text{ hour}/(365 \times 24) \text{ hour}] = 1 \text{ GW}$$

only a small proportion of which is hydroelectric as noted in the table, the remainder being conventional thermal. The one nuclear power station in Iran is at Bushehr, over 1200 kilometres from Iran. Of capacity 1000 MW, it has been contributing to the national grid since 2011. TEPCO[3] (following row) also uses natural gas, imported as LNG and regasified. The onshore Tokyo Windside wind farm close to Tokyo produces at 2 MW and has been in service for ten years [3]. Some of the hybrid buses in service in Tokyo use diesel blended with biodiesel as the fuel (as opposed to electrical) component, making them even less productive of CO_2 than their counterparts in London!

Shanghai Electric manufactures wind turbines at capacities up to 3.6 MW, in which case the diameter is 116 m. These are for offshore use, and a 2 MW variant is available for onshore use. A calculation for the 3.6 MW turbine analogous to that is section 3.5 for a turbine in use in Europe follows. The symbols are the same as in the previous calculation and so will not be redefined.

The efficiency of conversion of mechanical power to electrical at a wind turbine is 30 to 35%, so the figure above of 3.6 MW converts to about 10.3 MW mechanical power. Assigning this the symbol *W* (units watts):

$$W = 0.5mc^2$$

$$m = \rho cA \text{ and } A = \pi d^2/4$$

$$\downarrow$$

$$W = 0.5\rho \times (\pi d^2/4) \times c^3 \text{ W}$$

Using a value of 1.16 kg m^{-3} for ρ, from the above the turbine manufactured at Shanghai, when working at nameplate capacity, require a wind speed of:

12 m s^{-1} or 27 m.p.h.

It was noted in section 4.2 that there is a biodiesel plant in Shanghai. To the brief reference to it there we can add that it produces of the order of 50000 tonnes annually [4], realising a carbon mitigation of:

$$(37/43) \times 50000 \times (12/14) \times 44/12 \text{ tonnes of } CO_2 = 0.14 \text{ million tonnes of } CO_2$$

Turkey widely is well capitalised with wind farms, and there are two in the district of the national capital Istanbul. One is that at Catalca, with a nameplate capacity of 60 MW between the twenty turbines. The other is at Kemerburgaz and has a nameplate capacity of 24 MW between twelve turbines. There are 42 buses in service in Istanbul which are powered by natural gas [5] which, of course, will leave a smaller carbon footprint than buses doing an equivalent mileage with diesel. At sites close to Istanbul there is electricity generation from landfill gad (LFG). LFG is making its first appearance in this book: it is the only carbon-neutral form of methane that there is. It arises from decomposition of cellulosic waste over time of the order of years. In Istanbul in 2009, 71 GWh of electricity were made thermally with LFG as the fuel, eliminating a carbon footprint:

$$[(71 \times 10^9 \text{ J s}^{-1} \times 3600 \text{ s}/0.35)/889000 \text{ J mol}^{-1}] \times 0.044 \text{ kg mol}^{-1} \times 10^{-3} \text{ tonne kg}^{-1}$$
$$= 36000 \text{ tonnes of } CO_2$$

A great deal was said about South Korea is section 6.2, though the national capital Seoul did not feature explicitly, hence its appearance in this table. The Hyundai Corporation manufacture hybrid buses and these use liquefied petroleum gas (LPG) of which Korea imports a great deal) instead of diesel. This is marginally in the direction of carbon mitigation by reason of the moderately higher calorific value of LPG as compared to diesel. Biodiesel is widely available in Seoul. The Seoul Metropolitan Government collects waste cooking oil for conversion to biodiesel, and there is also biodiesel from plant oil and from animal fat available. Karachi had a short mention in section 8.3, which will be added to here. Compressed natural gas (CNG), a very sensible choice, has been declared to be the 'fuel of the future' for the bus network in Karachi [6]. This undertaking has been frustrated by failures for various reasons of the planned import of CNG buses. One which was imported was torched in a riot [6].

In Mumbai (following row) biodiesel is being obtained from Hyderabad in an annual quantity of 16.4 'lakh litres' for blending with conventional diesel in buses [7]. 'Lakh' in India denotes 10^5, so we can estimate the carbon mitigation as:

$$16.4 \times 10^5 \times 10^{-3}\ m^3 \times 900\ kg\ m^{-3} \times (37/43) \times (12/14) \times (44/12) \times 10^{-3}\ tonne\ kg^{-1}$$
$$= 4000\ tonnes\ of\ CO_2$$

This is small, and some of the buses in Mumbai are in lamentable condition. A greater effect might have been achieved by rebuilding or replacing the diesel engines in some of them without going to 'carbon neutrality'. Mexico City (final row) has recently introduced eight hybrid buses, and older taxis are to be compulsorily replaced with new models of higher fuel efficiency (though still using entirely non carbon neutral fuels).

13.2 Concluding remarks

Some of the cities 'selected' have been in less developed countries. This choice was on the basis that for cities in developed countries there'd have been little to add to what has been said earlier in the book about the countries themselves. The next (and final) chapter looks at isolated and/or sparsely populated regions of the world.

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14 Isolated and/or sparsely populated regions of the world

14.1 Introduction

Carbon dioxide build-up is a world issue awareness of which is seen almost as one of the responsibilities of citizenship. A 'citizen' of a part of the world not itself a major producer will therefore want to do his or her bit in the matter of carbon mitigation, and this is reflected in the activities and policies in the places discussed in this chapter.

14.2 Selected regions

Table 14.2. Countries to be covered in Chapter 14.

Region	Details
Falkland Islands, population ≈ 2800.	≈ 60000 tonnes annually of CO_2 released. Significant wind power activity.
Vatican City, population < 1000.	'Vatican Climate Forest' to have been set up in Hungary (see comments following table).
Malta, population 400000.	2TWh of electricity annually from imported oil. Tree planting programs.
Liechtenstein, population 34000.	PV activity (see comments following table).
New Caledonia, population 0.25 millions.	1.8 TWh of electricity generated annually. Exploratory work on unprocessed coconut oil as diesel substitute.
Maldives, population 0.33 millions.	A strong move away from fossil fuels for power generation.
Faroe Islands (Danish), population 49000.	0.07 TWh of electricity from hydro (2010 figure). Also wind power (see discussion below).
Saint Kitts and Nevis[2], population 51000.	0.13 TWh of electricity consumed annually.
Tuvalu, population 9500.	PV activity.

In the Falklands carbon mitigation is not the only factor having stimulated wind farm activity: conventional fuels are imported therefore expensive. In fact diesel was used entirely to generate electricity before wind power became available. Total generation at the present time is 0.02TWh per year, about 40% from wind power [1]. Carbon dioxide from the remaining 60% will be of quantity:

$$[(0.6 \times 0.02 \times 10^{12}\ \mathrm{J\ s^{-1}} \times 3600\ \mathrm{s}/0.35)/(43 \times 10^{6}\ \mathrm{J\ kg^{-1}})] \times (44/14) \times 10^{-3}\ \mathrm{tonne\ kg^{-1}}$$
$$= 9000\ \mathrm{tonnes}.$$

accounting then for about 15% of the total. The balance of 85% is accounted for by activities including servicing the fishing industry, vessel movements, oil exploration and of course motor vehicles. The matter of carbon dioxide emissions has been taken seriously in Vatican City. In 2007 a Hungarian company undertook to plant, in a national park in that country, a number of trees annually the carbon sequestration by which would exactly offset the carbon dioxide released by the Vatican City [2]. The land so afforested would be called the Vatican Climate Forest. It has not as yet become a reality. More sensibly and realistically, PV cells are to be installed on the roof of a large auditorium in the Vatican. These will produce electricity whether or not the auditorium is in use.

The annual carbon footprint of Malta's electricity generation will be:

$$(2 \times 10^{12}\ \mathrm{J\ s^{-1}} \times 3600\ \mathrm{s}/0.35)/(43 \times 10^{6}\ \mathrm{J\ kg^{-1}})] \times (44/14) \times 10^{-3}\ \mathrm{tonne\ kg^{-1}}$$
$$= 1.5\ \text{million tonnes of carbon dioxide.}$$

and there is major activity in tree planting in the country [3]. The Malta Resources Authority reports [4] that 2317000 litres (≈ 55000 bbl) of biodiesel were consumed in Malta in 2007, 2059000 litres (≈ 49000 bbl) in the transport sector. This was to the total exclusion of ethanol fuel. The 'Times of Malta' reported in July 2012 that the average age of a car in Malta is 13.86 years; there are many in the 15 to 25 year age bracket and not a few beyond that! These will emit more carbon dioxide than the figure of 100 g per mile which has been used previously in this book and which is typical of values applied by motor licensing authorities in countries such as the UK.

In 2010 a not quite negligible 4% of the energy requirement of Liechtenstein was met by wood fuel, a plus for carbon mitigation. There are several small photovoltaic installations which together supply of the order of 0.5 GWh annually to the grid. This tiny country appears to be responsive to the exigencies of carbon mitigation. Perhaps, as the only country wholly within the Alps, she senses a particular responsibility.

It is on account of its isolation that New Caledonia has been included in this chapter. Its capital Nouméa is said to be one of the most isolated capital cities in the world. (The same has been said of Wellington NZ.) About a quarter of New Caledonia's electricity is hydro. There has been a highly speculative proposal [5] that the mineral peridotite could be used in carbon sequestration by reason of its reaction with carbon dioxide. Proposals are hydraulic fracture of the peridotite deposits and admittance of carbon dioxide with which it would form a stable compound. There is major peridotite in New Caledonia. The idea is that the country would accept CO_2 as a 'negative import', that is, would charge to receive it, and would sequestrate it in the peridotite. This is an interesting and soundly based idea but whether it will be ever be implemented the author would not care to predict.

The Indian Ocean nation of Maldives once generated all of its electricity from imported diesel. There has not been total elimination of this, but there is now also generation using wood pellets from approved sources. There is no wind power as yet but there are plans plans (surely not unduly ambitious) for a 75 MW nameplate capacity wind farm near the capital Male, which will have thirty turbines. The Faroe Islands (next row) have a nameplate capacity of 4MW of wind power giving, on the usual criterion:

$$4 \times 10^{-6} \text{ TW} \times 2500 \text{ hour} = 0.01 \text{ TWh}$$

and this is about 4% of the current consumption of the Islands. St. Kitts and Nevis (following row) obtains all of its electricity from imported diesel. Once a major sugar producer, it has by government decree produced none since 2005, so an opportunity to get into the ethanol trade was missed. The multi-island Polynesian island of Tuvalu has a 40 kW PV capacity which cannot be declared negligible when considered against the following. The largest of the islands comprising Tuvalu is Vaiutpu, which has a peak demand during working hours of 50 kW.

14.3 Concluding remarks

There would be many potential MSc projects in identifying other remote 'corners of the world' and analysing their energy supply and demand, and even PhD projects if engineering and economic factors were brought together with precision and there were some field trips to the places of interest. This short chapter has hopefully informed a reader that many small and/or isolated places with little 'clout' at world level are showing responsibility to their own inhabitants and also fulfilling their obligations to world endeavours in carbon dioxide emission reductions.

14.4 References

[1] http://www.renewableenergyfocus.com/view/7404/40-wind-energy-in-the-falklands/

[2] http://www.nytimes.com/2007/09/03/business/worldbusiness/03iht-carbon.4.7366547.html?pagewanted=all

[3] http://www.di-ve.com/national/80-trees-planted-part-34u-survive

[4] http://www.co2star.eu/events/slovenia/Buttigieg.pdf

[5] http://www.unesco.org/csi/smis/siv/Forum/CoconutOilFuelPacific_JanCloin.pdf

Postscript

Someone born in the year of publication of this book will be either very elderly or deceased by 2100, which is the year upon which Kyoto targets are to a large degree focused. He or she will throughout life be continually reminded of the importance of carbon mitigation as its importance on the world agenda grows and grows. A time might even come when 0 AD is set aside as the baseline for numbering the centuries and one appertaining to carbon mitigation replaces it, perhaps the year in which the carbon dioxide level of the atmosphere first started to drop. In view of what is reported in Chapter 1 of this book, our forebears of about a century ago might be retrospectively be seen as having been irresponsible in their profligate use of coal and oil. Whatever, carbon mitigation will drive policymaking and influence affairs to a degree that could affect the very mindset of persons across the races and this makes a good understanding of the basics important. In a very modest way, this book has attempted that.

15 Endnotes

1. Reference [12] gives a value nearly twice this for as soon as 2017.
2. NYC, which might logically have belonged here, is covered in Table 5.1.
3. Tokyo Electric Power Company
4. A two-island nation, analogously to Trinidad and Tobago.