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REGIONAL WOOD ENERGY DEVELOPMENT PROGRAMME IN ASIA
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Energy and Environment Basics

Compiled in co-operation with

Technology and Development Group
University of Twente, Netherlands

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FOREWORD

Discussing energy problems without using adequate concepts and proper terminology, dimensions and units, makes as little sense as disregarding the universal laws of nature. It is virtually impossible to make a sensible contribution to energy development without reference to quantitative issues. This is well understood by scientists and engineers, but there are many more disciplines to contribute to the diverse problems of energy development. The same applies to some extent to issues of the (natural) environment. Also wood energy development is a science-based subject, for which contributions from many different disciplines are needed.

The present document aims to be of assistance to those who work in the field of energy and related aspects of environment, but do not have their education in science or engineering. It is not a compendium for specialists. It may rather serve as a basic training and reference material.

The document has been prepared in cooperation with the Technology and Development Group of the University of Twente in the Netherlands. Inputs and overall editing were provided by Jaap Koppejan, Associate Professional Officer at RWEDP, with assistance from other RWEDP staff. In due course, RWEDP aims to prepare a document on 'Wood Energy and Environment Basics' which may even more specifically serve those involved in developing wood and other biomass energy. Comments and suggestions from readers will be welcome.

In the mean time it is hoped that the present document will serve a large audience. More copies can be requested from RWEDP.

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1. BASIC INTRODUCTION TO ENERGY

It is not unusual to hear colleagues, friends or family members say “I’ve got no energy today!” when they don’t feel up to completing an assignment, playing sport or washing the dishes. This everyday expression is actually very close to the scientific definition of **energy**. Energy is the ability (or capacity) to do **work**. The word “work” here, to a scientist or engineer, has a much broader meaning than simply going to the office or factory. However, non-technical people can still think of energy as the ability to do all the hundred and one diverse things we might need or want to do in our daily lives, from switching on a light to building a house.

Energy itself is not a thing or substance but an idea, a theoretical concept, used to connect diverse processes, such as burning fuels, propelling machines or charging batteries, and to explain various observations about these processes. Central to the concept of energy is that processes which might at first sight appear to be very different, like those referred to in the previous sentence, actually have a number of common features. Describing these common features leads us to a greater understanding of what energy is.

1.1 Energy Forms and Conversions

A basic concept about energy is that while it has many forms (see Box 1.1), and can be **converted** from one form to another (though some of the conversions would have no practical value) or **transformed** from one grade of the same energy form to another (for example from high temperature heat to low temperature heat), it can never be “used up”, and the actual amount of energy stays the same. This is the basis of the **First Law of Thermodynamics:** in any process involving energy, the total quantity of energy is conserved.

However, from our observations of normal life, we know that in practical terms, energy does run out. Batteries in, for example, a torch eventually stop producing **electrical energy** and have to be replaced. What has actually happened is that the torch’s bulb has converted the electrical energy into light – the energy form it is designed to produce – and, to a large extent, waste heat. The original **chemical energy** stored in the battery has not disappeared, it has just radiated into the environment, where we can no longer make use of it. The energy may be lost to the system (the torch and battery),

BOX 1.1 FORMS OF ENERGY

Kinetic energy: energy possessed by a moving object, such as wind or water in a stream. Speed and mass of the object influence the amount of kinetic energy. The faster the wind blows or the more water flowing in a stream the more energy is available.

Potential energy: energy possessed by an object’s position relative to the earth’s surface. This is stored energy which if the object falls is converted into kinetic energy. For example, water behind a dam: the higher the dam or the greater the amount of water, the higher the potential energy.

Thermal energy (heat)**:** A form of kinetic energy due to the random motion of the atoms or molecules (the building blocks) of solids, gases or liquids. The faster the atoms or molecules move, the greater the thermal energy of the object, usually described as the hotter the object is.

Chemical energy: A form of energy stored in atoms or molecules. This energy is usually utilised by converting into heat (combustion) or electrical energy (batteries).

Electrical energy: Most familiar in the form of electricity, which is the organised flow of electrons (one of the building blocks of an atom) in a material, usually a metal wire.

Electromagnetic energy (radiation): A form of electrical energy which all objects, in different amounts, emit or radiate. The most familiar forms are light and sound.

Mechanical energy: The energy of rotation usually associated with a rotating shaft.

but the *total* amount of energy is the same before and after. It should be noted here that we tend to focus on the energy form we want (the useful energy – the light in our example) and regard the other as wasted (the heat), and so we neglect or overlook it. This can be an expensive mistake, and energy conservation efforts pay a lot of attention to reducing the size of this waste.

Energy conversions are just the ways in which we harness and utilise energy. For example, we convert the **potential energy** of water stored in a dam into the **mechanical energy** of a turbine, which in turn is converted into electrical energy. To pump water up from a well we do the reverse. In everyday English we talk about "generating" and "consuming" energy, especially when discussing electricity. These are, in fact, scientific impossibilities – what we are actually describing is *converting* one form of energy to another. By generating electricity we usually mean converting the **chemical energy** stored in a fuel such as coal or oil, by **combustion** into **heat energy**, which in turn is converted into the mechanical energy of a turbine, and then into electricity. What we in fact consume are fuels, which are forms of stored chemical energy.

1.2 Energy and Power

When utilising an energy conversion we are usually concerned with two things: the *quantities* of energy involved and the *rate* at which energy is converted from one form to another, or (particularly in the case of electricity) transmitted from one place to another via a **medium**, such as water or high-voltage cable. The rate per second at which energy is converted or transmitted is called the **power**. Thus there is a mathematical relation between the two concepts:

$$\text{energy} = \text{power x time} \qquad \textit{or} \qquad \text{power} = \frac{\text{energy}}{\text{time}}$$

In qualitative terms, this means that if you have a given quantity of energy, the greater the rate at which you use it, the larger the amount of power produced. Take, for example, the chemical energy stored in a tank of petrol, which, by a succession of conversion processes, eventually becomes the **kinetic energy** of the moving car. The more petrol allow into the engine per intake stroke (by depressing the accelerator), the more power the engine will produce and the faster the car will move. Another way to look at this is that the more power you want from the engine, the quicker you will use up the fuel.

In everyday English, the words "power" and "energy" are often used interchangeably. If the meaning is clear in the context, then a lack of scientific accuracy is not a problem. However, in energy planning it is vitally important you are clear which you mean.

When describing energy conversions, the energy resources undergoing transformation are usually characterised in terms of their quantities, and the conversion equipment in terms of the amount of

BOX 1.2 RELATIONSHIP BETWEEN ENERGY AND POWER

At what rate per hour does a 1 kW heater convert electrical energy into heat?

energy = power x time

1 kW is 1,000 watts
Since 1 watt is 1 joule per sec
1,000 watts is 1,000 joules per sec

In one hour there are 3,600 seconds

Substituting in the equation
energy = 1,000 x 3,600 joules
= 3,600,000 joules
= 3.6 MJ

Therefore a 1 kW heater converts 3.6 MJ of electrical energy into heat per hour.

power it consumes or produces. The next section looks at energy and power in quantitative terms.

1.3 Dimensions and Units of Energy and Power

There are many ways of measuring energy, and although most scientists internationally use the same unit, the **joule** (abbreviated as J), it is quite common to find other units in everyday use. Americans and many engineers, particularly when talking about steam, use **British Thermal Units** (abbreviated as BTUs), and in India the **calorie** (abbreviated as cal) is still common. National energy statistics use **tonnes of coal equivalent** or **barrels of oil equivalent**. It is possible and, for comparisons, desirable to convert the different units from one to the other, and Chapter 2 contains tables which give the appropriate factors to make these conversions.

BOX 1.3 NON-ELECTRICAL ENERGY UNITS

A boiler consumes half a cubic metre of natural gas in one hour. What is the power input?

The heat energy content of natural gas is 38 MJ per cubic metre. Therefore in one hour the boiler has converted 19 MJ of heat energy

power = energy/time
= 19/3,600
= 5,300 joules per second
= 5.3 kW

Power is almost universally measured in **watts** (abbreviated as W). 1 watt is defined as the power produced when converting 1 joule of energy per second, which can be written as 1 J/s (or 1 J s^{-1}) (see Box 1.2 for a worked example). 1 joule and 1 watt are very small quantities compared to the amounts converted in many types of equipment, so it is quite common to use multiples of ten for both quantities (for example 10^3 J; 10^6 W) or to abbreviate the powers of 10 with prefixes, for example **kilo**watt (1 kW = 10^3 W), **mega**watt (1 MW = 10^6 W), **kilo**joule (1 kJ = 10^3 J) and **giga**joule (1 GJ = 10^9 J)

BOX 1.4 MAGNITUDE OF 100 KJ OF ENERGY

100 kJ of energy is equivalent to:

- ⇒ radiation from the sun falling on the roof of a house (of about 40 m^2) in 2.5 s
- ⇒ heat released on burning 3.5 g coal or 2.9 g petrol
- ⇒ potential energy of object (1,000 kg) at a height of 10 m
- ⇒ energy captured by a windmill of 3 m diameter in 20 mins in a wind blowing at 5 m/s
- ⇒ energy stored in a car (1,000 kg) moving at 50 km/h
- ⇒ heat emitted when 3 cups of coffee (0.4 kg) cools from 80°C to 20°C
- ⇒ energy needed to melt 0.3 kg of ice
- ⇒ electrical energy consumed by 100 W light bulb in 17 minutes
- ⇒ rotation energy of flywheel 0.6 m diameter, 70mm thick rotating at 1,500 revolutions per second

Many electrical appliances are sold in terms of their power rating, for example a 60 W light bulb or 1 kW hot plate. It is therefore very common to measure electrical energy consumption (i.e. conversion) in terms of power and time. For example, a one kilowatt device running for one hour uses 1 kilowatt-hour (kWh), which is 3.6 MJ, of energy.

The form of the energy can also be distinguished in the output from a particular piece of equipment. For example, a steam turbine produces both thermal and mechanical energy that can be used by the equipment coupled to it. When it is not clear from the context, a subscript can be added to the abbreviation to indicate what form of output energy we refer to: thermal energy – $kW_{\mathbf{th}}$; electrical energy – $kW_{\mathbf{el}}$; mechanical – $kW_{\mathbf{m}}$. Non-electrical energy conversion processes can also be described in terms of power. (see Box 1.3 for a worked example.)

The joule and the watt belong to the international system known as **SI units**. A list of the common SI units is given in Chapter 2.

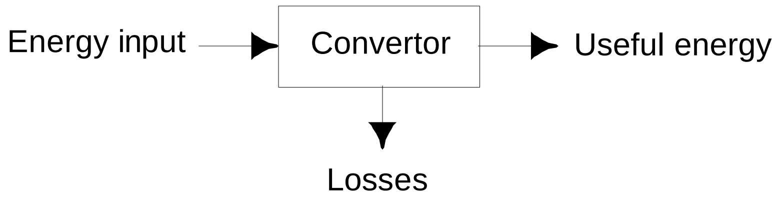
It is important not only to be able to make quantitative comparisons about energy but also to have an appreciation of the magnitudes of energy, in its different forms, and of power. Box 1.4 gives some representative examples of energy while Box 1.5 shows some comparative orders of magnitude of power and energy.

BOX 1.5 ORDERS OF MAGNITUDE OF ENERGY AND POWER

1 kWh	Roughly energy consumed by electric hot plate in one hour
1 MWh	Roughly energy needed to drive a car 1000 kilometres
25 TWh	Roughly energy demand in Philippines in 1991
1 kW	Power rating of an air conditioner
10 kW	Power rating of small tractor/power tiller
1 MW	Rated output of power station serving a small town of around 20,000 people.

1.4 More on Energy Conversions and Efficiency

It was noted above that when one form of energy is converted into another for a particular purpose, not all the energy ends up where you would like it, and energy is wasted or lost to the process. This loss is usually in the form of heat. The ratio of the useful energy output to the required input is the **efficiency** of the process – the higher the efficiency, the less energy is "lost". Efficiency is represented by the Greek letter η and is usually expressed as a percentage.



The efficiency of an energy conversion process is never 100%. It can be as high as 90% (for example in a well-run water turbine) or very much less than that (for example 10–20% in a typical internal combustion engine). Inefficiency can be reduced by good equipment design and use, but some is inherent in the nature of the energy conversion, and an understanding of these inherent inefficiencies is the key to optimising energy use. Some typical conversion efficiencies are given in Table 1.1.

Table 1.1 Typical conversion efficiencies of different energy conversion technologies

converter	**form of input energy**	**form of output energy**	**typical efficiency**
petrol engine	chemical	mechanical	20-25 %
diesel engine	chemical	mechanical	30-45 %
electric motor	electrical	mechanical	80-95 %
boiler and turbine	thermal	mechanical	7-40 %
hydraulic pump	mechanical	potential	40-80 %
hydro turbine	potential	mechanical	70-99 %
hydro turbine	kinetic	mechanical	30-70 %
generator	mechanical	electrical	80-95 %
battery	chemical	electrical	80-90 %
solar cell	light	electrical	8-15 %
solar collector	light	thermal	25-65 %
electric lamp	electrical	light	5 %
water pump	mechanical	potential	60 %
water heater	electrical	thermal	90-92 %
lpg stove	chemical	thermal	60-70 %
wood stove	chemical	thermal	12-30 %
charcoal stove	chemical	thermal	20-30 %
charcoal kiln	chemical	chemical	25-40 %

Box 1.6 HEAT AND TEMPERATURE

Heat is thermal energy due to the motion of atoms or molecules. When an atom or molecule collides with another of lower, energy a transfer of kinetic energy takes place which is always from the faster (hotter) to the slower (cooler). This flow of heat enables a scale of relative “hotness” to be defined, which is what is meant by “temperature”.

There are a number of different temperature scales. The SI scale used by scientists takes the starting point of zero as the point when molecules have no motion. The unit of temperature on this scale is the Kelvin (abbreviated to K). The most common scale in daily use is the Celsius scale (written as °C), in which zero corresponds to the freezing point of water.

Values on the two scales can be easily converted from one to another using the formula:

temperature (K) = temperature (°C) + 273

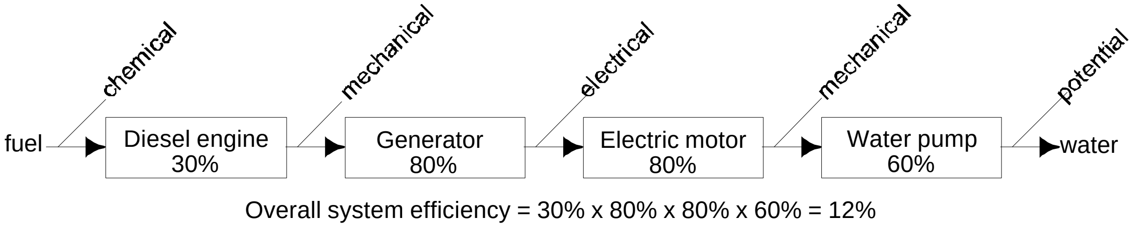
Another scale still used by many people is the Fahrenheit (written as °F). This is converted into the Kelvin scale as follows:

temperature (K) = 5/9F + 255

A Fahrenheit temperature is converted into a Celsius temperature by first subtracting 32 and then multiplying by 5/9.

A Celsius temperature is converted into a Fahrenheit temperature by first multiplying by 9/5 and then adding 32.

Figure 1.1 Efficiency of an energy conversion system



The process of converting the form of energy input to the final output form generally comprises a number of intermediate transformations or conversions. There are five conversion stages in the diesel-powered water pump system shown in Figure 1.1: the chemical energy of the fuel is converted, by the diesel engine, into mechanical energy to turn a shaft which the generator converts to electrical energy. An electric motor converts the electrical energy back to mechanical energy in the pump and the pump raises the water to the surface, and in so doing transforms the mechanical energy into the potential energy of the water. Each stage in the process has its own conversion efficiency and the overall system efficiency is found by *multiplying* the efficiencies of the individual stages.

Clearly, the more stages there are in a conversion process the lower is the overall system efficiency. This means not only a loss of useful energy, but a financial cost as well, so an energy conversion system should generally be designed with as few stages as possible. Another way to get round the problem, is to harness the waste heat from one stage and use it elsewhere. For instance, the exhaust gases from a boiler in an agro-processing factory, which usually contain a substantial amount of heat energy, can be used, via a heat exchanger, to dry the product. By reducing both wasted heat energy and the requirement for input energy at the drying stage, this increases the overall energy efficiency of the system.

This idea is the basis of **co-generation** or **combined heat and power** (CHP), where the waste heat from electricity generation is used as **process heat** in a factory. A good example is the sugar industry – in many cases, the factory generates its own electricity using a turbine (which is often coupled to a boiler using the crushed sugarcane fibres, or bagasse, as fuel). Rather than allowing it to run off into the atmosphere, the heat remaining in the exhaust gases is used, via a heat exchanger, to evaporate water out of the raw cane juice, an essential part of the extraction process. The overall efficiency of a co-generation system can be 80% or higher. Using the energy of the original source for two or more applications is known as **cascading**, where the grade of energy required is closely matched to the available energy.

Yet the efficiency of an energy conversion process depends not only on the equipment used, but also on the form of the input energy. Some forms can be converted more efficiently than others. This is related to their actual potential to do work (or **exergy**). The higher the exergy content of an amount of energy, the more easy it is to do a certain task. For example boiling a cup of water with 10 MJ of heat at 1000 °C will be much easier than boiling the same cup of water with 10 MJ of heat at 110 °C. After any conversion process, the exergy or ability to do useful work is less than it was before the conversion, either due to energy losses or quality degradation.

Chemical energy, kinetic energy of moving matter, stored potential energy and electrical energy can be shown to have an exergy content equal to 100% of their energy, so conversion to lower energy forms can easiliy be realised easily with only small energy losses. Below them are high temperature heat and then low temperature heat with less than 100% exergy content in the energy. Since during any conversion process exergy content can at best remain constant, the conversion from a lower grade energy form such as low temperature heat, to a higher-grade energy form such as electricity is inherently inefficient. The efficiency of electricity generation using a steam or gas turbine is limited to about 40% since exergy is lost during fuel combustion that cannot be retrieved in the turbine. Present research therefore focusses on increasing the turbine operating temperatures. It stands to reason that the use of difficult to produce, high grade energy carriers such as electricity to fullfil a low-grade energy demand such as boiling water should be avoided as it is irrational and expensive. Though maybe less convenient, it would be more efficient and cheaper to boil the water directly with gas.

BOX 1.7 POWER STATIONS AND WASTE HEAT: A SECOND LAW ANALYSIS

The Second Law of Thermodynamics can be expressed as an equation, which can be used to calculate the maximum theoretical efficiency of a conversion process where heat energy is converted to mechanical or electrical energy. Steam turbines used in many fossil fuelled power stations are heat engines. The efficiency depends upon the temperature of the steam reaching the turbine and the lower temperature of the steam leaving to be condensed. If these are called T_U and T_L respectively then:

$$\text{maximum theoretical efficiency} = (T_u - T_L)/T_u)$$

(The Kelvin temperature scale must be used in the formula.)

If steam enters the turbine at 550 ^oC and is ultimately cooled to 27 ^oC the maximum thermodynamic efficiency is given by:

Inserting the values

$$T_U = 550 + 273 = 823 \text{ K}$$
$$T_L = 27 + 273 = 300 \text{ K}$$

into the formula gives:

$$(823 - 300)/823 = 0.635 \text{ or } 63.5\%.$$

In practice the best steam turbines achieve around 66% of the theoretical maximum efficiency which means that the actual efficiency is likely to be: 0.66 x 0.635 = 0.42.

To obtain an overall system efficiency the turbine efficiency needs to be combined with boiler and generator efficiencies, both of around 88%:

0.88 x 0.42 x 0.88 = 0.33 or 33%

Box 1.7 gives an example of an energy efficiency analysis based on the Second Law of Thermodynamics.

1.5 Energy Flows

It was remarked earlier that energy conversions from the original source to the useful form often take place in a number of intermediate stages. The energy flows from one form to another at each conversion, transformation or transport step, and these steps can be considered as a chain. Constructing such a chain enables an energy analyst to look at the efficiencies of the different stages in order to reduce costs and avoid unnecessary losses.

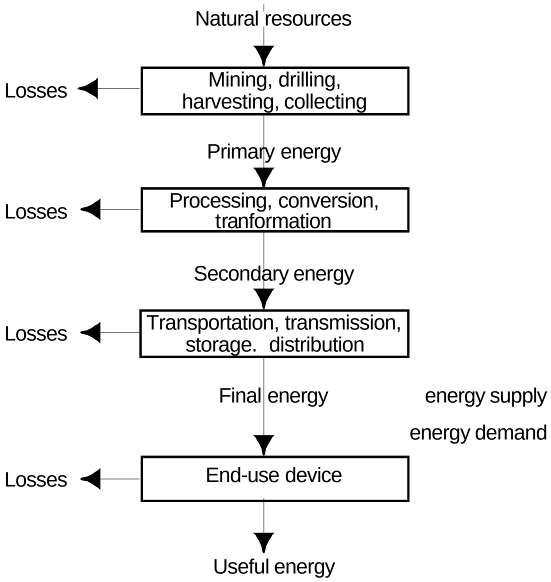


Figure 1.2 The energy chain

When constructing the chain, energy is classified into four types: primary, secondary, final and useful. **Primary energy** is the energy in the form in which it is available in the natural environment. **Secondary energy** is the energy ready for transport or transmission. **Final energy** is the energy which the consumer buys or receives and **useful energy** is the energy actually required to perform the work. To illustrate the difference between final and useful energy, consider a light bulb: the final energy of the process enters the bulb, but most is wasted as heat. The useful energy, the light, may represent less than 10% of the final energy. This example aside, useful energy is almost always in the form of heat or mechanical **shaft energy**. For or a few end uses, for example, communications equipment, electricity is the useful form.

An example of an energy flow or chain is the use of water to run a saw mill. The primary energy is potential energy stored in the water in a dam. The water is used in a hydro power station, where the potential energy is converted to electricity – the secondary energy. The electricity is transmitted to the saw mill, where it is converted to the useful form of shaft energy. In this case, the secondary and final forms are the same.

Figure 1.2 illustrates the concept of the chain and Figure 1.3 gives an example of a typical energy chain for fuelwood.

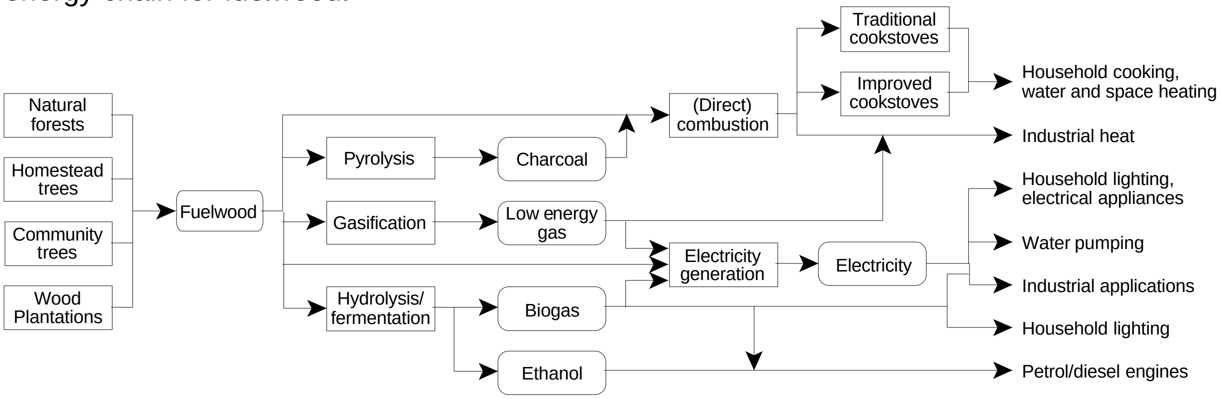


Figure 1.3 A possible energy chain for fuelwood

1.6 Primary Energy Sources

The previous section referred to primary energy sources as energy as it is available in the natural environment. These include:

Biomass energy: any material of plant or animal origin such as woody biomass (stems, branches, twigs) non-woody biomass (stalks, leaves, grass), agricultural residues (rice husk, coconut shell), and animal and human faeces. The energy can be converted through a variety of processes to produce a solid, liquid or gaseous fuel. The biomass usually needs some form of processing stage prior to conversion, such as chopping, mixing, drying or densifying.

Solar energy: energy from the sun comes as either **direct radiation** or **diffuse radiation**. Direct radiation is only collected when the collector (e.g. a leaf or a solar panel) faces the sun. Diffuse radiation comes from all directions and is even present on a cloudy day. The energy falling on a surface of a specified area is less for diffuse radiation than direct radiation. Solar energy can be converted through thermal solar devices to heat, or through photovoltaic cells to electricity.

Hydro energy: utilises the potential energy from water stored behind dams, weirs or natural heads (water falls) and the kinetic energy of streams or rivers. Water wheels and hydro turbines are used to convert this energy source to mechanical or electrical energy.

Wind energy: the kinetic energy from the wind is converted by wind turbines (also known as wind generators or windmills) into mechanical energy (usually for water pumping) or electrical energy.

Geothermal energy: heat flow from the earth's core to the surface by molten rock or hot water. The heat can be used for space heating, drying, process heat applications or electricity generation.

Animate energy: energy delivered by humans and animals. This is a major source of energy in agriculture in many developing countries, but never appears in national energy balances.

Ocean energy: includes three energy sources: wave and tidal, which both utilise the kinetic energy of moving water, and ocean thermal, which utilises the heat flow between the warm surface waters and cool deep waters of tropical oceans. All three are still at early stages of development, but the intention is to use them to generate electricity.

Fossil fuels: Coal, crude oil and natural gas. The main commercial fuels around the world.

Nuclear energy: energy released when the nuclei of atoms (usually uranium) break apart. This energy is utilised by converting it into electrical energy.

Although these sources are called primary, with the exceptions of solar, nuclear and tidal, they are not ultimate sources of energy. The remainder are come, either directly or indirectly, from solar energy.

1.7 Energy Terminology

Energy sources are sometimes classified under headings such as renewable, traditional, modern, commercial and conventional. The terminology is rather ambiguous, since it depends very much on the context. For example, wind energy is clearly renewable, but is it traditional? Windmills have been used for several centuries, making it traditional, but wind has been used to generate electricity only in this century, so perhaps it is modern. In different areas of a country a source may be classified differently. For example, fuel wood in rural areas is often non-commercial, whereas in towns it generally has to be bought. Table 1.2 shows the classification of a number of energy resources according to three criteria: familiarity (that is, conventional, traditional and non-conventional), renewability (renewable or non-renewable) and monetisation (commercial and non-commercial).

Renewable means that a source is not depleted by use – wind is always renewable, while biomass can be renewable if regrowth is matched by consumption. Fossil fuels are non-renewable, as they will eventually be depleted (i.e. run out) as there is no viable way to produce more of them. Another classification, **new and renewable**, covers all the renewable forms of energy plus ocean and geothermal. Some energy analysts also include nuclear energy in this category, though clearly not because it is renewable.

Whether an energy resource is **traditional** or **non-traditional** depends very much on the user's perspective. Many biomass users would be regarded as using a traditional source (that is, what they have always used) and they would regard using fossil fuels as non-traditional. However, it can be the conversion technology rather than the resource which determines the classification. Wood can be regarded as a traditional energy resource, but if it is used in a gasifier it produces a non-traditional energy source. Similar difficulties arise when categorising energy sources as **conventional** and **non-conventional**.

Commercial energy refers to those energy sources for which have to be paid for. This always includes the fossil fuels and some new and renewable sources. Biomass is usually classified as **non-commercial** – however, this depends again on where you are in the world.

Table 1.2 demonstrates that a fuel can be placed in more than one category and that there are no hard and fast rules. Classification depends on circumstances, and an energy analyst should be prepared to exercise some flexibility and make clear what fuel classification is being used.

Table 1.2 Energy supply terminology by different classifications

Resource	Familiarity			Reproducibility		Monetisation	
	Conventional	Traditional	Non-Conventional	Renewable	Non-Renewable	Commercial	Non-Commercial
Large scale hydropower	♦			♦		♦	
Coal	♦				♦	♦	
Oil and gas	♦				♦	♦	
Nuclear	♦				♦	♦	
Fuelwood		♦	♦	♦		♦	♦
Agricultural residue		♦	♦	♦			♦
Animal dung		♦	♦	♦		♦	♦
Animal labour	♦	♦		♦		♦	♦
Industrial waste		♦	♦		♦	♦	
Solar thermal		♦	♦	♦		♦	♦
Solar photovoltaic			♦	♦		♦	
Wind		♦	♦	♦		♦	♦
Small-scale hydropower		♦	♦	♦		♦	♦
Biogas			♦	♦		♦	

2. BASIC SI UNITS, PREFIXES, AND DERIVED SI UNITS USED

2.1 Basic SI Units

Basic Unit	Unit	Abbreviation
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	Kelvin	K

2.2 SI Prefixes

Prefix	Abbreviation	Factor	Prefix	Abbreviation	Factor
exa	E	10^{18}	deci	d	10^{-1}
peta	P	10^{15}	centi	c	10^{-2}
tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	µ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}
hecto	h	10^{2}	femto	f	10^{-15}
deca	da	10^{1}	atto	a	10^{-18}

2.3 Most Common Derived SI Units

name	unit	abbreviation
area	square metre	m^2
volume (contents)	cubic metre	m^3
speed	metre per second	m/s
acceleration	metre per second squared	m/s^2
frequency	hertz	Hz (= s^{-1})
pressure	Pascal	Pa (= N/m^2)
volume flow	cubic metre per second	m^3/s
mass flow	kilogram per second	kg/s
density (specific mass)	kilogram per cubic metre	kg/m^3
force	Newton	N (= $kg.m/s^2$)#
energy/heat/work	joule	J (= N.m)*
power/energy flow	watt	W (=VA=J/s)
energy flux	watt per square metre	W/m^2
calorific value (heat of combustion)	joule per kilogram	J/kg
specific heat capacity	joule per kilogram per Kelvin	J/kg K
voltage	volt	V (= W/A)

A mass of 1 kg exerts a force of approximately 10 N (Exact value depends on position on earth since force = g N, where g is acceleration due to gravity. g is 9.781 m/s^2 at the equator.)

* The joule can also be written in the form watt second (1 J = 1 W.s)

NB In many calculations, the symbol π (pi) is used. π is the ratio of a circumference of a circle to its diameter and can be represented by the value 3.14159 (although in many instances 3.14 would be sufficiently accurate).

2.4 Conversion of Non-SI Units to SI Units

Although scientists and engineers must be strict in their use of SI units for their calculations, in the every day world a number of non-SI units are still commonly used. Manufacturers of small scale energy equipment are no exception. For example, engines are still sold by cc (cubic centimetres of fuel-holding capacity) and hp (horse power), and water pumping windmill manufacturers often quote in terms of cubic feet of water pumped per hour. Even among manufacturers of the same type of equipment, consistency in the use of units is lacking. Therefore, in order to be able to compare the products of different manufacturers, it is important to be able to convert the different data to a common unit. The tables below give useful conversion factors for some common non-SI units. The conversion ratios given in the tables below can be used to convert the unit in the left-hand column to the unit in the top row, above the ratio. (For example, 1 inch = 25.4 mm, while 1 mm = 0.0394 inches.)

length

unit abbreviation	**millimetre mm**	**metre m**	**kilometre km**	**inch in**	**foot ft**	**mile m.**
mm	1	0.001	10^{-6}	0.0394	0.0033	5.4×10^{-7}
m	1,000	1	0.001	39.4	3.28	5.4×10^{-4}
km	10^{6}	1,000	1	39360	3280	0.5392
in	25.4	0.025	2.5×10^{-5}	1	0.083	1.4×10^{-5}
ft	305	0.305	3.0×10^{-4}	12	1	1.9×10^{-4}
m.	1.6×10^{6}	1,609	1.609	63,360	5,280	1

area

unit abbreviation	**square metre m^2**	**hectare ha**	**square kilometre km^2**	**square foot ft^2**	**acre acre**	**square mile sq.m.**
m^2	1	10^{-4}	10^{-6}	10.76	2.5×10^{-4}	3.9×10^{-7}
ha	10000	1	0.01	1.1×10^{5}	2.471	3.9×10^{-3}
km^2	10^{6}	100	1	1.1×10^{7}	247.1	0.386
ft^2	0.0929	9.3×10^{-6}	9.3×10^{-8}	1	2.3×10^{-5}	3.6×10^{-8}
acre	4,047	0.4047	4×10^{-3}	43,560	1	1.6×10^{-3}
sq.m.	2.6×10^{6}	259	2.590	2.8×10^{7}	640	1

volume

unit abbreviation	litre L	cubic metre m^3	cubic inch in^3	gallon (US) gal	gallon (Imperial) gal	cubic foot ft^3
L	1	10^{-3}	61.02	0.264	0.220	0.0353
m^3	1,000	1	6,102	264	220	35.31
in^3	0.0164	$1.6x10^{-5}$	1	$4.3x10^{-3}$	$3.6x10^{-3}$	$5.8x10^{-4}$
gal	3.785	$3.8x10^{-3}$	231.1	1	0.833	0.134
gal	4.546	$4.5x10^{-3}$	277.4	1.201	1	0.160
ft^3	28.32	0.0283	1,728	7.47	6.23	1

mass

unit abbreviation	gram g	kilogram kg	tonne t	pound lb	ton ton
g	1	0.001	10^{-6}	$2.2x10^{-3}$	$9.8x10^{-7}$
kg	1000	1	.001	2.205	$9.8x10^{-4}$
t	10^{6}	1,000	1	2,205	0.984
lb	453.6	0.4536	4.5x10-4	1	$4.5x10^{-4}$
ton	10^{6}	1,016	1.016	2,240	1

velocity

unit abbreviation	metres/second m/s	kilometres/hour km/h	feet/second ft/s	miles per hour mph	knots kt
m/s	1	3.60	3.28	2.237	1.768
km/h	0.278	1	0.912	0.621	0.539
ft/s	0.305	1.097	1	0.682	0.592
mph	0.447	1.609	1.467	1	0.868
kt	0.566	1.853	1.689	1.152	1

rotation

unit abbreviation	herz Hz	revolutions per minute rpm	radians/second rad/s
Hz	1	60	6.283
rpm	0.0167	1	0.1047
rad/s	0.159	9.549	1

flow rate

unit abbreviation	litre/minute L/min	cubic metres/second m^3/s	Imperial gallons/minute gal(Imp)/min	cubic feet/second ft^3/s (or cusec)
L/min	1	$1.7x10^{-5}$	0.220	$5.9x10^{-4}$
m^3/s	60,000	1	13,206	35.315
gal(Imp)/min	4.546	$7.6x10^{-5}$	1	2.7x103
ft^3/s	1,699	0.0283	373.7	1

force

unit abbreviation	newton N	kilonewton kN	kilogram force kgf	tonne t	pound force lbf	ton ton
N	1	0.001	0.102	$1x10^{-4}$	0.225	$1x10^{-4}$
kN	1,000	1	102	0.102	225	0.100
kgf	9.807	0.010	1	0.001	2.205	$9.8x10^{-4}$
t	9,807	9.807	1,000	1	2,205	0.984
lbf	4.448	0.004	0.5436	$4.5x10^{-4}$	1	$4.5x10^{-4}$
ton	9,964	9.964	1,016	1.1016	2,240	1

torque

unit	newton - metre	kilonewton - metre	pound - feet
abbreviation	**Nm**	**kNm**	**lbf.ft**
Nm	1	0.001	0.738
kNm	1,000	1	738
lbf.ft	1.365	1.4x10^{-3}	1

work/heat/energy (smaller units)

unit	calorie	joule	watt-hour	British Thermal Unit	foot-pound force	horsepower-hour
abbreviation	**cal**	**J**	**Wh**	**BTU**	**ft.lbf**	**hp.h**
cal	1	4.182	1.2x10^{-3}	3.9x10^{-3}	3.088	1.6x10^{-6}
J	0.239	1	2.8x10^{-4}	9.4x10^{-4}	0.7376	3.7x10^{-7}
Wh	860.4	3,600	1	3.414	2,655	1.3x10^{-3}
BTU	252	1,055	2.93	1	778	3.9x10^{-4}
ft.lbf	0.324	1.356	3.8x10^{-4}	1.3x10^{-3}	1	5.0x10^{-7}
hp.h	6.4x10^{5}	2.6x10^{6}	745.7	2,546	2.0x10^{6}	1

work/heat/energy (larger units)

unit	kilocalorie	megajoule	kilowatt hour	British Thermal Unit	horsepower hour	Metric ton of oil equivalent	Metric ton of coal equivalent
abbreviation	**kcal**	**MJ**	**kWh**	**BTU**	**hp.h**	**mtoe***	**mtce***
kcal	1	4.2x10^{-3}	1.2x10^{-3}	3.968	1.6x10^{-3}	100.3x10^{-9}	144.3x10^{-9}
MJ	239	1	0.2887	947.8	0.3725	23.88x10^{-6}	31.42x10^{-6}
kWh	860.4	3.6	1	3,414	1.341	85.98x10^{-6}	122.8x10^{-6}
BTU	0.252	1.1x10^{-3}	2.9x10^{-4}	1	3.9x10^{-4}	26.27x10^{-9}	37.53x10^{-9}
hp.h	641.6	2.685	0.7457	2,546	1	64.13x10^{-6}	91.61x10^{-6}
mtoe*	9.969x10^{6}	41,868	11,630	38.062x10^{6}	15,593	1	1.428
mtce*	6.979x10^{6}	29,310	8,142	26.645x10^{6}	10,916	0.7001	1

* These conversion ratios are based on the European Community norms of 1 tce = 29.31 GJ and 1 toe = 41.868 GJ. The United Nations uses slightly different conversion ratios. In practice, the calorific values of both oil and coal may vary significantly.

power

unit abbreviation	watt W (or J/s)	kilowatt kW	metric horsepower CV	foot-pound/ second ft.lbf/s	horsepower hp	British Thermal Units/minute BTU/min
W	1	0.001	1.4×10^{-3}	0.7376	1.3×10^{-3}	0.0569
kW	1,000	1	1.360	737.6	1.341	56.9
CV	735	0.735	1	558	1.014	41.8
ft.lbf/s	1.356	1.4×10^{-3}	1.8×10^{-3}	1	1.8×10^{-3}	0.077
hp	746	0.746	0.9860	550	1	42.44
BTU/min	17.57	0.0176	0.0239	12.96	0.0236	1

power flux

unit abbreviation	watt/square metre W/m^2	kilowatt/square metre kW/m^2	horsepower/square foot hp/ft^2
W/m^2	1	0.001	1.2×10^{-4}
kW/m^2	1,000	1	0.1246
hp/ft^2	8,023	8.023	1

calorific value (heat of combustion)

unit abbreviation	calorie/gram cal/g	megajoule/kilogram MJ/kg	British Thermal Unit/pound BTU/lb
cal/g	1	4.2×10^{-3}	1.8
MJ/kg	239	1	430
BTU/lb	0.556	2.3×10^{-3}	1

density (specific mass) and (net) calorific value (Heat of combustion) of some fuels

	density (kg/m^3)	**calorific value (MJ/kg)**
LPG	560	45.3
gasoline (petrol)	720	44.0
kerosene	806	43.1
diesel oil	850	42.7
fuel oil	961	40.1
wood, oven dried	varies	18-19
natural gas (1013 mbar, 0°C)	39.36 MJ/m^3	

NB These values are approximate, since the fuels vary in composition which affects both the density and calorific value.

*power equivalents**

	Mtoe/yr	**Mbd**	**Mtce/yr**	**GW$_{th}$**	**PJ/yr**
Mtoe/yr	1	0.02	1.55	1.43	45
Mbd	50	1	77	71	2,235
Mtce/yr	0.65	0.013	1	0.92	29
GW$_{th}$	0.70	0.014	1.09	1	32
PJ/yr	0.02	4.5x10^{-4}	0.034	0.031	1

* based on EC conversion factors

Mtoe/yr = Million tonnes of oil per year
Mbd = Million barrels of oil per day
Mtce/yr = Million tonnes of coal equivalent per year
GW$_{th}$ = Gigawatts thermal
PJ/yr = Petajoules per year

3. ENERGY ACCOUNTING

3.1 Equivalence and Replacement Values

When compiling energy statistics, or when comparing different fuel options for possible substitution of one energy source for another, energy planners need a common unit of measure. Primary energy can be physically quantified in a number of ways, depending on the energy type of the resource. For example:

- mass (tonnes of solid fuel such as coal or biomass)
- volume (barrels for liquids, such as oil, or cubic metres for gases, such as biogas)
- rate of work (horsepower)
- velocity (metres per second for wind)

Biomass can be difficult to quantify, since it is measured in a variety of non-standard units, such as head loads, buckets and bundles. A value in SI units has to be assigned to these non-standard units, which can lead to considerable uncertainty in the data.

For national energy statistics, fuels are usually classified either by their heat content (joules) or in fuel **equivalence values** (usually coal or oil equivalents). For the latter, an estimate is made of what quantity of coal (in tonnes) or oil (in tonnes or barrels) has the same energy content. Table 3.1 below gives equivalence values for some of the most common fuels.

Table 3.1 Energy equivalence values of major fuels

fuel	unit[a]	tonnes of coal equivalent [b] (tce)	tonnes of oil equivalent[b] (toe)	barrels of oil equivalent[c] (boe)	GJ[a]
coal	tonne	1.00	0.70	5.05	29.3
firewood[d] (air dried)	tonne	0.46	0.32	2.34	13.6
kerosene	tonne	1.47	1.03	7.43	43.1
natural gas	1,000 m^3	1.19	0.83	6.00	34.8
gasoline (petrol)	barrel[c]	0.18	0.12	0.90	5.2
gas oil/diesel	barrel[c]	0.20	0.14	1.00	5.7

[a] GJ/tonne is numerically equivalent to MJ/kg

[b] The energy content of 1 tce and 1 toe varies. The values used here are the European Community norms: 1 tce = 29.31×10^9 J and 1 toe = 41.868×10^9 J

[c] 1 barrel of oil = 42 US gallons = 0.158987 m^3

[d] The energy equivalent of wood can vary by a factor of 3, depending on the moisture content of wood and, to a lesser degree, species and ash content.

It is important to realise that equivalence values are not exact coefficients or conversion factors, since they can only express a *mean* value of the heat content of one fuel compared with the *mean* heat content of the same quantity of another reference energy source. It is a difficulty for energy planners that most fuels have varying heating values. This is because fuels are not homogeneous substances but are compounds, the make-up of which varies from one sample of the fuel to another. To complicate matters further, there are other parameters which influence the energy content, such as density and moisture content. This means that different reference sources use different values for their units of measure (footnote b in Table 3.1 indicates that the values given in the table are European Community norms, and this must be taken into account when comparing them with other equivalence values).

Another complication is that the energy required to achieve a certain output depends upon the efficiency of the conversion device used. This means that when considering *substituting* one energy form for another, more or less input energy maybe needed to serve the same end use, depending on what equipment is used to convert each energy form. In this case, energy equivalence values have a limited use for energy planners, since they are more interested in the *quantities* of the different forms of energy used. How much is needed to replace one source of energy by another becomes the unit of measure here. Coal or oil are usually used as the reference value for the **replacement value** of an energy form, again expressed in terms of tonnes of coal equivalent (tce) or tonnes/barrels of oil equivalent (toe or boe).

Table 3.2 gives examples of coal replacement values for some fuels. The end use has to be specified in order to reflect the different conversion efficiencies. (See for example the kerosene values for lamp and stove). The figures vary on a case-to-case basis.

Table 3.2 Coal replacement values of some energy forms

Fuel	Unit	Coal replacement per unit (kg CR)
Soft coke	kg	1.50
Kerosene (Pressure stove)	Litre	6.98
Kerosene (Wick-fed stove)	Litre	5.20
Kerosene (Lamps)	Litre	2.10
Electricity	kWh	0.70
L.Diesel.	Litre	7.68
H.S.Diesel	Litre	7.44
Charcoal	kg	1.81
Firewood (Closed chullah)	kg	0.95
Firewood (Open chullah)	kg	0.70
Dung-cake	kg	0.30
Vegetable wastes	kg	0.61

3.2 Energy Balances

An energy balance is a set of relationships accounting for all the energy which is produced and consumed, and matches inputs and outputs, in a system over a given time period. The system can be anything from a whole country to an area to a process in a factory. An energy balance is usually made with reference to a year, though it can also be made for consecutive years to show variations over time.

Energy balances provide overviews, and are basic energy planning tools for analysing the current and projected energy situation. The overviews aid sustainable resource management, indicating options for energy saving, or for policies of energy pricing and redistribution, etc. There are a number of different types of energy balance which can be made, depending on the information you need: the energy commodity account, the energy balance and the economic balance.

the energy commodity account

The energy commodity account includes all flows of energy carriers, from the point of extraction through conversion to end-use, in terms of their original, physical units such as kilotons of coal and GWh of electricity.

the energy balance

The energy balance is similar to the energy commodity account, except for the fact that all physical units are converted into a single energy unit (e.g. TJ, ktoe, ktce etc.). This type of balance uses mean energy content values because of the inevitable variations in fuel composition, especially with coal. This means that there are inherent inaccuracies within the balance, but as long as they are within accepted limits, this is common practice. The conversion ratios used always need to be noted with the balance.

the economic balance

In the economic balance, different forms of energy are accounted for in terms of their monetary value. However, variations in currency rate, subsidies, taxes etc. make it difficult to compare different energy forms, especially between countries.

An important part of preparing an energy balance is the construction of an energy chain to trace the flows of energy within an economy or system, starting from the primary source(s) of supply through the processes of conversion, transformation and transportation, to final/delivered energy and finishing with end use. The data can be laid out either in table form or in a flow diagram (see, for example, Figure 1.2).

All too frequently, energy balances are constructed in terms of primary energy without taking into account conversions or transformations. This can lead to incorrect conclusions. The most common example is electricity, a secondary energy form. Electricity is usually included in a primary energy balance either on the basis of the amount of fossil fuel needed to produce it, or, when the electricity is generated from hydro, nuclear or renewables, an energy equivalent or heat content is used. However, it is not simply a matter of taking a conversion of one single fuel to another, since the conversion efficiency varies with the primary energy source. For example, for hydro it is around 90% whereas for coal it is around 40%. The amount of energy required to produce the electricity needs to reflect these differences. To produce one unit of electricity would take at least twice the amount of energy (on a joule basis) using coal as using hydro.

An energy balance should include the following:

- commercial energy. It should be clearly specified which energy forms are included in commercial and in non-commercial energy categories (see the discussion in Section 1.7).;

- non-commercial energy, which usually includes biomass (woody and agricultural residues) and animate energy. Despite their important contribution to the energy supply, particularly in rural areas, these sources do not usually appear in national energy balances. They are difficult to quantify physically since they are traded and used in non-standard units and also they fall outside of the monetised economy, so their flows are not monitored. A few countries now include agricultural processing residues, such as bagasse and rice husk, in their energy balances.;
- non-energy products from primary energy carriers such as petrochemicals from crude oil, coal and natural gas, should be listed as a separate column.
- energy imports, exports, bunkers, stock changes, transformation (conversion of one fuel to another, for example coal to coke), distribution and conversion losses as well as, if relevant, self consumption by the energy industry, should all be included;
- an energy balance is usually constructed from two sides: 1) from end-uses back to total primary energy consumption, and 2) from resource extraction to primary energy supply. A statistical difference is sometimes included to balance for inaccuracies in supply and demand, for example, due to evaluation of losses. (These statistical differences can sometimes be as high as 10%.)

A number of inconsistencies can arise between energy balances from different countries:

- energy consumption for the extraction and preparation of primary energy sources (like coal mining) can be listed under energy consumption of the energy sector, or under losses, or the primary source may be valued as the extracted and prepared stock;
- apparent energy losses can be technical or physical (transmission and distribution) losses but can also be unmetered losses;
- some energy sources have multiple uses, such as wood (e.g. construction) or oil (e.g. lubrication), but the total amount, including non-energy uses, is often included.

The basic equation of an energy balance is:

source + import = export + variation of stock + use + loss + statistical differences

In this equation,

⇒ *sources* are local primary energy sources;

⇒ *imports* are energy sources which come from outside the country (or -depending on the boundary of the system under consideration- region, village etc.);

⇒ *exports* go to other countries, (regions, areas etc.);

⇒ *variations of stock* are reductions of stock (wood, oil) and storage;

⇒ *use* can be specified sectorally or by energy form or by end use. This includes use of fuels for non-energy purposes;

⇒ *losses* can be technical and administrative.

⇒ *statistical differences* arise since an energy balance is constructed from both resource- and end-use side with unavoidable inaccuracies.

A national energy balance is usually displayed as a matrix. The columns represent the various fuels and the rows represent the energy uses of the different activities. The cells of the matrix represent how much energy is added or subtracted by the activity of the row to the fuel in that specific column. Not all cells contain data.

Table 3.3 An example of a national energy balance matrix

Supply and consumption	Coal	Other solid fuel	Crude oil	Petroleum products	Gas	Hydro	Biomass	Non-energy use
national production								
+ imports								
- stock changes								
- exports								
total primary supply								
- energy transformations								
- sectors own uses								
- losses								
final energy production								
total final consumption								
industry sector								
transport								
agriculture								
commercial								
residential								
energy industry								

Table 3.3 shows an example of a blank energy balance sheet. The upper part of the matrix represents the production side and the lower part the consumption side. Brackets indicate negative figures. It could be broken down further, for example under industry different sub-sectors could be included (iron and steel, chemical, ferrous, paper, construction etc.) and transport could be defined in terms of form (road, rail, air or water).

3.3 Energy Auditing

Energy accounting is an energy balance prepared at the micro-level usually for a firm using different energy forms. It is the basis of energy conservation with the aim of a more rational use of energy. An **energy audit** is the basic tool of energy accounting and is a systematic method of identifying and accounting for energy flows through an industrial system or process.

An energy audit uses energy units rather than economic units. The starting point is an analysis based on the First Law of Thermodynamics, which looks at the energy input and output at each stage of a process.

Some energy audits also include an energy analysis based on the Second Law of Thermodynamics, which allows for the calculation of the minimum theoretical energy necessary for manufacturing a particular product. This value can then be used as a reference for comparison with actual energy use by an industry so enabling energy efficient targets to be set for reducing energy consumption.

The **process energy requirement** (PER) of a product is the direct energy input into the production process and related transport requirements. This value is of interest to the management of a factory. However, an energy planner may wish to take a much broader view and consider the energy content of the input materials (for example, in an agricultural processing factory, such as rice milling, the energy used in producing the fertilisers used to grow the rice). This form of analysis can be taken further to include the energy required by the machines to produce these materials, and even further to include the energy required by the machine tools to make the machines. This more extended analysis is known as the **gross energy requirement** (GER). The PER and GER figures themselves do not give information about types of energy used or variations in energy flows.

World Energy Consumption 1990 per Sub Region including alternative and traditional sources of energy

	TEC[a]			**Consumption of different sources of energy**				**Con/Cap**[e]	**Con/GNP**[f]
		Coal	Oil	Natural Gas	Fos.[b]	Alt.[c]	Trad.[d]		
	EJ	% of TEC						GJ/cap	MJ/$
World	**363**	**25**	**36**	**20**	**81**	**13**	**6**	**68.7**	**17.6**
North America	**95.8**	**22**	**38**	**24**	**83**	**15**	**2**	**348**	**16.7**
Western Europe	**61.0**	**22**	**43**	**16**	**80**	**19**	**1**	**142**	**10.5**
J.A.NZ[g]	**23.1**	**21**	**51**	**12**	**84**	**16**	**1**	**160**	**7.12**
East	**73.1**	**25**	**29**	**36**	**91**	**8**	**1**	**177**	**23.9**
Eastern Europe	14.7	46	25	19	90	9	1	118	38.1
ex-USSR	58.3	20	31	40	91	8	1	202	21.8
Africa	**15.1**	**21**	**27**	**9**	**57**	**6**	**37**	**23.4**	**38.9**
North and South Africa	6.45	na	na	na	92	3	5	42.7	28.5
sub-Sahara	8.63	na	na	na	30	9	61	17.6	54.4
Asia	**61.82**	**49**	**25**	**4**	**78**	**7**	**15**	**22.2**	**49.8**
China	30.1	72	15	2	89	5	6	26.4	76.6
India	10.6	41	23	4	68	7	25	12.6	36.8
Other	21.1	19	39	8	66	11	23	26.0	37.7
Latin America	**23.3**	**4**	**45**	**14**	**63**	**22**	**15**	**51.9**	**27.6**
Brazil	7.75	5	34	2	41	29	30	51.5	20.5
Mexico	5.95	5	49	22	75	20	5	67.0	34.8
Other	9.55	4	51	20	74	17	9	45.6	32.2
Middle East	**9.76**	**1**	**64**	**32**	**98**	**1**	**1**	**75.8**	**26.4**

[a] Total Energy Consumption; [b] Sum of fossil fuels (coal, oil, natural gas); [c] Alternatives (nuclear, hydro, wind, geothermal, etc.); [d] Traditional (woodfuel); [e] Consumption of energy per capita; [f] Consumption per dollar of Gross National Product produced; [g] J.A.NZ: Japan, Australia, New Zealand

Source: Energy Policy, Vol 22 (1), 1994

World Commercial Energy Production and Consumption in 1994 per sub region and major producing and consuming countries
(million tonnes of oil equivalent)

	TEC[a]	Production of different sources of energy			Consumption of different sources of energy				
		Oil[b]	Natural Gas	Coal[c]	Oil[b]	Natural Gas	Coal[c]	Nuclear Energy	Hydro-Electric.
TOTAL WORLD	**7923.8**				**3172.4**	**1824.2**	**2153.2**	**573.1**	**201.0**
North America	**2358.4**	**652.5**	**632.5**	**593.1**	**964.0**	**620.0**	**521.4**	**202.5**	**50.5**
USA	2028.6	386.3	487.9	550.1	807.9	533.2	492.5	173.6	21.4
Canada	222.5	106.2	121.7	39.5	79.5	63.5	24.9	27.8	26.8
Mexico	107.3	160.0	22.9	3.5	76.6	23.3	4.0	1.1	2.3
South & Central America	**306.0**	**267.2**	**63.3**	**23.6**	**186.3**	**64.7**	**17.2**	**2.1**	**35.6**
Argentina	46.3	35.1	20.0		19.6	21.9	0.8	2.1	2.0
Bolivia			3.0						
Brazil	102.3	34.5		2.5	66.7	4.2	10.1	<0.05	21.2
Colombia		23.4	3.9	17					
Ecuador		18.5							
Peru		6.5							
Trinidad		6.5							
Venezuela	49.3	138.0	23.3	1.3[f]	19.6	24.9	0.3	-	4.5
Western Europe	**1429.3**	**286.7**	**188.8**	**153.2**	**652.5**	**263.2**	**261.8**	**209.3**	**42.4**
Austria	22.9			0.5	11.3	5.8	2.5	-	3.3
Belgium & Luxembourg	55.2				26.8	10.1	8.4	9.9	<0.05
Denmark	20.6	9.1			10.1	2.5	8.0	-	<0.05
Finland	22.9				10.4	2.7	4.1	4.7	1.0
France	232.0		2.9	5.5	90.5	27.7	14.1	92.8	6.9
Germany	333.2		14.0	76.5	135.1	61.1	96.3	39.0	1.6
Greece	25.7			7.9	17.2	<0.05	8.2	-	0.2
Iceland	1.2				0.7	-	0.1	-	0.4
Republic of Ireland	9.4				5.2	2.2	2.0	-	0.1
Italy	150.1		18.1	0.1	92.3	40.9	12.8	-	4.1
Netherlands	80.2		59.3		36.3	34.2	8.8	0.9	-
Norway	20.3	129.3	27.6		9.8	-	0.8	-	9.8
Portugal	15.7				11.6	-	3.4	-	0.7
Spain	94.5			14.1	53.5	6.5	17.7	14.4	2.4
Sweden	43.7				16.6	0.7	2.1	19.0	5.1
Switzerland	23.8				12.7	2.0	0.2	5.7	3.2
Turkey	56.6			19.1	25.8	5.9	21.9	-	3.0
United Kingdom	217.8	126.7	58.9	29.2	83.1	60.9	50.2	22.9	0.6
Eastern Europe	**1270.3**	**375.5**	**628.5**	**370.8**	**290.9**	**544.5**	**349.6**	**60.6**	**24.9**
Former Soviet Union:	1001.3	361.8	603.8	224.7	231.8	493.5	210.3	45.0	20.8
- Russian Fed.	664.6	316.0	509.6	120.8	162.7	335.0	126.5	25.3	15.2
- Ukraine	158.0		15.3	48.6	19.8	73.2	46.1	17.8	1.1
- Kazakhstan		20.3		53.7					
- Azerbaijan		9.6							
- Uzbekistan			39.6						
- Turkmenistan			29.9						
Bulgaria				4.9					
Czech Rep & Slovakia	57.6			29.2	10.5	10.2	29.9	6.6	0.4
Hungary	23.6	0.50		3.7	7.9	8.0	4.0	3.6	<0.05
Poland	94.6			86.4	14.7	8.2	71.6	-	0.2
Romania		6.9	15.1	7.5					

World Commercial Energy Production and Consumption in 1994 per subregion and major producing and consuming countries

(million tonnes of oil equivalent)

(cont)

	TEC[a]	Production of different sources of energy			Consumption of different sources of energy				
		Oil[b]	Natural Gas	Coal[c]	Oil[b]	Natural Gas	Coal[c]	Nuclear Energy	Hydro-Electric.
Middle East	**297.0**	**956.8**	**114.6**	**1.1**	**179.8**	**110.7**	**5.1**	**-**	**1.3**
Abu Dhabi		94.1	13.3						
Dubai & N. Emirates		19.5							
Iran		178.0	27.9						
Iraq		24.5							
Kuwait		103.7							
Oman		40.5							
Qatar		20.8	11.6						
Saudi Arabia		427.5	33.9						
Syria		29.9							
Yemen		16.0							
Africa	**226.4**	**329.6**	**66.4**	**108.5**	**99.7**	**36.8**	**80.5**	**2.6**	**6.8**
South Africa	95.2			103.5	18.8	-	73.5	2.6	0.2
Algeria		55.7	45.3						
Angola		26.1							
Cameroon		6.4							
Congo		10.6							
Egypt		46.5	9.5						
Gabon		16.8							
Libya		67.6	5.6						
Nigeria		93.1	3.7						
Asia & Australia	**2036.4**				**799.2**	**184.3**	**917.6**	**96.0**	**39.5**
Australia	90.4	26.9	25.3	118.3	34.1	17.0	37.9	-	1.4
Brunei		8.5	8.4						
China	748.7	144.9	14.9	592.0	144.1	14.9	572.0	3.1	14.5
India	212.4	33.6	15.6	122.9	67.6	15.7	121.8	1.3	6.0
Indonesia	68.9	74.2	55.8	18.8	39.9	24.2	4.0	-	0.8
Japan	478.5				268.7	54.3	82.0	67.3	6.3
Malaysia	29.9	30.9	23.4		15.5	12.2	1.8	-	0.4
New Zealand	13.3			2.2	5.8	4.0	1.3	-	2.2
Pakistan			12.5	1.5					
Papua New Guinea		5.7							
Philippines	17.0				15.1	-	1.5	-	0.5
Singapore	25.0				23.7	1.4	-	-	-
South Korea	134.8				85.1	7.6	26.5	15.1	0.4
Taiwan	61.9				32.4	3.6	16.2	9.0	0.8
Thailand	45.0				29.3	9.1	46.4	-	0.4
Vietnam		6.9							

[a] Total Energy Consumption; [b] includes: crude oil, oil sands, and natural gas liquids (the liquid content of natural gas where this is recovered separately), excludes: liquid fuels from other sources, such as coal derivatives; [c] commercial solid fuels only, i.e. bituminous coal and anthracite (hard coal), and lignite and brown (sub-bituminous) coal

Source: BP Statistical Review of World Energy, June 1995

Figure 4.1. Growth in commercial energy consumption (1985-1988)

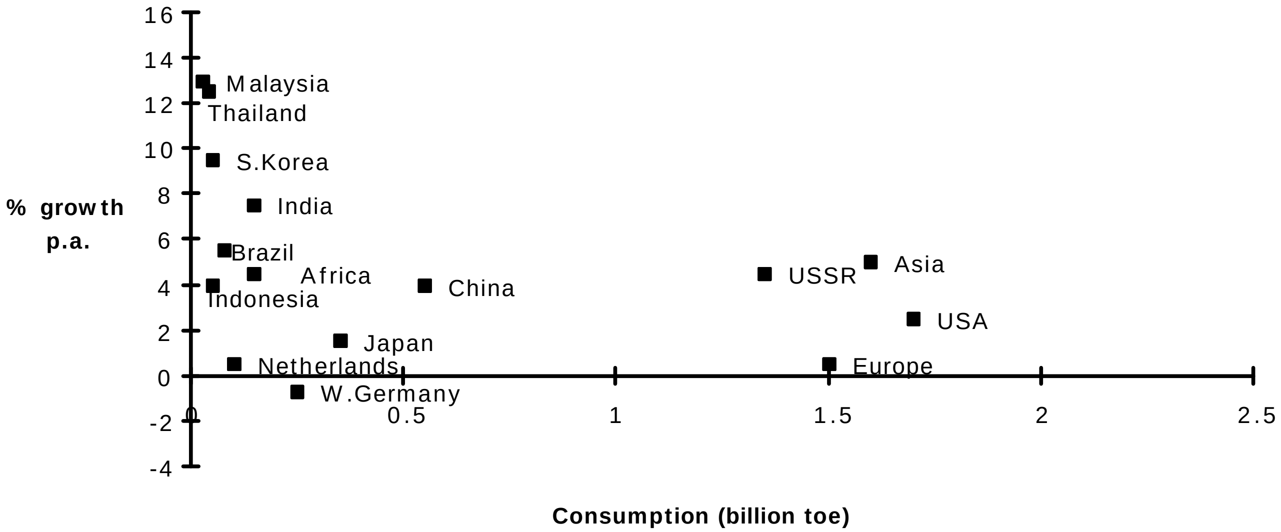


Figure 4.2. Growth in commercial energy consumption (1989-1992)

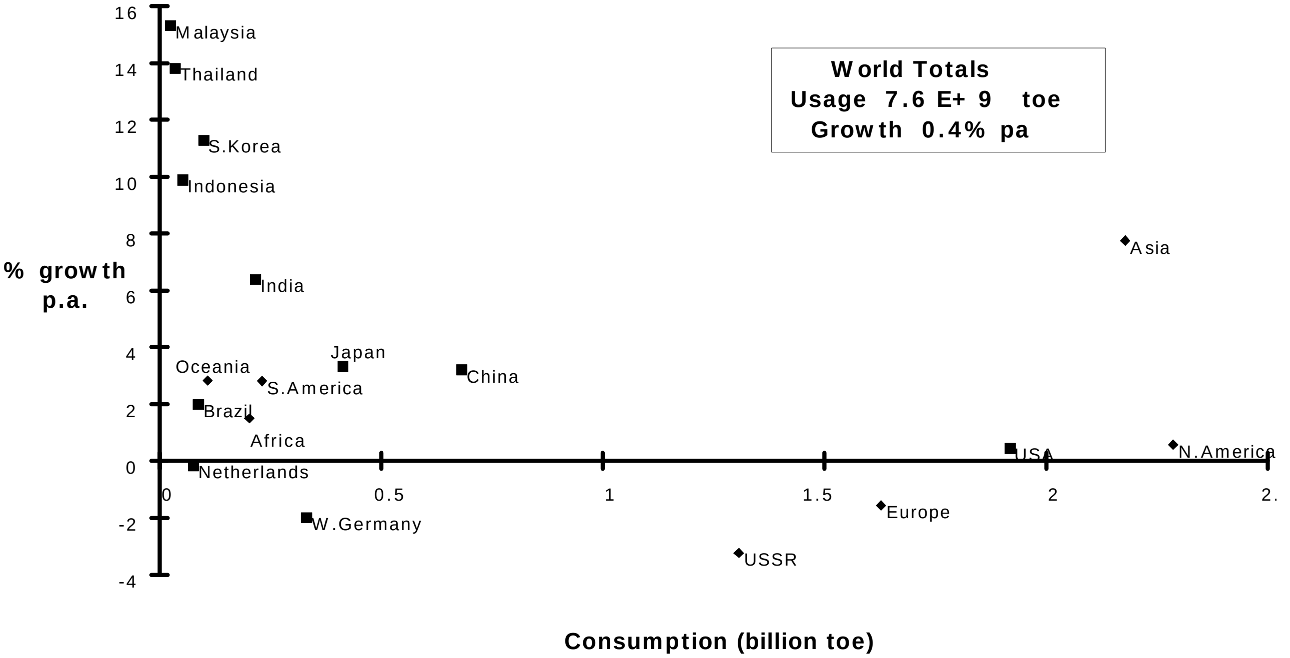


Table 4.3. Increase in energy use expected as a result of population increases

Year	***Population (billions)***	***Total energy use***		***Energy use per person***	
		(EJ/y)	***(TW*)***	***(GJ/Y)***	***(kW*)***
1990 (dev)	1.2	284	9.0	237	7.5
1990 (ldc)	4.1	142	4.5	35	1.1
1990 (world)	5.3	426	13.5	80	2.5
2025 (dev)	1.4	167	5.3	120	3.8
2025 (ldc)	6.8	473	15.0	69	2.2
2025 (world)	8.2	640	20.3	78	2.5

* = equivalent continuous power
dev = developed countries
ldc = less developed countries

4.2 Biomass Energy Consumption in RWEDP Member Countries

Table 4.4. RWEDP-specific data on biomass fuel use

	Biomass Energy Consumption (PJ)			**Av. annual growth in biomass en. cons. (%/y)**		**Av. ann. growth during 1981-1991 (%/y)**	
	1981	***1986***	***1991***	***1981-86***	***1986-91***	***population***	***GDP***
Bangladesh	243	262	277	1.6	1.1	2.5	4.1
Bhutan	7	9	12	4.7	4.9	2.2	6.5
Cambodia	41	47	54	2.9	2.5	3.3	5.3*
China	1,541	1,820	2,018	3.4	2.1	1.5	9.1
India	2,165	2,441	2,824	2.4	3.0	2.1	5.2
Indonesia	1,181	1,320	1,465	2.3	2.1	2.0	5.5
Lao PDR	29	33	39	2.5	3.0	2.9	NA
Malaysia	69	78	90	2.4	2.9	2.7	6.2
Myanmar	156	175	193	2.3	1.9	2.2	1.1
Nepal	113	197	206	11.7	0.9	2.8	4.5
Pakistan	192	233	296	4.0	4.9	3.3	6.0
Philippines	308	327	382	1.2	3.1	2.5	1.2
Sri Lanka	70	78	89	2.1	2.8	1.5	4.1
Thailand	484	546	526	2.5	-0.7	1.5	8.0
Vietnam	197	222	251	2.4	2.4	2.2	NA
Total	6,755	7,742	8,666	2.8	2.3	1.9	7.0

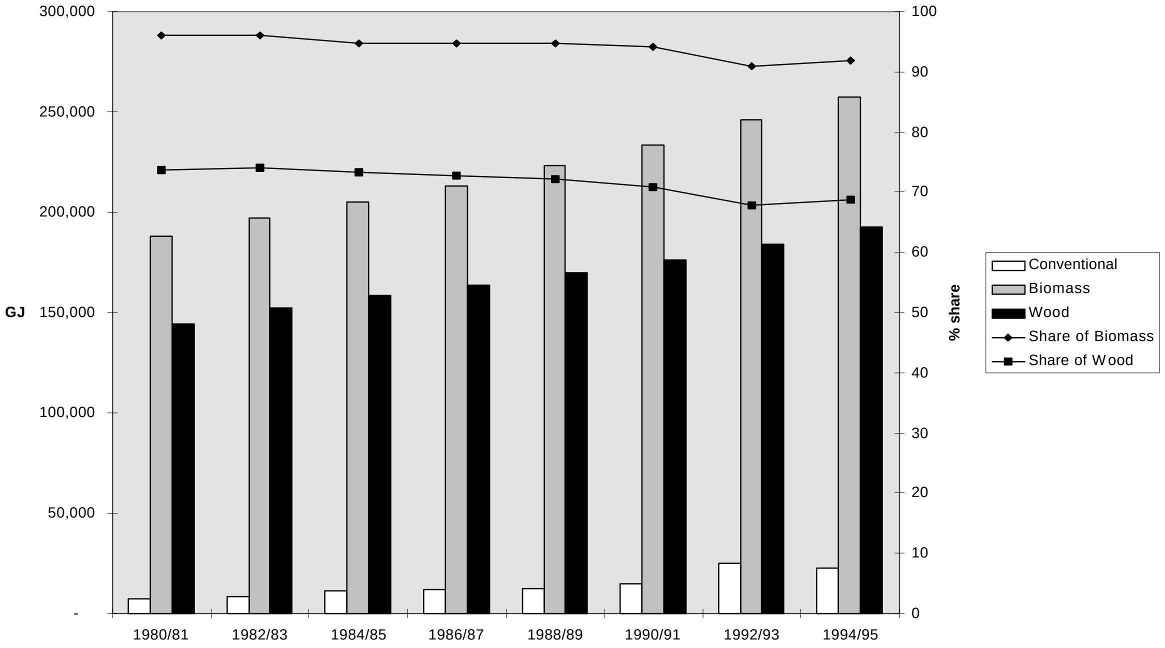
* for the period 1987-1993
Source: WRI, 1995

Table 4.5. Contribution of biomass in total energy supply

Country	**Year**	**Share of Biomass (%)**	**Share of Woodfuel (%)**	**Share of Biomass in Domestic Sector (%)**	**Source**
Bangladesh	1992	73	-	89	UN
Bhutan	1993	86	-	-	WRI
Cambodia	1995	85	82	98	MIME
China	1994	23	-	65	IEA
India	1992	33	-	78	UN
Indonesia	1994	36	-	73	IEA
Laos	1993	89	-	-	WRI
Malaysia	1992	7	-	21	AEEMTRC
Maldives	1994	23	23	84	UN
Myanmar	1992-93	86	86	99	DOE
Nepal	1994-95	92	69	98	WECS
Pakistan	1993-94	47	27	83	Energy Wing
Philippines	1994	39	-	84	IEA
Sri Lanka	1992	72	69	91	CEB
Thailand	1995	24	17	62	DEDP
Vietnam	1993	44	-	-	WRI

1 - no data available
2 Domestic and commercial sector
3 National energy balance
4 World Resource Institute
5 United Nations
6 AEEMTRC

Figure 4.3. Conventional vs. wood and biomass energy consumption in Nepal



Source: Energy Sector Synopsis Report 1992/93 (2049/50), Water and Energy Commission Secretariat, Ministry of Water Resources, 1994

5. FUELS AND COMBUSTION

Combustion occures when a **fuel** burns. This chemical reaction involves oxygen, and usually takes place in air (although for some special applications it takes place in pure oxygen), during which the chemical energy of the molecules is converted into heat energy. The main products are carbon dioxide and water.

All fuels consist primarily of carbon, hydrogen and, in some cases, oxygen, but in different proportions. (Although the term nuclear fuels is used, this is not strictly correct since the heat produced by nuclear reactions is not obtained through a combustion process.) The energy content of a fuel depends upon its chemical composition and a number of other parameters, such as density and moisture content. Biomass fuels in particular are subject to a wide variation in their energy content, not only because of the differences in chemical composition but also due to the influence of a number of parameters such as:

- moisture content,
- ash content, and
- bulk density.

5.1 Chemical Composition

All biomass consists of an organic fraction, an inorganic fraction and water. It is the organic fraction which burns, although the inorganic component does influence the combustion process and forms ash, the solid residue remaining after combustion. Ash is discussed below. Table 5.1 gives the typical elemental composition of some different species of woody biomass and agricultural residues.

Table 5.1 Elemental (or ultimate) analysis of selected biomass fuels (weight %, oven dry basis)

	Elemental per cent					
Biomass	**Carbon**	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulphur**	**Ash**
Black oak[1]	49.0	6.0	43.5	0.15	0.02	1.34
Douglas fir[1]	50.6	6.2	43.0	0.06	0.02	0.10
Red alder[1]	49.6	6.1	43.8	0.13	0.07	0.41
Cotton gin trash[1]	42.8	5.1	35.4	1.53	0.55	14.7
Rice hulls[1]	38.3	4.4	35.5	0.83	0.06	21.0
Rice straw[2]	41.44	5.04	39.94	0.67	0.13	17.4
Sugar cane bagasse[2]	46.95	6.10	42.65	0.30	0.10	3.90
Coconut shell and fibre[2]	51.50	5.70	41.00	0.35	0.10	1.80
Wheat straw[2]	48.53	5.53	39.08	0.28	0.05	6.53
Maize straw[2]	47.09	5.54	39.79	0.81	0.12	5.77

[1]Source: Strehler and Stutzle, Biomass Residues, in Biomass, Hall and Overend (eds), 1987
[2]Source: Rossi (1984) quoted by Tillman, Biomass Combustion, in Biomass, Hall and Overend (eds), 1987

5.2 Moisture Content

The moisture content of biomass is defined as the quantity of water in the material, expressed as a percentage of the material's weight. Moisture content is the most critical factor governing the amount of useful heat from biomass combustion. The water has to be evaporated first before heat is available for its end application. Put simply, the higher the moisture content the lower the useful energy available. The heat losses related to water in a biomass fuel are due to:

1. warming up the water stored in the plant tissues to the evaporation point;
2. evaporating this water; and
3. removal by water formed as vapour during combustion reactions.

The heat loss in (3.) is present when all fuels combust, and major design efforts are made to utilise this energy through the use of heat exchangers. Although all fuels contain trace amounts of water (attempts are made during processing, transport and storage to ensure this is kept to a minimum), it is in biomass that the levels are most significant. The moisture content varies between types of biomass, the length of time between cutting and using and the atmospheric humidity. When the biomass is cut it will lose moisture until it reaches equilibrium with its environment (a piece of wood from the same species would have a different moisture content in the monsoon climatic region than if it were in the Sahara desert). Therefore, when trying to compare the fuel characteristics of different types of biomass, it is important to state the moisture content.

Assigning a moisture content value can be confusing since there are three ways in which moisture content can be defined. The quantity of water can be a percentage of the biomass weight on:

- a wet basis;
- a dry basis; and
- a dry and ash free basis.

The consequence of this is that the same piece of biomass could be given three different values for moisture content! Therefore, not only should the heat content of a particular biomass type state at what moisture content the value is given, but the basis on which a moisture content itself is defined should also always be quoted.

When biomass is first cut it always contains some moisture. The mass of the material can be analysed in terms of three components: dry matter (W_{daf}), ash (W_{ash}) and water (W_{H_2O}). The total mass of the wet material (W_{wm}) is therefore given by:

$$W_{wm} = W_{daf} + W_{ash} + W_{H2O}$$

moisture content on wet basis (mcwb)
The mass of water is expressed as a percentage of the total mass of the biomass (water, ash, and dry, combustible matter).

$$\text{mcwb} = \frac{W_{H_2O}}{W_{daf} + W_{ash} + W_{H_2}o} = \frac{W_{H_2O}}{W_{wm}} \qquad (5.1)$$

moisture content on dry basis (mcdb)
The mass of water is expressed as a percentage of the mass of the dry matter plus the mass of the ash.

$$\text{mcdb} = \frac{W_{H_2O}}{W_{daf} + W_{ash}} = \frac{W_{H_2O}}{W_{wm} - W_{H_2O}} \qquad (5.2)$$

It is also possible to convert the values between the two systems:

$$mcdb = \frac{mcwb}{100 - mcwb} \times 100$$

and

$$mcwb = \frac{mcdb}{100 + mcdb} \times 100$$

Box 5.2 MOISTURE CONTENT ON DRY BASIS (mcdb)

Using data from Box 5.1 in equation 5.2:

$$mcdb = \frac{0.15}{0.8 + 0.05} = 0.176 = 17.6\%$$

moisture content on dry, ash free basis (mcdaf)
The moisture content can also be related to the mass of the dry combustible solid matter alone.

$$mcdaf = \frac{W_{H_2O}}{W_{daf}} = \frac{W_{H_2O}}{W_{wm} - W_{ash} - W_{H_2O}} \qquad (5.3)$$

Box 5.3 MOISTURE CONTENT ON DRY ASH FREE BASIS (mcdaf)
Using data from Box 5.1 in equation 5.3:

$$mcdaf = \frac{0.15}{0.80} = 0.188 = 18\%$$

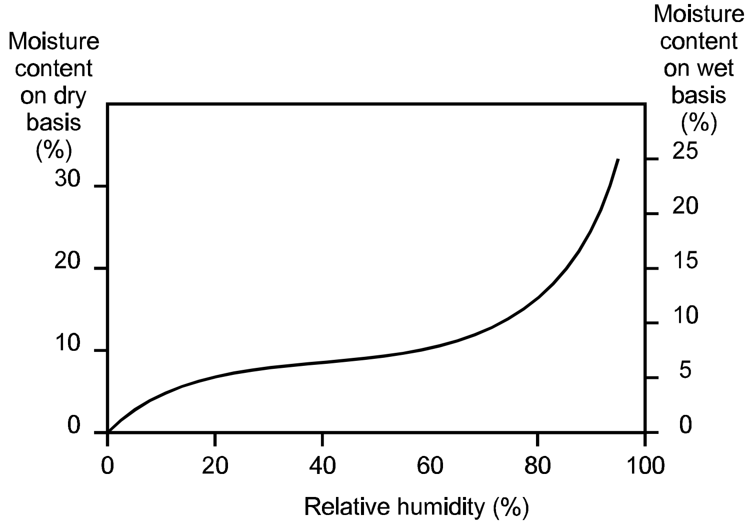
oven dried, air dried, green, wet biomass

Box 5.1 MOISTURE CONTENT ON WET BASIS (mcwb)
A 1 kg piece of wet biomass is found to contain 0.8 kg of dry matter, 0.05 kg of ash and 0.15 kg of water. Therefore, from equation (5.1) the mcwb is given by:

$$mcwb = \frac{0.15}{1} = 0.15 = 15\%$$

Another source of confusion is that data on the energy content of biomass is often referred to on the basis of the biomass being **oven dried**, **air dried**, **green** or **wet**. Oven dried means that the biomass was heated in an oven, under laboratory conditions, until a constant weight was recorded, i.e. until all the moisture had been driven off. Green means the biomass was weighed with the moisture content it had at the moment of cutting. However, this is not an accurate value, since all biomass begins to lose some moisture as soon as it is cut. Air dried means that the biomass was allowed to dry so that it was in equilibrium with atmospheric humidity (see Figure 5.1.). As was mentioned above, this is site specific. Wet biomass is sometimes used synonymously with green wood, but it actually includes both green and air dried biomass. Of these values, only oven drying gives a unique value. Therefore, any value assigned to the energy content of biomass should state at which moisture content the measurement was made. There is considerable debate about which value to use in calculations, since although oven dried gives the only consistent value it is not the form in which it is used.

Figure 5.1. Effect of relative humidity on equilibrium moisture content of wood (Household Energy Handbook, World Bank technical paper 67, 1987)



As a guide (since figures are highly dependent on local conditions), the moisture content of wood on a dry basis is around:

- 0% for bone dry or oven dried wood
- 6% for kiln dried wood
- 7-15% for air dried
- 28-35% for wet wood (for some species it is higher).

5.3 Ash Content

The size of the inorganic component of biomass varies widely and is made up of a wide range of elements. The ash content can be expressed in the same way as the moisture content on a wet basis, dry basis or an ash free basis. In general, the ash content on a dry basis is the one usually used.

ash content on a wet basis (ac_w)

$$ac_w = \frac{W_{ash}}{W_{daf} + W_{ash} + W_{H_2O}} = \frac{W_{ash}}{W_{wm}} \tag{5.4}$$

ash content on a dry basis (ac_d)

$$ac_d = \frac{W_{ash}}{W_{daf} + W_{ash}} = \frac{W_{ash}}{W_{wm} - W_{H_2O}} \tag{5.5}$$

ash content on a dry and ash free basis (ac_{daf})

$$ac_{daf} = \frac{W_{ash}}{W_{daf}} = \frac{W_{ash}}{W_{wm} - W_{ash} - W_{H_2O}} \tag{5.6}$$

Box 5.4 CALCULATING ASH CONTENT

Inserting the data from Box 5.1 into equations 5.4, 5.5, and 5.6 gives the following:

$$ac_w = \frac{0.05}{1.0} = 0.05 = 5.0\%$$

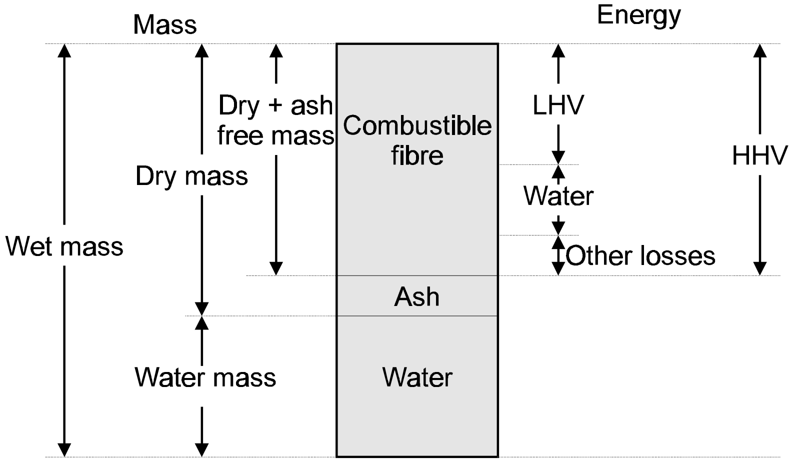
$$ac_d = \frac{0.05}{0.8 + 0.05} = 0.059 = 5.9\%$$

$$ac_d = \frac{0.05}{0.8} = 0.063 = 6.3\%$$

5.4 Heating Values

The energy released on combustion is indicated by the **heating value** of the fuel, which is the energy per unit mass of the fuel (J/kg) for solids (known as **specific energy**) and, for liquids and gases, the energy per unit of volume (MJ/L and MJ/m^3 at 1 atmosphere, both measured at 15°C - known as the **energy density**). There is no single heating value for a specific fuel. The two most commonly used measures are the **Higher Heating Value** (HHV) and the **Lower Heating Value** (LHV). These values are related to the physical state of the water produced on combustion. During combustion the water is produced initially as steam and therefore contains a lot of energy. If the steam escapes without doing any useful work then this is a loss of energy to the process. The energy available for completing the task in hand is therefore in practice less than the maximum; this is the LHV.

Figure 5.2. Relationship between several heating value definitions (Household Energy Handbook, World Bank technical paper 67, 1987)



Theoretically, one could fully condense and cool the steam to the original temperature before it is allowed to escape, then all heat would be recovered, and the corresponding heating value would be the Higher Heating Value (HHV). For calculations involving steam and gasifiers, the values have to be adjusted to take into account that the combustion products are at constant pressure, which is not reflected in the manner in which specific energy is measured in the laboratory.

A piece of wood contains free and bound water that are both released during combustion. Free water refers to the moisture content as described before, and can be removed when drying in an oven. Bound water is water that forms during combustion as a chemical reaction from hydrogen atoms in the cellulose and oxygen from outside.

Higher Heating Values on dry and ash free, dry and wet basis

As with moisture content, the HHV/LHV should, since the units are on a mass basis, be quoted with reference to the state of the fuel, that is, wet, dry or dry and ash free. The HHV_{daf} of all types of biomass is in the order of 20,400 kJ/kg (±15%). On an energy density basis biomass fuels have approximately one-tenth of the value of fossil fuels, such as oil or high quality coal.

$$\begin{aligned} HHV_d &= HHV_{daf} \times \frac{W_{daf}}{W_{daf} + W_{ash}} \\ &= HHV_{daf} \times \left(1 - \frac{W_{ash}}{W_{daf} + W_{ash}}\right) \\ &= HHV_{daf} \times \left(1 - ac_d\right) \qquad (5.7) \end{aligned}$$

$$\begin{aligned} HHV_w &= HHV_{daf} \times \frac{W_{daf}}{W_{daf} + W_{ash} + W_{H_2O}} \\ &= HHV_{daf} \times \frac{W_{wm} - W_{ash} - W_{H_2O}}{W_{wm}} \\ &= HHV_{daf} \times (1 - ac_w - mcwb) = HHV_{daf} \times (1 - ac_d) \times (1 - mcwb) \qquad (5.8) \end{aligned}$$

BOX 5.5 CALCULATING HIGHER HEATING VALUES

Using the value obtained in Box 5.4, the higher heating value on a dry basis can be obtained from equation 5.7:

$$HHV_d = 20{,}400 \times \left(1 - 0.059\right) = 19.196\, kJ/kg$$

The higher heating value on a wet basis can be obtained from equation 5.8 and the value calculated in Box 5.1:

$$HHV_W = 20{,}400 \times \left(1 - 0.059\right) \times \left(1 - 0.15\right) = 16{,}317\, kJ/kg$$

BOX 5.6. USE OF 1M^3 BIOGAS

1 m^3 of biogas is enough for:
Cooking: three meals for a family of 5 (China)
Lighting: equal to a 60 watt bulb for 6 hours
Driving: a 3 tonne lorry for 2.8 km
Running: a 1hp engine for 2 hours
Generating: 1.2 kWh of electricity

NB Values are approximate due to variation in methane content of biogas

Source: after van Buren 1979.
From: Bioenergy and the environment - J. Pasztor and L. Kristoferson, 1990

Lower Heating Value on dry, ash free basis

The calculation of this value needs an ultimate analysis[1] of the hydrogen content of the fuel, represented as $\left[H\right]_{daf}$:

$$\begin{aligned} LHV_{daf} &= HHV_{daf} - \left[H\right]_{daf} \times 20{,}300 \\ &\quad - mcdaf \times 2{,}260 \end{aligned} \tag{5.9}$$

Lower Heating Value on dry basis

$$\begin{aligned} LHV_{d} &= LHV_{daf} \times \frac{W_{daf}}{W_{daf} + W_{ash}} \\ &= LHV_{daf} \times \left[1 - \frac{W_{ash}}{W_{daf} + W_{ash}}\right] \\ &= LHV_{daf} \times \left(1 - ac_{d}\right) \end{aligned} \tag{5.10}$$

Lower Heating Value on wet basis

$$\begin{aligned} LHV_{w} &= LHV_{daf} \times \frac{W_{daf}}{W_{daf} + W_{ash} + W_{H_2O}} = LHV_{daf} \times \frac{W_{wm} - W_{ash} - W_{H_2O}}{W_{wm}} \\ &= LHV_{daf} \times \left(1 - ac_{w} - mcwb\right) = LHV_{daf} \times \left(1 - ac_{d}\right) \times \left(1 - mcwb\right) \end{aligned} \tag{5.11}$$

BOX 5.7 CALCULATING LOWER HEATING VALUES

Using the data calculated in Box 5.5 and taking the hydrogen content in the fuel as 6% on a dry, ash free basis, the lower heating values can be obtained from equations 5.9, 5.10 and 5.11 as follows:

$$\begin{aligned} &LHV_{daf} \\ &= 20{,}400 - 0.06 \times 20{,}300 - 0.188 \times 2{,}260 \\ &= 18{,}757\ kJ/kg \end{aligned}$$

$$LHV_{d} = 18{,}757 \times \left(1 - 0.059\right) = 17{,}650\ kJ/kg$$

$$\begin{aligned} LHV_{w} &= 18{,}757 \times \left(1 - 0.059\right) \times \left(1 - 0.15\right) \\ &= 15{,}030\ kJ/kg \end{aligned}$$

5.5 Bulk Density

Density is defined as mass per unit volume. However, for biomass, due to the structure of the material or the form in which it is to be utilised, there are three ways in which this density can be expressed: **true density**, **apparent density** and **bulk density**. Biomass has a porous structure, which means there are spaces between the cells, which contribute to the volume but not to the mass.

True density is the mass per unit volume of solid matter of biomass. Apparent density is defined as mass per unit volume enclosed within the boundary of the biomass particle, where the volume includes the solid volume and the pore volume.

When biomass comes in small pieces, such as rice husk or sawdust, the density depends on whether the pieces are piled loosely or have been compacted, since there are also spaces between the particles (known as void volume). The density measured in this case is the bulk density and obviously depends upon the degree of compaction. The volume includes the solid volume, pore volume and void volume. For biomass the bulk density is either expressed on an oven dry weight basis (mcod=0%) or an as received (wet) basis (mcwb), and should be at standard packing conditions. Biomass densification reduces pore and void volume of the particles.

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[1] Ultimate analysis of a fuel determines the carbon, oxygen, hydrogen, nitrogen, sulphur and ash content.

The three volumes are related as follows:

$w_a = w_s (1 - \varepsilon_p)$
$w_b = w_a (1 - \varepsilon_b)$
w_s = true density, mass/volume
w_a = apparent density, mass/volume
w_b = bulk density, mass/volume
ε_p = particle porosity = $\frac{\text{volume of pores}}{\text{volume of pores and volume of solid}}$
ε_b = bed porosity = $\frac{\text{volume of external voids}}{\text{volume of external voids and volume of particles}}$

The bulk density of biomass show wide variations, from 150 to 200 kg/m^3 for cereal straw to around 600 to 800 kg/m^3 for solid wood.

Table 5.2 Typical characteristics of biomass fuels used at present commercially for energy generating purposes

Biomass type	**Lower heating value on wet basis LHV_w (kJ/kg)**	**Moisture content on wet basis MC_w (%)**	**Ash content on dry basis Ac_d (%)**
Bagasse	7,700-8,000	40-60	1.7-3.8
Cocoa husks	13,000-16,000	7-9	7-14
Coconut shells	18,000	8	4
Coffee husks	16,000	10	0.6
Cotton residues:			
stalks	16,000	10-20	0.1
gin trash	14,000	9	12
Maize:			
cobs	13,000-15,000	10-20	2
stalks			3-7
Palm oil residues:			
fruit stems	5,000	63	5
fibres	11,000	40	
shells	15,000	15	
debris	15,000	15	
Peat	9,000-15,000	13-15	1-20
Rice husks	14,000	9	19
Straw	12,000	10	4.4
Wood	8,400-17,000	10-60	0.25-1.7
Charcoal	25,000-32,000	1-10	0.5-6

5.6 Fuel Characteristics

Although all biomass fuels have similar Higher Heating Values (HHV), they show a large variation with respect to **physical** (moisture content, bulk density), **chemical** (volatile matter content, ash content) and **morphological** (size, size distribution) characteristics. These characteristics influence the choice of conversion technology suitable for a particular fuel. For example, wood and charcoal can be used with a wide range of conversion technologies with little need of pre-processing, whereas many agricultural residues, for example, rice husk and bagasse, require more dedicated equipment usually with pre-treatment to make handling and transport easier, for example briquetting. Table 5.2 gives Lower Heating Value, moisture content and ash content for some biomass fuels commonly used for commercial energy generation.

Table 5.3. Energy content of various fuels

Fuel type	LHV on wet basis
Coal	27 GJ/tonne
Coke	28 GJ/tonne
Petrol	34 GJ/m^3
Diesel fuel	36 GJ/m^3
Heavy oil	39 GJ/m^3
Ethanol	26 GJ/tonne
Liquefied fuel gas	46 GJ/tonne
Natural gas	0.03 GJ/m^3
LNG (Liquefied Natural Gas)	20 GJ/m^3
Peat (50% moisture content)	9 GJ/tonne
Peat (35% moisture content)	12 GJ/tonne
Wood (fresh)[1]	8 GJ/tonne
Wood (stored)[1]	14 GJ/tonne
Dung (15% moisture content)[1]	12.6 GJ/tonne
Biogas	22 MJ/m^3
Crop residues[1]	14 - 18 GJ/tonne
Pellets, briquettes[1]	18 GJ/tonne

1 All energy content values are approximate since they depend on chemical composition and moisture content and significant variations for these fuels occur.

6. WOOD PRODUCTION FIGURES

Table 6.1. Energy and production characteristics for various tree and palm species

Scientific Name	Annual Average Yield (m3/ha.yr)	Average Rotation Length (yrs)	Possible Regeneration[a]	Nitrogen Fixing[b]	Use Priority[c]	Oven-dry density kg/m^3	HHV[d] (MJ/od kg)
Acacia auriculiformis	10-20	8-12	S, C	Y	F	600-800	17.7-20.3
Acacia decurrens	17	8	S, C		F	-	18.7
Acacia farnesiana	-	-	S, C		F	840	19.2
Acacia leucopholea	19	20	S, C		F	-	21.8
Acacia mangium	30	-	S, C	Y	F	650	-
Acacia mearnsii	10-25	7-10	S, C	Y	F	700-850	16.7-19.3
Albizia falcataria	30-40	5-15	S, C	Y	P, T, F	330	18.1
Albizia lebbeck	5	10-15	S, C	Y	T, F	550-600	21.8
Albizia procera	-	-	S, C	Y	T, F	660	19.7
Alnus nepalensis	10-20	15-20	S, C	Y	F, P	320-370	16.0-18.3
Alstonia macrophylla	-	-	S	N	P, T	560	19.2
Anthocephalus cadamba	1 5	9	S	N	P, T	330	18.9-19.8
Antidesma ghaessimbilla	-	-				600	19.1
Avicennia officinalis	-	-	S	-	F	630-700	18.5
Bruguiera gymnorrhiza	5-10	30	S	-	T, F	700-1,000	20.4
Bruguiera parviflora	6-10	30	S	-	F	700-1,000	18.7
Bruguiera sexangula	5-10	30	S	-	F	810	19.4
Calliandra calothyrsus	10-20[e]	1	S, C	Y	F, T	510-780	18.9-19.9
Cassia fistula	-	-	S, C	N	T, F	520	18.4
Cassia siamea	10-15	5-10	S, C	N	F, T	600-800	18.8
Cassuarina equisetifolia	5-15	7-10	S	Y	T, F	800-1,200	19.0-21.1
Ceriops tangal	-	-	S		F	810	19.6
Cocus nucifera			S	N	T, F		19.0
Cordia dichotoma	-	-	S		T	660	18.4
Dalbergia latifolia	15	20	S, C	Y	T	-	19.8
Dalbergis sissoo	-	-	S, C	Y	T	680	19.0-21.0
Derris indica	10-15	4-5	S, C	N	T, F	-	19.3
Diospyros philippinensis	-	-	S	N	T	750	18.6
Diospyros philosanthera	-	-	S	N	T	580	18.1
Eucalyptus camaldulensis	17-35[f]	7-10[f]	S, C	Y	T, F	430	19.0-21.0
Eucalyptus deglupta	-	-	S, C	Y	P, T, F	430	18.7
Eucalyptus globulus	10-30	5-15	S, C	Y	T, F	800-1,000	20.1-21.0
Eucalyptus grandis	17-60	6-10	S, C	Y	T, F	400-550	19.0-20.5
Eucalyptus urophylla	19	9	S, C	Y	F, T	-	-
Gigantochloa apus	15	5	S			-	18.4
Gfiricidia sepium[g]	8-20	8	S, C	Y	P, F	740	19.0-20.6
Grevillea robusta	15	10-15	S		T, F	570	
Gre wia multiflora	-	-	S			450	
Inga vera	-	3-5	S, C	N		570	-
Lagerstroemia speciosa	10	15	S	N	T	590	19.3

Scientific Name	Annual Average Yield (m3/ha.yr)	Average Rotation Length (yrs)	Possible Regeneration[a]	Nitrogen Fixing[b]	Use Priority[c]	Oven-dry density kg/m^3	HHV[d] (MJ/od kg)
Leucaena diversifolia	25	-	S, C	Y	T, F	540	-
Leucaena leucocephala	30-40[h]	5-10[h]	S, C	Y	F, T	530-580	17.5-19.5
Prosopis pallida	8	-	S	N	F	800	19.0-20.5
Pterocarpus indica	10	15	S, C	Y	T, F	-	-
Rhizophora apiculata	5-10	30	S	Y	T, F	700-1,000	20.1
Rhizophora mucronata	5-10	30	S	Y	T, F	700-1,000	21.3
Samanea samau	15	-	S, C	Y	T, F	520	-
Schima noronhae	5-12	8	S			-	20.0
Schleichera oleosa	10	25	S			-	18.7
Sesbania grandiflora	15-25[i]	3-7[i]	S, C	Y	F	420	19.3
Swietenia Macrophylla	17	25	S, C	N	T	-	20.7
Syzygium cumini	-	-	S, C	N	F	770	20.1-20.5
Tamarindus indica	5	25	S, C	Y	T, F	-	
Terminalia catappa	10-15	10-15	S	N	F	590	
Trema orientalis	10	8	S, C	N	F	250	-
Xylocarpus granatum	-	-	S	N		560	16.3
Xylocarpus moluccensis			S	N		580	15.4
Zizyphus talanai		-	S	N		690	18.3

Sources: Adapted from the University of Philippines (1981) and NAS (1980).

Notes:

Characteristics are presented for more than 60 trees or palms that have been or may be used as energy sources. However, many species also have alternative or better uses, such as timber. The values in the table above are not always comparable; since data come from a variety of studies, uniformity of measurements and consistency of definitions cannot be assured. Some data are based on small species trials, making these date only instructive, not definitive. Great care needs to be taken, especially with air-dry density and calorific value estimates. Unfortunately, the moisture content for the air-dry weight was usually not given in most research.

Calorific values generally are assumed to be high heat values-oven-dry energy contents. Rounding errors and varying measurement conditions, however, make the data on HHV suggestive at best. These problems may not be too critical to rough estimates since energy contents do not vary widely among most species. An average "wood" value often used is 15 MJ/kg at 15 percent mcwb, or 13 MJ/kg at 25 percent mcwb. The table does not mean to suggest that every species be used as fuelwood; it merely gives particular characteristics.

a Regeneration code: C means tree can be coppiced; S means that regeneration is primarily from seeds or plantings.

b Nitrogen-fixing code: Y means that the plant has the ability to fix nitrogen and thereby will enrich the soil; N means that the plant does not fix nitrogen.

c Use priority provides a hierarchy of uses for the plant, with P indicating pulpwood, T timber, and F fuelwood. The typical ranking of use priority is indicated by the order of the symbols, although priority may change among different users.

d HHVs may vary by 10-20 percent.

e Average yields often increase to 30-65 m3/ha.yr after the first cutting at six months to a year.

f Values are given for good sites; poor, dry sites average 2-11 m3/ha on a 10-14 year rotation.

g Also known as Gliricidia maculata.

h Well-managed plantations of giant L. leucocephala report 50-100 m3/ha.yr on a 3-5 year rotation.

i Data for well-managed plantations.

7. ELECTRICITY PRODUCTION AND CONSUMPTION

Figure 7.1. Growth in electricity consumption (1985-1988)

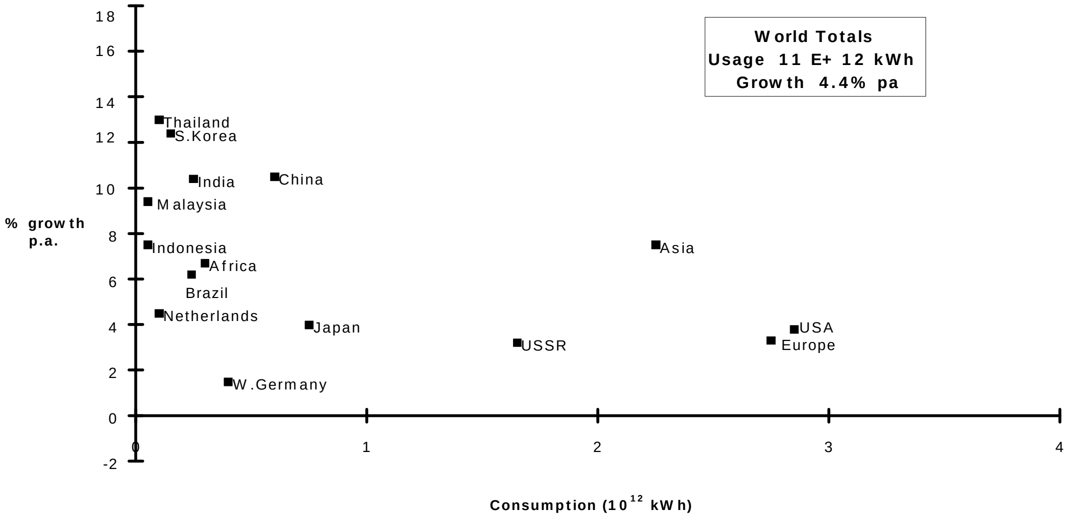

Figure 7.2. Growth in electricity consumption (1989-1992)

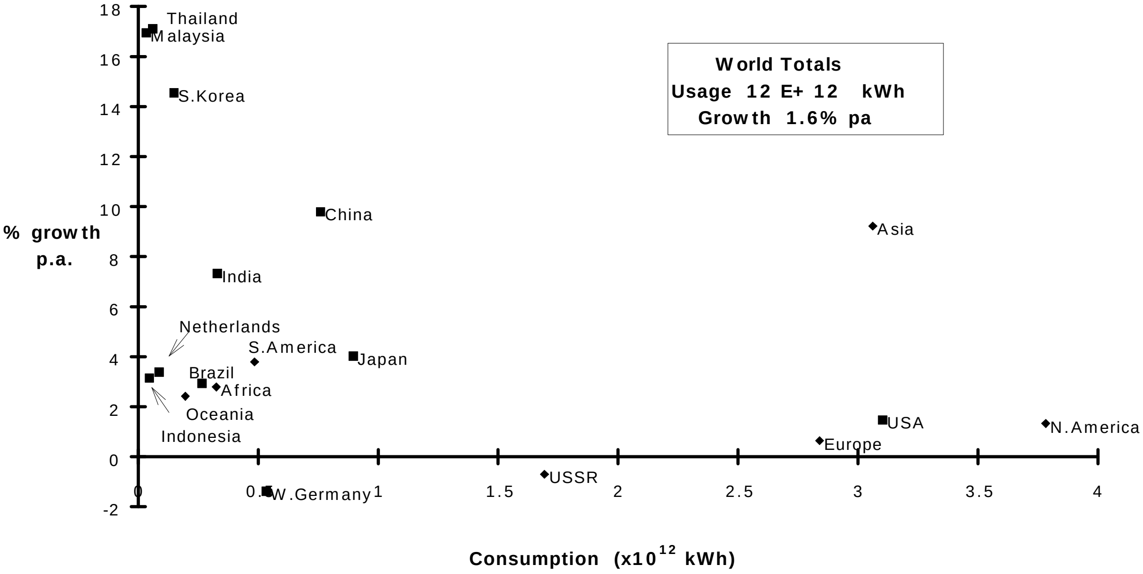

Figure 7.3. Electricity consumption versus Gross Domestic Product (1991)

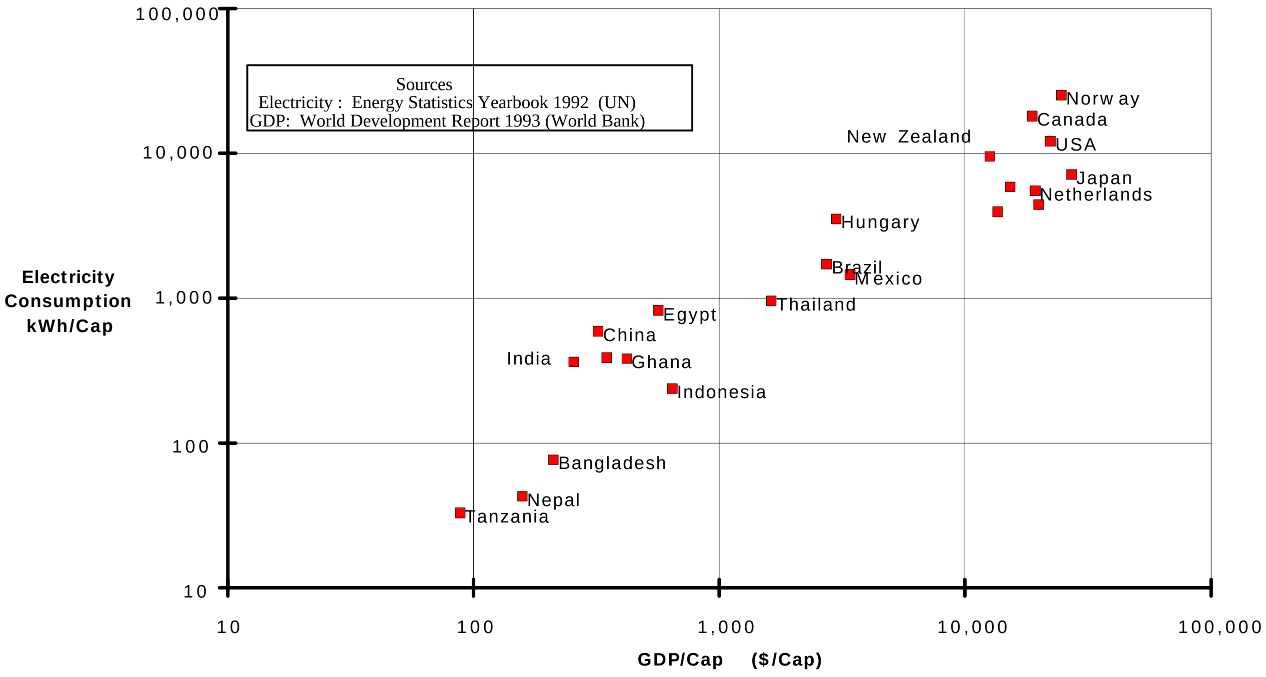

Figure 7.4. Electricity as a part of total energy consumption in German industry

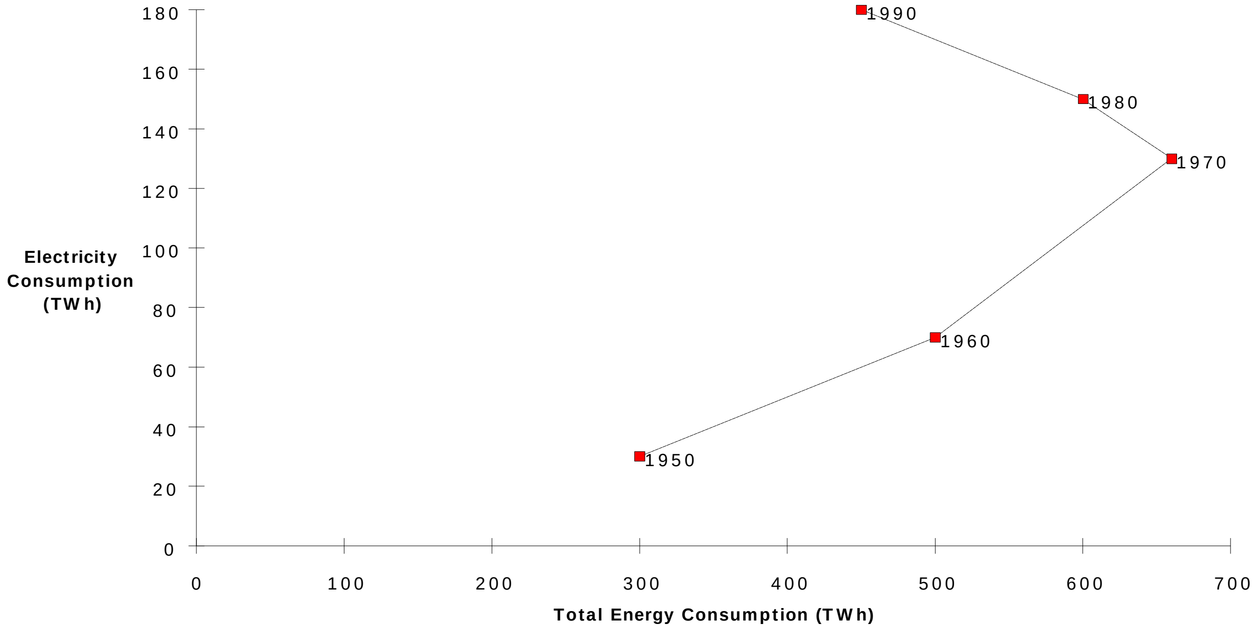

Table 7.1. Growth in electricity consumption in RWEDP countries

Country	Aggregate Consumption (GWh)			Per Capita Consumption (kWh)		
	1980	1990	growth (%/y)	1980	1990	growth (%/y)
Bangladesh	1,406	4,705	13%	16	42	10%
Bhutan	-	-	-	-	-	-
China PDR	259,212	541,174	8%	264	479	6%
India	82,367	184,222	8%	122	223	6%
Indonesia	6,560	27,741	16%	44	156	13%
Lao PDR	-	183	-		44	-
Malaysia	7,967	19,093	9%	579	1,075	6%
Maldives	2	22	27%	11	103	25%
Myanmar	854	1,840	8%	26	45	6%
Nepal	162	524	12%	11	28	10%
Pakistan	10,349	29,229	11%	125	261	8%
Philippines	12,637	20,087	5%	263	331	2%
Sri Lanka	1,392	2,608	6%	94	154	5%
Thailand	12,730	36,896	11%	272	655	9%
Vietnam	-	-	-	-	-	-
Total/average	395,688	868,425	8%	1,835	3,608	7%

Note: For Bhutan, Lao PDR and Vietnam, not all data is available.
Source: ADB (1993)

Table 7.2. Share of number of households with access to electricity (1990)

Country	share of total number of households[1]	share of rural households[2]
Bangladesh	12%	10%
China PDR	66%	80%
India	80%[3]	25%
Indonesia	24%	22%
Malaysia	82%	80%
Myanmar	6%	6%[3]
Nepal	9%	2%
Pakistan	37%	30%[3]
Philippines	61%	54%
Sri Lanka	29%	18%
Thailand	71%	65%
Vietnam	NA	15%[3]

[1] Source: ADB, 1993

[2] Source: Ramani et al, 1993

[3] This figures represent the percentages of villages electrified.

Figure 7.5. National electricity demand forecasts for the Netherlands

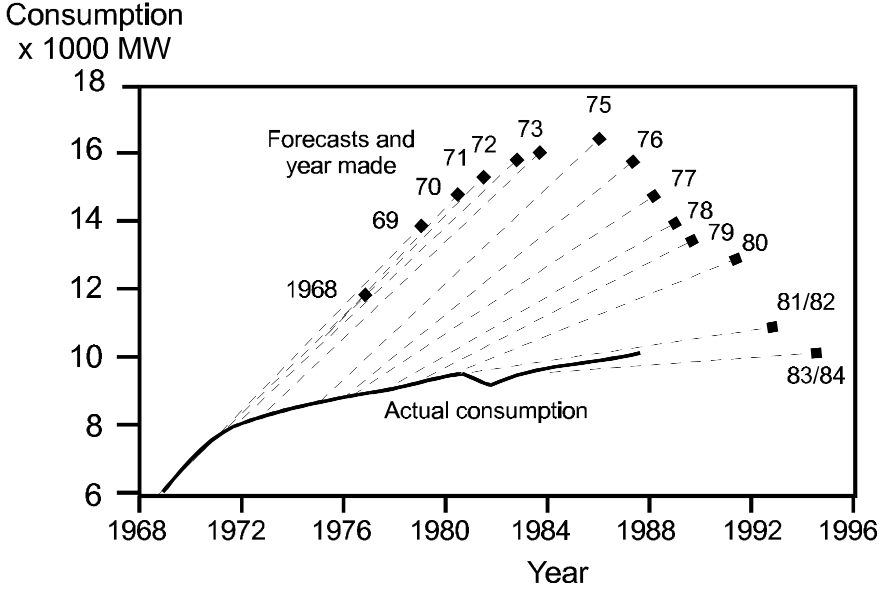

Table 7.3. Technical and non-technical losses
(in percent of net generation)

	Technical	**Non-technical**	**Total**
Sri Lanka	14	4	18
Panama	17	5	22
Sudan	17	14	31
Bangladesh	14	17	31
Liberia	13	22	35
Malaysia	11	17	28
Ivory Coast	8	4	12

Source: M. Munasinghe et al., A review of World Bank Lending for Electric Power, World Bank, Washington, DC, Energy Series Paper No. 2, p. 60.

Table 7.4. Distribution of technical energy losses (percent)

	Madagascar	Kenya	Bangladesh	Target[a]
Power plant transformers	2.2	0.5	0.5	0.3
Transmission lines	2.7	5.2	2.2	3.8
Sub-stations	0.8	0.9	1.1	0.3
Primary lines	2.1	2.1	4.2	2.5
Distribution transformers and low tension network	4.2	6.3	6.0	1.5
Total	12.0	15.0	14.0	8.3

[a] Target levels are those found in a relatively efficient, well-run system.

Source: IDEA, "Improving Power Sector Efficiency in Developing Countries," draft contractor report to the Office of Technology Assessment, October 1990, p. 26.

From: Fuelling Development - Energy Technologies for Developing Countries, - Congress of the United States Office of Technology assessment, 1992.

Table 7.5. Some typical fuel consumption rates for engine generators

Size (kW)	**Fuel**	**Consumption rate liters/kWh**	**Fuel operating costs $/kWh**
4.0	gasoline	0.71	0.71
7.5	gasoline	0.63	0.63
20	diesel	0.40	0.20
50	diesel	0.28	0.14
100	diesel	0.24	0.12
1,000	diesel	0.28	0.14

Note: both fuels priced at 50 US cents/litre.

Table 7.6. Initial capital costs of electricity generating systems

Technology	Size (kW_p)	Initial capital cost ($\$kW_p$)
Engine generator:		
- gasoline	4.0	760
- diesel	20.0	500
Micro-hydro	10-20	1,000-2,400
Photovoltaic	0.07	11,200
Photovoltaic	0.19	8,400
Wind turbine	0.25	5,500
Wind turbine	4	3,900
Wind turbine	10	2,800

Note: Costs are for entire system, including conversion device, electric generator, and associated electrical equipment. Prices for wind turbine and photovoltaic systems include batteries. kW_p ratings are for peak output, average output will be somewhat lower depending on the resource. Prices for wind turbine, photovoltaic, and engine generators are actual retail prices in the USA in 1990. Prices for micro-hydro are averages across several installations.

Source: Fuelling Development - Energy Technologies for Developing Countries, - Congress of the United States Office of Technology assessment, 1992.

Table 7.7. Operating, maintenance, and fuel costs for different technologies used to generate electricity (diesel fuel price of $0.50/litre assumed)

Technology	O&M costs (cents/kWh)	Fuel costs (cents/kWh)
Engine generator	2	20 (diesel)
Micro Hydro	2	0
Photovoltaics	0.5	0
Wind turbines	1	0

Source: Fuelling Development - Energy Technologies for Developing Countries, - Congress of the United States Office of Technology assessment, 1992.

Table 7.8. Approximate lifetimes of off-grid renewable generating technologies

Technology	Lifetime (years)
Engine Generator (diesel)	8-10
Micro Hydro	20-30
Photovoltaics	20-30
Wind Turbine	15-25
Batteries	3-5

Source: Fueling Development - Energy Technologies for Developing Countries, - Congress of the United States Office of Technology assessment, 1992.

Table 7.9. Land requirements for power stations

Technology	size (MW)	Area (m^2)	km^2/MW
dendro-thermal	50	300,000,000	6
solar thermal central receiver plant	1-10	6,216-71,084	0.007-0.01
solar thermal parabolic trough	80	16,800	0.021
pv concentrator	0.025-0.3	245-11,880	0.009-0.013
hydro	24-12,600	96,000-42,000,000,000	0.004-9.1

Source: World Bank, 1994, Renewable Energy Technologies, A review of the status and costs of selected technologies

Table 7.10. Estimates of annual electricity consumption, Bangkok (1989)

Appliance	Power (W)	Usage (hours/year)	Annual consumption (kWh)
Colour TV	79	2,014	159
Refrigerator	109	5,760	628
Rice cooker	1,149	230	264
Clothes washer	1,567	91	143
Air conditioner:			
- Window	1,815	1,442	2,617
- Central	2,257	1,564	3,530
Ceiling fan	77	2,061	159
Water heater	4,418	54	239

Source: Fueling Development: Energy Technologies for Developing Countries, Congress of the United States Office of Technology assessment, 1992.

Table 7.11. Power rating of home energy appliances

Appliance		**Power Rating**
Incandescent bulbs		25-100 W
Fluorescent tube light	24°	20 W
	48°(Slim light)	36 W
	48°	40 W
Night lamp		5 W
Mosquito repellent		5 W
Fans		60 W
Air coolers		115 W
Air conditioners (1-1,5 ton)		1,000-1,500 W
Refrigerators (165 litres)		225 W
Mixer/blender/juicer		450 W
Toaster		800 W
Hot plate		1,000-1,500 W
Oven		1,000 W
Electric kettle		1,000-2,000 W
Iron		450-700 W
Water heater		
- 1,1/2-2 litre capacity (Instant Geysers)		3,000 W
- 10-20 litre (Storage type)		2,000 W
- Immersion Rod		1,000 W
Vacuum Cleaner		700-750 W
Washing Machine		325 W
Water Pump		750 W
T.V.		60-120 W
Radio		15 W
Video		40 W
Tape Recorder		20 W
Stereo System		50 W

Source: Gujarat Energy Agency, India

8. TRANSPORTATION

Table 8.1. Energy efficiency of trucks in selected countries

Country/region	Truck name	Capacity (metric tons)	Energy consumption (MJ/tonne/km)
OECD	Mercedes Benz 1217	7.0	1.0
OECD	Man-VW 9136 (1980)	5.9	1.0
India	TATA 1201 SE/42	5.0	2.1
India	Ashok Leyland Beaver	7.5	1.6
China	Jiefang CA-10B	4.0	2.3
China	Dongfeng EQ140	5.0	1.8

Note: OECD and Indian trucks use diesel, Chinese trucks use gasoline.

Source: J. Yenny and L. Uy, World Bank, Transport in China, Staff Working Paper No. 723, 1985, p.70.

Table 8.2. Estimated traction power of animals operating farm equipment

		Low Speed Traction			High Speed Traction		
Type of animal	Weight (kg)	Speed (km/hr)	Force (newton)	Power (W)	Speed (km/hr)	Force (newton)	Power (W)
Horse							
light	385	2.4	435	290	4	396	440
medium	500	2.4	660	440	4	468	520
heavy	850	2.4	990	660	4	864	960
Bull							
light	210	2.4	330	220	4	198	220
medium	450	2.4	660	440	4	468	520
heavy	900	2.4	1,215	810	4	864	960
Water Buffalo							
light	400	2.4	550	370	3.2	416	370
medium	650	2.4	885	590	3.2	664	590
heavy	900	2.4	1,215	810	3.2	911	810

Source: K V Ramani, A K N Reddy, and M N Islam, "Rural Energy Planning: A Government Enabled Market Based Approach", APDC, Kuala Lumpur, Malaysia, 1995

9. ENERGY INTENSITY

Table 9.1. Energy consumption in the EU for the production of a number of products

product	resources	production volume (ktonne)	primary energy demand (PJ)	(% of total)	energy intensity[*] (GJ/tonne)
steel	ore, scrap	137,774	2635	5.7	19.1
aluminium	alumina	2,319	369	0.8	159.1
copper	ore, scrap	1,266	14	0.0	11.1
zinc	ore	1,719	67	0.1	39.0
alumina	bauxite	4,900	72	0.2	14.7
ammonia	fossil fuels	12,479	443	1.0	35.5
chlorine	salt	8,490	287	0.6	33.8
soda ash	salt	5,750	75	0.2	13.0
phosphor	ore	240	40	0.1	166.7
methanol	natural gas	2,000	34	0.1	17.0
oil products	crude oil	463,725	1421	3.1	3.1
petro-chemicals	HC feedstocks	27,734	2237	4.8	80.7
styrene	ethylene, benzene	3,000	27	0.1	9.0
VCM	ethylene, chlorine	4,360	36	0.1	8.3
poly-ethylene	ethylene	5,955	36	0.1	6.0
poly-propylene	propylene	2,440	29	0.1	11.9
PVC	VCM	3,930	23	0.1	5.9
cement	limestone	171,922	665	1.4	3.9
building bricks	clay	47,760	133.5	0.3	2.8
glass	sand, cullets	20,410	181.9	0.4	8.9
paper	pulp, waste paper	35,010	778.0	1.7	22.2

[*] Calculated by dividing the total primary energy demand by the production volume of a product

Source: Potentials for improved use of industrial energy and materials - E. Worrell, 1994

Table 9.2. Average energy intensities of building materials

Material	**Energy intensity (MJ/kg)**
Concrete aggregate	0.18
Concrete	0.8
Brick and tile	3.7
Cement	5.9
Plate glass	25.0
Steel	28.0

Source: Mogens H. Gogand Kishore L. Nadkarni, "Energy Efficiency and Fuel Substitution in the Cement Industry with Empahsis on Developing Countries, "World Bank Technical Paper No. 17, Washington, DC, 1983.

10. GREENHOUSE GASES

Table 10.1. The principal greenhouse gases

	CO_2	CH_4	CFC-11	CFC-12	N_2O
concentration	(ppm_v)	(ppm_v)	(ppt_v)	(ppt_v)	(ppb_v)
pre-industrial	280	0.79	0	0	280
present	353	1,072	280	484	310
radiative forcing per molecule (CO_2^{-1})	1	21	12,400	15,800	206
lifetime in atmosphere (years)	50-200	14.5 +/- 2.5	65	130	120
global warming potential[1] relative to CO_2					
20 years	1	62	4,500	7,100	290
100 years	1	24.5	3,500	7,300	320
500 years	1	7.5	1,500	4,500	180
percentage contribution to total radiative forcing 1980-1990	55	15	24 (all CFC's)		6
current increase (per cent/year)	0.5	0.9	4		0.25

Data from IPCC Working Group I, quoted in Climate Change and Energy Efficiency in Industry, IPIECA, 1991

[1] The warming effect of an emission of 1 kg of each gas relative to CO_2 based on the present day atmosphere. The figures for CH_4 and N_2O are those recently been revised by the IPCC and not as in the original text.

Table 10.2. Emissions of pollutants from electric power generation: the total fuel cycle [(a)] *(tons per gigawatt hour)*

Energy source	CO_2	NO_2	SO_2	TSP[(b)]	CO	HC	Nuclear waste	Total
Conventional coal	1,058.2	2.986	2.971	1.626	0.267	0.102	NA	1,066.1
Fluidised bed coal	1,057.1	1.551	2.968	1.624	0.267	0.102	NA	1,063.3
Natural gas IGCC	824.0	0.251	0.336	1.176	NA	NA	NA	825.8
Nuclear	8.6	0.034	0.029	0.003	0.018	0.001	3.641	12.3
Photovoltaic	5.9	0.008	0.023	0.017	0.003	0.002	NA	5.9
Biomass	0[(c)]	0.614	0.154	0.512	11.361	0.768	NA	13.4
Geothermal	56.8	TR[(d)]	TR[(d)]	TR[(d)]	TR[(d)]	TR[(d)]	NA	56.8
Wind	7.4	TR[(d)]	TR[(d)]	TR[(d)]	TR[(d)]	TR[(d)]	NA	7.4
Solar thermal	3.6	TR[(d)]	TR[(d)]	TR[(d)]	TR[(d)]	TR[(d)]	NA	3.6
Hydropower	6.6	TR[(d)]	TR[(d)]	TR[(d)]	TR[(d)]	TR[(d)]	NA	6.6

notes:
[a]: the total fuel cycle includes resource fuel extraction, facility construction and plant operation.
[b] TSP: Total suspended particulates.
[c] With biomass fuel regrowth program.
[d] TR: trace elements.
NA: not applicable.

Sources:
(a) Meridian Corporation, Energy System Emissions and Material Requirements. Prepared for the Deputy Assistant Secretary for Renewable Energy, US Department of Energy, Washington DC, February 1989, pp. 25-29.
(b) Carbon dioxide data adapted by the Council for Renewable Energy Education from Dr. Robert L. San Martin, Deputy Assistant Secretary for Renewable Energy, Environment Emissions from Energy Technology Systems: The Total Fuel Cycle, US Department of Energy, Washington DC, spring 1989, p. 5. Other emissions data from Assistant Secretary for Environment, Safety and Health, Energy Technologies and the Environment, Environmental Information Handbook, Office of Environmental Analysis, US Department of Energy, October 1988, pp. 333-334.

Table 10.3. Average CO_2 emissions from selected fossil fuel sources (tonnes per TJ of fuel burned)

	Coal[2]	**Gas**	**Petrol**	**Diesel**	**Oil**
Carbon	24.2	13.8	18.2	18.8	19.8
CO_2[1]	88.7	50.6	66.7	68.9	72.6

Notes
1. NB 1 tonne of C combusts to give 3.667 tonnes of CO_2
2. The amount of CO_2 emitted from a given unit of coal will vary since the C content can be in the range 50-80%.
3. Limestone is frequently mixed with hard coal at combustion to control sulphur emissions which cause acid rain. This practice serves to add a small increment to the CO_2 output, though this effect has been estimated to be no more than 0.4 tonnes CO_2/TJ.

11. AIR EMISSION STANDARDS

Table 11.1. Exposure limits for a healthy indoor environment

agent	reference value	references
neighbour noise	+ 5 dB	
radon	1 Bq.m^{-3} EER; year	(WHO, 1987)
particulate matter (PM10)	40 :g.m^{-3}; year, 140 :g.m^{-3}; 24 h	(RIVM, 1987)
benza-pyrene	1 ng.m^{-3}; year	(WHO, 1987)
benzene	12 :g.m^{-3}; year	(RIVM, 1987)
lead in air	0.5 :g.m^{-3}; year	(GR, 1984)
lead in drinking water	50 :g.L^{-1}	(WLW, 1984)
nitrogen dioxide	300 :g.m^{-3}; 1 h, 150 :g.m^{-3}; 24 h	(GR, 1979)
carbon monoxide	40 mg.m^{-3}; 1 h, 10 mg.m^{-3}; 8 h	(GR, 1975)
sulphur dioxide	350 :g.m^{-3}; 1 h	(WHO, 1987)
ozone	150-200 :g.m^{-3}; 1 h, 100-120 :g.m^{-3}; 8 h	(WHO, 1987)
formaldehyde	120 :g.m^{-3}; 0.5 h	(GR, 1984)
dichloro methane	1.7 mg.m^{-3}; 8 h	(RIVM, 1987)

Note: Chemical agents of which exceeding the reference values indoors is not expected, is inevitable or is considered to be not significant.

Table 11.2. Non-carcinogenic and carcinogenic agents

Agent	Carcogenic/ Non-Carcogenic	Reference values
1,2-dichloroethane	C	36 :g.m^{-3}; year
acrylonitrile	C	3.8 :g.m^{-3}; year
arsenic	C	20 ng.m^{-3}; year
cadmium	NC	10 B 20 : gm^{-3}; year
carbon disulphide	NC	100 :g.m^{-3}; 24 h
external ionising radiation	C	mainly inevitable
hexavalent chromium	C	1 ng.m^{-3}; year
hydrogen sulphide	NC	150 :g.m^{-3}; 24 h
internal radiation in consequence of radon:		
- in ambient air	C	inevitable
- in construction material	C	mainly inevitable
manganese	NC	1 :g.m^{-3}; year
mercury	NC	1 :g.m^{-3}; year
styrene	NC	800 :g.m^{-3}; 24 h
sulphuric acid	NC	(not considered significant)
tetrachloro ethane	NC	5 mg.m^{-3}; 24 h
toluene	NC	3 mg.m^{-3}; 24 h
trichloro ethane	NC	1 mg.m^{-3}; 24 h
vanadium	NC	1 :g.m^{-3}; 24 h
vinyl chloride	C	4,000-40,000 opt. fibres.m^{-3}; year

Source: Zorgen voor morgen (Cares for Tomorrow, National Environmental Assessment), Nationale Milieuverkenning 1985-2010 - Rijks Instituut voor Volksgezondheid en Milieuhygiene (RIVM) (Dep. of Health and Environment), 1989

Table 11.3. Air emission guidelines in the Netherlands

	condition for emission-standard[a] when untreated mass-flow is smaller/bigger than: (gram/hour)	emission-standard mg/m^3
minimalisation-obligation for:		see end note c
extremely hazardous pollutants:		
polyhalogene-dibenzo-dioxines		
polyhalogene-dibenzo-furanes		
polychlorine-bifenyls		
carcinogenic pollutants		
carcinogenic material:		
<u>*with threshold-value*</u>[b]:		
asbestos (cat. sA.1)		0.10
arsenic and -compounds (cat. sA.1), calculated as As	> 1.0	0.20
cadmium and -compounds ((cat. sA.1), calculated as Cd	> 1.0	0.20
formaldehyde (cat. O.1)	> 100	20
silica (silicon dioxide) fibres (cat. sA.1	> 1.0	0.20
<u>*without threshold-value*</u>:		
category C.1	> 0.5	0.10

(compounds that are classified as carcinogenic based on epidemiological research)

benzo(a)anthracene
benzo(a)pyrene
benzo(b)fluoranthene
beryllium and -compounds, calculated as Be
chromium (VI) -compounds, calculated as Cr
benzo(j)fluoranthene
benzo(k)fluoranthene
dibenzo(a,H)anthracene
2-naphthylamine (+ salts)
2-nitropropane

category C.2	> 5.0	1.0

(compounds that are classified as carcinogenic based on chronic animal experiments)

3,3-dichloridebenzidine (+ salts)
nickel and -compounds, calculated as Ni
dimethylsulphate
ethylene-oxide

category C.3	> 25	5.0

acrylo-nitrile
benzene
buta-1,3-diene
1,2-dibromine-methane
1,2-dichloro-ethane
epi-chlorine-hydrine
hydrazine (+ salts)
propene oxide
vinyl-chloride

particulate matter (category S)	< 500	50[a] 10[b]
	> 500	25[a] 10[b]

a without filtering separator
b with filtering separator

particulate inorganic matter		
category sA.1	> 1.0	0.20

mercury and inorganic mercury compounds, calculated as Hg
iron-penta-carbonyl
platinum compounds, calculated as Pt
rhodium compounds, calculated as Rh
thallium and -compounds, calculated as Tl
vanadium compounds, calculated as V
Silica fibres
silver and -compounds, calculated as Ag
Asbestos fibres
Arsenic and -compounds
Cadmium and -compounds

category sA.2 > 5.0 1.0

chromium-chloride
cobalt smoke and -compounds, calculated as Co
silica (quartz) as respirable matter (excluding silica fibres)
rhodium and not-water-soluble -compounds, calculated as Rh
lead and inorganic lead compounds, calculated as Pb
selenium and -compounds, calculated as Se
tellurium and -compounds, calculated as Te
copper smoke, calculated as Cu

gaseous or vaporous inorganic matter

category gA.1 > 10 1.0

arsenic hydrogen (arsine)
chlorine cyanide
chlorine dioxide
phosphorus hydrogen (phosphine)
phosgene

category gA.2 > 50 5.0

bromide and -compounds, calculated as HBr
chlorine gas (Cl_2)
hydrogen sulphide
fluorine and -compounds, calculated as HF
hydrogen cyanide

category gA.3 > 300 30

chlorine compounds, calculated as HCl

category gA.4 > 5,000 200

ammonia
sulphur oxides, calculated as SO_2
nitrogen oxides, calculated as NO_2

particulate organic matter

< 100	50[a] 10[b]
> 100	25[a] 10[b]

a without filtering separator
b with filtering separator

category sO.1

alkyl-lead-compounds
di-phenyl-ether
di-phenyl-methane-2,4-diisocyanate
methyl-amine
2-methyl-aniline
methyl-bromide
methyl-phenols
ethanol
methyl-propionate
1-methyl-2,4-phenylene-diisocyanate
1-methyl-2,6-phenylene-diisocyanate
nitrobenzene
ftaal-acid-anhydride
2-furaldehyde
maleic-acid-anhydride
methanol
pyridine
sec-amyl acetate
1,1,2,2-tetra-chloro-ethane
tetra-chloro-methane
methyl-(2-methyl)-propionate
thio-alcohols
thio-ethers
nitro-cresols
nitro-phenols
organo-tin-compounds
propene acid
propanol
benzyl chloride
biphenyl
butyl acrylate
chloro acetic acid
2-chloro-ethanol
chloro-methane
1,1,2-trichloro-ethane
1,2-dichloro-methane
tri-chloro-phenols
tri-chloro-methane
tri-ethyl-amine
aniline
anthracene
acetic acid-anhydride
di-methyl-amine
N,N-di-methyl-aniline
1,4-dioxin
nitro-toluenes
ethyl-amine
ethyl-propionate
phenol
formic acid
1,1-dichloro-ethylene
di-chlorine-phenols
di-ethylamine

category sO.2:

i-amyl-acetate
n-amyl-acetate
acetic acid
aromatic hydrocarbons
butanol
ethane
tri-chlorine-ethylene
tri-methyl-benzene
vinyl-acetate
vinyl-benzene
xylene
chlorine-benzene
2-chloro-propane
2-chloro-1,3-butadiene
cyclo-hexanol
cyclo-hexane
1,4-dichloro-benzene
i-butanol
n-butanol
2-butanol
2-but-oxy-ethanol
butyl-lactate
carbon disulphide
ethyl benzene
2-hydroxy-methyl furan
2,2-imino-diethanol
iso-foron
iso-propenyl-benzene
iso-propyl-benzene
di(2-ethyl-hexyl)phthalate
N,N-dimethyl-acetamide
2,4-dimethyl-phenol
N,N-dimethyl-formamide
2,6-dimethyl-hepta-4-ol
2-ethoxy-ethanol
propane acid
propanal
n-propyl-acetate
tetra-chloro-ethylene
tetra-hydro-furan
1,1,1-tri-chlorine-
2-methoxy-ethanol
methyl-acetate
methyl-benzene
methyl-cyclo-hexane
methyl-formate
naphthalene

category sO.3

aliphatic hydrocarbons
alkyl-alcohols
acetic-acid-ester
benzene
2-butanol
iso-butyl-acetate
n-butyl-acetate
chlorine-ethane
di-butyl-ether
di-ethyl-ether
di-methyl-ether
1,2-ethane diol
ethanol-amine
ethylene
ethyl-acetate
ethyl-formate
4-hydroxy-4-methyl-2-methanol
2-iso-propoxy-propane
methanol
methyl-benzoate
3-methyl-2-butanol
n-methyl-pyrrolidine
4-methyl-2-pentanol
olefinic hydrocarbons
paraffinic hydrocarbons
3-pentanol
2-pentanol
petroleum
pinenen
propanol
i-propyl acetate

gaseous or vaporous organic matter

category gO.1	> 100	20
category gO.2	> 2,000	100
category gO.3	> 3,000	150

[a] the emission-standard quoted in the column "emission-standard" only applies when the mass-flow of the untreated gas meets the condition that it is bigger than the value as quoted in this column

[b] the minimal dose is below which no carcinogenic effects are to be expected

[c] zero-emission should be target.

Source: Nederlandse Emissie Richtlijnen Lucht - Stafbureau NER (Netherlands Air Emission Guidelines), 1992 e.v.

Table 11.4. U.S. National ambient air quality standards, 1988 (NAAQS)

Pollutant	**Primary (health-based) standard**		**Secondary standard**
	Averaging time	*Concentration*	
TSP[a]	annual geometric mean[b]	75 mg.m^{-3}	same
	24 hours	150 mg.m^{-3}	
SO_2	annual arithmetic mean[c]	80 mg.m^{-3} (0.03 ppm)	for 3 hours
	24 hours	365 mg.m^{-3} (0.14 ppm)	1300 mg.m^{-3} (ppm)
	3 hours	1300 mg.m^{-3} (0.5 ppm)	
CO	8 hours	10 mg.m^{-3} (9 ppm)	
	1 hour	40 mg.m^{-3} (35 ppm)	
NO_2	annual arithmetic mean[c]	100 mg.m^{-3} (0.05 ppm)	same
O_3	daily max 1 hour avg	235 mg.m^{-3} (0.12 ppm)	
Lead	maximum quarterly avg	1.5 mg.m^{-3}	
Hydrocarbons	3 hours	160 mg.m^{-3} (0.24 ppm)	same

[a] Total Suspended Particles

[b] The geometric mean is obtained by taking the nth root of the product of n numbers. This tends to reduce the impact of a few very large numbers in a set.

[c] An arithmetic mean is the average determined by dividing the sum of a group of data points by the number of points

Source: US EPA

Table 11.5. US automobile emission standards (grams per mile)

pollutant	**1968**	**1985**	**1994**
Hydrocarbons	3.4	0.41	0.4
NO_x	-	1.0	0.6
CO	34	3.4	10

Source: US EPA

Table 11.6. Annual emissions of air pollutants, Lahore Pakistan, 1985

	Particulates		**SO_2**		**CO**		**Hydrocarbons**		**NO_X**		**Aldehydes**	
Source	**tonnes**	**%**	**tonnes**	**%**	**tonnes**	**%**	**tonnes**	**%**	**tonnes**	**%**	**tonnes**	**%**
Motor vehicles	2,014	26	1,377	49	123,054	96	29,536	91	14,565	73	209	89
Railway	171	2	756	27	657	-	447	1	1,878	9	26	11
Natural gas	54	1	5	-	193	-	51		1,553	8	-	-
Wood, coal, solid waste	1,119	14	302	11	4,622	4	1,569	5	3424	9	-	-
Industrial unit	4,406	57	358	13	285	-	1,010	3	162	1	-	-
TOTAL EMISSIONS	7,764		2,798		128,811		32,613		21,582		235	

Source: UNIDO, 1994

Table 11.7. Estimated air pollutants from various economic sectors in Pakistan
(thousand tonnes)

	1977/78			**1987/88**			**1997/98**		
Sector	**CO_2**	**SO_2**	**NO_X**	**CO_2**	**SO_2**	**NO_X**	**CO_2**	**SO_2**	**NO_X**
Industry	12,308	19	n/a	26,680	423	n/a	53,429	982	n/a
Transport	7,068	52	n/a	10,254	57	n/a	18,987	105	n/a
Power	3,640	4	3	11,216	95	n/a	53,062	996	76
Domestic	16,601	5	n/a	24,054	16	n/a	3,998	40	n/a
Agriculture	845	5	n/a	4,490	28	n/a	6368	40	n/a
Commercial	1726	11	n/a	2,587	13	n/a	4,261	25	n/a

n/a = not applicable

Source: UNIDO, 1994

Table 11.8. Emission standards in the Netherlands for waste burning installations

compound	**emission standard (mg/m^3)**
total particulates	5
hydrochloric acid	10
fluorides	1
CO	50
organic compounds (as C)	10
SO_x	40
NO_x	70
heavy metals:	
Sb+Pb+Cr+Cu+Mn+V+As+Co+Ni+Se+Te	1.0
Cd	0.05
Hg	0.05
Poly Chloro Dibenzo Dioxins	0.1 ng/m^3
Poly Chloro Dibenzo Furans	0.1 ng/m^3

Source: Combustion guidelines 1989; lowering air emissions - letter of Directorate Generale Environment of Netherlands Ministry of Health and Environment to 12 provinces in 1989.

Table 11.9. Emission standards in the Netherlands for heating systems, gas turbines and piston-engines

Heating systems

		SO$_2$		**NO$_x$**		**particulate matter**	
type	general condition	sub-condition	standard (mg/m^3)	sub-condition	standard (mg/m^3)	sub-condition	standard (mg/m^3)
solid fuel	>300MW$_{th}$		200	200			
	<300MW$_{th}$		700	100			
liquid fuel		>300MW$_{th}$	200	p, A	300	>50MW$_{th}$	100 or 50[D]
		<300MW$_{th}$	1,700	p, B	150	<50MW$_{th}$	no standard
				b, A	300		
				b, B	110		
cokes-furnace gas			400, mw until 200	p	100		20
blast-furnace gas			150, mw until 120		60		
refinery gas			800[C]				
liquid petrol gas			5				
remaining gas			35				

Gas turbines and gas turbine installations

	g NO$_2$/GJ
gas turbines	200 0/30
gas turbine installations	65 0/30

Piston engines

	NO$_x$ condition	g NO$_2$/GJ
gas engines	>50kW	140 0/30 mw until 100 0/30
	<50kW	800 0/30 mw until 270 0/30
diesel engines	>50kW	400 0/30 mw until 150 0/30
	<50kW	1200 0/30 mw until 400 0/30

A liquid fuel generated inside the plant N>0.3%
B remaining liquid fuels
C gas from a refinery
D dependent on ash-content of the fuel
p process-furnaces
b boiler
0 gas-turbine or engine efficiency
mw margin width: the licence authority has freedom to dictate stricter standards (with the indicated limit) when a specific situation requires this

Source: Guidelines "Act Emission Norms Combustion Installations" A - Dumas and Mulder-Bakker, Netherlands Min. of Environment, 1993

Table 11.10. Review of Dutch boundary, guide and target values of pollutants

name of matter	**boundary value**	**guide value**	**target value**	**remark**
acrolein; propenal	20			99,99 percentile (hourly average)
	4			
acrylo nitrile; ethylene-nitrile	1		0.1	annual average
benzene	10		1	
1,2-dichloro-ethane			1	annual average
di-chlorine-methane; methylene-chloride		20	annual average	
ethylene	300	120		99.99 percentile (hourly average)
	30	12		
1,2-epoxy ethane			0.03	annual average
phenol			1	annual average
fluorides	2.8			daily average
	0.8			monthly average
	0.4			growth-seasonally average
formaldehyde; methanol	100			99.99 percentile (hourly average)
	40			98 percentile (24 hourly average)
	30			95 percentile (24 hourly average)
carbon-monoxide	6,000			98 percentile (8 hourly average)
	40,000			99.99 percentile (hourly average)
lead	2			98 percentile (24 hourly average)
	0.5			annual average
methyl-bromide; bromine-methane			1	annual average
			100	hourly average
ozone	240			hourly average, max. 5 d/a exceeding
		120		hourly average, max. 1 d/a exceeding
benzo(a)pyrene	0.005	0.0005		annual average
propylene-oxide; propyl-oxide; 1,2-epoxy propane	1		annual average	
nitrogen-dioxide	135	80		98 percentile (hourly average)
	175			99.5 percentile (hourly average)
		25		50 percentile (hourly average)
styrene			8	annual average
tetra-chlorine-ethylene	2,000	1,000	25	annual average
	8,300			98 percentile (hourly average)
		8,300		99.5 percentile (hourly average)
tri-chlorine-ethylene	50		50	annual average
	300			98 percentile (hourly average)
tri-chlorine-methane; chloroform			1	annual average
vinyl chloride; chlorine-ethylene			1	annual average
sulphur-dioxide	75	30		50 percentile (24 hourly average)
	200	80		95 percentile (24 hourly average)
	250	100		98 percentile (24 hourly average)
sulphur-hydrogen	2.5			99.5 percentile (hourly average)
particulate matter; black smoke	30			50 percentile (24 hourly average)
	75			95 percentile (24 hourly average)
	90			98 percentile (24 hourly average)
	150			24 hourly average

Source: Nederlandse Emissie Richtlijnen - NER (Netherlands Emission Standards), June 1991

Table 11.11. Estimated emission factors of selected fuels

Fuel	Heating Value (MJ/kg)	TSP $d<10\mu m$ (mg/m^3)	CO_2 (Vol %)	CO (mg/m^3)	HCs (ng/m^3)	NO_2 (mg/m^3)	SO_2 (mg/m^3)
Wood	16	4-20	8	12-156	1300	0.31	0.16
Dung	12.5	5-80	-	17-175	8200	0.14	0.24
Charcoal	30	5.5	-	-	-	0.075	0.83
Coal (Indian)	23	24.9	-	-	4200	0.17	1.7

Source: K R Smith, “Air, Health and Pollution”, 1987, quoted in “Manual on Simple Monitoring Techniques for the Control of Indoor Air and Combution Quality Standards in Developing Countries”, J Usinger, WHO/HEP-GTZ, 1996.

Table 11.12. WHO standards for health affecting limits of various pollutants

Pollutant	Concentration	Time limit
Carbon Monoxide	100 mg/m^3	15 min
	60 mg/m^3	30 min
	30 mg/m^3	1 hour
	10 mg/m^3	8 hours
Formaldehyde	100 $\mu g/m^3$	30 min
Lead	1 $\mu g/m^3$	1 year
Nitrogen dioxide	400 $\mu g/m^3$	1 hour
	150 $\mu g/m^3$	24 hours
Ozone	200 $\mu g/m^3$	1 hour
	120 $\mu g/m^3$	8 hours
Sulphur dioxide	500 $\mu g/m^3$	10 min
	350 $\mu g/m^3$	1 hour
	125 $\mu g/m^3$	24 hours
Suspended Particles	120 $\mu g/m^3$	24 hours
Thoracic Particles	70 $\mu g/m^3$	24 hours
Benzene	2.5 $\mu g/m^3$	1 year
Asbestos	500 fibres/m^3	1 year
Radon	100 Bq	1 year
Tobacco smoke	as little as feasible	not inside bedroom of young children or the sick

Source: Quoted in “Manual on Simple Monitoring Techniques for the Control of Indoor Air and Combustion Quality Standards in Developing Countries”, J Usinger, WHO/HEP-GTZ, 1996.

Table 11.13. Comparison of smoke exposures and concentrations due to traditional and improved cook stoves in South Asia: summary of studies

Location	pollutant	Traditional Stoves		Improved Stoves		stat. variance	date
		number	mean	number	mean		
Nepal (personal monitoring)							
Two mid-hill villages	TSP	22	3.14 mg/m^3	27	1.13 mg/m^3	<0.5%	1986
India (personal monitoring)							
Two Gujarat villages	TSP BAP	21 21	6.4 mg/m^3 3.7 μg/m^3	14 14	4.6 mg/m^3 2.4 μg/m^3	n.s. n.s.	1983
Four Gujarat villages	TSP	21	3.6 mg/m^3	23	3.9 mg/m^3	n.s.	1987
One Harayana village[a]	TSP	51	3.2 mg/m^3	36	2.8 mg/m^3	n.s.	1987
Two Karnataka villages[a,b]	TSP	39	3.5 mg/m^3	40	2.6 mg/m^3	n.s.	1987
Nepal (area monitoring)							
Two mid-hill villages	CO	27	300 ppm	26	67 ppm	<0.1%	1986
7-day means[c]							
(kitchen)	NO_2	5	0.26 ppm	5	0.04 ppm	<1.0%	1986
(bedroom)	NO_2	4	0.02 ppm	4	0.04 ppm	n.s.	
(kitchen)	HCHO	5	0.33 ppm	4	0.04 ppm	n.s.	
(bedroom)	HCHO	4	0.04 ppm	4	0.13 ppm	n.s.	
Nepal, Kathmandu valley (simulated cooking)							
old stoves	CO	16	600 ppm	28	400 ppm	<5%	1985
new, well installed stoves	CO	28	400 ppm	11	100 ppm	<0.5%	1985

Notes: Except where noted all measurements were taken during the cooking period in the dry season either by use of personal monitoring equipment worn by the cook or with stationary monitors placed nearby.

HCHO Formalehyde

n.s. not significant, that is less than 0.5%

a These measurements were taken in all three major seasons (summer, winter, monsoon).

b Also measured were exposures of women cooking with traditional stoves placed under a fireplace-style hood. With 24 measurements, the mean was 1.6 mg/m^3, which is significantly lower than either the traditional stove or the improved stove in the same village (p<1%).

c The p value for combined kitchen and bedroom NO_2 concentrations in homes with traditional versus improved stoves is <2.5% while that for HCHO is not significant.

Source: K Smith, “Biofuels, Air Pollution, and Health: A Global Review”, Plenum Press, New York, 1987, quoted in K V Ramani, A K N Reddy, and M N Islam, “Rural Energy Planning: A Government Enabled Market Based Approach”, APDC, Kuala Lumpur, Malaysia, 1995

Table 11.14. Nominal particulate dose commitment and dose-equivalent energy for alternative cooking methods

	Coal Power Plant and Electric Stove		Wood Fuel Cook stove	
	Conversion Factor	Quantity	Conversion Factor	Quantity
Energy into pot		1.0 MJ Heat		1.0 MJ Heat
Stove Efficiency	80%	1.2 MJ Heat	20%	5.0 MJ Heat
Transmission	80%	1.6 MJ Heat		
Conversion	30%	5.2 MJ Heat		
Density	20 MJ/kg	0.3 kg Coal	15 MJ/kg	0.33 kg Wood
Emission Factor	200 g/kg	52 g TSP	2 g/kg	0.66 g TSP
Flue gas control	85%	8.0 g TSP	0	0.66 g TSP
Dose commitment or Dose-equivalent energy[b]	2.5 g/t	0.2×10^{-4} g/MJ or 50,000 MJ/g	1,200 g/t	1×10^{-3} g/MJ or 1000 MJ/g

Notes

a Dose commitment = (Dose equivalent energy) - 1 = grams particulates inhaled by humans per unit useful energy; in this case MJ heat into cook pot.

b Dose equivalent energy = (Dose commitment) - 1 = MJ useful energy per gram of inhaled particulates.

Source: K Smith, “Biofuels, Air Pollution, and Health: A Global Review”, Plenum Press, New York, 1987, quoted in K V Ramani, A K N Reddy, and M N Islam, “Rural Energy Planning: A Government Enabled Market Based Approach”, APDC, Kuala Lumpur, Malaysia, 1995

Table 11.15. Nominal dose commitments for RSP, CO, NO$_X$, and HCHO resulting from cooking one meal on an unvented stove[a]

Stove	**RSP (mg)**	**CO (mg)**	**NO$_X$ (mg)**	**HCHO (mg)**
Wood fired[b]	17.0	340.0	8.5	0.69
Gas[c]	0.012	5.9	0.27	0.05
Kerosene[d]	4.2	58	1.5	0.069

Notes

HCHO = Formalehyde

a 40 m^3 kitchen, 5 ACH, 1.5 hour cooking period, one burner in use

b Wood stove: 2 kg/h, 15 MJ/kg, 10% efficient, 135 mg/MJ-RSP, 2700 mg/MJ-CO, 68 mg/MJ NO$_X$, 2.7 mg/MJ HCHO. Mixing behaviour lower exposures by 50%.

c Gas stove: 3.8 MJ/h, 80% efficient, 0.4 mg/MJ RSP. 200 mg/MJ-CO. 9.0 mg/MJ NO$_X$, 1.7 mg/MG-HCHO.

d Kerosene Stove: (RSP and CO measurements of Nutun cook stove, others from highest reported levels for kerosene heaters): 5.0 MJ/h, 60% efficient, 64 mg/MJ RSP, 920 mg/MJ-CO, 26 mg/MJ NO$_{X,}$, 1.2 mg/MG-HCHO.

Source: K Smith, “Biofuels, Air Pollution, and Health: A Global Review”, Plenum Press, New York, 1987, quoted in K V Ramani, A K N Reddy, and M N Islam, “Rural Energy Planning: A Government Enabled Market Based Approach”, APDC, Kuala Lumpur, Malaysia, 1995

Table 11.16. Kerosene stove emission factors (g/kg)

Date of quoted study	Stove type	TSP	CO	HCHO	NO_2/NO
1982	Radiant and convective	-	3.2	-	0.7/0.7
1983		0.06	-	-	-
1983	Radiant	0.01	2.8	0.05	0.6/0.5
1984		-	4	-	0.5-0.7
1984		-	5.5	-	0.2/0.07
1984		-	4.4	-	0.1
1985	Radiant	-	5.7	-	0.16/0.06
	Convective	-	0.03	-	0.13/0.7
	Multi-stage	-	0.06	-	0.11/0.27
1985	Radiative	0.022[a]	-	-	-
	Convective	0.017[a]			
1987 (1)	Kerosene	5.0	67	-	-
	Nutan	2.8	41		
1987	Wood fired	2.0	40	0.4	0.5

Notes
All studies except (1) relate to unvented space heaters.
Original units in square brackets which have been converted into common unit (g/kg).
Kerosene has net energy of 43.5 MJ/kg and a mass density of 0.78.
HCHO = Formaldehyde

[a] Total PAH from radiant heater found to be 0.04 mg/kg and from convective heater 0.005 mg./kg. This compares with about 1.0 mg/kg for BaP alone in wood combustion.

Source: K Smith, “Biofuels, Air Pollution, and Health: A Global Review”, Plenum Press, New York, 1987, quoted in K V Ramani, A K N Reddy, and M N Islam, “Rural Energy Planning: A Government Enabled Market Based Approach”, APDC, Kuala Lumpur, Malaysia, 1995

Table 11.17 Conversion of ppm to mg/m³ and vice versa

Gas	**Mass of mol (g/mol)**	**Factor to convert ppm into mg/m^3**	**Factor to convert mg/m^3 into ppm**
Carbon monoxide CO	28	1.16	0.86
Nitrogen dioxide NO_2	46	1.91	0.52
Sulphur dioxide SO_2	64	2.66	0.37
Formaldehyde HCHO	30	1.25	0.8
Benzol C_6H_6	78	3.25	0.31

Example

The level of Carbon Monoxide in a flue gas exhaust was found to be 10 mg/m^3. The corresponding ppm is given by: 0.86 x 10 = 8.6 ppm.
The formaldehyde level was found to be 0.3 ppm. The corresponding concentration in mg/m^3 is given by: 1.25 x 0.3 = 0.375 mg/m^3.

Source: J Usinger, “Manual on Simple Monitoring Techniques for the Control of Indoor Air and Combustion Quality Standards in Developing Countries” , WHO/HEP-GTZ, 1996.

12. GLOSSARY OF ENERGY AND ENVIRONMENTAL TERMS

Acid rain or acid deposition
A complex chemical and atmospheric phenomenon that occurs when emissions of sulphur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in either a wet or dry form. The wet forms, popularly called acid rain, can fall as rain, snow or fog. The dry forms are acidic gases or particulates.

Active solar energy
The advanced use of sunshine through solar photovoltaic or solar thermal conversion technologies.

Air quality standards
The level of pollutants prescribed by regulations that may not be exceeded during a specified time in a defined area.

Agricultural residues
By-products of the agricultural production system, including straws, husks, shells stalks and animal dung, with a large number of uses, including an energy resource. Residues can be divided into two groups: crop residues, which remain on the field after harvest, for example, cotton stalks; and agro-processing residues, produced off-field at a central production sight, for example, rice husk.

Agro-processing residues
See under agricultural residues.

Alternative energy system
A phrase used to describe new energy technologies and production processes that are seen as alternatives for traditional and conventional energy sources.

Anaerobic digestion
The natural process of decomposition of organic material by bacteria under anaerobic conditions (i.e. in the absence of oxygen), a by-product of which is biogas.

Animate energy (or power)
Utilisation of human and animal muscles to do work.

Assimilation
The ability of a body of water to purify itself of pollutants.

Base load
The average minimum demand on an electricity system, usually measured over a 24 hour cycle.

Basel Convention
The Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and their Disposal (1989) aims to control the trans boundary movement and disposal of hazardous wastes.

Biochemical oxygen demand (BOD)
A measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The greater the BOD, the greater the pollution.

Biocoal
Compacted solid fuel made from carbonised wood waste or low ash agro-residues.

Biodegradability
The ability to break down or decompose rapidly under natural conditions and processes.

Bio-diesel
Modified (trans-esterified) vegetable oils, such as soya bean, palm oil, jatropha, which have similar chemical properties to diesel and therefore can be used as a direct substitute.

Biodiversity
Biological diversity, the variety of species within a given area.

Biogas
A mixture of gases consisting of around 60 to 70% of methane (depending on conditions) produced by the process of anaerobic digestion in a closed container (digester). Biogas burns with similar properties to natural gas.

Biological magnification
Refers to the process whereby certain substances such as pesticides or heavy metals move up the food chain, work their way into a river or lake and are eaten by large birds, animals or humans. The substances become concentrated in tissues or internal organs as they move up the chain.

Biological oxidation
The way bacteria and micro-organisms feed on and decompose complex organic materials. Used in self-purification of water bodies and in activated sludge waste-water treatment.

Biological treatment
A treatment technology that uses bacteria to consume waste. This treatment breaks down organic materials.

Biomass
A generic term to describe all forms of organic matter including wood, agricultural waste, animal dung and human waste. The term can be extended to include derivatives, such as ethanol, which can be used as fuels. (The scientific definition is the total dry organic matter or stored energy content of living organisms in a given area.)

Biosphere
The portion of the earth that supports life, including the surface waters and the air. Similar to ecosphere.

Biotechnology
Techniques that use living organisms or parts of organisms to produce a variety of products, from medicines to industrial enzymes, to improve plants or animals or to develop micro-organisms for specific uses such as removing toxins from bodies of water or killing pests.

Briquetting
Densification of loose organic material, such as rice husk, sawdust, coffee husks, to improve fuel characteristics including handling and combustion properties.

Brundtland Report
Popular name for report produced in 1987 by the World Commission on Environment and Development. This United Nations-sponsored body produced a global agenda for change and specified how sustainable development could be achieved. The commission was chaired by Gro Harlem Brundtland, the then – and subsequently re-elected – prime minister of Norway.

Cadmium
Toxic heavy metal used mainly for metal plating and as a plastic pigment. Significant by-product in zinc smelting and of concern in phosphate manufacture.

Capacity factor
The actual output of a technology divided by the theoretical maximum output of the technology operating at peak design resource levels.

Capital cost
The investment in plant and equipment, including construction costs but not operation, maintenance or energy costs.

Carbon cycle
The circulation of carbon in the biosphere. Carbon is an essential part – a building block – of the molecules that make up all living cells. In the atmosphere it circulates as carbon dioxide, which is released by respiration, combustion and decay and fixed in complex carbon compounds during photosynthesis in plants and certain micro-organisms.

Carbon dioxide (CO_2)
A colourless, odourless, non-poisonous gas that results from respiration, combustion and decay and is normally present in ambient air.

Carbonisation
The heating of biomass in the absence of air to remove the volatile component, leaving a solid high carbon product, charcoal.

Carbon sink
See **Sink**.

Carcinogen
Any substance that can cause or contribute to the onset of cancer.

Catalytic converter
An air pollution abatement device that removes pollutants from motor vehicle exhaust, either by oxidising them into carbon dioxide and water or reducing them to nitrogen and oxygen.

Chemical oxygen demand (COD)
A measure of oxygen required to oxidise all compounds in water, both organic and inorganic.

Chlorofluorocarbons (CFCs)
A family of inert, non-toxic and easily liquefied chemicals used in refrigeration, air conditioning, packaging and insulation or as solvents and aerosol propellants. Because CFCs are not destroyed in the lower atmosphere they drift into the upper atmosphere, where their chlorine components destroy ozone.

Cleaner production
A concept of industrial production that minimises all environmental impacts through careful management of resource use, of product design and use, systematic waste avoidance and management of residuals, safe working practices and industrial safety. Sometimes called pollution prevention or waste minimisation.

Clean technologies
Production processes or equipment with a low rate of waste production. Treatment or recycling plants are not classed as clean technologies.

Co-generation
Sequencial production of both heat and power using the same fuel. An example is the use of expanded steam left over after generating electricity for heating purposes. The concept is applied extensively in many wood and agro-processing industries (such as, sugar and palm oil mills).

Combined Heat and Power (CHP) Generation
Simultanous production of both heat and power. The difference with co-generation is that the generation of heat and power may be done as parallel processes, which results in a lower overall efficiency.

Combustion
Chemical reaction between a fuel and oxygen which usually takes place in air. More commonly known as burning. The products are carbon dioxide and water with the release of heat energy.

Commercial energy
Energy traded in the market for a monetary price, usually conventional energy, such as coal or oil, but also traditional energy, such as fuelwood, which is traded in urban and semi-urban areas in many developing countries.

Coppicing
Technique of utilising the ability of some trees species to re-generate from the stump after a cutting.

Cradle-to-grave
Term used to imply the whole life cycle of a product, from raw material to final disposal.

Crop residues
See under agricultural residues.

Decentralised energy systems
Small scale energy producing facilities deigned to meet local demand only.

Demand side management
The planning, implementation and monitoring of activities designed to encourage consumers to modify their pattern of energy use.

Dendropower
The conversion of wood energy to electricity or shaft power.

Dilution ratio
The relationship between the volume of water in a stream and the volume of incoming water. If affects the ability of the stream to assimilate waste.

Dioxin
Any of a family of compounds known chemically as dibenzo-*p*-dioxins. They are of concern because of their potential toxicity and contamination in commercial products. Tests on laboratory animals indicate that dioxins are among the more toxic man-made chemicals known.

Disposal
Final placement or destruction of toxic, radioactive or other wastes; surplus or banned pesticides or other chemicals; polluted soils; and drums containing hazardous materials from removal actions or accidental releases. Disposal may be accomplished through use of approved secure landfills, surface impoundments, land farming, deep well injection, ocean dumping or incineration.

Dissolved oxygen (DO)
The oxygen freely available in water. Dissolved oxygen is vital to fish and other aquatic life and for the prevention of odours. Traditionally, its level has been accepted as the single most important indicator of a water body's ability to support desirable aquatic life. Secondary and advanced waste treatment are generally designed to protect DO in waste-receiving waters.

Dump
A site used to dispose of solid wastes without environmental controls.

Eco-efficiency
Maximization of industrial output from a given level of resource input, thus ensuring waste minimisation and appropriate use of human, renewable and non-renewable resources.

Ecology
The relationship of living things to one another and their environment, or the study of such relationships.

Ecologically sustainable industrial development (ESID)
Patterns of industrialisation that enhance the contribution of industry to economic and social benefits for present and future generations without impairing basic ecological processes.

Ecosystem
The interacting system of a biological community and its non-living environmental surroundings.

End-of-pipe treatment (abatement)
Treating pollutants at the end of a process (by, for example, filters, catalysts and scrubbers) instead of preventing their occurrence.

End-use
The final use of energy at the level of the user, for example, lighting, cooking, space-heating and motive power.

Energy
Capacity (or ability) to do work.

Energy auditing
A systematic method of identifying and accounting for energy flows through an industrial system or process to assist in identifying options to reduce energy use.

Energy balance
An energy balance is a set of relationships accounting for all the energy which is produced and consumed, and matches inputs and outputs, in a system over a certain time period. The system can be a country, a region, a village, a farm, a household, a factory, or a process.

Energy carrier
A liquid, gaseous or solid fuel or electricity to provide energy.

Energy convertor
Device, process of system which transforms energy from one form into another, for example, diesel engine, generator, electric motor, water pump.

Energy efficiency
Conversion ratio of output and input energy of energy production technologies and end-use appliances.

Energy equivalent
Theoretical value comparing energy contents of two different fuels, not including differences in transformation efficiencies.

Energy intensity
Amount of energy needed per unit of physical or monetary output.

Energy need
Actual end-need for which energy is required, for example, illumination, mobility, warmth.

Energy replacement value
The amount of a particular energy form which in practice is needed to do the same job as another energy form or fuel.

Energy service
View of energy as a resource to perform a desired task to meet end-needs

Environment
The sum of all external conditions including physical and social factors, affecting the life, development and survival of an organism.

Environmental compliance audit
Systematic review and testing by professional environmental auditors of the management, production, marketing, product development and organisational systems of an enterprise to determine and assess compliance with environmental regulations.

Environmental impact assessment
An analysis to determine whether an action would significantly affect the environment.

Eutrophication
The slow ageing process in which a lake, estuary or bay becomes a bog or marsh and eventually disappears. During the later stages, or eutrophication, the water body is choked by overabundant plant life as the amounts of nutritive compounds such as nitrogen and phosphorus increase. Human activities can accelerate the process.

Expressed demand
Equal to consumption. Demand that is expressed in relation to energy supply availability and the user's purchasing power or physical capacity to acquire.

Externality
The cost or benefits to parties other than the supplier and purchaser of an economic transaction.

FAO
Food and Agricultural Organisation of the United Nations.

Feedback
When a change in one variable in a system, for example, increase in temperature, triggers changes in a second variable, such as cloud cover, which in turn ultimately affects the original variable, that is, increasing or diminishing the warming. A positive feedback intensifies the initial change, a negative feedback reduces the initial change.

Final energy
Energy which the consumer buys or receives to perform a desired task with an end-use device.

Fossil fuels
The non-renewable energy resources of coal, petroleum or natural gas or any fuel derived from them. Exploitation of new reserves has a long development period.

Fuel wood
Trunks and branches of trees as well as residues from wood processing industries and scrapwood which are used as an energy source, largely through direct combustion.

Gasification
Conversion of solid fuels (biomass and coal) at high temperatures in the absence of air to give combustible gases.

Generating capacity
The capacity of a power plant to generate electricity, often expressed in watts-electric (e.g. MW_e).

GDP
Gross Domestic Product. The total market value of all the goods and services produced within a nation (excluding income from abroad) during a specified period.

GEMS
Global Environment Monitoring System, managed by UNEP. Makes comprehensive assessments of major environmental issues and thus provides the scientific data needed for the rational management or natural resources and the environment, provides early warning of environmental changes by analysing monitoring data.

Global warming
The consequences of the greenhouse effect, caused by rising concentrations of greenhouse gases. The suspicion is that global warming will disrupt weather and climate patterns. It could lead to drought in some areas and flooding in others. One of the most serious environmental problems facing the world.

GNP
Gross National Product. The local market value of all the goods and services produced by a nation (including income from abroad) during a specified period.

Good housekeeping
Efficient management of the property and equipment of an institution or organisation. In the context of Cleaner Production, it often refers to the procedures applied in the operation of a production process.

Greenhouse effect
The warming of the earth's atmosphere, caused by a build-up of carbon dioxide or other trace gases. It is believed by many scientists that this build-up allows light from the sun's ray to heat the earth but prevents a counterbalancing loss of heat.

Greenhouse gases
The gases, such as carbon dioxide, water vapour, methane, nitrous oxides and CFCs, that trap the sun's heat in the lower atmosphere and prevent it from escaping into space. Major source of increased concentration in the atmosphere is the combustion of fossil fuels. See **Greenhouse effect**.

Gross Energy Requirement (GER)
Total energy input required for one unit of product

Groundwater
The supply of fresh water found beneath the earth's surface (usually in aquifers) that is often used for supplying wells and springs. Because groundwater is an important source of drinking water, there is growing concern about areas where agricultural or industrial pollutants or substances from leaking underground storage tanks are contaminating groundwater.

Halons
Bromine-containing compounds with long atmospheric lifetimes whose breakdown in the stratosphere can cause depletion of ozone. Halons are used in fire-fighting.

Hazardous waste
By-products of society that can pose a substantial hazard to human health or the environment when improperly managed. Characterised by at least one of the following: ignitability, corrosivity, reactivity or toxicity.

Heavy metals
Metallic elements with high atomic weights, e.g. mercury, chromium, cadmium, arsenic and lead. They can damage living organisms at low concentrations and tend to accumulate in the food chain.

Hydrocarbon (HC)
Chemical compounds consisting entirely of carbon and hydrogen.

IE/PAC
Industry and Environment Programme Activity Centre of UNEP, in Paris; formerly called the Industry and Environment Office.

IEA
International Energy Agency of the OECD

Incineration
1. Burning of solid, liquid or gaseous materials.
2. A treatment technology involving destruction of waste by controlled burning at high temperature, e.g. burning sludge to remove the water, to reduce the remaining residues to a safe, non-combustible ash that can be disposed of safely on land, in some waters or in underground locations.

INEM
International Environmental Management Association. Co-ordinates and supports national associations of environmentalist business management associations or business enterprises. Described in the European Community publication *Business and Environment*.

IPCC
Intergovernmental Panel on Climate Change.

IRPTC
International Register of Potentially Toxic Chemicals, at Geneva. A co-operative activity of UNEP/WHO/ILO. Maintains a global system for assessing environmental effects of chemicals. Topics include identification of knowledge gaps; chemical hazards; evaluation and control of chemicals in the environment; numerical data; production, use and characteristics of chemicals; laws and regulations affecting man, living species and natural resources.

Landfills
1. Sanitary landfills are land disposal sites for non-hazardous solid wastes, where the waste is spread in layers, compacted to the smallest practical volume and cover material applied at the end of each operating day.
2. Secure chemical landfills are disposal sites for hazardous waste. They are selected and designed to minimise the chance of hazardous substances being released into the environment.

Leachate
A liquid produced when water collects contaminants as it trickles through wastes, agricultural pesticides of fertilisers. Leaching may occur in farming areas, feedlots or landfills and may result in hazardous substances entering surface water, groundwater or soil.

Life cycle cost
The cost of a good or service over its entire life cycle.

Mercury
A heavy metal that can accumulate in the environment and is highly toxic if breathed or swallowed. See **Heavy metals**.

Minimisation
Actions to avoid, reduce or in other ways diminish the hazards of wastes at their source. Recycling is, strictly speaking, not a minimisation technique but is often included in such programmes for practical reasons.

Monoculture
The exclusive cultivation of a single species, a common practice in modern agriculture and forestry.

Montreal Protocol
The Montreal Protocol on Substances that Deplete the Ozone Layer, adopted 16 September 1987, sets limits for the production and consumption of damaging CFCs and halons.

NIMBY
Acronym for "not in my back yard." Political jargon to describe a situation in which the electorate might agree to, say, industrial dumping or incineration, as long as it does not take place near their homes.

Nitrate
A compound containing nitrogen that can exist in the atmosphere or as a dissolved gas in water and that can have harmful effects on humans and animals. Nitrates in water can cause severe illness in infants and cows.

Non-commercial energy
Energy which does not have a monetary price, usually refers to fuelwood, agricultural residues or animal waste, which are self collected or traded through barter.

Non-point source
Pollution sources that are diffuse and do not have a single point of origin or are not introduced into a receiving stream from a specific outlet. The pollutants are generally carried off the land by storm-water run-off. The commonly used categories for non-point sources are agriculture, forestry, urban areas, mining, construction, dams and channels, land disposal and salt-water intrusion.

Non-renewable energy
Any form of primary energy, the supply of which is finite and hence its use depletes the existing stock. It generally refers to fossil fuels.

Non-woody biomass
Stalks, leaves, grass, animal and human waste.

NO_x
Chemical formula that stands for all the oxides of nitrogen, mainly NO_2, but also N_2O, NO, N_2O_3, N_2O_4 and NO_3, which is unstable.

Nutrient
Any substance assimilated by living organisms that promotes growth. The term is generally applied to nitrogen and phosphorus in waste water but is also applied to other essential and trace elements.

Off-site facility
A hazardous waste treatment, storage or disposal area that is located away from the generating site.

Ozone (O_3)
Found in the lower layers of the atmosphere, the stratosphere and the troposphere. In the stratosphere (the atmospheric layer beginning 7-10 miles above the earth's surface), ozone is a form of oxygen found naturally which provides a protective layer, shielding the earth from ultraviolet radiation's harmful health effects on humans and the environment. In the troposphere (the layer extending up 7-10 miles above the earth's surface), ozone is a chemical oxidant and a major component of photochemical smog. Ozone can seriously affect the human respiratory system and is one of the most prevalent and widespread pollutants. Ozone in the troposphere is produced through complex chemical reactions between nitrogen oxides, which are among the primary pollutants emitted by combustion sources, hydrocarbons, which are released into the atmosphere by the combustion, handling and processing of petroleum products, and sunlight.

Ozone depletion
Destruction of the stratospheric ozone layer, which shields the earth from ultraviolet radiation harmful to life. This destruction of ozone is caused by certain chlorine- and/or bromine-containing compounds (chlorofluorocarbons or halons), which break down when they reach the stratosphere and catalyse the destruction of ozone molecules.

Passive solar energy
The direct use of natural sunshine for lighting, heating or convective ventilation in buildings in order to replace conventional conversion technologies.

PCBs
A group of toxic, persistent chemicals (chemical name: polychlorinated biphenyls) used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant.

Peak load
The average maximum power demand on an energy system, especially for electricity generation, over a period of time, usually a 24 hour cycle.

Phenols
Organic compounds that are by-products of petroleum refining, tanning and the manufacturing of textiles, dyes and resins. Low concentrations cause taste and odour problems in water; higher concentrations can kill aquatic, animal and human life.

Phosphates
Certain chemical compounds containing phosphorus.

Phosphorus
An essential chemical food element that can contribute to the eutrophication of lakes and other water bodies. Increased phosphorus levels result from discharge of phosphorus containing materials into surface waters.

Photochemical smog
Air pollutant formed by the action of sunlight on oxides of nitrogen and hydrocarbons.

Pollutant
Generally, any substance introduced into the environment that has the potential to adversely affect the water, soil or air. See **Residual**.

Pollution
Generally, the presence of matter or energy whose nature, location or quantity produces undesired environmental effects.

Power
The rate at which energy is converted or transmitted in a given period of time.

Primary energy sources
Any natural energy source available in nature which can be transformed into a useful energy form, such as coal, solar, biomass.

PVC
A tough, environmentally indestructible plastic (chemical name: polyvinyl chloride) that releases hydrochloric acid when burned.

Recycling
The process of minimising the generation of waste by recovering useable products that might otherwise become waste. Examples are the recycling of aluminium cans, waste paper and bottles.

Reserves
The portion of a resource base that is proven to exist and can be economically recovered, that is, the value of the product exceeds the production and transportation costs.

Residual
A pollutant remaining in the environment after a natural or technological process has taken place, e.g. the sludge remaining after initial waste-water treatment or particulates remaining in air after the air passes through a scrubbing or other pollutant removal process.

Resources
The total existing stock of a resource, including discovered and not yet discovered portions, regardless of the economic feasibility of recovering the resource.

Risk assessment
The qualitative and quantitative evaluation performed in an effort to define the risk posed to human health and/or the environment by the presence or potential presence and/or use of specific pollutants.

Rotation period
Age of a tree when it becomes mature for harvest

Rural electrification
The extension of supply of electricity to the rural areas, conventionally by extending the national grid based on centralised generating power plants but now taken to include small scale decentralised generating systems.

RWEDP
Regional Wood Energy Development Programme in Asia.

Scrubber
An air pollution control device that uses a spray of water or reactant or a dry process to trap pollutants in emissions.

Secondary energy
Energy in a form ready for transport or transmission.

Sink
In air pollution, the receiving area for material removed from the atmosphere, e.g. by virtue of photosynthesis, plants are sinks for carbon dioxide.

Solar Photovoltaics
Technologies which convert sunshine into electricity using solar cells (photosensitive silicon cells).

Solar Thermal Energy
Energy derived from converting sunshine into direct heating applications, such as water heating, or to produce electricity in a steam generating plant.

Solvents
Liquids that dissolve other substances. Chemical solvents are used widely in industry. They are used by pharmaceutical makers to extract active substances; by electronics manufacturers to wash circuit boards; by paint-makers to aid drying. Most solvents can cause air and water pollution and can be a health hazard.

Standing stock
Total volume of trees in a specified area.

Sulphur dioxide (SO_2)
A colourless, irritating pungent gas formed when sulphur burns in air, one of the main air pollutants that contribute to acid rain and smog. Comes from the combustion of the sulphur present in most fossil fuels.

Suspended Particulate Matter (SPM)
Fine liquid or solid particles such as dust, smoke, mist, fumes or smog, found in air or emissions.

Sustainable development
Development that meets present needs without compromising the ability of future generations to meet their own needs. Necessarily based on limited data due to our current inability to forecast accurately 50-100 years ahead.

Synergistic
Interaction between two or more forces such that their combined effect is greater than the sum of their individual effects.

Tradeable permits
Market mechanism for controlling pollution; it entails issuing permits to pollute up to fixed limits and grants the right to sell unused portions of the permits.

Traditional energy
Forms of energy derived from locally available biomass, animate power and other renewable energy sources using rudimentary production processes and technologies.

Tree production rate
Annual increment of standing stock per unit area.

UNCED
United Nations Conference on Environment and Development; it took place at Rio de Janeiro in June 1992 and was convened by the General Assembly in its resolution 44/228.

UNDP
United Nations Development Programme.

UNEP
United Nations Environment Programme.

Unsatisfied demand
The difference between expressed demand and effective (or satisfied) demand, also called suppressed demand

Useful energy
Energy which is available to perform the task required by the end-user, such as heat, light or shaft power.

UV-B
Short wavelength ultraviolet radiation.

Waste
Unwanted materials left over from a manufacturing process and refuse from places of human or animal habitation.

Waste reduction audit
Highly cost-effective technique that follows material inputs into the production process and accounts for them quantitatively, in any form (solid, liquid, gaseous), to identify losses (wastes), which can then be reduced by changes in input materials, process technology, product design and recycling.

Waste minimisation
The reduction of waste by changing materials, processes or on-site disposals arrangements in a way that is profitable for the enterprise and the environment. Also called waste reduction.

Water quality standards
Ambient standards for water bodies. The standards address the use of the water body and set water quality criteria that must be met to protect the designated use or uses.

WCED
World Commission on Environment and Development

WEC
World Energy Council

WICE
World Industry Council for the Environment, a division of the International Chamber of Commerce that raises environmental awareness on the part of industry in developing and developed countries.

Wind farm
A group (or array) of wind turbines connected to a grid for producing electricity.

Woody biomass
Stems, branches, shrubs, hedges, twigs and residues of wood processing.