Sustainable Living: the Role of Whole Life Costs and Values

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& Robert Vale

ROUTLEDGE

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Preface

Lifetime studies are becoming commonplace in product evaluations. However, this does not apply to buildings and related activities owing to the relatively longer period involved, which leads to uncertainty. Many books which deal with the design and construction of sustainable houses have been published. However, sustainability also depends on the post-occupation activities of the users, which have not been highlighted. This book attempts to fill that gap in knowledge through the use of results from a recently completed research project.

The book demonstrates the implications of choices the designers, developers and building-users make to achieve sustainability in the residential building sector, through an analysis that covers the full lifespan. It identifies the problems associated with current practices through a lifespan model that considers costs, embodied and operating energy use, environmental impact, and global warming potential. The model was developed based on current practices employed in New Zealand and highlights the need for a new holistic approach to be taken. By considering the full lifespan, and many items such as finishes, furniture and appliances, which are usually disregarded in evaluations, the text demonstrates the importance of material and systems selection and user behaviour. It discusses the major issues ranked based on their importance for achieving greater sustainability in residential projects and highlights those which are not in common knowledge.

The book also demonstrates the practical use of life cycle analysis for achieving best practice in construction and use of residential buildings. It provides a practical guide to designers and the general public in applying the lessons learnt to individual projects to achieve sustainability in residential buildings.

The book consists of a general discussion of issues ranked based on their importance for achieving sustainability, with case studies intended for the general reader and detailed justification of the importance of issues for the more specialised reader.

Illustrations

Acknowledgements

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Part A:

Construction Industry and Resource Issues

1 Introduction

Housing trends worldwide are changing rapidly, and population is increasing. There is a pressing need to understand the current state of the consumption of energy attributable to the residential sector of the global economy, and the resultant environmental impacts which, in turn, govern the sustainability of human practices. Many books which deal with the design and construction of sustainable houses have been published. However, the sustainability of houses, owing to their relatively long useful lifetime, also depends on the post-occupation activities of the users, and this is often forgotten. Studies have found that energy use and environmental impacts during this phase could far outweigh those during the construction phase. Therefore, if countries are to fulfil their international commitment to reduce greenhouse gas emissions and the resultant environmental impact, this represents a serious gap in knowledge.

This book attempts to fill that gap in knowledge through the use of results from a recently completed research project funded by the Foundation for Research Science and Technology (FRST) in New Zealand. The book is based on the results of a study of single houses in the relatively mild climate of Auckland and demonstrates the implications of choices the designers, developers and building users can make to achieve greater sustainability in the residential building sector through an analysis that covers the full lifespan of the house. It identifies the problems associated with current practices through a lifespan model which considers costs, embodied and operating energy use, environmental impact, and global warming potential. The model was developed based on current construction practices employed in New Zealand and highlights the need for a new holistic approach to be taken. By considering full lifespan, and many items such as finishes, furniture and appliances, which are usually disregarded in evaluations, the text demonstrates the importance of material and systems selection and user behaviour. It discusses the major issues ranked based on their importance for achieving greater sustainability in residential projects and highlights those which are not common knowledge.

The book also demonstrates the practical use of life cycle analysis for achieving best practice in the construction and use of residential buildings. Although commercial buildings are different from housing in terms of scale, construction, usage, and user behaviour, etc., the discussion in the book will be relevant to the small commercial buildings which make up the greater part of commercial development, because they use similar construction technology to houses, but it will not relate well to city centre high rise buildings. It provides a practical guide to designers and the general public in applying the lessons learned to individual projects to achieve sustainability in residential buildings.

The situation

From ancient times people have reacted to the natural environment and, using an acquired ability to manipulate building materials, have created a built environment not only to offer protection from the vagaries of the weather but to express an understanding of the world. Though these traditional constructions, which used materials and construction methods locally available in the vicinity, were in harmony with the environment, and were part of a sustainable environment for very many years, the conditions under which these were effective have now changed to a point where these traditional methods no longer seem wholly appropriate. The relationships between the way a particular society lived, what was built, and how it was built were interdependent relationships.

As an example, the small cottage with minimal window openings in a temperate climate was an ideal building for a society that was largely agricultural and where workers spent long hours in the open air. Home was a retreat and a place for sleeping once it was dark, so there was little need for natural light within the building. Now the reverse is true and in many cultures people spend all day away from the house in another building, or place of work. However, they expect the benefit of light when they are home in the evening, and so energy has to be expended to provide this light. The use of natural ventilation is another simple practice that has suffered because of the need for people, and often both adults in a family, to work, to support a household, with children also spending their waking hours away from home in school and after school activities. The old-fashioned wisdom was that rooms should be ventilated and that the best time to do this was midday when temperatures are highest and relative humidity is lowest. Such ventilation removed moisture from the dwelling as well as refreshing the air. Now, with the family away from home all day, windows cannot be left open for ventilation because of security concerns and in the evening it is too cold to ventilate the house by opening them. Therefore artificial methods have to be found to ventilate the building, again with expenditure of energy, because of the change in lifestyle. Rather than allowing climate and situation to create a way of living, as happened in the past, energy (mostly fossil fuel energy), is used to overcome problems created by an imposed way of life. Current society has not only moved away from environmental determinants of behaviour but also expects to be able to support a chosen way of life within a market economy independent of climate or access to resources.

Different ways of living and attitudes to home ownership can also have an effect on the choice of materials for house construction. Where dwellings are seen as a long-term investment the materials that go into making up that investment and the maintenance methods used have to be appropriate. In Singapore, the government initiative to provide affordable housing has produced a situation wherein lower middle class people can buy their own apartments. In order to make the dwellings affordable, normally in apartment blocks, the Singapore government has become a landowner, buying land for a price related to its zoned or actual use rather than its potential use in the free market. Moreover, there are policies in place for upgrading the dwellings, again subsidised, so that residents do not have to pay the full cost (Yuen 2005). The aim of government intervention is to provide all citizens with access to decent housing. As the government is the major provider of housing, the Housing and Development Board in Singapore[1] has been able to set up systems in place to either produce material, in the case of bricks, tiles, sand and granite, or to manage production of the materials required.

This approach to durable and affordable material acquisition could be contrasted with the experience in China, where the escalation in land values means that estates of apartment blocks are demolished prior to the end of their useful life. In the 1990s, along with other reforms, housing provision became part of the free market. Since then local authorities have been encouraged by developers to demolish old buildings in urban areas. While developers are able to provide increased floor area on these vacated sites, the local authorities view new modern buildings in the city centre as a boost to the local economy. As most buildings are demolished prior to achieving their full life expectancy, which is 50 years in China, it is the environment that loses out in this instance. Life expectancy of apartments in urban areas is now around 30 years and the resources used for construction of these apartment buildings have now become a waste disposal problem (Chen 2005: p. 54). It is hard to conceive of any developer wishing to invest more on durable materials in an attempt to make apartment buildings more sustainable with such a short projected life.

The same phenomenon can be found in societies where many people have their own house, while housing turnover is also vigorous. This is the case in New Zealand where the average time spent living in a particular house is around 7 years. With the thought of moving in the near future there is little incentive for home owners to invest in sustainable technologies such as solar water heaters or additional insulation as they cannot foresee any significant return on such investments. A large backlog of maintenance, which could be risky in terms of resources already contained in privately owned housing in New Zealand, has also been linked to this situation in the past. However, recent research suggests that houses lived in for less than 7 years were in need of less maintenance than those which had been lived in for longer.

> *It seems that the longer that we stay in the same house, the more likely that the house will be in the worst category* [in terms of maintenance required]. *This may relate to owners moving before conditions deteriorate, a fall-off in renovation effort with continued occupancy, or to renovation performed by the previous owner*
>
> Clark *et al*. 2005: p. 19

Here the use of housing as an investment may be encouraging better use of resources because of the deisre to maximise on the investment in the house before moving on. These examples show that the life and the resources used for housing may be controlled to a far greater extent by government policies and the norms of society than by the choices made by designers at the time the dwellings were constructed.

To keep up with the progress in social, economical, environmental and technical knowledge the construction industry has been subjected to many changes. Many studies have shown that the quality of the built environment has a direct impact on human physiological and psychological well-being (Olgyay 1963; Boardman 1991). At the same time, there is continuing pressure to create an environment conducive to higher levels of comfort, and this, together with the increasing population, means that society expends higher levels of energy than it did in the past. As buildings use more energy to maintain higher levels of comfort, efficiency improvements have tended to move along with the increased comfort expectations, but although buildings constructed today are sometimes more efficient in terms of resource use than many built two to three decades ago, still they place undue demands on the Earth.

Environmental effects of energy use

Energy issues have been a growing concern since the 1970s. Initially the main concerns were the depletion of resources and the security of supply. As a result, developments in nuclear power generation, and an emphasis on energy conservation (which is to use less energy and to accept a lesser degree of service) including measures to improve energy efficiency (which is to use less energy and enjoy the same service) of buildings such as the greater use of thermal insulation, emerged.

Over subsequent years however, the main concern has changed to the problems related to global warming and climatic change. During the early 1980s many research papers (Bach 1980; Hansen et al. 1981; Lovins 1981) were published on these subjects. Greenhouse gas emissions are now considered to be contributing to global warming (Houghton et al. 2001). Carbon dioxide, which is generated by burning fossil fuels, clearing land, making cement from limestone, etc., all of which are activities attributable to buildings and development, is one of the principal greenhouse gases which contribute to global warming. The Intergovernmental Panel on Climate Change (IPCC), which was formed in 1988, has estimated an increase in mean global temperature of $0.6 \pm 0.2^{\circ}C$ during the twentieth century and projected that this increase would be $1.4-5.8^{\circ}C$ by the year 2100 (Houghton et al. 2001; Trenberth 2001). Although this may not seem much, it is well above anything that the ecosystems of the earth have experienced for many centuries. Such an increase could change the wind patterns, frequency and intensity of storms, rainfall and other aspects of climate. In New Zealand, there is evidence for both progressive warming of $0.6^{\circ}C$ and rise in sea level of 10–20 mm over the last century although it has not been proven to be an outcome of global warming (MfE[2] 2001: pp. 6–7). Owing to the complex nature of the earth's climatic system and the uncertain picture of the direct impact of human activity on the biosphere, the term 'global warming' has tended to be replaced by the term 'climate change'.

Climate change

Bell et al. (1996: p. 19) argue that the effects of increased carbon dioxide concentrations on the climate comprise direct and indirect effects which modify the outcome of each other. The direct mechanisms have been identified as:

- effect of biomass die-back owing to increased temperatures, which releases additional carbon dioxide;
- effect of reduced snow and ice cover in the poles owing to initial warming, which reduces the fraction of solar radiation reflected at high altitudes; and
- effect of release of methane from methane hydrates in deep oceans owing to warming which follows initial anthropogenic release of carbon dioxide.

Indirect mechanisms have been identified as:

- effect of rapid plant growth owing to high concentrations of carbon dioxide in the atmosphere, which reduces initial concentration of carbon dioxide; and
- effect of increased evaporation of water, which could assist in the formation of clouds of the correct type which in turn could increase the reflectivity of the atmosphere, thereby reducing the initial warming.

Since these positive and negative effects and their interaction have not yet been properly understood, the final outcome in terms of the system is hard to estimate with reasonable accuracy. The level of uncertainty increases when the possible direct and indirect impact on human society is considered, owing to the ability of human beings to adapt to and modify their surroundings. Some adaptations could exacerbate the problem: if temperatures rise, an increased use of air conditioners to maintain comfort would lead to increased burning of fossil fuels and escalation of the problem.

Because of these problems, current global environmental policy, such as it is, is based on the understanding that:

- human activities are currently emitting carbon dioxide into the atmosphere at a rate higher than can be absorbed by the oceans and sinks, thereby increasing the atmospheric concentration; and
- the effect of this increased concentration on the global climate is uncertain but could be harmful to all or part of the human population (ibid.). However, the next IPCC report due to be released in 2007 is expected to confirm that the risks may be more serious than previously anticipated (Adam 2006).

The New Zealand Climate Change Programme established in June 1988, explored the possible impacts of climate change on New Zealand. To bring these global issues down to the scale at which they impact directly on the lives of ordinary people, the significance of these changes to housing in New Zealand (and elsewhere in the world) can be summarised as follows.

- **Temperature changes**: An increase in average and extreme summer temperature.

  Although a global increase of 1.4–5.8°C in average temperature is expected by the year 2100, for New Zealand the increase is expected to be only about two thirds of this as the climate of the small land mass of New Zealand is influenced by the large water bodies of the South Pacific and Southern Ocean. While this increased temperature in temperate regions could lead to reduced space and water heating demand during winter, the incidence of summer overheating could increase for houses that have not been designed with adequate passive solar shading features. Any warming in tropical and subtropical areas could lead to higher demand for space conditioning throughout the year. Therefore, incorporating features such as additional insulation and shading for windows to prevent unwanted sun penetration, provision of natural ventilation systems, etc. could be beneficial for maintaining comfortable internal temperatures in summer. The energy requirement for water heating – which is a significant component of the operating energy of NZ (New Zealand) houses – is expected to decrease by 3% per 1°C increase in temperature, owing to the higher temperature of the incoming cold water (Camilleri 2000: p. 17). However, higher temperatures could also reduce the lifetime of building materials such as plastics and surface coatings used in houses, leading to shorter replacement cycles and hence increasing the energy contained in building materials in the house through the need for extra replacement components.

- **Rainfall changes**: An increase in both amount and intensity of rainfall over temperate regions with a decrease in amount of rainfall and increase in drought over subtropical regions.

  Severe changes to regional climate patterns such as Asian monsoons and El Nino southern oscillations could increase the incidence of severe flooding and drought. These extreme climate events could lead to more frequent severe flooding, landslides and soil erosion, which could increase the damage to buildings, leading to an increase in flood insurance premiums or even to withdrawal of insurance cover. Increased damage to the built environment again requires more resources for replacement settlements.

- **Sea level rise**: An increase in the mean sea level.

  Owing to the thermal expansion of sea water and melting of glacier and polar ice, the global mean sea level is expected to increase by up to 84 cm by the year 2100, although for New Zealand this increase is expected to be about 34 cm (MfE 2001: p. 14). A rise in sea level could lead to the obvious problem of increased coastal flooding and foreshore erosion, but, in addition, the rising water table may also reduce the capacity of existing drainage systems, causing inland flooding and hence damage to foundations and walls of houses, with a consequent further drain on resources.

While the most visible environmental damage in European and North American regions could be said to have occurred prior to 1980, for Central Asian, Far Eastern and Middle Eastern regions this has taken place since 1970 as indicated by the trend in total CO_2 emissions (see Figure 1.1). Consumption of fossil fuels such as oil, gas and coal either directly by individuals (as fuel for cooking, heating, lighting or transport) or indirectly (as fuel for manufactured products and services) can cause environmental damage, either on a local scale, for example in the form of increased air pollution in urban areas, or on a global scale through the contribution to global warming. In 1996, the resource consumption of the average person living in the industrialised countries was 4 times that of the average person in lower income countries (Loh 2000: p. 1). The disparity in the carbon dioxide emissions of various regions of the world in 1996 is shown in Table 1.1.

Recently there has been a surge in development activities in China and India, the two most populated countries of the world with a combined total of around a third

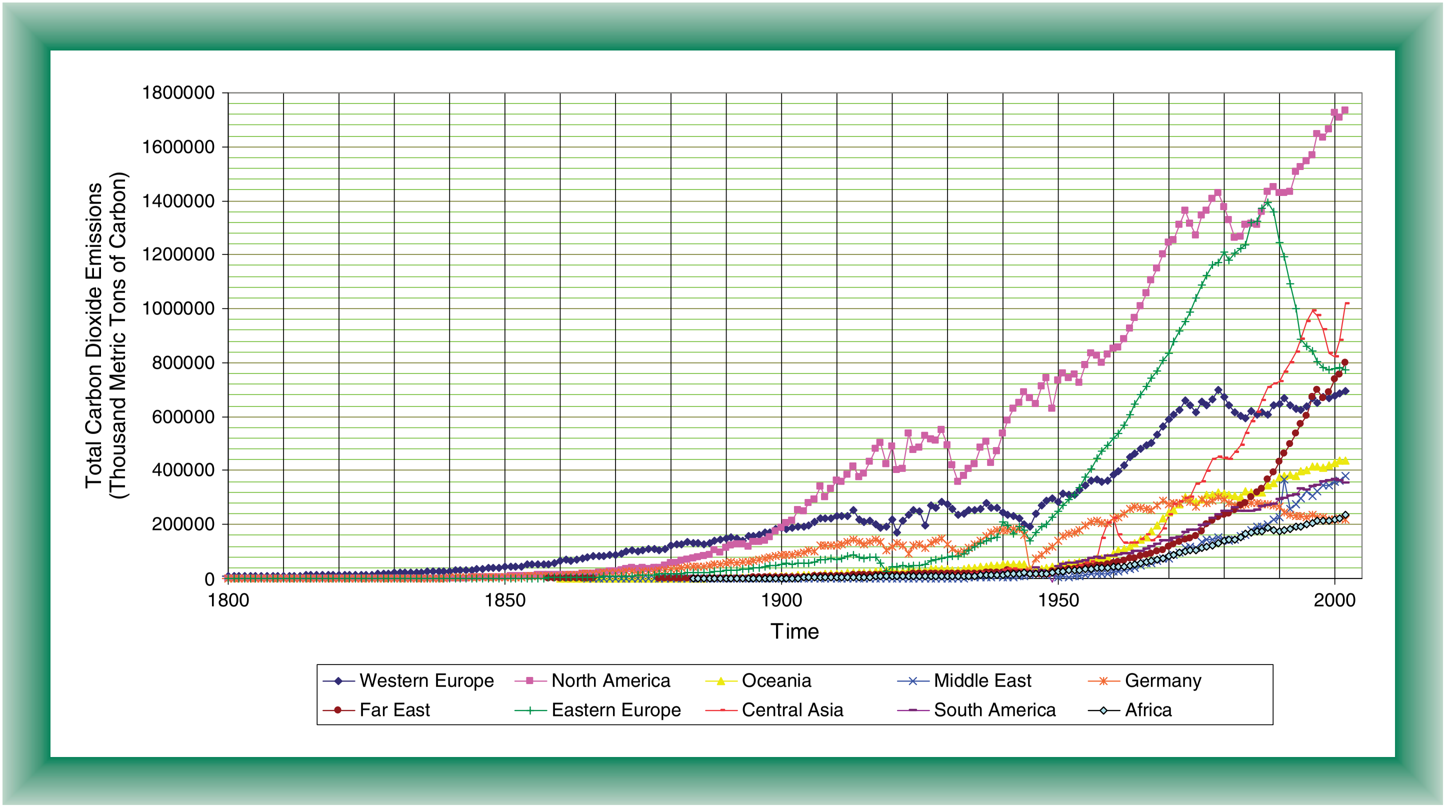

Fig. 1.1 Total global CO_2 emissions by region from 1800 to 2002.
(Based on: Marland, G., Boden, T. A. and Andres, R. J. (2005) Global, Regional, and National Fossil Fuel CO_2 Emissions. *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, TN, USA. Available at: http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm [accessed 8 March 2006].)

Table 1.1 Carbon dioxide emissions by region in 1996

Region	Population (millions)	CO_2 emissions (tonnes/person/year)
Asia/Pacific	3,222	2.3
Africa	710	0.9
Latin America & the Caribbean	484	2.3
Western Europe	384	9.0
Central & Eastern Europe	343	7.7
Middle East & Central Asia	307	4.0
North America	299	19.0

Based on: Loh, J. (ed.) (2000). *Living Planet Report 2000*. World Wide Fund for Nature (formerly World Wildlife Fund), p. 14

of the global population. Although, as a result, their consumption per person has not yet increased to the levels enjoyed by the rich industrialised countries, owing to the higher numbers of people involved this development could lead to greater environmental damage. Total CO_2 emissions resulting from energy use and per capita emissions in 2003 for selected countries are as shown in Table 1.2.

Climate change is a global problem caused by regional activities and therefore has to be tackled through local action. At the 1992 United Nations Framework Convention on Climate Change (UNFCCC) the precautionary principle was adopted and it was decided that the countries represented should aim at reducing carbon dioxide emission rates. Since this was insufficient to bring about the necessary changes, in December 1997, the Kyoto Protocol was adopted. According to the Kyoto Protocol, developed countries which have signed up to it are legally bound to reduce their emissions to set targets. Many countries, including New Zealand, have agreed to the Kyoto Protocol, which came into force in February 2005, although some important countries have not signed up to it, such as the USA and Australia.

New Zealand's greenhouse gas emissions

Although the total greenhouse gas emissions of New Zealand are comparatively small, (around 0.5% of global emissions) by the year 2003 emissions were 22.5% above their level in 1990 (MfE 2005: p. 11). According to the Kyoto Protocol, New Zealand must stabilise its emissions at the 1990 level, on average, during the period 2008–2012.

Table 1.2 Total CO_2 emissions due to energy use and per capita emissions in 2003

	Total (million metric tonnes)	Intensity (tonnes/person/year)
OECD countries		
New Zealand	38.46	9.91
Australia	376.83	19.10
France	409.18	6.80
UK	564.56	9.53
Canada	600.18	19.05
Germany	842.03	10.21
Japan	1,205.54	9.44
USA	5,802.08	19.95
Non-OECD countries		
India	1,016.50	0.96
Russia	1,503.10	11.21
China	3,307.40	2.72

Based on: Energy Information Administration (2005). *International Energy Annual 2003*. Available at: http://www.eia.doe.gov/emeu/international (accessed 3 February 2006)

The composition of the greenhouse gas emissions of New Zealand (Gg CO_2 equivalent) is shown below (See also Figure 1.2).

Carbon dioxide	46.0%
Methane	35.4%
Nitrous oxides	17.9%
Other gases	0.6% (such as hydrofluorocarbons [HFCs], perfluorocarbons [PFCs], and sulphur hexafluoride [SF_6])[3]

Unlike other developed countries the agricultural sector contributes close to half the emissions for New Zealand. On a CO_2 equivalent basis this sector was responsible for 49% of the total emissions in 2003. Both methane and nitrous oxides are released mainly by the agricultural sector. Emissions due to the energy sector vary widely from year to year owing to the use of thermal power stations (largely natural gas with some coal) to supplement electricity production from hydro power stations during dry years. This again is different from many other countries where there is a steady increase in the use of gas and coal for electricity generation, linked to rising living standards and possible rising populations, as discussed.

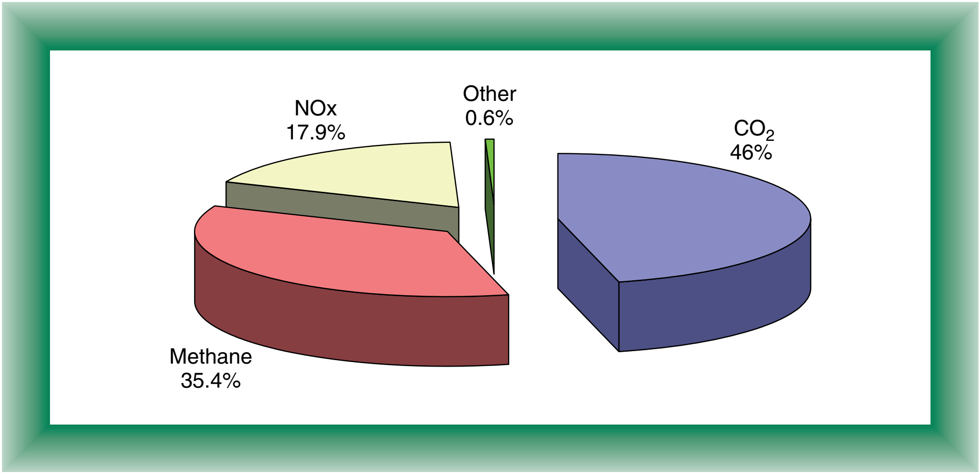

Fig. 1.2 Composition of greenhouse gas emissions of New Zealand.

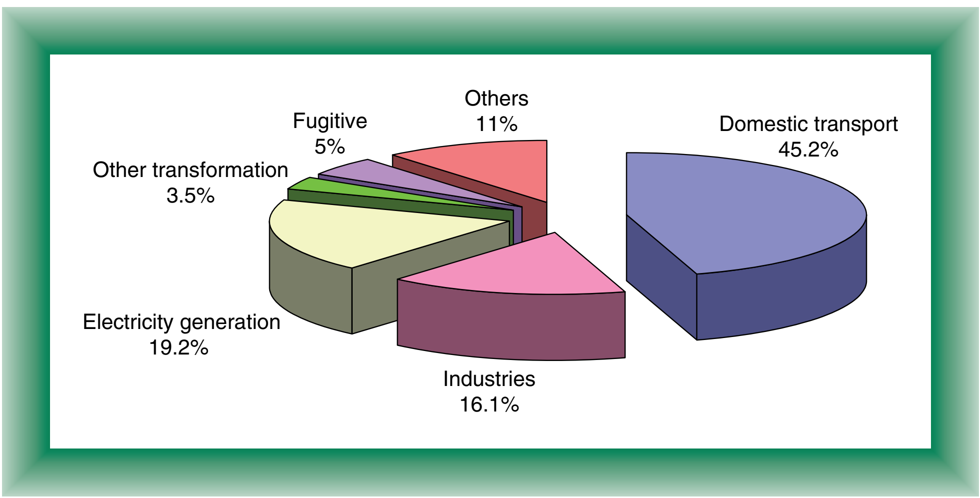

Fig. 1.3 CO_2 emissions for New Zealand by various sectors.

Carbon dioxide emissions for New Zealand by various sectors are as follows (see also Figure 1.3).

Domestic transport	45.2%
Industries	16.1%
Electricity generation	19.2%
Other transformation	3.5%

Fugitive	5.0%
Other sectors	11.0%

(such as commercial/institutional, residential and agriculture/forestry sectors).

Over the period 1990 to 2004, total emissions increased by about 33.8%, owing to increased use of natural gas and coal in electricity generation, and increased consumption of diesel and petrol for domestic transport (MED[4] 2005a: p. 2). The increase in emissions in the domestic transport sector since 1990 has been 61.6%. The energy sector[5] has been identified as contributing over 90% of the man-made carbon dioxide emissions in New Zealand (MED 2005b: p. 13). In 2004, the total delivered energy use increased by 2% (MED 2005b: p. 10). The main use of delivered (consumer) energy was for the domestic transport sector followed by industrial activities. During the period 2003 to 2004, the commercial, residential and transport sectors increased their share of consumer energy by 0.6%, 0.4% and 0.1% respectively, while the agricultural sector decreased by 0.9% (MED 2005b: p. 11). Consumer energy usage by various sectors of the economy is shown in Figure 1.4.

In addition to the amount of energy consumed, carbon dioxide emissions depend on the type of fuel used. Composition of delivered energy by fuel type is shown in Figure 1.5. Emissions due to liquid fuels are a result of the steady growth in the transport sector since 1990.

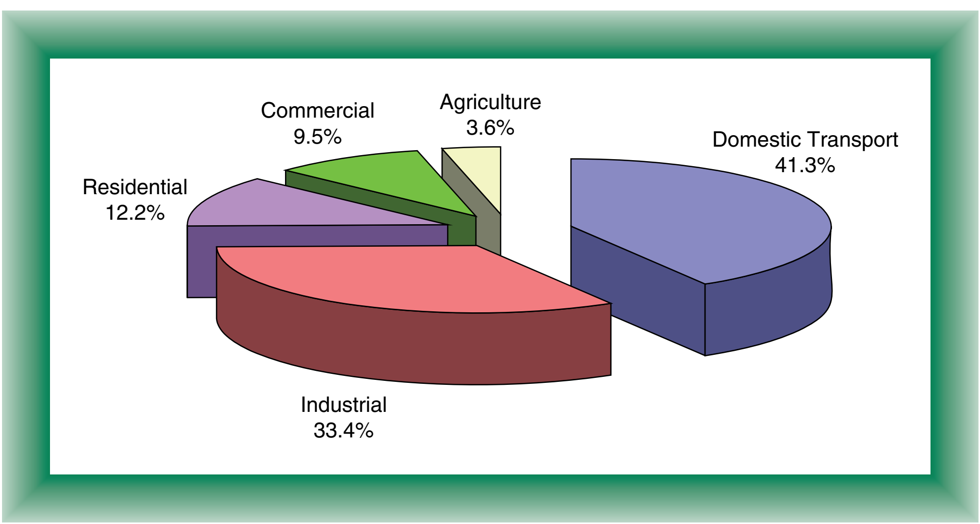

Fig. 1.4 Consumption of consumer energy by various sectors of the New Zealand economy (2004).