ANALYSIS OF
ENERGY EMBODIED IN CEMENT
PRODUCED IN SRI LANKA

By

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DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and behalf, it contains no material previously published or written by another person nor material, which to substantial extent, has been accepted for the award of any other acedemic qualification of a university or other institute of higher learning except where acknowledgment is made in the text.

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Abstract

Analysis of the embodied energy in cement produced in Sri Lanka was carried out considering national boundaries. National energy input to the cement manufacturing was the main focus of this study and therefore any energy involvement outside Sri Lanka was not taken in to consideration in this analysis. The total embodied energy content was analyzed in three levels. In level 1, direct energy consumption in manufacturing of cement at Puttalam cement factory was analyzed and energy consumption for ancillary inputs was considered in the level 2. Energy consumption for raw material extraction and transportation within the country was analyzed in level 3.

The direct delivered energy consumption was assessed by carrying out an energy survey at Puttalam cement factory. Then this direct energy was referred to primary energy by considering the national energy mix in electricity generation together with transmission and distribution losses in electricity distribution, power plant efficiencies, and energy consumption in refining petroleum fuels.

The total national energy requirement to produce one ton of cement in Sri Lanka was found to be 4896 MJ based on the present energy mix of electricity generation. This varies between 4982 MJ/MT and 4732 MJ/MT according to the future energy mix of the electricity generation and the transmission loss reduction plan of Sri Lanka.

The outcome of this study can be used to select the best material for building construction from cement based products and in the formulation of energy conservation policies like the Building Code. In addition the outcome of the study can be used as inputs for further research relevant to energy content of materials.

CONTENTS

List of Tables

Chapter 2

Chapter 4

Chapter 5

Chapter 6

Annexes

List of Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 7

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Chapter 1

Research Problem Being Analyzed

This chapter presents an overview of the present status of energy in the country. Demand and consumption pattern, major primary energy resources, breakdown of energy consumption by sectors, annual electrical energy consumption and power generation capacities are presented. The specific research problem under study including objectives of the study along with rationale and justification for a typical study is also given.

1.1 Background of the Energy Scenario of Sri Lanka

In year 2000 the annual primary energy consumption in Sri Lanka was 9.2 Million TOE [17] and this was mainly shared by petroleum - 38.8 %, hydro electricity - 8.3%, and biomass - 52.9%. In economic sense, the per capita energy consumption was 0.48 TOE in year 2000. The primary energy demand is increasing at a rate of 12 % annually [17]. The sectoral consumption is by industry –24.4%, transport – 23.2 % and household, commercial & others 52.4%.

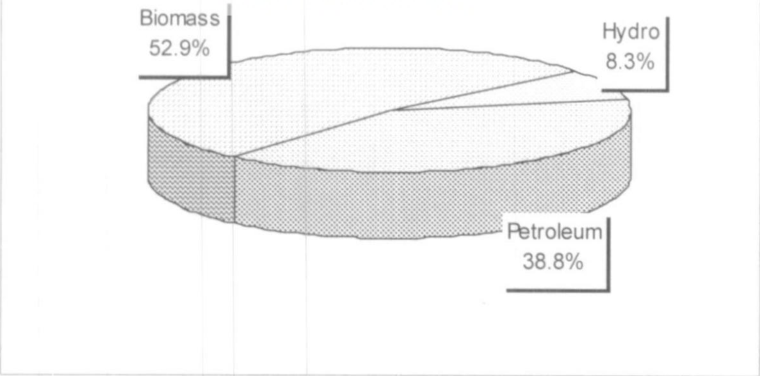


Figure 1.1 : Energy Supply by Source- 2000 [17]

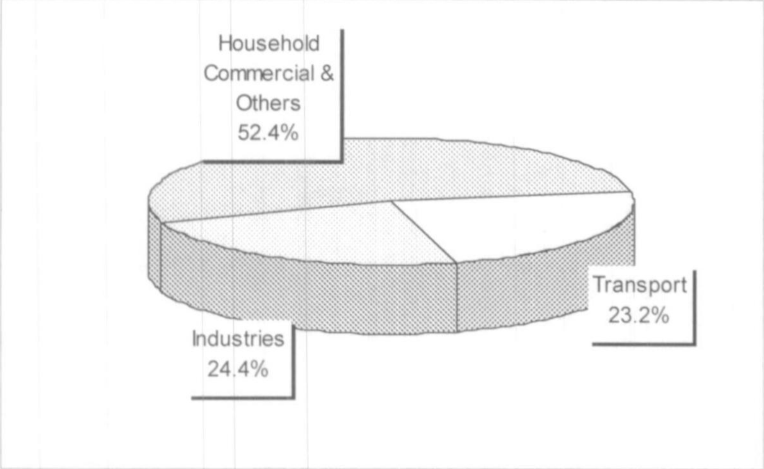


Figure 1.2 : Energy Consumption by Sectors [17]

1.1.1 Energy Resources

In general, apart from hydro and biomass, there are no major energy resources in Sri Lanka. The estimated annual major hydro energy potential is 6750 GWh and 50 % of this has already been exploited through an installed capacity of 1143MW [12]. Apart from the major hydro potential, it is estimated that about 170-180 MW with annual energy output of around 350 GWh of small hydro potential is available. The potential for renewable energy sources such as wind, geothermal and OTEC is also very minimal. It is estimated that the coastal belt from Hambantota to Kirinda offers an exploitable wind energy capacity of 200 MW with an annual yield of 350 GWh. It is further known that a significant wind energy potential is available on the coastal belt from Puttalam to Jafna and Jafna to Trincomale and in certain areas of the hill country such as Ambewala and Uva basin. A few sites have been identified for OTEC resources but more research is needed to realize them. Solar insolation in Sri Lanka is considerably high with an annual rate of 1.86 TWh per square km on average. However, the use of solar energy for commercial application is limited due to economic reasons in the case of electricity, and low quality in the case of thermal energy applications. Therefore Sri Lanka is a poor country in terms of energy resources and the future energy demand is likely to depend largely on imported energy resources.

1.1.2 Electrical Energy

The total electrical energy generation during the year 2000 is 6843 GWh and 21.4 % of this accounts for distribution & transmission losses and power plant consumption [12]. Therefore net electrical energy consumption is 5379 GWh. This electrical energy is generated by the total installed capacity of 1777.5 MW, which shares 64.5% hydro and 35.5 % thermal sources [12]. The 10-year average annual growth rate of electrical energy demand is 8.2 % [12].

1.1.3 Petroleum Energy

In year 2000, annual petroleum consumption was in the range of 3.8 million TOE [17] and Figure 1.3 below shows the petroleum demand growth. This petroleum is consumed in power generation 20.9 %, industry 12.6 %, transport 56.8 % and domestic purposes 9.7 % [17].

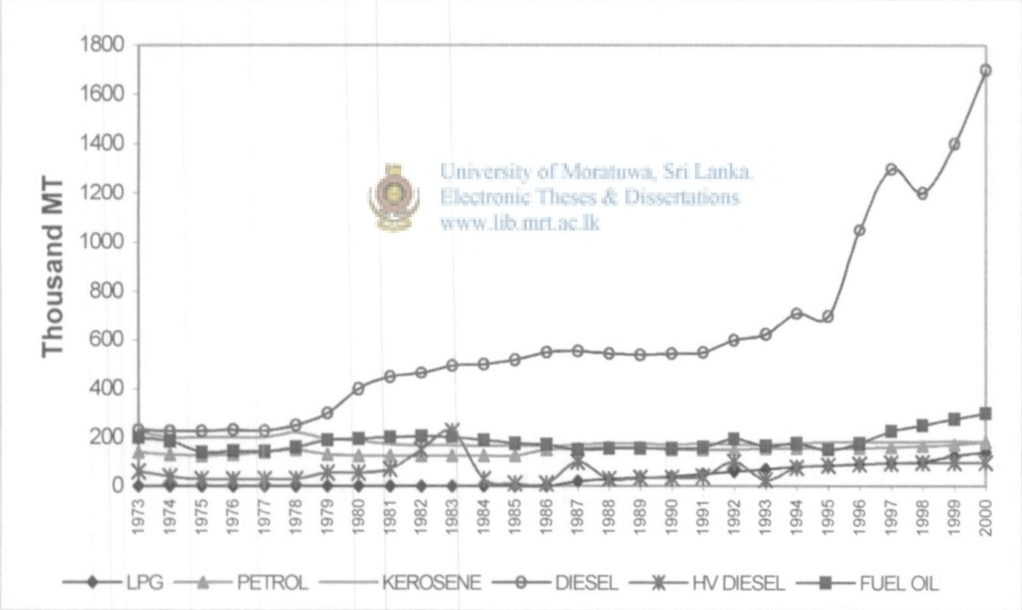


Figure 1.3 : Petroleum Demand Growth [16]

There are no natural reserves of petroleum in Sri Lanka at present. The bulk of the country's petroleum requirement is imported as crude oil, which is then processed at the refinery with an installed refining capacity of 51,000 barrel/day. In year 2000 while 2348928 MT of crude oil and 1403700 MT of processed petroleum were imported to Sri Lanka, 118660 MT of processed petroleum was exported.

1.2 Research Problem at the Scene

Facing of growing future energy demand in the country is a critical issue in coming decades. It is estimated that almost all the earnings from the plantation industries have to be spent on importation of fossil fuel requirements for power generation by year 2008, [50], as depicted in Fig 1.4.

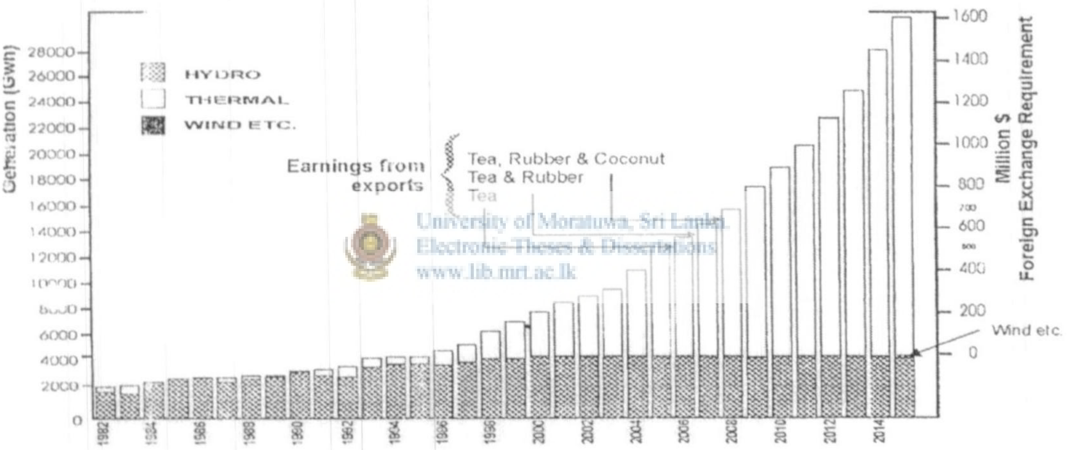


Figure 1.4 Fossil Fuel Requirement for Power Generation [50]

In this scenario, energy conservation will have to play vital role and therefore use of materials & products which have low national energy embodied is one of the options towards this. Cement is identified to be one of heavily consumed product in Sri Lanka other than food and manufacturing of cement is very energy intensive process. Therefore quantification of national energy inputs to cement from its cradle to product is very important.

1.3 Objectives of the Study

General Objective

To determine the amount of national energy input to production of cement from its cradle level of the production process to its final level

Specific Objectives

1. Assessment of total energy consumption at the Puttlam Cement Factory.
2. Assessment of total delivered energy input of the raw material.
3. Assessment of transport energy consumption in raw material supply.
4. Referring of delivered energy in to primary energy
5. Analysis of national energy embodied in cement.
6. Sensitivity analysis of different scenario of future energy mix.

1.4 Rationale and Justification

Energy plays a vital role in a country's economic & Social development and it is expected to be more important in Sri Lanka, in the coming years, due to the increasing energy demand, environmental concerns, limitations of supply capacities due to lack of financial and energy resources etc.. But Sri Lanka is an energy scared country. A multidimensional approach is therefore required, keeping in view the various economical options available through effective demand management. Thus, energy conservation and efficient use of energy becomes a major invisible supply option

One of the effective options available in demand management is to use of low embodied energy material, products and services. Cement is considered to be high embodied energy material [80]. It is estimated that 0.6 % of total energy consumption of the USA is for cement production [5] and cement production contribute to 8% of total man made CO_2 emission in the world [5].

The main candidate for cement consumption is construction of buildings and infrastructures. In building construction, concrete is leading all the building materials [14] in Australia. This may be valid in Sri Lankan context too.

There are various alternatives available to the cement related products used in built environment. Clay bricks & cement blocks, clay tiles & asbestos sheets, concrete & timber are the some examples. In order to compare these products with respect to energy, the national energy embodied in cement produced in Sri Lanka is very important to us.

The embodied energy values vary from country to country due to various reasons such as country energy mix, production process, raw material availability, etc. (More factors that affect to embodied energy figures are discussed in other chapters). This also justifies the finding of embodied energy value of cement produced in Sri Lanka, prior to take any decision on cement alternatives.

This chapter discussed the background of the energy scenario of Sri Lanka and the research problem being analyzed with rationale and justification. The next chapter will discuss more about the embodied energy and state of the art of embodied energy analysis around the world.

Chapter 2
Literature Survey

This chapter starts with a discussion on the currently employed energy analysis methods and theory of embodied energy analysis. The benefits of embodied energy and factors affecting the embodied energy are then highlighted. Finally results of some research and studies carried out in the world are discussed and the data found in literature related to embodied energy are also given.

2.1 Introduction

Energy plays a vital role in satisfying human needs. It is involved in almost every stage in the society. When a product or service comes out for consumption they have gone through several stages starting from the extraction of raw material. At all these stages some forms of energy is consumed. The aggregation of all these energy forms is called "***embodied energy***" of that product. In other words embodied energy of a product is the aggregated energy consumed by all the processes associated with the production of that product from the acquisition of natural resources to product delivery. This includes mining and manufacturing of material and equipment, transport of material and the administrative functions. It has to be clearly understood that embodied energy does not refer to energy available or inherent in a material or product. A more accurate term for embodied energy is "Cumulative Energy Demand" because it represents the sum of all the energy inputs to a product system. For example, the total embodied energy of a 750g loaf of bread in UK is 20 MJ which is approximately equivalent to 700g of coal [12]. Table 2.1 below shows the energy break down of this.

Table2.1: Energy Breakdown of a Loaf of Bread in the UK

Process	Description	% Embodied Energy
Farm	Fertilizer	11.6
	Tractor fuel	7.3
	Other	0.4
Mill	Transport	1.4
	Other	2.0
	Milling fuel	7.4
Bakery	Transport	5.0
	Other ingredients	9.4
	Baking fuel	23.6
	Packaging	8.3

The energy embodied in plant & equipment (tractor, mill, bakery etc.) has not been accounted here. But this could also be accounted in embodied energy analysis. Following statements show the importance of the consideration of embodied energy in decision making.

- The energy embodied in existing building stock in Australia is equivalent to ten years' total energy consumption by the entire nation [14].

- In New Zealand , a typical house takes 10 years to use as much energy running the house as it did to build it.[6]

- The embodied energy is found to be approximately equal to operation energy of a typical office building in a temperate climate over the life of the building [35]

- A typical 3-bedroom house has an embodied energy content equivalent to 20 tones of CO_2 which would require tree planting in an area capable of supporting 20 trees to be created. In other words, to offset the amount of CO_2 produced in housing development would require woodland planting of something like at least the same area as the housing development site [2].

2.2 Energy Analysis

With the industrial revolution, the world energy consumption has been increased at alarming rate resulting scarcity of energy resources under present technological statues and environmental pollution in both globally, regionally & locally. This demands a need of accurately quantification of industrial & commercial energy use, which is known as Energy Analysis. There are four different levels of approaches, which can be introduced for this, namely End use energy analysis, Primary energy analysis, Embodied energy analysis and Life cycle energy analysis.

2.2.1 End Use Energy Analysis (EUEA)

End use energy, sometimes known as delivered energy, analysis considers only energy consumption and losses at the final consumer level such as industries, commercial establishments and households etc. It does not look in to what happens at the generation point. The main objective of EUEA is to improve the end use energy efficiency and energy audit is the main tool for this purpose.

2.2.2 Primary Energy Analysis (PEA)

Primary energy analysis goes beyond one step from the EUEA and considers conversion efficiencies in the energy generation. The starting point of primary energy is the chemical energy content of the fuel used in energy generation. The primary energy is defined as summation of down stream end use or delivered energy and upstream waste heat [19].

2.2.3 Embodied Energy Analysis (EEA)

The concept of conserving energy can be taken one step further by taking long term approach to analyze total energy consumption known as ***embodied energy***. Embodied energy analysis is an assessment that includes the energy required to extract raw material from nature plus the energy use in primary and secondary manufacturing activities to provide a finished product or service [38]. In other words, total energy content or embodied energy in a product or service includes primary energy consumption at manufacturing of it, energy contained in raw materials, energy needed to transport, energy contained in plant & equipment and infrastructure and energy needed to supportive services in manufacturing processes, such as maintenance of plant & equipment, administrative functions, etc.

2.2.4 Life Cycle Energy Analysis (LCEA)

Life cycle energy analysis is the total primary energy requirement for the product from its cradle to grave [19]. This involves energy associated with its user phase and disposal stage of a product in addition to its embodied energy content. The main objective of life cycle energy analysis is to evaluate the energy & environmental implication of different technological and strategic alternatives so that society (or some subset of it such as a country like Sri Lanka) can satisfy it's demand for various services with minimal impacts. Life cycle inventory is the main tool use for this. LCEA is very important in many ways because it highlights real energy & environmental implications. For an example, a research in life cycle analysis of heavy vehicle has concluded "use of natural-gas-based alternatives fuel in truck neither saves energy nor minimize green house gas emission but it minimize petroleum consumption" [31]. But many environmentalists promote

LNG as clean source of energy by considering only user phase environmental implications. Life cycle energy analysis clearly shows the energy involvement in various stages and processes of a product.

2.3 Theory of Embodied Energy Analysis

Embodied energy analysis covers all the steps starting from raw material extracting from the nature up to manufacture of a finished product or service. Therefore, obviously the analysis should be broken in to some distinct levels. There are four different levels at which energy analysis can be carried out, as shown diagrammatically in Figure 2.1[19].

Level 1

In this level, all the direct fuel/energy use at the final process(es) of making an economic product or service are considered. For an example, in the case of a manufacturing process, electricity, fuel for thermal energy, fuel for internal transport of goods and raw material should be included in this analysis.

Level 2

In this level, energy involvement of ancillary inputs to the final process(es) are analyzed. Direct energy and energy in material and transport of them, energy required in maintenance of plant and equipment, energy related to administrative functions and related transport, etc. are considered.

Level 3

Energy analysis of raw material consumed in the final process is considered in this level. This involves extracting raw material from the nature, their processing and transport them to the final process.

Level 4

In this level, energy involvement in capital such as plant and equipment, infrastructure etc. are considered. This will include the machines required to make machine too.

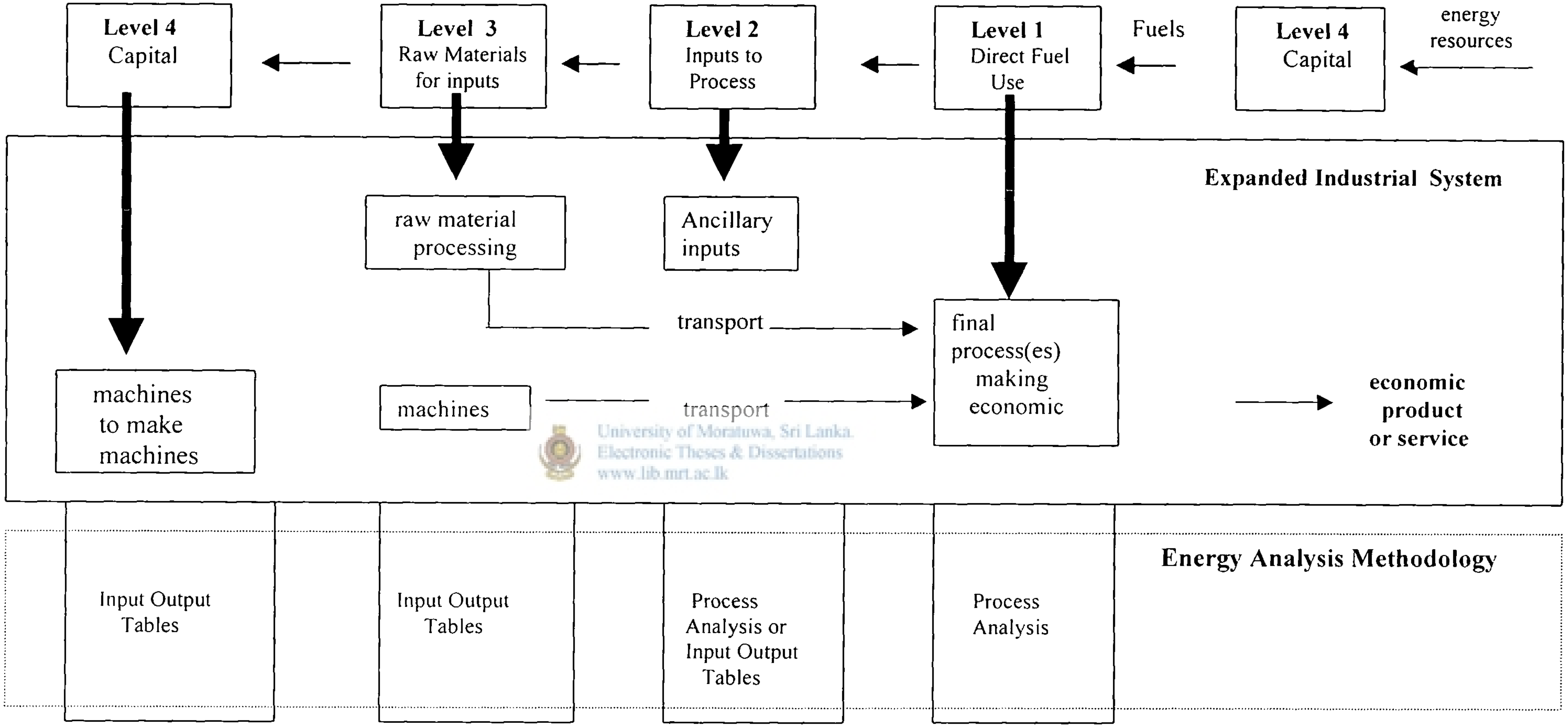


Figure 2.1: Different Levels of Embodied Energy Analysis

2.4 Factors Affecting the Embodied Energy

The embodied energy content of a material or product is influenced by various factors such as recycling & reuse, type of primary energy use, production process, system boundary in analysis, etc. The effect of these factors has resulted variation of available embodied energy data. Identification of those factors is very important in many ways; it helps to

- Produce low embodied energy product
- Decide embodied energy figures for material in analyzing
- Use low embodied energy product
- Conserve energy and environment

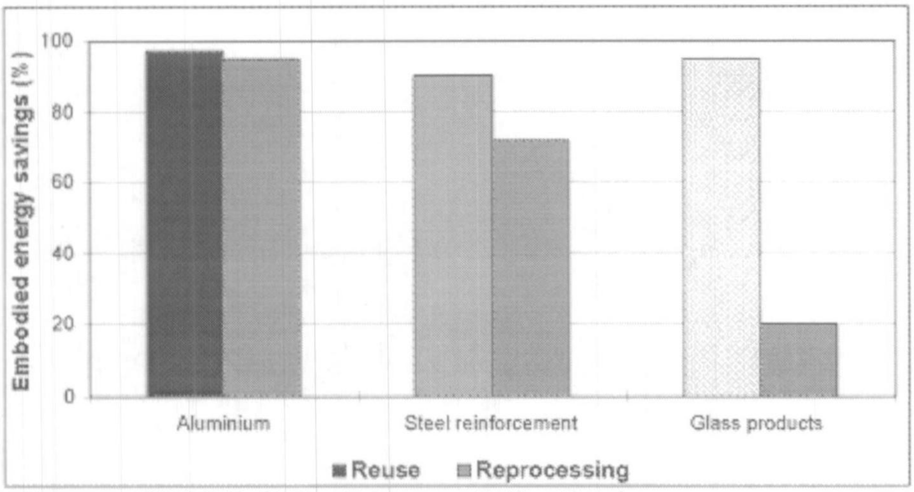
2.4.1 Recycling and Reuse

Recycling is the reuse of a material to produce same material or another product at the end of its life. Use of scrap iron to produce steel, use of waste paper to produce paper are some examples of recycling. ***Reuse*** is the use of material & a product in several times for the same kind of purpose or some other purpose. For example when demolishing a concrete structure, steel used in the concrete for reinforcement can be used to produce concrete again. Recycling and reuse reduce embodied energy of a material substantially. Hence one way of reducing life cycle energy is use of recycle material and material reusing [38]. Some materials can technically be recycled an indefinite number of times [20]. Steel is one of best examples for this. It requesting four times more energy to produce steel from virgin than to recycle it [20]. Table 2.2 below illustrates the effect of recycling in embodied energy in some common materials.

Table 2.2 : Effect of Recycling in Embodied Energy

Material	Embodied Energy MJ/Kg	
	Virgin	Recycled
Aluminum	191	8.1
Steel	32	10

Reuse of material saves more embodied energy than reprocessing as shown in Figure 2.2 below.



Source : CSIRO Built Environment - Online Brochure

Figure 2.2 : Embodied Energy in Reuse and Reprocessing

2.4.2 Energy Source

Types of energy sources have great influence on the embodied energy content of a material. Fuel manufacturing processes, conversion efficiency, location of energy resources with respect to the plant, quality of fuel, energy mix of a country, supply side management are the main contribution for this.

Conversion efficiency in hydro electricity is very much higher than that of the fossil fuel based generated electricity. Moreover in the fossil fuel based generated electricity, conversion efficiency is varied due to the various factors such as type of technology, type of fuel, capacity of power plant etc. Table 2.3 below compares the conversion efficiency of generating electricity from fossil fuels.

Table 2.3 : Efficiency of Thermal Power Plants [12]

Plant Type	Efficiency
Gas Turbine – Open Cycle	22 – 30
Gas Turbine – Combined Cycle	48
Steam Turbine	22 - 25
IC engine	38 –42

Fuel manufacturing processes depend on the type of fuel and hence the energy quantities involved are also varied.

Location of energy sources with respect to the plant envisaged effect to the embodied energy of fuel because of the transport involvement: depending on whether locally available or to be imported, and extraction method: depend on off shore, sea or land.

Energy mix of a country is very important when analyzing embodied energy of a product produced in that country, because of the fraction of primary energy involvement in a unit of delivered energy depends on the energy mix.

Supply side management contributes to total energy content of a unit of delivered energy. For example transmission & distribution losses in Sri Lankan electrical sector is 18.5%, whereas, this in Australia is 7 %. Hence if a product is manufactured in Australia and Sri Lanka with a similar condition, Sri Lanka would need 10% more energy than Australia.

2.4.3 Production Process

Embodied energy of a material can greatly be influenced by the process by which it is produced. Variation of method of production, type of plants and equipment used, type of energy and fuel used and operational efficiency, are the main causes for this. For example, Australians most energy efficient cement manufacturing plant consume less than 3.5 GJ of direct end use energy per ton of cement clinker while least efficient plant require up to 8 GJ per ton [11].

The effect of method of process is very well illustrated in steel making. The two main processes of steel making are basic oxygen steel and electric arc steel. The embodied energy of steel produced in basic oxygen process is 38 MJ/Kg where as steel produced in electrical arc process is 19MJ/Kg [30]. In cement making there are two commonly applied processes, namely wet & dry processes. In wet process ingredients are fed in to rotary kiln of up to 200m that operate at increasing temperatures of the kiln to 1500^0C. These temperatures allow the reaction of calcium and silicon compounds. In the dry process the ingredients are pre-heated up to 900^0C in a series of cyclone (using recovered kiln gases) and are then added to a shorter kiln (of around 60m) to reach the required temperature of approximately 1450^0C. The dry process kilns are proven to be more energy efficient, requiring 50% less energy than the wet process kiln [38].

Plant operational efficiency is also a contributing factor to variations in embodied energy in a material. If the operational efficiency is very low, specific energy consumption of a product made in that plant is higher. Poor maintenance, high breakdowns, high reject rates, poor quality control and poor supervision are some factors caused low operational efficiency. Energy audits conducted in industrial sector of Sri Lanka, by the NERD Centre, have shown energy saving potential of 10% by just implementing simple energy conservation measures [44].

2.4.4 Transport

Transport has to be considered as one of the most important factor in determining the total embodied energy. The modern world could not exist without the low cost movement of people and commodities. Oil powered transport dominates the economic infrastructure that links and sustains present day communities, agricultural systems and the global economy. Billion of people now depend on food production that requires substantial inputs of petroleum fuels to power farm machinery and transport. Oil supplies 40% and natural gas supplies 22% of the world's commercial energy [8]. Road, rail, water and air transport consumes 60% of this oil and gas [8].

When one travels in a car a mass of one ton or more is moved. Most of the fuel goes to move the car; but there is lot more. The Woppertol Institute in Germany has estimated that about 1520 tones are moved in the sequential processes of metal mining, refining, shipping, plastic, glass manufacture and assembling of a car [49].

Transport energy requirement in material or product mainly depends on mode of transport, distance to be transported and fuel used for transportation. The basic modes of transport are road, rail, sea and air. Table 2.4 below compares the energy requirement in transport of steel between Canada and UK [30].

Table 2.4 : Comparison of Transport Energy of Steel

Mode of Transport	Energy Consumption MJ/Ton	
	Canada	U K
Road	1.18	4.50
Rail	0.49	0.60
Ship	0.12	0.25

Even within the particular mode, say road, energy consumption per kg varies depending on the type of vehicle used to transport them. Energy consumption of transport one kg of a material in a heavy truck is very much lower than the transport in a light vehicle due to the scale of handling.

Even within a single vehicle, per kg transport energy consumption depends on the load factor. When considering the above factors one may argue that just in time (JIT) concept for logistics in productivity improvement as an energy intensive concept because it encourage shift from rail to road and involve more deliveries being made in smaller vehicles not filled to capacity.

Transport energy component in embodied energy content of a material depends also on the type of fuel used in vehicle. A study carried out in "Life-cycle Analysis for heavy vehicles" by Lindo at el, 1998 has concluded that "Use of natural gas based alternative fuels in trucks neither saves energy nor minimizes GHG emissions, but it does minimize petroleum consumption" [31]. According to a study carried out in Air Force Institute of Technology, USA, electric vehicles do not reduce green house gas emission substantially when compared with internal combustion engine vehicles, but it may benefit public health by relocating air pollutants from urban centres, where traffic is concentrated, to rural areas where electricity generation and mining generally occur [43].

Conditions and the capacity of the roads are also contributed to the transport energy consumption. Heavy traffic volume increases the fuel consumption. For example, an average car used in USA consumed 13.8 Lit/100 km in city travel where as in highways it consume only 9.3 Lit/ 100 km [41].

Table 2.5 below shows the CO_2 emissions in terms of kg per passenger km [9].

Table 2.5: CO_2 Emission - kg/passenger km

Express coach	02
Auckland yellow bus	02
Electric car (2 seats)	04
Honda shuttle (5 people)	05
Diesel Inter city 125 train	06
Quick car ferry	08
1.8 litre Diesel car	09

2.4.5 Raw Material

When the raw material are concerned, the type, source and quality are the main contributing factors to the raw material component of the embodied energy of a material or a product. Some products can be produced using various types of materials and therefore energy requirement is also varied. Use of scrap steel has resulted up to 50% reduction in embodied energy content of steel [20]. Table 3 below shows how the percentage of scrap as raw material in the process of steel production affects the amount of CO_2 produced from the process [15]. This CO_2 emission is directly proportional to the energy consumption.

Table 2.6. CO_2 Produced from Varying Raw Material in Steel Production [15]

Process	Total kg - CO_2 per ton - Liquid Steel
Ore-pellet - coke -BF -BOF (25% scrap)	2010
Ore-pellet -Cores –BOF	3084
Ore-pellet -Middren –EAF	1874
100% Scrap –EAF	641
60% scrap - (Ore-40% iron carbide) – EAF	982
50% scrap, (Ore - 50% Fastmet) –EAF	1872
Ore-100% Iron carbide – EAF	1089

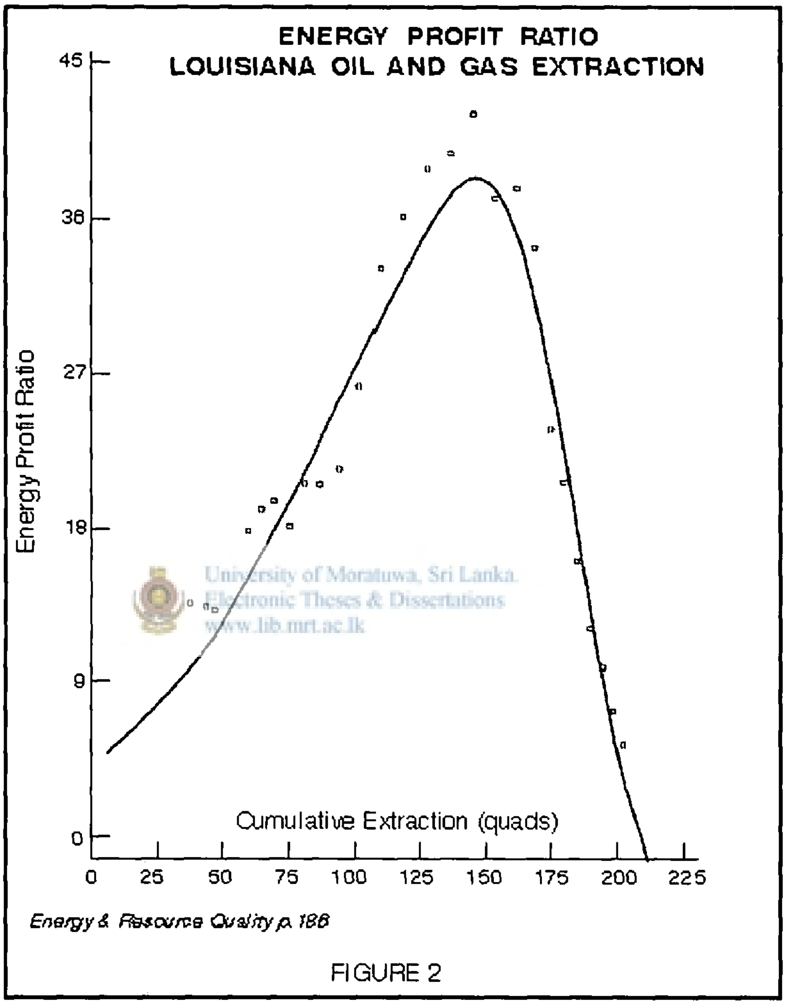
BOF - Basic Oxygen Furnace *EAF - Electric Arc Furnace*

Another example is use of slag from the steel production process (particularly in the blast furnace) in the process of making cement. Limestone required for cement production can partly be replaced with slag and replacement of one ton of limestone would save between 3 to 5 GJ of energy [15].

Source of raw material is also very important mainly because of distance involve and related transport energy requirement. If the imported raw material is used, it will consume more energy to transport than use of locally available raw materials. Another important factor in source of raw material is in extracting raw material from the earth, how much of depth one has to dig to extract them, more depth to be dug consumes more energy. This is very well illustrated in the production of oil. The energy cost of extracting the last few barrels of oil steadily increase and production become uneconomical when the energy consumed in production approaches the energy produced.

Figure 2.3 below shows the profile of energy profit ratio (EPR) for oil and gas production in Lousiana, USA [22]. Energy profit ratio is defined as:

$$EPR = \frac{\text{Energy Content of Fuel}}{\text{Energy used in producing the fuel}}$$



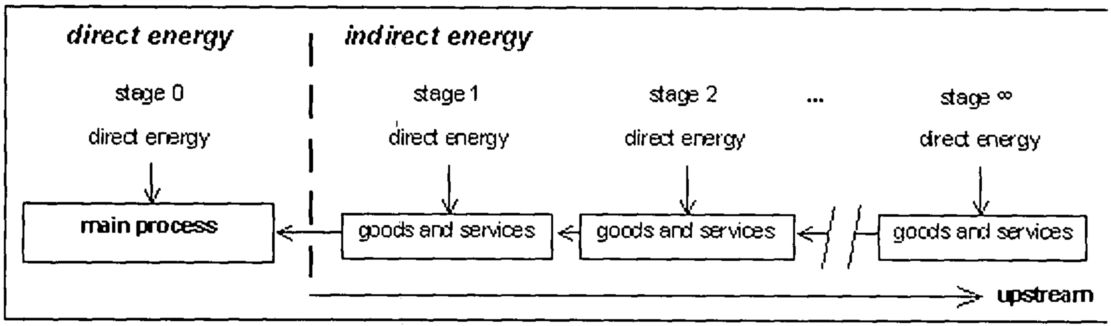
Energy & Resource Quality p. 186

FIGURE 2

Figure 2.3 Energy Profit Ratio

2.4.6 System Boundary

System boundary selected for analyzing embodied energy has many effects on the final figures. Up streams steps involved in the analysis can go up to infinite number.



Source : after Boustead and Hancock, 1979, p. 79

Figure 2.4: Extent of Up Stream Process

Embodied energy value depends on the energy figure used for each up stream process; whether primary energy values or values of embodied energy content of Energy etc. The other factor is which component has been included in the analysis. Whether human energy included or not, employees transport means included or not, administrative services included or not, roads and rail maintenance are included in transport energy use or not are some important questions arise in the analysis.

Comparison of the energy efficiency of gasoline powered car with an electricity operated car illustrates the important of the boundary [13]. The gasoline powered car has an engine transmission combined efficiency of about 0.2. The electric car, with a 0.8 battery charge – discharge efficiency and a motor control system – transmission efficiency of about 0.8 gives a net efficiency of 0.64, operating at much higher efficiency than the gasoline fueled car. If the energy producing facilities for each of these technologies are included in the calculation, however a very different picture is emerged. Oil production, refining and delivery systems are estimated to be 0.88 efficient at returning the energy originally present in the crude oil. Multiplying this by fractional efficiency of the gasoline powered car produce an overall efficiency of 0.17. The relatively low efficiency of thermal electricity generation coupled with fuel production and delivery and electricity loss during transmission gives and overall efficiency of delivered electricity about 0.24. Combining this information with higher efficiency of electric automobile driving system gives an overall efficiency of about 0.15, quite comparable to the overall efficiency of gasoline powered system. In this system it has considered only conversion losses of energy. If it would considered maintenance of automobile and related up stream components, the final figures will vary and some time overall picture may also vary.

2.5 Embodied Energy in Fuels and Energy

In embodied energy analysis, reference point of energy value is very important, because total energy value of a fuel depends on the reference point since it involves several conversion losses, process losses & delivery losses. In calculating embodied energy of fuel both upstream energy consumption and up stream energy losses have to be accounted. Up stream energy consumption means, energy consumption for all the activities involved in fuel manufacturing process from extracting of fuel from the reserves up to production of fuel. Up stream energy losses are loss of fuel during these processes. Accordingly total energy content of a fuel is the summation of up stream losses, up stream consumption and the chemical energy content of final fuel, if the reference point is taken as fuel in the reserve. Figure 2.5 below shows the energy loss chain in coal based power generation [14].

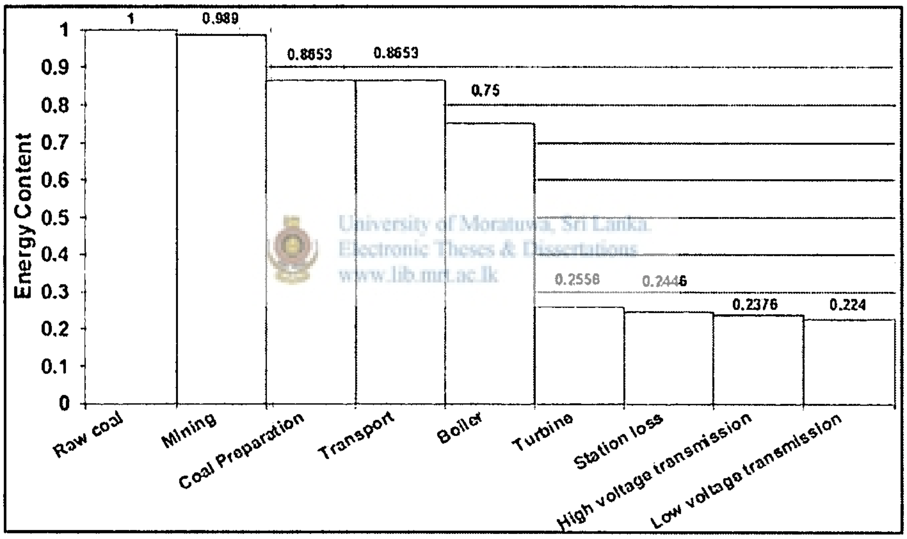


Figure 2.5: Energy Loss Chain in Coal Based Power Generation

According to this data only about 22% of the energy in the coal that is mined is converted into useful delivered energy. When coal comes to the plant (Boiler in this case) 13.5% of energy has been lost. In the above figure up stream energy consumption has not been accounted. In a coal fueled power plant energy pay back ratio is equal to 11 [37] .

The energy pay back ratio (EPR) of a power plant is defined as

$$\text{EPR} = \frac{\text{Energy output GJ}_e\text{/year}}{\Sigma \text{ Upstream Energy Input GJ}_{th}\text{/year}}$$

The operational energy consumption of the power plant is not included in summation of upstream energy inputs.

2.6 Practical Problems & Issues

There are several practical problems that come across when one need to exercise life cycle energy analysis of a product or material or one need to use embodied energy concept to product optimization with respect to energy & environmental concerns. Among these problems followings are the major issues.

- Unavailability of enough data
- Quality of available data
- Variability of data
- Age of data

In the embodied energy field, most of the research that have been conducted are in the field of built environment. Therefore, it is very difficult to find out embodied energy data for materials other than building materials. In the Sri Lankan context, there are only few research studies which have been conducted in this field. Therefore local data is hardly available. Since embodied energy value depends on many parameters, it varies between country to country and therefore having local data is very important.

Next important factor is the quality of available data. It is hardly found the system boundary within which data have been derived. As discussed in the section 2.4.6 in this report system boundaries have a great effect in embodied energy values. For example, if primary energy is reported instead of delivered (or end use) energy, the value may be 30 to 40% higher for common building material [3]. Other important issue is the variability in estimation of embodied energy. There is a significant variation among published values. For example, Sinclair (1986) found a variation in embodied energy of a brick from 5 to 50 MJ. These variations are due to the effect of factors, discussed in the section 2.4 of this report. For an example more than half of the world's Aluminum smelting capacity uses hydro electricity as its energy source, while more than a 50% of Aluminum is produced from recycled material [1]. Aluminum from these sources has vastly different embodied energy value than that from smelter powered by coal fired electricity, such as in Australia. Table 2.7 below shows the embodied energy value of some common building material from different source.

Table 2.7:Embodied Energy of Some Building Material

Material	Embodied Energy MJ/kg	Source
Cement	7.8	Alcorn [4]
	9.0	Buchanal [10]
Timber	2.5	Alcorn [4]
	9	Buchanal [10]

The most important issue in the use of embodied energy data is how old are them. The changes that had taken place during the past decades in the world have effected the energy consumption of a product in every stage of its life cycle. Among these changes technological enhancement, resource depletion, social-cultural & political changes, population increase, global environmental concerns are the main important factors.

As a result of technological enhancement, power plants efficiency has improved substantially. With the improvement of material and technologies in transmission & distribution, losses have come down. Combined effect of these results in reduction of the ratio of primary energy to delivered energy. Advanced process technologies reduce direct energy consumption. For example moving from wet process to dry process in cement manufacturing reduces direct energy consumption by 50% [18].

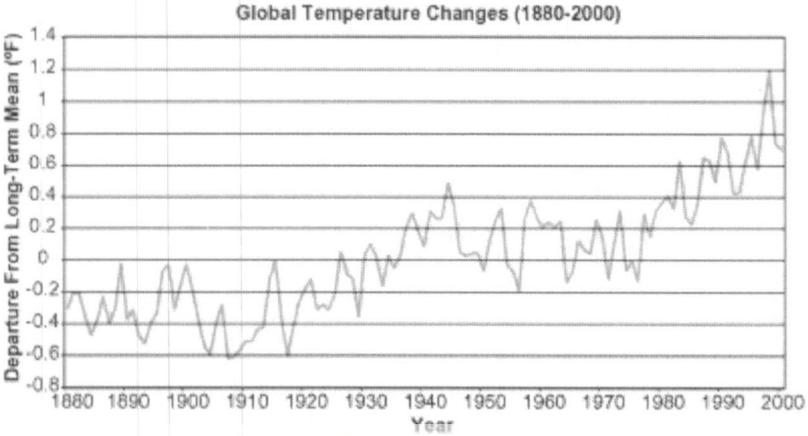
The present social & political pressures for global environmental concerns are much more than that of in early days. Therefore adoption of various methods and devices to a production facility to address environmental concerns has increased specific direct energy consumption of product.

Changes of people living standards demand high quality products, which in turns increase embodied energy as described in the previous section.

World population is increased at the rate of 1.7% [34], which is one factor for increase in world energy demand. This results in move from cheap (in terms of energy) energy resources & reserves to expensive ones.

2.7 Embodied Energy & Global Warming

One of the most concerning environmental issue at present is the change of climate as a result of global warming. Global warming is the increase of mean global ambient temperature due to the man made activities. It is estimated that the sea level could rise by 15 to 95 cm by 2100 due to the thermal expansion of water and the melting of inland glaciers [28]. Several steps and mechanisms have been implemented and being implemented to address this issue. Kyto protocol and Agenda 21 are some of them.



Source: U.S. National Climatic Data Center, 2001

Figure 2.6: Global Temperature Change [28]

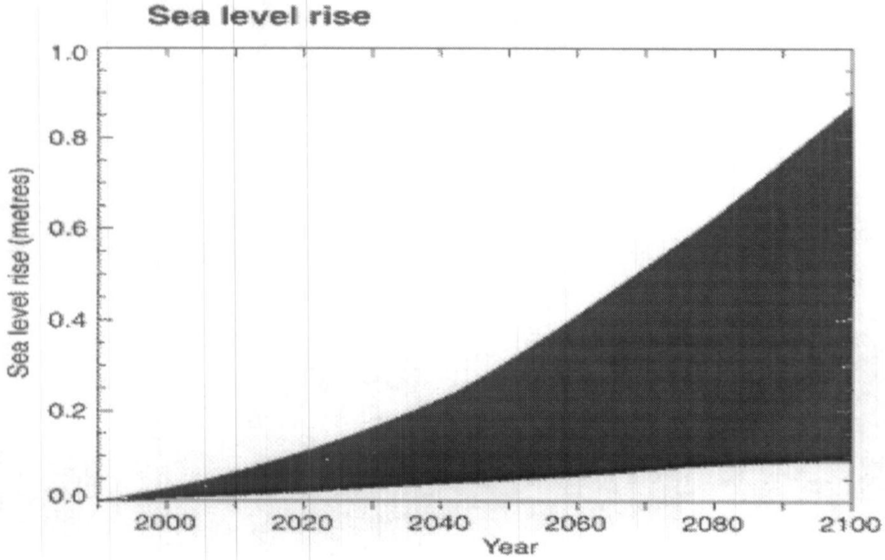


Figure 2.7: Sea Level Rise [28]

The main contributor for the global warming is the green house effect. There is a natural green house caused by trapping of long-wave radiation from the earth to atmosphere, which keep the earth some 30^0 C warmer than it would otherwise have been. This natural green house effect is caused by presence of vapor, clouds, carbon dioxide, methane and nitrous oxide, etc. in the atmosphere [28] and these gases are called "Green house Gases". However, present GHG concentration in the atmosphere is far higher than the concentration over the past centuries.

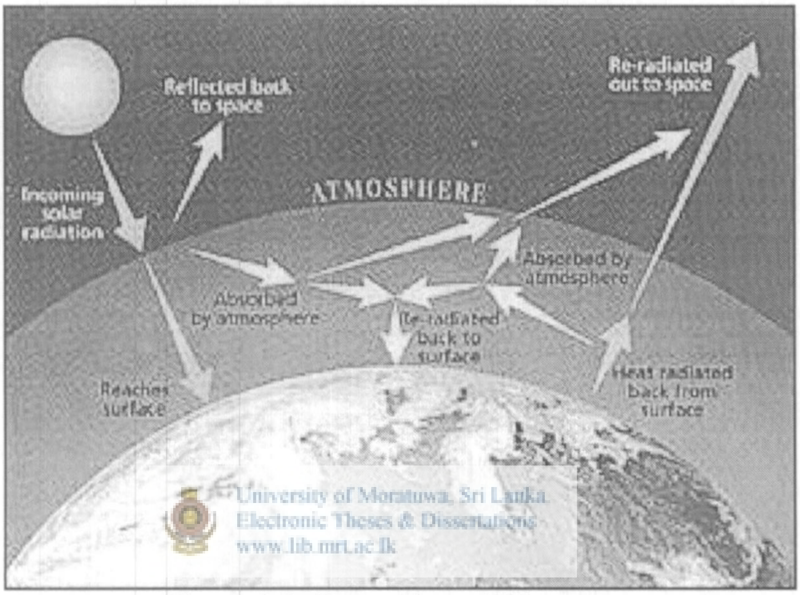


Figure 2.8: Green House Effect

The contribution of the GHG to the global warming is termed as global warming potential (GWP) and GWP factor for CO2 is taken as 1. Table 2.8 below shows the GWP factors of the GHG.

Table 2.8: The Main Green House Gases

GHG	GWP Factor (100 year time horizon)	Atmospheric Life (Years)
CO2	1	50-200
CH4	21	12-17
N2O	310	120-150
CFC12	125-152	102
HcPc12	126	13
CF4	6500	50,000
SF6	23900	1000

Source : 1PCC (1996a)

The GWP factor is varied with the years of time horizon. Table 2.14 in section 2.10 in this report gives GWP factors for 20 years of time horizon.

However, total effect depends on the GWP factors and the amount of GHG. Figure 2 below shows the amount of GHG emission in Sri Lanka based on 1994 figures .

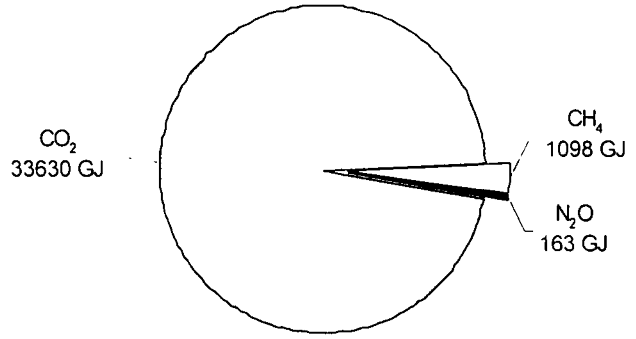


Figure 2.9 : GHG Emission in Sri Lanka - 1994

According to this CO_2 is the main contributing factor. Major source of CO_2 are fossil Fuel combustion, land use conversion & cement production. It is estimated that cement production contributes 20 % of global man made CO_2 emission. Fossil fuel consumption is the one of main factors being responsible for total man made CO_2 emission in the world. The atmospheric life time of CO_2 is 50-200 years [28]. Therefore CO_2 released in 200 years ago, as a result of those day's energy consumption, is contributing to today's effect. Most of the energy consumed in the past is embodied in plant & equipment, infrastructure & buildings, that we are enjoying today. Therefore embodied energy is very well related for the global warming. Figure 2.10 below shows the effect of fuel combustion and cement production to the CO_2 emission.

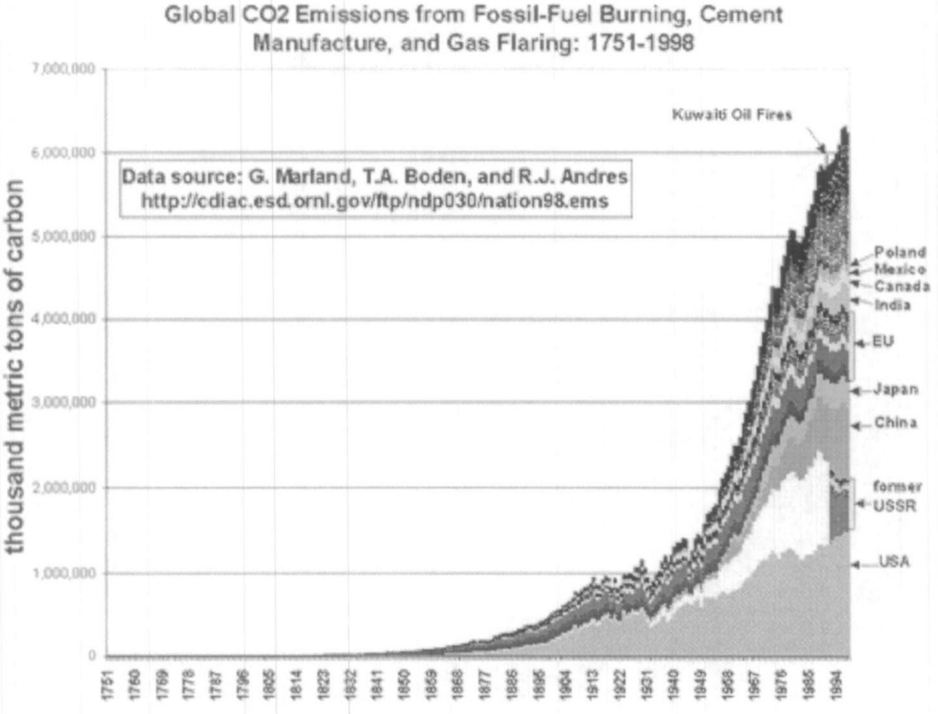


Figure 2.10: Global CO_2 Emission

2.8 Benefits of Embodied Energy Analysis

Understanding and adopting embodied energy concepts is very much beneficial to the society. It helps

- to maintain sustainability of world eco system
- to take decision to move from high energy intensive activities to low energy intensive activities for the energy scared commodities
- to decide to use of various alternatives
- to adopt energy conservation measures

Sustainability of world eco system is mainly depended on the way of addressing global environmental problems in front of us today. Global warning is the one of the most focussing problem in today's contest. Global warming & embodied energy are very well interrelated as discussed in section 2.7 of this report.

To meet future energy demand of energy scared countries, one of the best option available is move away from energy intensive activities. In order to access the energy intensity of a product or activity, most required and appropriate tool is use of embodied energy data. There are various alternatives are available to perform a task. The data, standards and guidelines are very much needed to select best alternative, specially in national levels. For example in building construction various materials such as concrete, steel and wood can be used alternatively pre dominating each other. In the comparison of three type houses in Australia it is found that a predominately steel house contains 553 GJ of embodied energy, predominately concrete house contain 396 GJ of embodied energy and predominately wood house contains 232 GJ of embodied energy [10]

In the further analysis of these result by JONNA Glover, it is concluded that wood is the best construction material for general housing on the basis of embodied energy as well as reducing air emission (specially the production of CO_2) and use of fossil fuel [41].

When adopting energy conservation measures to reduce end use delivered energy consumption, embodied energy analysis is very important, especially in national level. For example, if the embodied energy contents of insulation material used for insulation of a building in order to reduce air conditioning load is higher than the its user phase energy saving, net energy gain is negative in national perspective.

2.9 State of the Art of Embodied Energy Studies in the World

The most of the work carried out in this field of life cycle energy analysis are related to the built environment. Studies in the other areas are rarely found. From the literature that I found, most of the studies have been carried out in Australia, New Zealand, USA & UK. Some important and interesting research and their findings are out lined in the following sections.

2.9.1 Life – Cycle Embodied Energy in Office Ffurniture

(Andrew McCourbrice and Graham Trelor, School of Architecture & building, Deakin University, Celong, Australia.)

The energy required to operate office building has been the focus of much research in past three decades in Australia, but only few studies have been done in quantifying embodied energy in buildings. They have accounted energy embodied in structure, enclosure, finishers & services but not much attention has been given to the energy embodied in the office furniture. Material & furniture are consumed over life of a building in maintenance and refurbishment. This can be called "Recurrent Embodied Energy". McCoubrie (1996) theorized that due to typical high replacement cycles of office furniture compared to other building elements, embodied energy could be very significant over to life of building. Therefore in this study a range of 'typical' office furniture items have been exercised in term of their embodied energy by considering 40 years of building life cycle.

Figure 2.11 compares the average embodied energy of the 13 furniture types analyzed by McCoubrie [35]

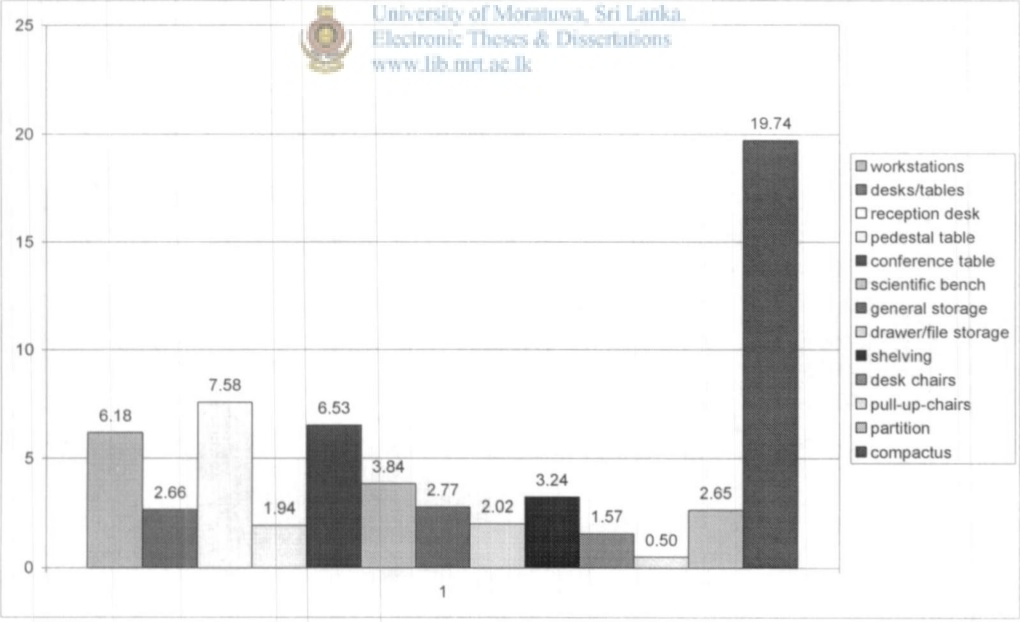


Figure 2.11: Embodied Energy of Office Furniture (GJ/Item)

According to this study in medium rise office building, the initial non-furniture embodied energy has found to be approximately 11.2 GJ/m^2. The operated direct energy was estimated to be 8.0GJ/m^2. The delivered energy embodied initially in furniture was estimated to be 1.5 GJ/m^2 and the delivered energy embodied in recurrent non-furniture elements was assumed to be 3.15 GJ/m^2 . The largest single item in the simulated life cycle energy analysis was replaced furniture of 8.4 GJ/m^2 which when added to the initial furniture delivered embodied energy, comprised 31% of the total life cycle delivered energy.

2.9.2 Life Cycle Analysis of Heavy Vehicles

Various alternative fuels and improved engine & vehicle systems have been proposed in order to reduce emission and energy use associated with heavy vehicles (predominantly trucks). The trend in heavy vehicles is towards use of light- weight materials, tires with lower rolling resistance and treatments to reduce aerodynamic drag. In this paper they have compared the life cycle energy use and emissions from the fuels using selected alternatives such as Fisher-Tropsch diesel fuel and advanced fuel-efficient engines. From this study they have found that

- The direct impacts of the vehicle cycle --producing the truck itself-- were determined to contribute only modestly to the totals, in contrast to research of similar studies with automobiles. The main reasons are the long distances traveled by trucks at low fuel economy.

- Changes in material could have a significant impact. Aluminum for steel slightly increases total energy use for production of the vehicle

- Total energy use is greatest for the conventional truck burning F-T diesel.

- All the alternative fuel options consume more total energy than the equivalent cases burning petroleum diesel fuel.

- Use of natural gas based alternative fuel in trucks neither saves energy nor minimizes GHG emissions, but it does minimize petroleum consumption.

2.9.3 Energy Payback Time of Photovoltaic Modules

(Karl, E. Knapp, Energy and Environmental Economice Inc., St. Fransisco, Theresa L. Jester, Siemens Solar Industries, Camarillo,)

This research has been conducted to investigate energy requirements and net energy production of photovoltaic modules. They have found that the energy payback time for thin film copper indium diselenide in cell production is just under two years. Over their lifetime, these solar panels generate nine to seventeen times the energy required to produce them. Crystalline modules achieve an energy break-even in a little over three years.

2.9.4 The Energy Intensity of Photovoltaic Systems

(Andrew Blakes & Klaus Weber, Centre for sustainable energy system, Australian National University, Canberra October 2000)

This research is also conducted to find out energy payback ratio (EPBR) of solar photovoltaic systems. They have found that EPBT of present solar panel operating in Australia is 7 years and mounting & installation of the system adds further 1 to 4 years depending upon whether it is on a roof or in an open field. This gives a total EPBT for a PV system of 8 to 11 years. But it is expected EPBT of a PV produce in year 2010 will be a 1.7 years.

2.9.5 Energy Payback Ratio and CO_2 Emission Associated With Electricity Generation from a Natural Gas Power Plant

(P J Meier and C L Kalunski, Fusion Technology Institute, University of Wisconsin – Madison, February 3, 2000)

In this study it has been found that the energy payback ratio for natural gas power plant is low (4) compared to coal (11), Fission (16), Fusion (26) and Wind (23).

2.9.6 Which is better ? Steel, Concrete or Wood

(Jonna Glover, Department of Chemical Engineering, University of Sydney)

In the study it has been found that predominantly steel house containing 553 GJ of embodied energy, predominantly concrete house containing 396 GJ and predominantly wood house containing 232 GJ of embodied energy. Hence he has concluded that wood is the best construction material for general housing on the basis of embodied energy as well as reducing air emission and use of fossil fuels.

2.9.7 Energy Use from Cradle to Grave for Three Single Family Houses

(Karin Adelberth, dept. of building physics, Luna University)

In this study three numbers of single family houses in west of Stockholm have been chosen for life cycle energy analysis. The total life cycle energy uses in these three single-family houses are 27100, 30600 and 31600 MJ/m^2 on usable floor area during 50 years. The results shows that 15% of the total energy is made up of energy required in the manufacture of building material and energy required for transportation, erection and demolition accounts for less than 1% of the total energy use. 84% is user phase energy consumption.

2.9.8 Using Monte Carlo Simulation in Life Cycle Assessment for Electric and Internal Combustion Vehicles

(Mccleese, David, La puma-Peter, Air Force Institute of Technology, Wright-Patterson Air Force base, USA)

This study has been carried out to predict life cycle emissions & energy consumption differences between the internal combustion engine vehicle (ICEV) versus electric vehicles (EV) on per km travel basis. Three EV technologies have been considered: lead-acid, nickel-cadmium and nickel metal hybrid batteries. They have found that life cycle energy consumption per km driven for the EV's is comparable to the ICEV. The EV will not reduce green house gas substantially and may even increase them based on the current US reliance on coal for electricity generation. The EV may benefit public health by relocating air pollutants from urban centres, where traffic is concentrated, to rural areas where electricity generation and mining generally occur.

2.9.9 Embodied Energy & Life Cycle Energy Analysis in Built Environment

A list of some published work on embodied energy & life cycle energy analysis in built environment is given below.

Australia

1. Development of a CAD based model for assessing the comparative embodied energy impacts of alternative materials to assist in determining the environmental impact (embodied energy and CO_2 emissions)
2. Aspects of sustainable construction in domestic residential development (can current forms of environmental assessment be combined or modified to produce a model for assessment of comparative sustainability of housing development options)
3. Energy analysis of the construction of office buildings, Master of Architecture thesis, October 1994
4. Energy use in the built environmental and its greenhouse gas implications. Proceedings of the International Symposium on Energy, Environment and Economics, University of Melbourne 1995 *nicht vorhanden!*

Canada

1. C2000 Program
2. Development of an environmental skills registry
3. Building Environmental performance criteria

Denmark

1. A framework system for environmental assessment of buildings
2. Life-cycle-based building design. Energy and environmental model, calculating tool and database
3. Environmental data for building materials in the Nordic countries. Norwegian Building Research Institute.
4. Environmental data for selected building materials. Consumption of fossil fuels and emissions of CO2 and SO
5. Inventory of Emissions to the Air from Danish Sources 1972-1992

Finland

1. Environmental impacts of building materials
2. Sustainable residential area. Assessment of environmental impacts of four typical Finnish residential areas.
3. Environmental emissions of production and use of fuels
4. Greenhouse gas emissions related to energy production and consumption in Finland

France

1. The parameters of the environmental impact assessment of heating systems in residential buildings.
2. Development of qualitative methodology of environmental quality assessment of high school projects in Parisian area.
3. ATEQUE: French workshop on building environmental quality assessment
4. Atmospheric pollution evaluation, pollution from the residential sector in France - September 1995

Germany

1. Life-time energy - and material-flow balances of buildings
2. KOBEK combined calculation method for construction costs, energy requirement and environmental load
3. OGIP optimization of total energy requirement, construction costs and environmental load in integrated planning
4. GEMIS Total emission model of integrated systems
5. GISBAU Risk information system compiled by the professional associations of building sector

Japan

1. The estimation of energy consumption and CO2 emission due to housing construction
2. Evaluation of building design using life cycle CO2 analysis
3. Practical application of the life cycle assessment theory to construction
4. Environmental life cycle analysis of electricity supply systems
5. A life cycle Energy analysis program as a design tool

Netherlands

1. Environmental information in the Building Sector
2. Environmental impact of comfort installations in dwellings
3. Handbook of Sustainable Renovation
4. Experimental environmental classification of house construction
5. ECO Quantum, draft report on method development

New Zealand

1. The embodied energy content and thermal performance of commercial office type low rise multistory buildings constructed from a range of building materials
2. Embodied Energy Coefficients of Building Materials

Norway

1. Testing the Environmental Profile-method
2. Some Environmental and Economic Aspects of Energy Saving Measures in Houses
3. Buildings in a Life Cycle Perspective
4. Buildings in a Life Cycle Perspective

Sweden

1. The Environmental Manual
2. Environmental Assessment of Building Components
3. Energy use from cradle to grave for three single-family houses
4. Energy use from cradle to grave for multi-family houses
5. Environmental assessment of Buildings-National program

Switzerland

1. Environmental Life Cycle Inventory of Energy Systems - Bases for an ecological comparison of energy systems and the inclusion of energy systems in LCA
2. Life Cycle Assessment, Evaluation and further development of Valuation Methods
3. Environmental Life Cycle Inventory and Life Cycle Impact Assessment of building materials, Bases for an ecological comparison of building constructions
4. Declaration form for ecological features of building materials, interpretation for users
5. Building Constructions according to Ecological aspects

United Kingdom

1. Environmental Handbook for Building & Civil Engineering Projects - 2 volumes
2. BREEAM/New offices: Version 1/93: BRE 1993. BREEAM/Superstores

United States of America

1. Environmental Knowledge Base Advisor for Facility Life-Cycle Decisions

2.9.10 Data for Life Cycle Energy Calculation

Following Tables include various data that were found from the literature around the world.

Table 2.9 : Embodied Energy of Building Materials

Material	Density	Low value		High value	
	kg/m^3	GJ/ton	GJ/m^3	GJ/ton	GJ/m^3
Natural aggregates	1500	0.030	0.05	0.12	0.93
Cement	1500	4.3	6.5	7.8	11.7
Bricks	~1700	1.0	1.7	9.4	16
Timber (prepared softwood)	~500	0.52	0.26	7.1	3.6
Glass	2600	13	34	31	81
Steel (steel sections)	7800	24	190	59	460
Plaster	~1200	1.1	1.3	6.7	8.0

Source: Building Research Establishment, UK, 1994

Table 2.10 - Embodied Energy of Fuel Oil

Fuel Oil, 1000 kg

		Crude oil Production	Refining	Transport	Precombustion	Production
	Units	Processing	Process	no precombustion		
Electric	kWh	22.30	11.90		34.20	22.30
Natural gas	m3	4.08	0.00		4.08	4.08
	MJ	149.33	0.00		149.33	149.33
Fuel oil heavy	l	0.17	61.80		61.97	0.17
	MJ	6.76	2457.79		2464.55	6.76
Tanker	km			4500.00		
	MJ			473.55	473.55	473.55
Pipeline	km			125.00		
	kWh			2.43	2.43	2.43
Barge	km			1000.00		
	MJ			466.80	466.80	466.80
Total thermal energy	MJ				3554.22	1096.44
Total electric energy	kWh				36.63	24.73
Conversion factor					0.38	0.38
Energy requirement	MJ				3903.03	1331.91

Sources: Franklin, Shell, GEMIS

Table 2.11 Comparison of Embodied Energy Data Available for Steel [20]

Author	Description	Embodied Energy (MJ/kg)
Alcorn	Steel, recycled, sections	8.9
	Steel, recycled, wire rod	12.5
	Steel, virgin, general	32.0
Buchanan	Steel, sections	59.0
	Steel, rods	34.9
	Steel, general	34.9
	Steel, pipes	56.9
FEMP	Steel (GFF range)	25.7-39.0
Lawson	Steel	35.0
	Basic Oxygen Steel, coated sheet	38.0
	Basic Oxygen Steel, stud	38.0
	Electric Arc Furnace Steel, reinforcing rod	19.0

Table 2.12 Comparison of Embodied Energy Data Available for Wood [20].

Document	Description	Embodied Energy (MJ/kg)
Alcorn	Timber, kiln dried, dressed	2.5
	Timber, glulam	4.6
	Timber, medium density fibreboard	11.9
Buchanan	Timber, kiln dried, treated	9.4
	Timber, glulam	9
	Timber rough	1.7
	Timber, air-dried, treated	2.4
	Timber Formwork	0.6
	Hardboard	41.2
	Softboard	31.0
FEMP	Lumber (GFF range)	4-7
	Particleboard (DOE range)	14-20
	Plywood	18
Lawson	Timber, softwood stud	3.5
	Timber, particleboard (softwood)	8.0
	Timber hardboard (hardwood)	24.0
	Timber, imported Western Red Cedar frame	4.5
	Timber hardwood engineered product	11.0
	Timber floors	1.9
	Timber frame, timber weatherboards, plasterboard	1.5
	Timber studs with plasterboard	1.3

Table 2.13 Comparison of Embodied Energy Data Available for Concrete [20].

Document	**Description**	**Embodied Energy (MJ/kg)**
Alcorn	Cement	7.8
	Fibre board cement	13.1
	Concrete block	0.9
	Concrete, glass reinforced	3.4
	Concrete, 30Mpa	1.4
	Concrete, pre-cast	2.0
Buchanan	Cement	9.0
	Concrete, insitu	1.6
	Concrete, pre-cast	2.0
FEMP	Concrete (GFF range)	1.2-2.0
Lawson	Cement Render	2.0
	Cement Mortar	2.0
	Concrete - in situ	2.0
	Autoclaved Aerated on Autoclaved	9.5
	Concrete Raft Slab	8.4
	150mm Aerated Concrete	5.4
	150mm Concrete Slab	8.8
	Auto Aerated Concrete	4.8

Table 2.14: Global Warming Potentials (20 year time horizon) [31]

Global Warming Gas	**GWP Factor CO2 = 1**	**Global Warming Gas**	**GWP Factor CO2 = 1**
Carbon Dioxide (CO_2):	1	CFC 12 (CF_2Cl_2):	7,100
Methane (CH_4):	56	CFC 13 (CF_3Cl):	11,000
Nitrous Oxide (N_2O):	280	CFC 14 (CF_4):	3,500
Halon 1301 (CF_3Br):	5,600	CFC 114 (C_2F_4Cl):	6,100
CFC 11 ($CFCl_3$):	4,500	HCFC 22 (CHF_2Cl):	4,200

Table 2.15: Specific CO_2 Equivalent Emission for Fuels

Fuel Type	t CO_2 /GJ Primary Energy
Natural Gas	0.065
Coal	0.115
Biomass	0.015

Table 2.16: Potential Production Energy Savings of Recycled Materials

	Energy required to produce from virgin material (million Btu/ton)	Energy saved by using recycled materials (percentage)
Aluminum	250	95
Plastics	98	88
Newsprint	29.8	34
Corrugated Cardboard	26.5	24
Glass	15.6	5

Source: Roberta Forsell Stauffer of National Technical Assistance Service (NATAS), published in *Resource Recycling*, Jan/Feb 1989).

Table 2.17 Average Fuel Consumption of Vehicles [41]

Vehicle Class	Average MPG	Mode	BTU/Pass-Mile
Passenger Cars	21.4	Car	3,672
Vans, Pickup Trucks, SUVs	17.1	Other Light Duty Vehicle	4,591
Motorcycle	50	Aviation	4,200
Single Unit Truck	6.8	Transit, Bus	3,729
Combination Truck	5.9	Intercity Bus	1,000
Buses (all types)	6.7	Intercity Rail	2,400

Table 2.18: Energy Used By Mode (MJ/Passenger km) (Lenzen, 1999) [41]

Mode	Embodied	Fuel	Total
Urban			
Light Rail	0.7	1.4	2.1
Bus	0.7	2.1	2.8
Ferry	1.2	4.3	5.5
Bicycle	0.5	0.3	0.8
Heavy Rail	0.9	1.9	2.8
Car, Petrol	1.4	3.0	4.4
Car, Diesel	1.4	3.3	4.8
Car, LPG	1.4	3.4	4.8
Private Bus	0.5	1.2	1.7
Non-Urban			
Bus	0.3	1.0	1.3
Rail	0.7	1.2	1.9
Private Air	12.4	6.5	18.9
Carter Air	9.1	8.7	17.8
Regional Air	5.4	4.3	9.7
Domestic Air	2.7	3.1	5.7
International Air	0.9	2.2	3.1

Table 2.19 : Embodied Energy Coefficients [23]

Material	MJ/kg	MJ/m^3	MJ/m^2	Age of Data
Aggregate, general	0.10	150		1993
Virgin rock	0.04	63		1994
River	0.02	36		1994
Aluminium, virgin	191	515700		1994
Extruded	201	542700		1995
Extruded, anodised	227	612900		1995
Extruded, factory painted	218	588600		1995
Foil	204	550800		1995
Sheet	199	537300		1995
Aluminium, recycled	8.1	21870		1995
Extruded	17.3	46710		1995
Extruded, anodised	42.9	115830		1995
Extruded, factory painted	34.3	92610		1995
Foil	20.1	54270		1995
Sheet	14.8	39960		1995
asphalt (paving)	3.4	7140		1995
Bitumen	44.1	45420		1995
Brass	62.0	519560		1994
Carpet	72.4			
felt underlay	18.6			1992
Nylon	148			1992
Polyester	53.7			1992
Polyethylterepthalate (pet)	107			1992
Polypropylene	95.4			1992
Wool	106			1994
Cement	7.8	15210		1994
Cement mortar	2.0	3200		1994
fibre cement board	9.5	13550	102/7.5mm	1994
soil-cement	0.42	819		1995
Ceramic				
Brick	2.5	5170		1994
brick , glazad	7.2	14760		1991
Pipe	6.3			1994
Tile	2.5	5250		
Concrete				
Block	0.94			1994
Brick	0.97			1994
GRC	7.6	14820		1994
Paver	1.2			1994
per-cast	2.0			1994
Ready mix, 17.5 MPa	1.0	2350		1994
30 MPa	1.3	3180		1994
40 MPa	1.6	3890		1994
Roofing tile	0.81			1991
Copper	70.6	631 160		1994
Earth, raw				
Adobe block, straw stabilised	0.47	750		1994
Adobe, bitumen stabilised	0.29			1991
Adobe, cement stabilised	0.42			1995
Rammed soil cement	0.80			1994

Material	MJ/kg	MJ/m^3	MJ/m^2	Age of Data
Pressed block	0.42			1995
Fabric				
Cotton	143			1991
Polyester	53.7			1991
Glass				1994
float	15.9	40060	240/6mm	1994
Toughened	26.2	66020	396/6mm	1994
Laminated	16.3	41080	246/6mm	1994
Tined	14.9	375450		1994
Insulation				
Cellulose	3.3	112		1995
Fibreglass	30.3	970		1991
Polyester	53.7	430		1991
Polystyrene	117	2340		1991
wool (recycled)	14.6	139		1995
Lead	35.1	398030		1995
Linoleum	116	150930	337	1991
Paint	90.4	118/l	6.5	1994
Solvent based	98.1	128/l	6.1	1994
Water based	88.5	115/l	7.4	1994
Paper	36.4	33670		1988
Building	25.5		4.97	1995
Kraft	12.6			1994
Recycled	23.4			1991
Wall	36.4			1988
plaster, gypsum	4.5	6460		1991
plaster board	6.1	5890	33/9.5mm	1995
Plastics				1994
ABS	111			1991
high density polyethelene (HDPE)	103	97340		1994
low density polyethelene (LDPE)	103	91800		1994
Polypropylene	64.0	57600		1994
Polystyrene, expanded	117	2340		1994
Polyurethane	74.0	44400		1991
PVC	70.0	93620		1992
Rubber				
Natural latex	67.5	62100		1991
Synthetic	110			1994
Sand	0.10	232		1993
Sealants and adhesives				
Phenol formaldehyde	87.0			1994
urea formaldehyde	78.2			1990
Steel ,recycled	10.1	37210		1995
Reinforcing, sections	8.9			1995
wire rod	12.5			1995
Steel ,virgin, general	32.0	251200		1994
galvanised	34.8	273180		1994
imported, structural	35.0	274570		1994
Stone ,dimension				
Local	0.79	1890		1993
Imported	6.8	1890		1994

Material	MJ/kg	MJ/m^3	MJ/m^2	Age of Data
straw, baled	0.24	30.5	15.2	1978
Timber, softwood				1992
air dried, roughsawn	0.3	165		1995
kiln, dried, roughsawn	1.6	880		1995
air dried, dressed	1.16	638		1995
kiln dried, dressed	2.5	1380		1994
Mouldings, etc	3.1	1710		1995
Hardboard	24.2	13310		1994
MDF	11.9	8330		1994
Glulam	4.6	2530		1992
Particle board	8.0			1994
Plywood	10.4			1994
Shingles	9.0			1991
Timber, hardwood				
air dried, roughsawn	0.50	388		1994
kiln dried, roughsawn	2.0	1550		1994
vinyl flooring	79.1	105990		1991
Zinc	51.0	364140		1994
Galvanising, per kg steel	2.8			1994

This chapter started with discussing the currently employed energy analysis method and theory of embodied energy analysis. In the chapter 6, this theory will be used for analysis of the embodied energy of cement. At the end of this chapter some data used for embodied energy analysis is given and some of these will be used in analysis in chapter 6.

Chapter 3

Methodology and Scope of the Study

This chapter discusses the factors included in the calculation of embodied energy of cement and the methodology adopted to find out relevant data.

3.1 Scope of the Study

This project is aimed towards the finding out of national energy involvement in the manufacturing of cement in Sri Lanka. Hence the system boundary of the energy flow of the study is selected as “Sri Lanka”. Therefore any energy involvement outside Sri Lanka for cement manufacturing is not accounted for in the study. The energy analysis was done in three levels as described below. In the Level 1, electrical energy consumption, fuel oil consumption and diesel consumption for internal transport and earth moving machinery in the Puttlam cement factory were considered. In the Level 2 analysis, energy consumption for supportive services such as employee transport, machinery maintenance, employee uniforms, etc. were considered. In the Level 3 analysis, energy consumption for raw material extraction & transports to the factory was considered.

3.2 Energy and Material Consumption in Puttlam Cement Factory

A preliminary energy audit was conducted to find out required data from the Puttlam cement factory. Monthly electrical energy consumption, furnace oil consumption, diesel consumption, raw material consumption, cement production, employee transport modes, etc. were collected during this survey.

3.2.1 Energy for Raw Material

A preliminary energy survey was conducted to collect energy and production details in Aruwakkaru limestone quarry. Energy consumption of excavation of laterite was estimated by using capacity and energy consumption of earth moving machines. For gypsum only transport energy is considered.

3.3 Referring Delivered Electrical Energy to Primary Energy

In referring the delivered electrical energy to primary energy, following factors were considered.

- Transmission and distribution losses
- Electrical energy mix
- Power plant efficiencies
- Energy requirement to produce one unit of electricity from thermal plants
- Energy consumption to produce fuel
- Fuel transport energy

The first three factors were taken from the long-term generation expansion plan – 2002 to 2016 prepared by the generation & planning unit of the Ceylon Electricity Board (CEB) in year 2001.

A preliminary survey was conducted at the Lakdhanavi power project, sapugaskanda, to find out the energy requirement to produce one unit of electricity from oil based thermal power plants.

3.4 National Energy Embodied in the Petroleum Fuels

A preliminary energy survey was conducted at the petroleum refinery of Ceylon Petroleum Corporation, in order to find out energy requirement to refine crude oil. The total fuel consumption in refinery and electrical energy consumption at the Kelaniya water intake plant were considered. The amount of refined petroleum fuel imports, amount of petroleum fuel refined in Sri Lanka, electrical energy consumption in Kolonnawa & Sapugaskanda petroleum handling & distribution complexes were considered, when finding out the national energy embodied in the petroleum fuels.

3.5 Energy Requirement in Transport

In the calculation of transport energy following factors were considered.

- Fuel consumption per km
- Servicing energy requirement per km
- Fuel filling energy requirement per km
- Engine oil requirement per km and energy requirement to produce engine oil

Servicing energy requirement was obtained from energy consumption figures from few service stations and fuel pumping energy was obtained from few fuel filling stations. A preliminary survey was conducted in Caltex Lubrication Lanka Ltd factory to find out energy requirement to produce lubricating oil.

3.6 Referring Delivered Thermal Energy to Primary Energy

The national energy embodied in petroleum fuels and transport energy requirements to transport them to the final destination were considered here.

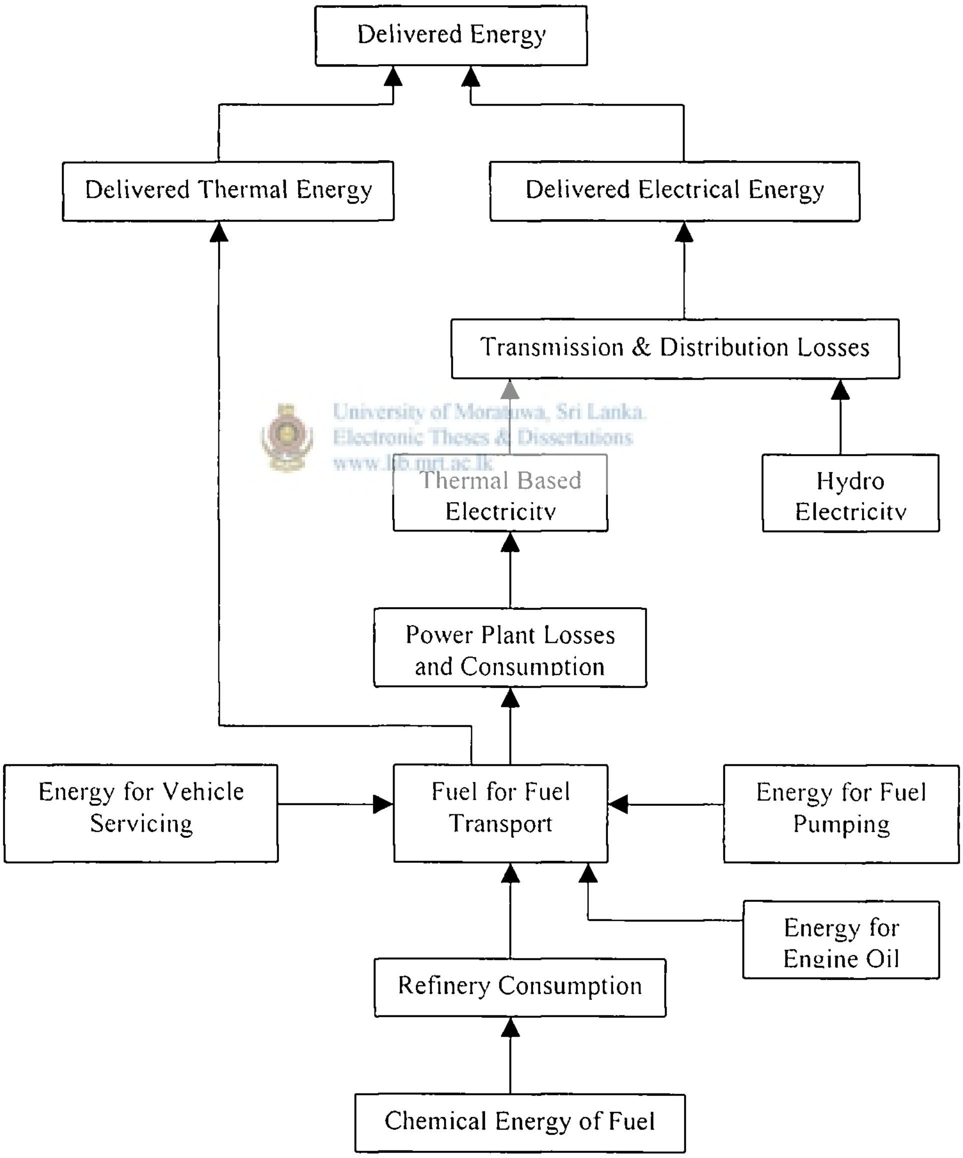


Figure 3.1: Referring Delivered Energy to Primary Energy

Chapter 4

Assessment of Energy and Material Flow

-Puttlam Cement Factory-

This chapter presents the data collected in the energy audit conducted at Puttlam cement factory. It covers process involvement in extraction of raw material from earth to production of cement. The location of raw materials, means of transport of raw materials and other related materials and products will also be discussed. The data given in this will be used in the analysis of this study.

The Puttlam Cement Factory is located at Palavi, 8 km from the Puttlam town. It produces Ordinary Portland Cement.

4.1 Raw Material

The main raw materials used for cement production in this factory are limestone, laterite and gypsum. Limestone and laterite are extracted in Sri Lanka whereas gypsum is imported. Table 4.1 below shows the source of these raw materials and Table 4.2 shows the raw material consumption during the Year 2001.

Table 4.1: Details of Raw Material Supply

Raw Material	Source	Transported by	Transport Distance km
Lime stone	Aruwakkaru Quary	Train	35
Laterite	Laterite pits Anamaduwa	Trucks Capacity – 5 tons	35
Gypsum	Imported	Lorry (from Colombo)	130

Table 4.2: Annual Consumption of Raw Materials

Raw Material	Ton
Lime Stone	639746
Laterite	20427
Gypsum	14907

Limestone is extracted from the limestone mines at Aruwakkaru and transported to the factory by train with 15 no. of wagon having capacity of 22 Tones each. Two types of limestone are mined and composition of these is given in Table 4.3 below.

Table 4.3: Composition of Limestone

Parameter	Composition (%)	
	High Quality	**Low Quality**
LOI	36.82	33.6
Silica	11.28	17.35
Alumina	2.64	2.88
Fe_2O_3	1.19	1.65
CaO	46.94	42.81
MgO	0.35	0.32
SO_3	0.01	0.01
K_2O	0.11	0.17
Na_2O	0.00	0.08

LOI – Lost on ignition

The quantity of limestone transported to the factory and fuel consumption for transport, are shown in Table 4.4.

Table 4.4: Quantity of Limestone – Year 2001

Month	Lime Stone (MT)			Transport Fuel Consumption (Litre)		
	CGR Train	**Own Train**	**Total**	**CGR Train**	**Own Train**	**Total**
January	20893	0	20893	10624	0	10624
February	38317	0	38317	19484	0	19484
March	30348	48779	79177	15457	19344	34801
April	37699	0	37699	19170	14505	33675
May	30727	53343	84070	15625	25545	41170
June	43053	39430	82483	21892	13901	35793
July	50989	47603	98587	25925	23385	49310
August	38108	51130	89238	19378	23560	42938
September	14644	42230	58874	7446	20295	27741
October	0	15446	15446	0	10090	10090
November	0	0	0	0	0	0
December	0	34962	34962	0	19684	19684
Total			**639746**			**325312**

Laterite is extracted from laterite pits located at Anamaduwa and transported to Puttlam factory by trucks. The capacity of a truck is 5 tons and in the Year 2001, 20427 tons were transported to the factory. The Table 4.5 below shows the composition quality of the laterite.

Table 4.5 : Composition of the Laterite

Component	%
LOI	13.99
Silica	28.40
Alumina	20.78
Fe_2O_3	36.10

Gypsum is totally imported to Sri Lanka and transported from Colombo to factory by lorries having capacity of 3.5 Tons.

4.2 Energy

The commercial energy requirement of Puttlam cement factory is met through electricity, furnace oil and diesel. The Figure 4.1 depicts share of these in year 2001.

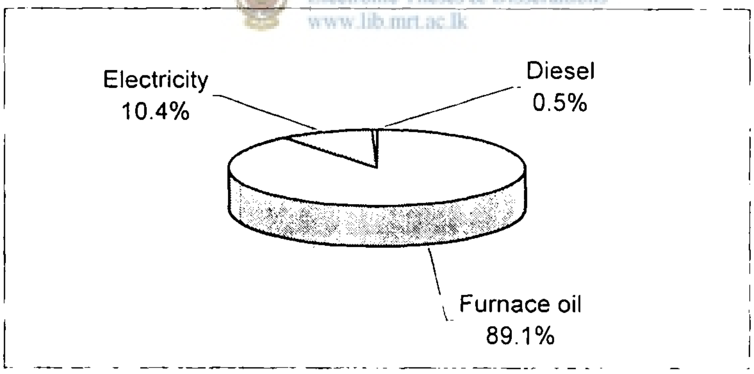


Figure 4.1 : Share of Energy by Source

Total electrical energy requirement is met through the national grid and power interruptions occur very rarely. Even during the "Power cuts" special supply is given to the factory by CEB. A 200 kVA standby generator is available to use in emergency power break downs and this is enough only for just to maintain kiln rotation and other emergency requirements until the power comes. The total annual generation by the stand by generator is negligible when compared to the grid supply. The total electrical energy consumption in year 2001 is 59.3 Million kWh and monthly break down is shown in Table 4.6.

Table 4.6 : Monthly Electricity Consumption of the Factory – 2001

Month	kWh	kVA
January	-	-
February	4,161,400	9,550
March	5,631,900	9,737
April	5,064,600	9,562
May	5,360,300	10,011
June	5,180,300	9,9973
July	5,607,900	9,952
August	5,164,700	9,864
September	3,838,100	6,932
October	3,914,000	9,181
November	5,475,300	9,623
December	4,926,400	-

The furnace oil is used in kilns and total annual consumption in Year 2001is 42583.8 MT. The type of furnace oil used is 1500 sec. Table 4.7 shows the monthly furnace oil consumption.

Table 4.7 : Furnace Oil Consumption - 2001

Month	MT
January	4213.8
February	2808.0
March	4019.0
April	3613.5
May	3713.0
June	3744.0
July	3950.0
August	3626.0
September	2118.0
October	2449.0
November	4234.5
December	4095.0
Total	**42583.8**

Diesel is used for internal transport requirement in the factory and standby power generation. In year 2001, 275500 ltrres of diesel were consumed for internal transport and consumption for stand by power generation is negligible. Internal transport includes operation of heavy machinery for handling & loading of raw material and shunting train for internal transport of limestone to the crushers. Table 4.8 below shows the diesel consumption in shunting train engine

Table 4.8: Diesel Consumption in Shunting Train Engine - 2001

Month	Litre
January	496
February	2770
March	3568
April	2258
May	4065
June	1689
July	1858
August	2550
September	1430
October	0
November	0
December	990

Table 4.9 Fuel Consumption in Heavy Equipment - 2001

Month	Diesel Consumption litre	
	Own	Hired
January	14422	17518
February	13837	16999
March	5576	7749
April	7749	10267
May	7440	10434
June	7086	8432
July	9404	9809
August	10069	11615
September	4853	13625
October	11345	7664
November	0	15034
December	14432	18379

Table 4.10: Heavy Vehicles Running Hours

Month	Dumper	FEL 1	FEL2	Dozer	Baco	EDC Loder
January	484	327	310	245	0	0
February	367	13	202	296	144	197
March	241	0	308	173	74	24
April	299	0	334	254	175	0
May	333	0	421	206	141	0
June	175	0	372	136	110	0
July	187	0	275	156	105	0
August	211	0	285	280	101	0
September	342	0	413	353	100	0
October	278	0	386	162	68	0
November	363	0	445	210	60	148
December	229	64	338	252	249	97
Total	3596	404	4089	2723	1324	466

A very small quantity of LP gas is used for ignition of the kiln and total annual consumption is estimated to be 500 kg.

4.3 Production Process

Production starts at the factory from the limestone crushing in two crushers. Limestone is fed to the crusher by rail wagons and it crushed to 25 mm size. Table 4.11 below shows the total amount of limestone crushed in the crusher plant.

Table 4.11 : Crusher Output - 2001

Month	Output Ton	Month	Output Ton
January	21952	July	98133
February	40325	August	90068
March	80464	September	60453
April	37983	October	20156
May	83572	November	975
June	82190	December	33555
Total	**650266**		

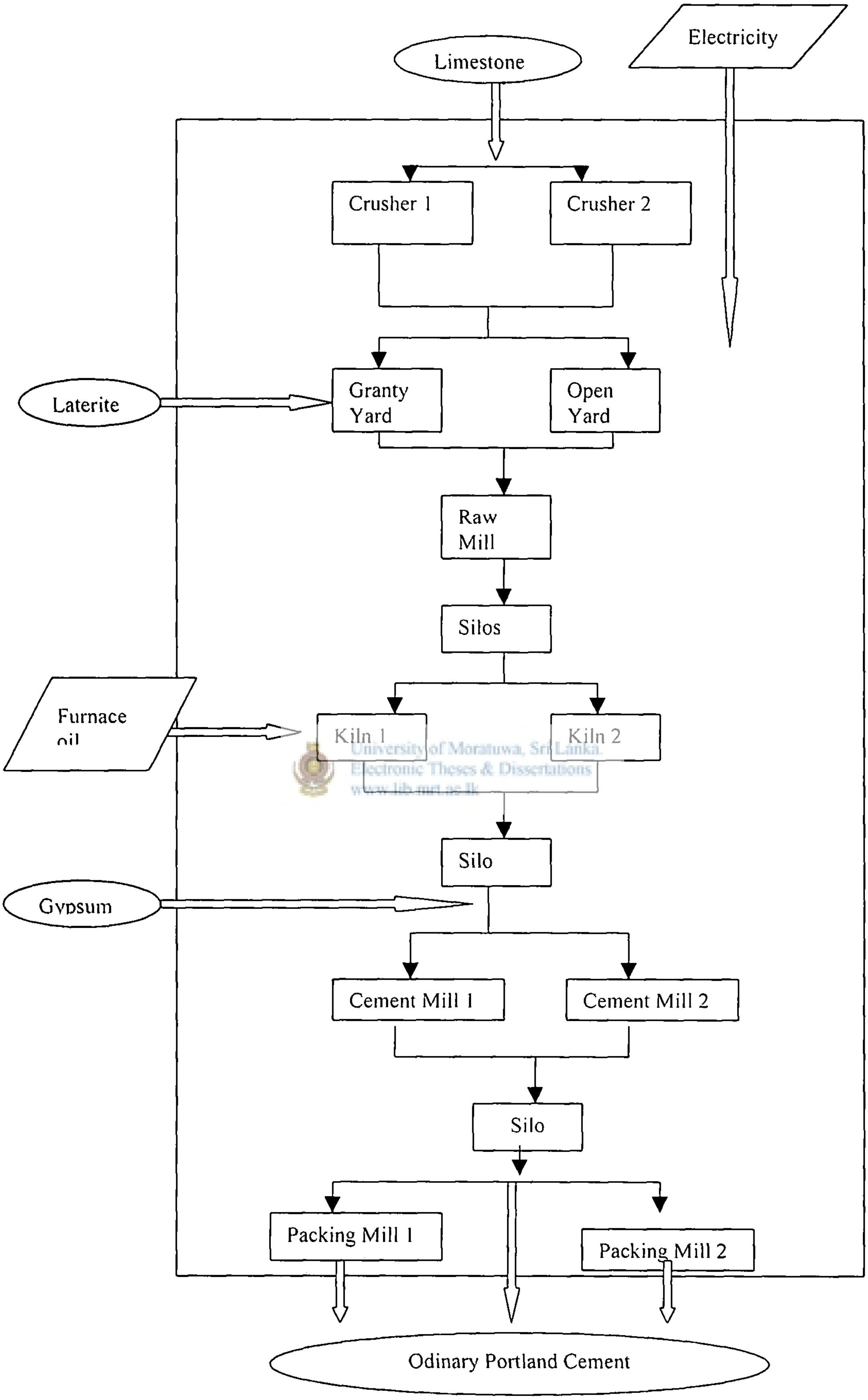


Figure 4.2; Process Flow Diagram - Puttalam Cement Factory

The crushed limestone is then send to granty yard and open yard through conveyor belts. At the granty yard, limestone is mixed with laterite and mixture is fed to raw mill.

At the raw mill, the lime-laterite mixer is ground to very fine particles through two ball mills. Then these are stored in silos. The average electricity consumption of the raw mill is 17 kWh/ton

Table 4.12: Raw Mill Output – 2001

Month	Output Ton	Month	Output Ton
January	72130	July	73495
February	48670	August	61986
March	72824	September	37412
April	63061	October	45340
May	65922	November	76712
June	65653	December	75675

Then the ground mixture of limestone & laterite is fed to the two rotary kilns through waste heat recovery pre heaters counter currently. So the mixture is pre heated to 950^{0}C, before entering to the kiln. At the kiln reactions are taken place at 1450^{0}C and clinker is formed. The fuel used in the rotary kiln to meet required heat energy is 1500 sec furnace oil.

Table 4.13 : Clinker Productions & Energy Consumption – 2001

Month	Clinker (MT)	Furnace Oil (MJ)
January	43494	4213.8
February	28624	2808.0
March	40559	4019.0
April	37230	3613.5
May	40559	3713.0
June	39459	3749.0
July	41244	3950.0
August	38000	3626.0
September	22238	2118.0
October	25829	2449.0
November	45118	4234.5
December	45550	4095.0
Total	**447904**	**42588.8**

The average electricity consumption of the kiln is 53 kWh/MT of clinker. The clinker is mixed with Gypsum and ground at the ball mills at the cement mill to produce Ordinary Portland Cement. Then these Portland cement is stored in the cement silos and send to the packing plant to pack & bulk sales. The average electricity consumption of cement mill is 43 kWh/MT.

Table 4.14 : Cement Production - 2001

Month	Cement (MT)
January	52624
February	36911
March	45348
April	41707
May	39945
June	38508
July	45955
August	47209
September	46095
October	40443
November	43501
December	31000
Total	**509246**

4.4 Human Resources

544 male employees & 23 female employees are employed at the Puttlam Cement Factory and details are shown in the Table 4.15 below.

Table 4.15 : Details of the Employees at Cement Factory, Puttlam – 2001

Category	Number
Executive	55
Technical & Supervisory grade	50
Clerical & Allied	47
Operators	321
Contract	94

Table 4.16 below shows the employee's transport details.

Table 4.16: Employees' Transport Details

Shift	Transport Mode	No. of Employees				Total
		0 - 5	5 - 10	10 - 25	>50	
Day shift 5 day per week 250 days per year	Bicycle	30	50	08	-	88
	Motor cycle	10	40	20	-	70
	Car – single	06	09	-	-	15
	Bus	08	22	30	80	140
	Van - Group	-	08	16	-	24
12 hr. shift 4 days duty 4 days off 180 days per year	Bicycle	25	35	08	-	68
	Motor Cycle	2	25	13		40
	Car-single	-	-	-	-	-
	Bus	05	20	35	20	80
	Van – Group	-	04	08	-	12
3 Shifts 5 days per week 300 days per year	Bicycle	4	8	-	-	12
	Motor Cycle	-	3	3	-	6
	Bus	-	5	12	-	12

4.5 Ancillary Inputs

Other than the main row material and energy consumed, there are some other recurrent inputs are needed in cement manufacturing. Lubrication oil, engine oil, greece, uniforms, etc. are few examples.

All the employees are given uniform and safety shoes. Details are shown in Table 4.17 below.

Table 4.17 : Details of Uniforms

No. of Uniform per person per year	02 kits
Type of Uniform Male Female	 Shirt & Trouser Saree
Clothes per uniform Male Female	 5m 5m
No. of safety shoes per person per year	1
No. of Gum Boots	Only for supervisors & engineers. One per 3 years
Helmat	One per each for 5 years.
Rain coat	Site officers. One for 5 years.

4.6 Extraction of Limestone

Limestone is extracted at the limestone pits in " Aruwakkaru" quarry site located at 160 km road distance from Colombo. Firstly top soil is removed up to about 25 – 30 feet and then limestone rock is blasted using explosives. Table 4.18 below shows the average annual consumption of explosives.

Table 4.18: Annual Consumption of Explosives

Explosive	Consumption
NH_4NO_3	100000 kg
Special Gelenite	6000 kg
Electrical Detonators	6500 Nos

All the above explosives are imported to Sri Lanka and stored in Welisara Navy stores. These are brought to quarry site from Welisara stores on the day of explosion. One journey accompanying one lorry and two other light vehicles.

4.6.1 Fuel Consumption in Heavy Vehicles and Other Machinery

Table 4.19: Details of Heavy Vehicles and Machinery - 2001

Vehicle/Machine	Operated Machine Hours
Front End Loader 1	945
Front End Loader 2	2600
Dozer 1	1783
Dozer 2	536
Dumper 1	549
Dumper 2	2080
Dumper 3	2013
Dumper 4	2025
Motor Grader	515
Compressor	1194
Drilling Machine	1793
Loco Engine	2836
Cummins Generator	3684

Monthly diesel consumption for the machines, vehicles and generators are shown in Table 4.20

Table 4.20: Monthly Diesel Consumption – 2001

Month	Diesel Consumption – ltrs				
	Machines	Vehicles	Generators	Hired Machines	Total
January	31987	2594	3214	7766	45561
February	36043	2982	2955	23366	65346
March	43319	2763	3378	44335	93795
April	39670	3112	2733	24534	70049
May	27181	2709	3005	43200	76095
June	44255	3380	1576	45599	94810
July	38572	2517	2002	51404	94495
August	52048	3844	1918	46200	104010
September	33107	1961	3074	35975	74117
October	25930	2932	2227	35800	66889
November	8657	2898	1496	15463	28514
December	12134	2160	1746	13000	29040
Total	392903	33852	29324	386642	842721

4.6.2 Electrical Energy Consumption

Electricity is used for offices and area lighting. Monthly electricity consumption is shown in Table 4.21 below.

Table 4.21: Monthly Electricity Consumption – 2001

Month	kWh
January	17580
February	14260
March	16150
April	18970
May	15670
June	14720
July	12370
August	7790
September	7600
October	6232
November	5113
December	14445
Total	150900

4.6.3 Water Consumption

Water is supplied internally from tube wells and externally in bowsers . Annual external water supply is 2130 numbers of 4000 Ltrs bowsers for internal use and 1600 numbers of 2000 ltrs bowsers for road wetting.

4.6.4 Production

Table 4.22 shows the monthly usable production of limestone.

Table 4.22: Monthly Production – 2001

Month	Production MT
January	32216
February	49905
March	94120
April	36060
May	90960
June	82340
July	112257
August	100580
September	76060
October	56530
November	22400
December	23225
Total	776653

4.6.5 Oil Consumption

Oil is changed in heavy vehicles and machinery in four stages as given below.

In every 250 running hours : Engine oil
In every 500 running hours : Engine oil
In every 750 running hours : Engine oil
In every 1000 running hours : All oils : Engine oil, Hydraulic oil, Transmission oil

Details of oil consumption of each type of vehicle are shown in Table 4.23 and Table 4.24 shows the annual oil consumption of each machine.

Table 4.23: Details of Oil Consumption : 2001

Vehicle Type	Purpose	Type	Lit/change	Lit/hr
Dozer	Engine	SAE 30	55	0.220
	Hydraulic	DS10	160	0.160
	Transmission	DS 30	180	0.180
		DS 30	120	0.120
Dumper	Engine	SAE 30	37	0.150
	Hydraulic	SAE 30	175	0.175
	Transmission	DS 10	120	0.120
Front End Loader	Engine	SAE 30	37	0.150
	Hydraulic	SAE 30	175	0.175
	Transmission	DS 10	120	0.120
Motor Grader	Engine	SAE 30	25	0.100
	Hydraulic	DS 10	45	0.045
	Transmission	SAE 30	45	0.045
		SAE 30	80	0.080
Loco Engine	Engine	SAE 30	28	0.112
	Transmission	HC 32	105	0.105
Compressor	Engine	SAE 40	37	0.115
	Hydraulic	DS 10	90	0.090
Drill Machine		EP 150	10 ltrs/day	

Table 4.24: Annual Oil Consumption: 2001

Machine	Oil Consumption – Ltrs				
	SAE 30	DS 10	DS 30	DS 40	HC22
Front End Loader 1	307	113	-	-	-
Front End Loader 2	845	312	-	-	-
Dozer 1	392	285	535	-	-
Dozer 2	118	86	161	-	-
Dumper 1	178	66	-	-	-
Dumper 2	676	250	-	-	-
Dumper 3	654	242	-	-	-
Dumper 4	658	243	-	-	-
Motor Grader	117	25	-	-	-
Compressor	-	107	-	180	-
Drilling Machine	-	-	-	-	-
Loco Engine	-	-	-	318	298
Cummins Generator	-	-	-	-	-

4.5.6 Human Resource

Seventy eight numbers of employees are employed at the Arukkaru quarry as given below. The absentee rate is 8%.

Executives	5
Clerical	4
Supervisors	6
Store man	2
Operator Level	61
Total	**78**

Except the engineer all the other staff come to work within 15 km and all are provided with transport by company vans. Engineer is traveled by a car in 125 km distance, once in two days.

This chapter presented the energy and production related data collected during the energy audit conducted at the Puttlam cement factory and Aruwakkaru limestone quarry. These data are used in chapter 6 for analysis of embodied energy of cement produced in Sri Lanka.

Chapter 5
Analysis of National Energy Supply

This chapter makes an overview of electricity generation & distribution system in Sri Lanka. This includes past, present & future electricity mix, generation efficiencies and distribution & transmission loss of the system. These figures will be useful when delivered energy figures are converted to primary energy in the analysis of the data in this study. The operational energy data of the Lakdanavi power plant and petroleum refinery – Sapugaskanda are also included.

5.1 Electricity Mix – Past, Present & Future

For the last couple of decades, electricity generation system of the country has been predominantly dependent on hydro resource as shown in Fig 5.1 [12].

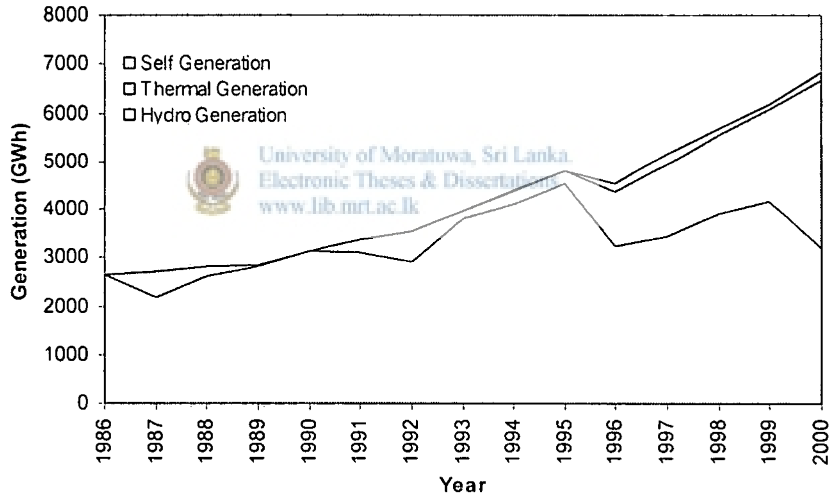


Fig 5.1 : Historical Electricity Generation

In Year 2000, total installed capacity is 1780.5 MW and this shares between 1147 MW hydro and 630.5 MW thermal and 3 MW wind [12]. In energy terms total hydro generation is 3197 GWh and total thermal generation 3486 GWh & wind generation 3.4 Gwh [12]. Table 5.1 below shows the details of existing hydro power plants by year 2000 [12].

Table 5.1– Existing Hydro Power Plants - 2000

Plant Name	Units x Capacity	Capacity (MW)	Annual Avg. Energy (GWh)	Commissioning
Laxapana (KM)*				
Canyon	2 x 30	60	163	Unit 1 Mar 1983 Unit 2 1988
Wimalasurendra	2 x 25	50	114	Jan 1965
Old Laxapana	3 x 8.33 + 2 x 12.5	50	279	Dec 1950 Dec 1958
New Laxapana	2 x 50	100	467	Unit 1 Feb 1974 Unit 2 Mar 1974
Polpitiya	2 x 37.5	75	409	Apr 1969
Laxapana Total		**335**	**1432**	
Mahaweli Complex				
Victoria	3 x 70	210	769	Unit 1 Jan 1985 Unit 2 Oct 1984 Unit 3 Feb 1986
Kotmale	3 x 67	201	494	Unit 1 Apr 1985 Unit 2 & 3 Feb 1986
Randenigala	2 x 61	122	392	Jul 1986
Ukuwela	2 x 19	38	172	**Unit 1 Jul 1976** Unit 2 Aug 1976
Bowatenna	1 x 40	40	54	Jun 1981
Rantambe	2 x 24.5	49	219	Jan 1990
Mahaweli Total		**660**	**2100**	
Other Hydro				
Samanalawewa	2 x 60	120	361	Oct 1992
Other Hydro Total		**120**	**361**	
Small Hydro Plants				
Inginiyagala	2x2.475 + 2x3.15	11	-	Jun 1963
Uda Walawe	3 x 2	6	-	Apr 1969
Nilambe	2 x 1.6	3	-	July 1988
Private Plants	-	12.5	-	-
Small Hydro Total		**32.5**	-	
Existing Total		**1147**	**3893**	

*KM – Kehelgamu Oya – Maskeli Oya

Table 5.2: Details of Existing Thermal Plants – 2000 [12]

Plant Name	No. of Units x Name Plate Capacity (MW)	No. of Units x Capacity used for Studies (MW)	Annual Max. Energy (GWh)	Commissioning
Kelanitissa Power Station				
Gas turbine (Old)	6 x 20	6 x 16	600	Nov 80, MAr 81, Apr 81, Dec 81, Mar 82
Gas turbine (New)	1 x 115	1 x 115	813	Aug 97
Steam (Fuel oil)	2 x25	2 x 20	250	Jun 62, Sep 63
GT part of JBIC CCy	1 x 104	1 x 104	790	Nov 2001
Kelanitissa Total		**335**	**2453**	
Sapugaskanda power				
Diesel	4 x 20	4 x 18	488	May 84, May 84, Sep 84, Oct 84
Diesel (Ext.)	8 x 10	8 x 9	444	4 Units Sep 97 4 Units Oct 99
Sapugaskanda Total		**144**	**932**	
Small Thermal Plants				
Chunnakam	1 x 8	1 x 8	-	May 99
Small Thermal Total		8	-	
Inde. Power Producers				
Lakdhanavi	22.5	22.5	156	1997
Asia Power Ltd.	51	41	330	1998
Colombo Power (Pvt.) Ltd.	64	60	420	Mid 2000
Inde. Power Producers		**123.5**	**906**	
Existing Total Thermal		**630.5**	**4291**	

Table 5.3 shows the details of committed and candidate power plants for future power generation.

Table 5.3: Committed and Candidate Power Plants [12]

Plant	Capacity (MW)	Fuel	Thermal Retirements	Date
Matara medium-term diesel plants	20	Auto Diesel	-	2002
GT part of 163MW AES Combined Cycle at Kelanitissa (BOO)	109	Auto Diesel		
Completion of 165MW Combined Cycle at Kelanitissa (funded by JBIC)	61	Auto Diesel	2x20MW Kelanitissa Oil Steam Plant	2003
Completion of 163MW AES Combined Cycle at Kelanitissa (BOO)	54	Auto Diesel		
Horana medium-term diesel plants	20	Auto Diesel		
Pielstick plant	22	Auto Diesel		
Kukule	70	Hydro		2004
Combined Cycle at Kerawalapitiya	300	Aut Diesel	-	2005
Gas Turbine	105	Auto Diesel	-	2007
Upper Kotmale	150	Hydro	-	2008
Coal Steam West Coast	300	Coal	-	2008
Coal Steam West Coast	300	Coal	-	2010
Coal Steam West Coast	300	Coal	22.5MW Lakdhanavi plant 20MW Matara diesel plants	2012 2012
Coal Steam Trincomalee	300	Coal	4x18 MW Sapugaskanda diesel plant 20MW Horana diesel plants	2013 2013
Coal Steam Trincomalee	300	Coal	60MW Colombo Power Barge Plant	2015
Gas Turbine	175	Auto Diesel	-	2016

Table 5.4 shows the forecast annual generation by each plant from Year 2002 to 2016 and Figure 5.2 depicts this pictorially.

Table 5.4: Forecasted Annual Electrical Energy Demand - GWh [12]

Plant Name	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
HYDRO															
Existing major hydro	3891	3891	3891	3891	3889	3889	3889	3889	3889	3889	3889	3889	3889	3889	3889
Kukule			303	303	303	303	303	303	303	303	303	303	303	303	303
Upper Kotmale							530	530	530	530	530	530	530	530	530
Hydro Generation	3891	3891	4194	4194	4194	4194	4724	4724	4724	4724	4724	4724	4724	4724	4724
Thermal															
Existing and Committed															
Gas Turbine –KPS	413	369	203	15	50	153	7	30	6	21	12	10	29	22	45
Steam-Fuel Oil –KPS	233														
Diesel Sapugaskanda	483	478	483	484	486	488	473	481	365	467	240				
Diesel Ext. Sapugaskanda	443	443	443	443	443	443	443	443	440	443	439	327	408	275	336
Diesel Lakdanavi	155	96	62	6	20	42	42	10	2	6					
Diesel Asia Power *	330	330	330	330	330	330	330	330	328	330	322	217	275	151	232
Barge Mounted Plant	419	419	419	419	419	419	419	419	414	416	393	237	307		
Diesel Plant - Horana		130	132	133	135	136	122	132	68	110	40				
Diesel Plant - Matara	135	130	133	133	135	136	129	133	76	112					
Comb. Cycle - KPS	801	1249	1245	1249	1251	1251	1240	1250	1183	1231	922	399	689	381	639
Comb. Cycle - BOO	320	526	978	197	410	682	76	187	44	112	42	31	69	55	94
Diesel-Pielstick		143	146	147	148	149	144	145	97	134	51	27	50	30	48
New Plants															
Kerawalapitiya Comb.Cycle				1623	1957	2153	920	1428	431	820	276	175	332	219	390
West Coast Coal							2272	2272	4544	4544	6815	6687	6797	6458	6705
Gas Turbine						31	2	7	2	8	5	4	13	9	51
Trinco Coal												2272	2272	4544	4544
Thermal Generation	3730	4313	4575	5179	5782	6411	6579	7266	8000	8753	9555	10385	11242	12145	13082
Total Generation	7621	8204	8769	9373	9976	10605	11303	11990	12724	13477	14279	15109	15966	16869	17805
System Demand	7646	8225	8774	9376	9983	10614	11304	11993	12725	13482	14282	15110	15973	16874	17813

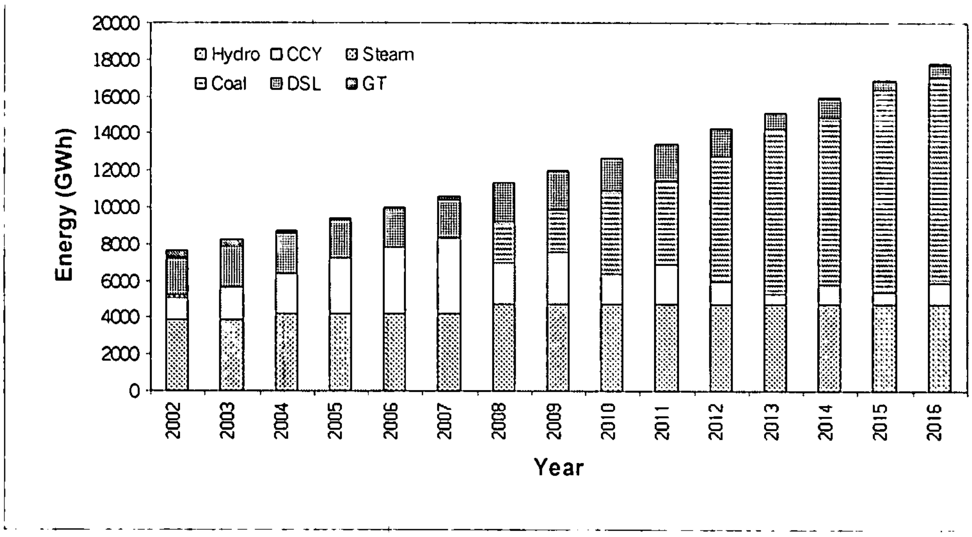


Figure 5.2 : Future Energy Generation [12]

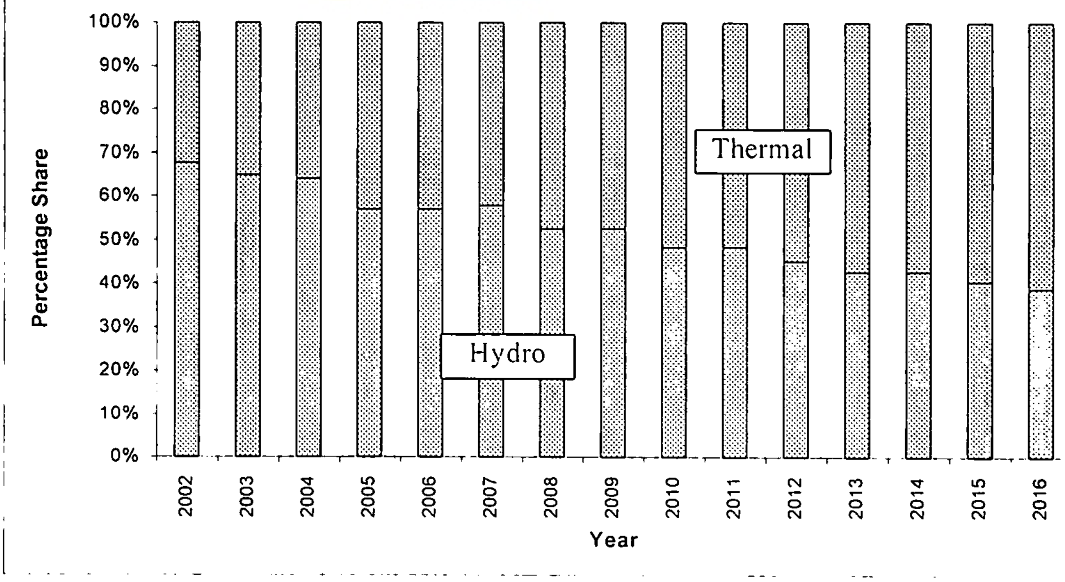


Figure 5.3 : Thermal – Hydro Mix [12]

Table 5.5 – Annual Generation , Base Case Plan : 2001 [12]

Year	Annual Energy (GWh)					
	Hydrological Condition					
2002	**1**	**2**	**3**	**4**	**5**	**Avg**
Gas Turbine-KPS	2	2	43	157	489	98
Steam Plant-KPS	150	220	248	249	249	233
Diesel Sapu	445	487	487	487	487	483
Diesel Sapu-Ext	443	443	443	443	443	443
Gas Turb. 115MW-KPS	80	53	278	586	682	315
DSL Lakdanavi	143	156	156	156	156	155
DSL Asia Power	330	330	330	330	330	330
GT of JBIC CCY	631	819	819	819	819	801
GT of AES CCY	126	216	334	432	438	320
Barge CPL 60MW	417	419	419	419	419	419
DSL Matara 20MW	125	136	136	136	136	135
Total Thermal	2891	3282	3693	4216	4649	3731
Total Hydro	4756	4364	3953	3427	2761	3891
Total Generation	7646	7646	7646	7643	7410	7622
Total Demand	7646	7646	7646	7646	7646	7646
2003						
Gas Turbine-KPS	4	5	30	126	482	87
Diesel Sapu	395	487	487	488	488	478
Diesel Sapu-Ext	443	443	443	443	443	443
Gas Turb. 115MW	113	31	239	512	665	282
DSL Lakdanavi	33	48	99	146	145	96
DSL Asia Power	330	330	330	330	330	330
CCY JBIC 165 MW	1231	1251	1251	1251	1251	1249
CCY AES 163MW	242	423	550	655	655	525
Barge CPL 60MW	419	419	419	419	419	419
DSL Horana 20MW	81	436	136	136	136	130
DSL Matara 20MW	84	136	136	136	136	130
DSL Pielst 22MW	93	149	149	419	149	143
Total Thermal	3468	3858	4269	4789	5297	4314
Total Hydro	4756	4364	3953	3427	2761	3891
Total Generation	8223	8223	8222	8217	8058	8205
Total Demand	8225	8225	8225	8225	8225	8225
2004						
Gas Turbine-KPS	2	3	11	24	314	42
Diesel Sapu	447	488	487	488	488	483
Diesel Sapu-Ext	443	443	443	443	443	443
Gas Turb. 115MW	12	15	93	270	658	161
DSL Lakdanavi	5	5	60	117	130	62
DSL Asia Power	330	330	330	330	330	330
CCY JBIC 165 MW	1191	1251	1251	1251	1251	1245
CCY AES 163MW	502	721	1007	1278	1255	978
Barge CPL 60MW	419	419	419	419	419	419
DSL Horana 20MW	100	136	136	136	136	132
DSL Matara 20MW	114	136	136	136	136	133
DSL Pielst 22MW	124	149	149	149	149	146
Total Thermal	3689	4095	4522	5039	5709	4576
Total Hydro	5084	4678	4250	3730	3044	4194
Total Generation	8773	8773	8772	8770	8754	8770
Total Demand	8774	8774	8774	8774	8774	8774

Table 5.5 (Contd.)– Annual Generation , Base Case Plan : 2001

Year	Annual Energy (GWh)					
	Hydrological Condition					
2005	**1**	**2**	**3**	**4**	**5**	**Avg**
Gas Turbine-KPS	1	2	2	3	3	2
Diesel Sapu	449	488	487	488	488	484
Diesel Sapu-Ext	443	443	443	443	443	443
Gas Turb. 115MW	4	5	6	9	72	13
DSL Lakdanavi	2	2	2	3	37	5
DSL Asia Power	330	330	330	330	330	330
CCY JBIC 165 MW	1233	1251	1251	1251	1251	1249
CCY AES 163MW	25	86	133	234	775	197
Barge CPL 60MW	419	419	419	419	419	419
DSL Horana 20MW	114	136	136	136	136	133
DSL Matara 20MW	114	136	136	136	136	133
DSL Pielst 22MW	134	149	149	149	149	147
Com. Cycle 300MW	1023	1252	1631	2043	2092	1623
Total Thermal	4292	4697	5125	5644	6329	5180
Total Hydro	5084	4678	4250	3730	3044	4194
Total Generation	9375	9375	9375	9374	9373	9375
Total Demand	9376	9376	9376	9376	9376	9376
2006						
Gas Turbine-KPS	4	5	6	9	40	10
Diesel Sapu	473	488	487	488	488	486
Diesel Sapu-Ext	443	443	443	443	443	443
Gas Turb. 115MW	12	14	19	25	240	41
DSL Lakdanavi	4	4	18	14	90	20
DSL Asia Power	330	330	330	330	330	330
CCY JBIC 165 MW	1251	1251	1251	1251	1251	1251
CCY AES 163MW	94	162	343	642	1024	410
Barge CPL 60MW	419	419	419	419	419	419
DSL Horana 20MW	125	136	136	136	136	135
DSL Matara 20MW	125	136	136	136	136	135
DSL Pielst 22MW	137	149	149	149	149	148
Com. Cycle 300MW	1479	1765	1991	2204	2185	1957
Total Thermal	4896	5301	5728	6244	6929	5783
Total Hydro	5084	4678	4250	3730	3044	4194
Total Generation	9980	9979	9978	9974	9974	9977
Total Demand	9983	9983	9983	9983	9983	9983
2007						
Gas Turbine-KPS	6	6	8	12	24	10
Diesel Sapu	488	488	488	488	487	488
Diesel Sapu-Ext	442	443	443	443	443	443
Gas Turb. 115MW	31	58	121	127	553	144
DSL Lakdanavi	8	22	35	54	125	42
DSL Asia Power	330	330	330	330	330	330
CCY JBIC 165 MW	1251	1251	1251	1251	1251	1251
CCY AES 163MW	294	321	638	1085	1157	682
Barge CPL 60MW	419	419	419	419	419	419
DSL Horana 20MW	136	136	136	136	136	136
DSL Matara 20MW	136	136	136	136	136	136
DSL Pielst 22MW	149	149	149	149	149	149
Gas Turbin 105MW	14	16	19	28	132	31

Table 5.5 (Contd.)– Annual Generation , Base Case Plan : 2001

Year	Annual Energy (GWh)					
	Hydrological Condition					
2007 Contd.	**1**	**2**	**3**	**4**	**5**	**Avg**
Com. Cycle 300MW	1823	2157	2186	2216	2217	2153
Total Thermal	5526	5930	6357	6872	7557	6412
Total Hydro	5084	4678	4250	3730	3044	4194
Total Generation	10609	10608	10607	10602	10601	10606
Total Demand	10614	10614	10614	10614	10614	10614
2008						
Gas Turbine-KPS	0	0	0	1	1	0
Diesel Sapu	343	487	487	488	488	473
Diesel Sapu-Ext	442	443	443	443	443	443
Gas Turb. 115MW	3	4	4	7	23	7
DSL Lakdanavi	1	1	2	2	15	3
DSL Asia Power	330	330	330	330	330	330
CCY JBIC 165 MW	1140	1251	1251	1251	1251	1240
CCY AES 163MW	19	21	26	120	353	76
Barge CPL 60MW	419	419	419	419	419	419
DSL Horana 20MW	79	115	126	136	136	122
DSL Matara 20MW	87	126	135	136	136	129
DSL Pielst 22MW	102	149	149	149	149	144
W.CST COAL 300M	2272	2272	2272	2272	2272	2272
Gas Turbin 105MW	1	1	2	3	3	2
Com. Cycle 300MW	378	443	872	1281	1885	920
Total Thermal	5617	6063	6518	7037	7903	6579
Total Hydro	5687	5214	4785	4266	3400	4724
Total Generation	11304	11304	11303	11303	11303	11303
Total Demand	11304	11304	11304	11304	11304	11304
2009						
Gas Turbine-KPS	2	2	2	4	4	3
Diesel Sapu	421	487	487	488	488	481
Diesel Sapu-Ext	442	443	443	443	443	443
Gas Turb. 115MW	10	11	13	33	126	28
DSL Lakdanavi	3	3	4	18	41	10
DSL Asia Power	330	330	330	330	330	330
CCY JBIC 165 MW	1237	1251	1251	1251	1251	1250
CCY AES 163MW	62	75	107	244	741	187
Barge CPL 60MW	419	419	419	419	419	419
DSL Horana 20MW	94	136	136	136	136	132
DSL Matara 20MW	104	136	136	136	136	132
DSL Pielst 22MW	114	149	149	149	149	145
W.CST COAL 300M	2272	2272	2272	2272	2272	2272
Gas Turbin 105MW	4	5	6	9	9	7
Com. Cycle 300MW	789	1031	1450	1792	2045	1428
Total Thermal	6305	6751	7206	7723	8589	7266
Total Hydro	5687	5214	4785	4266	3400	4724
Total Generation	11991	11991	11991	11989	11989	11990
Total Demand	11993	11993	11993	11993	11993	19993
2010						
Gas Turbine-KPS	0	0	1	1	1	1
Diesel Sapu	211	279	361	476	483	365
Diesel Sapu-Ext	416	443	443	443	443	440

Table 5.5 Contd.)– Annual Generation , Base Case Plan : 2001

Year	Annual Energy (GWh)					
	Hydrological Condition					
2010 Contd.	**1**	**2**	**3**	**4**	**5**	**Avg**
Gas Turb. 115MW	4	4	5	8	8	6
DSL Lakdanavi	1	2	2	2	2	2
DSL Asia Power	306	330	330	330	330	327
CCY JBIC 165 MW	933	1120	1226	1251	1251	1183
CCY AES 163MW	20	23	27	38	192	44
Barge CPL 60MW	368	419	419	419	419	414
DSL Horana 20MW	28	33	66	105	115	68
DSL Matara 20MW	43	34	74	115	124	76
DSL Pielst 22MW	48	70	96	127	138	97
W.CST COAL 300M	4541	4544	4544	4544	4544	4544
Gas Turbin 105MW	1	2	2	4	4	2
Com. Cycle 300MW	116	180	344	596	1269	431
Total Thermal	7038	7484	7939	8458	9324	8000
Total Hydro	5687	5241	4785	4266	3400	4724
Total Generation	12725	12725	12725	12724	12724	12724
Total Demand	12725	12725	12725	12725	12725	12725
2011						
Gas Turbine-KPS	2	3	3	5	5	3
Diesel Sapu	370	444	487	487	487	467
Diesel Sapu-Ext	443	443	443	443	443	443
Gas Turb. 115MW	12	14	16	23	24	17
DSL Lakdanavi	4	4	5	6	19	6
DSL Asia Power	327	330	330	330	330	330
CCY JBIC 165 MW	1080	1239	1251	1251	1251	1231
CCY AES 163MW	51	56	61	147	423	112
Barge CPL 60MW	387	419	419	419	419	416
DSL Horana 20MW	63	87	115	135	135	110
DSL Matara 20MW	79	87	116	135	136	112
DSL Pielst 22MW	95	119	140	149	149	134
W.CST COAL 300M	4544	4544	4544	4544	4544	4544
Gas Turbin 105MW	5	6	7	11	12	8
Com. Cycle 300MW	330	445	756	1126	1699	820
Total Thermal	7793	8239	8693	9211	10076	8754
Total Hydro	5687	5241	4785	4266	3400	4724
Total Generation	13480	13479	13479	13477	13476	13478
Total Demand	13482	13482	13482	13482	13482	13482
2012						
Gas Turbine-KPS	1	1	2	3	3	2
Diesel Sapu	95	120	265	302	401	240
Diesel Sapu-Ext	402	443	442	443	442	438
Gas Turb. 115MW	7	8	9	14	15	10
DSL Asia Power	272	317	330	330	330	321
CCY JBIC 165 MW	530	745	946	1117	1181	922
CCY AES 163MW	29	32	36	49	81	42
Barge CPL 60MW	299	386	401	419	419	393
DSL Horana 20MW	12	12	31	64	106	40
DSL Pielst 22MW	13	23	44	78	120	51
W.CST COAL 300M	6805	3816	6816	6816	6816	6815
Gas Turbin 105MW	3	4	4	6	7	5

Table 5.5 (Contd.)– Annual Generation , Base Case Plan : 2001

Year	Annual Energy (GWh)					
	Hydrological Condition					
2012 Contd.	**1**	**2**	**3**	**4**	**5**	**Avg**
Com. Cycle 300MW	126	133	167	372	958	276
Total Thermal	8594	9040	9495	10013	10879	9556
Total Hydro	5687	5214	4785	4266	3400	4724
Total Generation	14281	14280	14280	14279	14279	14280
Total Demand	14281	14281	14281	14281	14281	14282
2013						
Gas Turbine-KPS	1	1	2	2	3	2
Diesel Sapu-Ext	203	287	320	392	425	326
Gas Turb. 115MW	5	6	7	11	12	8
DSL Asia Power	110	196	226	243	278	217
CCY JBIC 165 MW	126	194	364	557	905	399
CCY AES 163MW	23	26	29	40	41	31
Barge CPL 60MW	114	175	248	281	355	237
DSL Pielst 22MW	12	12	12	44	92	27
Trinco Coal 300MW	2272	2272	2272	2272	2272	2272
W.C. Coal 300M	6446	6583	6717	6791	6811	6687
Gas Turbin 105MW	3	3	4	5	6	4
Com. Cycle 300MW	108	115	123	204	509	175
Total Thermal	9423	9869	10324	10842	11708	10385
Total Hydro	5687	5241	4785	4266	3400	4724
Total Generation	15110	15110	15110	15109	15108	15109
Total Demand	15110	15110	15110	15110	15110	15110
2014						
Gas Turbine-KPS	4	4	5	8	8	6
Diesel Sapu-Ext	338	383	414	440	440	408
Gas Turb. 115MW	18	20	22	29	31	24
DSL Asia Power	206	210	292	313	325	275
CCY JBIC 165 MW	293	506	728	826	1019	689
CCY AES 163MW	56	59	64	77	107	69
Barge CPL 60MW	215	278	286	375	405	307
DSL Pielst 22MW	15	19	44	77	118	50
TRINCO COAL 300MW	2272	2272	2272	2272	2272	2272
W.CST. COAL 300M	6686	6790	6815	6815	6815	6797
Gas Turbin 105MW	9	10	11	17	18	13
Com. Cycle 300MW	169	175	227	447	1005	332
Total Thermal	10281	10727	11181	11697	12562	11242
Total Hydro	5687	5241	4785	4266	3400	4724
Total Generation	15968	15967	15967	15963	15962	15966
Total Demand	15973	15973	15973	15973	15973	15973
2015						
Gas Turbine-KPS	3	3	4	6	6	4
Diesel Sapu-Ext	154	232	292	299	363	275
Gas Turb. 115MW	13	15	17	223	24	18
DSL Asia Power	49	106	153	190	259	151
CCY JBIC 165 MW	128	150	347	576	843	381
CCY AES 163MW	45	48	53	65	67	55
DSL Pielst 22MW	14	14	24	41	83	30
TRINCO COAL 300MW	4544	4544	4544	4544	4544	4544
W.CST. COAL 300M	6080	6355	6465	6616	6702	6458

Table 5.5 (Contd.)– Annual Generation , Base Case Plan : 2001

Year	Annual Energy (GWh)					
	Hydrological Condition					
2015 Contd.	**1**	**2**	**3**	**4**	**5**	**Avg**
Gas Turbin 105MW	7	7	8	13	13	9
Com. Cycle 300MW	148	154	178	229	562	219
Total Thermal	11184	11629	12084	12600	13466	12145
Total Hydro	5687	5241	4785	4266	3400	4724
Total Generation	16871	16870	16869	16866	16866	16869
Total Demand	16874	16874	16874	16874	16874	16874
2016						
Gas Turbine-KPS	4	4	5	7	7	5
Diesel Sapu-Ext	285	320	310	392	409	336
Gas Turb. 115MW	34	35	39	46	48	40
DSL Asia Power	160	231	229	251	278	232
CCY JBIC 165 MW	279	451	674	774	963	639
CCY AES 163MW	83	86	90	101	119	94
DSL Pielst 22MW	17	17	44	72	106	48
TRINCO COAL 300MW	4544	4544	4544	4544	4544	4544
W.CST. COAL 300M	6477	6631	6734	6785	6803	3705
Gas Turbin 35MW	5	6	7	9	10	7
Gas Turbin 105MW	34	37	41	53	55	44
Com. Cycle 300MW	201	206	306	503	1060	390
Total Thermal	12122	12568	13022	13538	14403	13082
Total Hydro	5687	5241	4785	4266	3400	4724
Total Generation	17809	17808	17807	17804	17803	17807
Total Demand	17813	17813	17813	17813	17813	17813

5.2 Efficiency of Power Generation

System boundary of efficiency that considered here is primary energy content of the delivered fuel. In the case of hydro electricity and wind electricity, the primary energies are potential energy of water & kinetic energy of wind respectively. But for this study system boundaries for the hydro & wind is taken as generated electricity and therefore the efficiencies are considered as 100%.

The operating efficiencies of the existing and proposed thermal power plants are shown in Table 5.6 below.

Table 5.6: Efficiency of Thermal Power Plant [12]

Type & Plant	Full Load Efficiency %
Gas Turbine 115 MW – KPS	30.1
Gas Turbine 20 MW – KPS	22.0
Combined Cycle 165 MW - KPS	48.0
Steam 20 MW - KPS	23.0
Diesel 18 MW- SUP	44.0
Diesel 9 MW -SUP	44.0
Pielstic 22 MW - SUP	44.0
Diesel 22.5 MW - Lakdanavi	44.0
Coal 300 MW - Trinco	37.5
Coal 300 MW – West Coast	37.5
Gas Turbine 35 MW	28.1
Gas Turbine 105 MW	30.1
Combined Cycle 150 MW - Kera	43.7
Combined Cycle 300 MW	48.1
Diesel – Furnace Oil 10 MW	44.0
Diesel – Residual Oil 10 MW	44.0
Steam –Furnace Oil 150 MW	35.8
Steam –Furnace Oil 300 MW	37.5

5.3 Transmission and Distribution Losses

The estimated transmission and distribution (T&D) losses in National energy network is 21.4% in year 2000 and this is much more higher than the developed countries. Table 5.7 shows the projected reduction of the T&D losses as per long term generation expansion plan.

Table 5.7: Planned T & D Loss Reduction [12]

Year	Percentage Losses - Based on Gross Generation			
	Generation	Transmission	Distribution	Total
2001	1.0	2.0	16.3	19.3
2002	1.0	1.9	15.5	18.5
2003	1.0	1.9	14.8	17.8
2004	1.0	1.7	14.1	16.8
2005	1.0	1.7	13.4	16.1
2006	1.0	1.7	12.6	15.4
2007	1.0	1.7	12.2	14.9
2008	1.0	1.8	12.0	14.8
2009	1.0	1.8	11.8	14.6
2010	1.0	2.0	11.6	14.6
....	....	....	....	....
2021	1.0	2.0	11.6	14.6

Note : Values were kept constant from 2010 onwards

5.4 Lakdanavi Power Plant

Ladanavi (Pvt.) Ltd. is an independent power producer and operate on BOO (Built, Operate and Own) basis. The power plant is commissioned in 1997 and installed capacity is 22.5 MW. It consists of 11 Numbers of 2 MW diesel generators operating on 1500 Sec furnace oil. The Operating energy data of the plant is shown in Table 5.8 below.

Table 5.8: Operating Energy Data

Description	Year 2000	Year 2001
Generated MWh	197688	200120
MWh Sold	191464.1	192822.1
MWh – In house consumed-own generation	6224.3	7298
Furnace oil consumption (for all generators) kg	45759430	4679911
Engine oil consumption ltrs	191300	211300
Auto Diesel Consumption Ltrs	7000	6500

Table 5.9 : Employee Data

Category	Number
Management	01
Engineers	07
Clerical	01
Superintendents	07
Skilled mechanics/Electricians	22
Unskilled workers	22
Drivers	05

Table 5.10 : Employees Transport Details

Transport Method	Number of Employees				
	0-5 km	5-10 km	10-25 km	25-50 km	>50 km
Bicycle	2				
Motor Cycle		1	1	1	
Car – Single	3	3	2		
Bus	4	1	4	17	6
Van – Single		1		1	
Walking	14				

5.5 Petroleum Energy

The bulk of the country's petroleum products requirement is imported as crude oil, which is then processed at a refinery of capacity of 51,000 barrels per day. Ceylon Petroleum Corporation acquires part of its crude oil requirement through contracts with government oil companies of Iran, Saudi Arabia, Egypt, UAE & Malaysia while the balance is bought in the spot market. Table 5.11 below shows the petroleum imports during the past five years.

Table 5.11: Petroleum Imports [16] [17]

Product	1000MT					
	1995	1996	1997	1998	1999	2000
Crude oil	1871.60	2040.58	1820.19	2155.09	1834.63	2348.93
Kerosene	30.90	-	9.84	4.59	15.66	10.15
Super Petrol	10.99	-	23.11	4.59	29.60	4.95
Auto Diesel	378.34	594.17	848.00	585.55	880.23	988.87
AV Gas	0.13	0.03	0.11	0.09	0.14	0.14
LPG	65.16	67.95	86.63	97.91	126.66	133.59
AV. Tur.	111.75	166.92	207.39	167.28	252.12	199.85

Table 5.12 shows the mix of final petroleum produces supplied to the market.

Table 5.12: Refined Petroleum Products Mix – 1999 [16]

Product	Refined at Refinery- Sapugaskanda		Imported	
	MT	%	MT	%
Petrol	169339	85	29603	15
Auto Diesel	588488	40	880232	60
Furnace Oil	441703	100	0	0
Residue Oil	189694	100	0	0
Av.Tur	53927	18	252120	82
Kerosene	167263	91	15659	9
LP Gas	13103	9	126657	91
Naptha	99468	100	0	0

Total petroleum requirement of the country is distributed from Kolonnawa storage tanks.

5.5.1 Refinery

Total amount of crude oil imported to the country is refined at the Sapugaskanda refinery. During the year 2001, 2.008 million MT of crude oil is processed at the refinery and corresponding refined production are shown in Table 5.12 below.

Table 5.13: Petroleum Production : 2001

Product	Quantity MT
Premium Mogas	189313
Kerosene	179139
Auto Diesel	614055
Fuel Oil	
2500	238006
500	26138
800	33572
1000	128756
1500	260873
Naptha	104720
Asphalt	45118
AVTOR	89294
SBP	2214
LPG	15470

Source: Ceylon Petroleum Cooperation

The total energy requirement to refine crude oil in the refinery is met through fuel oil and fuel gas. The electrical energy requirement is also produced in house using steam turbine. Table 5.14 below shows the monthly fuel consumption in the refinery.

Table 5.14: Monthly Fuel Consumption - 2001

Month	Fuel Oil - MT	Fuel Gas - MT
January	1026	1357
February	1670	718
March	2562	3909
April	2416	3895
May	2384	3775
June	2127	4075
July	2532	3736
August	2426	4276
September	2553	4096
October	2653	4572
November	2411	4474
December	2579	4151
Total	**27339**	**43034**

Apart form the own consumption some amount of oil is lost at the process. The total amount of lost in year 2001 is 12,609 MT. In average 4.2% of the crude oil accounts for in house consumption & losses.

Refinery consumes about 2500 Tons of water per day. The total water requirement is processed at the water supply plant at Kelaniya and then pumped to the refinery. During the year 2001, 700 MWh of electricity is consumed at the water supply plant.

Crude oil is pumped to the refinery from the ship, in which crude oil is brought, at the sea. Therefore energy required to pump crude oil is not accounted here since it is outside of the system boundary of this study.

The total electrical energy consumption at the Kolonnawa distribution complex is 950 MWh in year 2001.

The total electrical energy consumption at the Sapugaskanda storage complex is 450 MWh in year 2001.

This chapter made an overview of electricity generation and distribution system in Sri Lanka including electricity mix, generation efficiencies and transmission and distribution losses. The data given in this chapter is used in the calculation given in chapter 6.

Chapter 6

Analysis of Embodied Energy in Cement

This chapter analyzes the national energy embodied in cement manufactured in Sri Lanka. First, the embodied energy in delivered energy is calculated using data related to petroleum production and electricity production. Then the embodied energy in cement is calculated in three levels.

Some suffices are introduced to standard energy unit in the calculation as given below

MJ_e → Electrical Energy in MJ
kWh_d → Delivered Electrical Energy in kWh
kWh_{th} → Thermal Energy in kWh
$kWh_{th,d}$ → Delivered Thermal Energy in kWh
$kWh_{e,g}$ → Generated Electrical Energy in kWh
$MJ_{e,d}$ → Delivered Electrical Energy in MJ
MJ_d → Delivered Energy in MJ
$MJ_{th,d}$ → Delivered Thermal Energy in MJ
MJ_{GCV} → Thermal Energy based on Gross Calorific Value of a Fuel

6.1 Embodied Energy in Delivered Energy

When energy is delivered to the final consumer, it has undergone several energy consuming steps such as production, storage and delivery. In this analysis this energy overhead is accounted.

6.1.1 Petroleum Fuels

This analysis considers direct energy consumption in refinery, energy consumption in refinery water supply, and energy consumption at Kolonnawa distribution complex. Calculations are mainly based on Year 2001 consumption figures.

Energy Consumption at Refinery

Total annul fuel oil consumption in the refinery = 27339 MT

Gross calorific value of fuel oil = 44100MJ/MT

Annual fuel oil energy consumption *(a)* = 27339 x 44100 MJ

(a) = **1177.05×10^6 MJ**

Annual fuel gas consumption = 43034 MT

GCV of fuel gas = 4598 MJ/MT

Annual fuel gas energy consumption *(b)* = **$1978.70 \text{ X } 10^6$ MJ**

Annual fuel loss = 12609 MT

Annual fuel energy loss = 43054 x 12609 MJ

(c) = **542.87×10^6 MJ**

Annual delivered electrical energy consumption in refinery

water supply system = 700 MWh

= 2520000 MJ_e

By considering electricity mix, power plant efficiencies and system losses

Primary energy consumption for electricity = 2.337 MJ/MJ_e

Equivalent primary energy for water supply = 252000 X 2.337 MJ

(d) = **$5.9 \text{ X} 10^6$ MJ**

Total annual energy consumption = *a*+*b*+*c*+*d*

= 1117.05 + 1978.7+542.9 +5.9 GJ

(T_e) = 3704513399 MJ

Annual Petroleum production (T_p) = 1926668 MT

∴ Total Energy Consumption in petroleum production = T_e/T_p

$$= \frac{3704513399 \text{ MJ}}{1926668 \text{ MT}}$$

$$= \mathbf{1922.76} \frac{\text{MJ}}{\text{MT}}$$

Delivered Annual electrical energy consumption at

Kolonnawa Complex = 950 MWh_d

Delivered Annual electrical energy consumption at

Sapugaskanda Stores Complex = 450 MWh_d

Total liquid petroleum consumption = 2887496 MT

% production of refined liquid petroleum = 59.22 %

Share of annual electrical energy consumption at Kolonnawa and Sapugaskanda stores complex to refined liquid petroleum = 0.5922 X (950 + 450) MWh

= 829.03 MWh_d

= 2984525.44 MJ

Equivalent primary energy consumption = 2984525 X 2.337 MJ

T_{ks} = 6974417 MJ

∴ Total annual energy consumption for refined petroleum = $T_e + T_{ks}$

= 3704513399 + 6974417

= 3711487816 MJ

Total energy consumption in refined petroleum at delivery $= \frac{3711487816 \text{ MJ}}{1926668 \text{ MT}}$

= 1926.38 MJ/MT

% of refined liquid petroleum imports = 40.78 %

Corresponding electrical energy consumption at Kolonnawa and Sapugaskanda Stores Complex = 0.4087 X (450+950)

= 570.96 MWh_d

Equivalent primary energy = 4803356 MJ

Annual quantity of imported oil (1999) = 1177614 MT

∴ National energy consumption of Imported oil = 4.08 MJ/MT

Table 6.1 below shows the calculated energy content of petroleum fuels at delivery based on 1999 petroleum mix

Table 6.1: Energy Content of Petroleum Fuels at Delivery

Type of Fuel	Fuel Consumption MT		MJ/MT	MJ/Lit	MJ/MJ_{gcv}
	Imported	Refined in Sri Lanka			
Fuel Oil	0	687345	1923	1.81	0.0447
Diesel	880232	614055	793	0.67	0.0173
Petrol	29603	189319	1663	1.20	0.0371
Kerosene	15659	179139	1768	1.38	0.0380
Naptha	0	104720	1922	1.31	0.0409

6.1.2 Calculation of Transport Energy

In order to calculate total national energy requirement to drive 1 km with a particular vehicle, followings are considered in this study.

(a) Fuel consumption per km
(b) Energy consumption to pump fuel to the vehicle
(c) Energy consumption for servicing the vehicle
(d) Energy consumption to produce engine oil used in the vehicle.

Other recurrent energy that is required to run a vehicle is not considered here by assuming those are not comparatively significant.

6.1.2.1 Energy Consumption to Produce Lubricant Oil

Energy consumption to produce lubricant oil is calculated based on the energy consumption figures of Caltex Lubrication Lanka Ltd. Only the direct energy consumption is considered here because effect on energy consumption of other levels is insignificant to the final result of this study (Embodied energy of cement). Only the national energy mix and power plant efficiency are considered when transferring delivered electrical energy to primary energy.

In Caltex factory,

Annual electrical energy consumption = 718300 kWh$_d$
Equivalent primary energy = 2.337 x 718300 kWh$_{th}$
= ***6042839 MJ***
Annual diesel consumption = 120462 Lit
GCV of diesel = 38.39 MJ /Lit
National energy content in Diesel = 0.67 MJ/Lit
Equivalent primary energy = (38.39 +0.67) x 120462 MJ
= ***4704490 MJ***
Annual furnace oil consumption = 79200 Lit
GCV of furnace oil = 40.47 MJ /Lit
National energy content in furnace oil = 1.81 MJ/Lit
Equivalent primary energy = (40.47 +1.81) X 79200 MJ
= ***3348430 MJ***

∴ Total primary energy = 14095758 MJ

Annual production of lubricant oil = 43000000 Lit

Energy consumption for lubricant oil = $\frac{14095758 \text{ MJ}}{43000000 \text{ Lit}}$

= 0.328 MJ/Lit

% Market share of locally blended lube oil = 96 %

National energy content of lubricant oil in the market = 0.96 x 0.328 MJ/Lit

= 0.315 MJ/Lit

The sequence of engine oil changed in vehicles and corresponding calculated energy content in engine oil are shown in Table 6.2 below.

Table 6.2: Sequence of Engine Oil Changes [42]

Type of Vehicle	Running km	Amount - Lit	Engine Oil Energy Content - J/km
Motor Cycle	2000	0.75	118
Motor Car - Petrol	3000	4.50	472
Motor Car – Diesel	3000	4.50	472
Van	3000	6.00	6294
Mini Bus	4000	8.00	6294
CTB Bus	4000	12.00	9441
Lorry – 350	5000	8.5	535
Trucks - 5000 Tons	5000	15.00	9441
Bowser	5000	13.5	8497

6.1.2.2 Energy Consumption for Servicing Vehicles

The energy requirement for servicing of vehicles were estimated using annual energy consumption of selected service stations. Only the power plant efficiency, distribution & transmission losses and energy mix are considered when transferring delivered electricity to primary energy.

Monthly electricity consumption = 160 kWh_d
Equivalent primary energy = 1351 MJ
Annual vehicles serviced = 375 Nos.
Servicing energy consumption per vehicle = 3.6 MJ/vehicle

The recommended servicing sequence and corresponding calculated servicing energy requirement is shown in Table 6.3 below.

Table 6.3: Energy Consumption of Vehicle Service

Type of Vehicle	Service Sequence Running km	Energy Consumption kJ/km
Motor Cycle	2000	1.80
Motor Car- Petrol	3000	1.20
Motor Car – Diesel	3000	1.20
Van	3000	1.20
Mini Bus	4000	0.90
CTB- Bus	4000	0.90
Lorry	5000	0.72
Track	5000	0.72
Bowser	5000	0.72

6.1.2.3 Energy Consumption for Fuel Pumping

The energy consumption for fuel pumping to vehicles is estimated by energy consumption of selected patrol sheds.

Annual energy consumption = 459 kWh
Equivalent primary energy = 3859 MJ
Annual fuel pumped = 20000 lit
Energy for fuel pumping = 0.019 MJ/lit

6.1.2.4 Total Energy Consumption in Vehicle Operations

The calculated total energy consumption in vehicle operation is given in Table 6.4 below.

Table 6.4: Energy Consumption of Vehicles

Vehicle Type	Fuel Type	Fuel Consumption Lit/km	Energy Consumption –MJ /km	
			Direct Fuel	Total
Motor Cycle	Gasoline	0.020	0.645	0.671
Motor Car	Gasoline	0.100	3.226	3.349
Motor Car	Diesel	0.080	3.199	3.258
Van	Diesel	0.100	3.839	3.909
Mini Bus	Diesel	0.125	4.799	4.886
CTB- Bus	Diesel	0.250	9.597	9.770
Lorry	Diesel	0.167	6.397	6.513
Track	Diesel	0.250	9.597	9.770
Bowser	Diesel	0.200	7.678	7.816

The calculated energy consumption per passenger km is given in Table 6.5.

Table 6.6: Energy Consumption per Passenger km

Vehicle Type	Number of Passengers	MJ/Passenger km
Motor Cycle	1	0.67
Motor Car – Petrol	1	3.35
Motor car - Diesel	1	3.26
Van	12	0.33
Mini Bus	30	0.16
CTB- Bus	45	0.22

6.1.3 Electricity

Let

f_i = Operational efficiency of thermal plant i

G_i = Total generation of plant i

The primary energy required to generate one unit of electricity from thermal power plants, PE_e

$$PE_e = \frac{\sum\left(\frac{G_i}{f_i}\right)}{\sum G_i} \quad \frac{kWh_{th,d}}{kWh_{e,g}}$$

Let the embodied energy factor e_i, be defined as

$$e_i = \frac{\text{Total power plant energy consumption other than fuel chemical energy}}{\text{Total energy generation}}$$

$\therefore$ Total energy input to the power plant = $G_i\left[\frac{1}{f_i}+e_i\right]$

$\therefore$ Total primary energy in electricity production = $\frac{\sum G_i\left(\frac{1}{f_i}+e_i\right)}{\sum G_i} \quad \frac{kWh_{th,d}}{kWh_{e,g}}$

By considering energy required to produce fuel and fuel transport,

Let the fuel embodied energy factor Pi, be defined as

P_i = MJ of energy consumption per MJ of energy content of fuel

Let the fuel transport energy factor t_i, be defined as

t_l = MJ of transport energy consumption per MJ of energy content of fuel

Then

Total primary energy requirement, PE_{th}

$$PE_{T,th} = \frac{\sum G_i\left(\frac{1}{f_i}+e_i\right)\left(1+P_i+t_i\right)}{\sum G_i} \quad \frac{kWh_{th}}{kWh_{e,g}}$$

The electricity produced in a hydro electricity plant is considered as primary energy for hydro generation. Let the total hydro generation be G_h GJ, then

Total primary energy requirement to produce one unit of electricity,

$$\mathrm{PE}_{Total} = \frac{G_h + \sum\left(\frac{1}{f_i} + e_i\right)\mathrm{Gi}\left(1 + P_i + t_i\right)}{G_h + \sum G_i} \qquad \rightarrow eq.(1)$$

6.1.3.1 Calculation of i Factors in Equation (1)

Calculations are carried out based on the Year 2002 forecasted figures of electricity generation.

i. Generation Factor- G_i

G_i is taken from Table 5.5 in Chapter 5.

ii Efficiency Factor - f_i

f_i is taken from Table 5.6 in Chapter 5.

iii Power plant operational embodied energy factor - e_i

e_i will be calculated for the Lakdhanavi power plant and e_i of the other thermal power plants assumed to be equal to value of Lakdhanavi power plant. Calculations are based on yearly average data from Table 5.8.

Electricity consumption for power generation = **6761.1** $\mathrm{MWh_e}$
Diesel consumption for supportive services = 6750 lit
= 6750 x 38.39 MJ
= 263613 MJ
= **73.2** $\mathrm{MWh_{th}}$
Annual engine oil consumption = 201300 lit
Engine oil source = Caltex
Energy required to produce engine oil = 0.328 MJ/lit
= 0.328 x 201300 MJ/Annum
Number of lorries per year = 58

Transport distance = 10 km

∴ Transport energy consumption = 65.13 MJ/Annum

∴ Annual total engine oil energy consumption = 66053 MJ

= **18.35** MWw$_{th}$

Employee transport energy consumption

Annual working days per employee = 300 days

Using the data in Table 5.10 energy consumption for employees transport were calculated as shown in Table 6.6

Table 6.6: Employee Transport Energy Consumption

Transport mode	**Passenger km**	**Energy Consumption MJ/Annum**
Motor Cycle	37500	25176
Car single	49500	165773
Van single	2700	10555
Bus – mini	651000	106019
Total	740700	**307524**

Total annual employee transport energy consumption = 307524 MJ

= 85.42 MWh$_{th}$

∴ Total annual energy consumption in power generation (excluding direct fuel used) = 671.1 + 73.2 +18.35 + 85.42

= 853.1 MWh

Total annual energy generation = 198904 MWh

$$\therefore e_i = \frac{853.1}{198904}$$

= 0.00429

iv Fuel transport energy factor - t_i

The calculated t_l values are shown in Table 6.7 below.

Table 6.7: Fuel Transport Energy Factors - t_i

Power Plant	Fuel Transport		Annual Fuel Consumption - Bowsers	t_l MJ/MJ fuel
	Mode	Distance km		
Diesel – Lakdanavi	Bowser	2	43369514	0.000129
Disel Matara	Bowser	160	31493050	0.010858

Fuel for all the other oil based thermal power plants are delivered by pipe lines and therefore fuel transport energy is considered as negligible.

v Fuel embodied energy factor - P_l

P_l is calculated based on the energy consumption of the refinery.

Table 6.8 below summarizes these factors for the power plants operated in Year 2000.

Table 6.8: i Factors of the Power Plants - 2000

Power Plant	f_l	t_l	e_l	P_i	G_l GWh
Gas turbine – KPS	0.22	--	0.00429	0.01734	98
Steam – KPS	0.23	--	0.00429	0.04466	233
Diesel – Sapu	0.383	--	0.00429	0.04466	483
Diesel – Sapu, Ext.	0.416	--	0.00429	0.04466	443
Gas turbine 115 MW	0.301	--	0.00429	0.01734	315
Diesel – Lakdanavi	0.402	0.000129	0.00429	0.04466	155
Disel – Asia Power	0.402	--	0.00429	0.04466	330
GT of JBC CCY	0.301	--	0.00429	0.01734	801
GT of AES CCY	0.301	--	0.00429	0.04085	320
Barge CPL	0.402	--	0.00429	0.01734	419
Disel Matara	0.402	0.010859	0.00429	0.01734	135

Total Hydro electricity generation = 3891 GWh

Total thermal generation = 3731 GWh

Transmission and distribution losses of the system = 18.5%

By substituting above values in equations 1 to 8

Fuel energy requirement to generate one unit of electricity in thermal plants = 2.986 kWh_{thd}/ $kWh_{e,g}$

Primary energy requirement to generate one unit of electricity in the system (Only considering plant efficiencies) = 1.972 kWh/ $kWh_{c,g}$

Primary energy requirement to generate one unit of electricity in the system with T & D losses = 2.337 kWh/ $kWh_{e,d}$

Total primary energy requirement to generate one unit of electricity in thermal plants = 3.087 kWh_{thd}/ $kWh_{e,g}$

Total primary energy requirement to generate one unit of electricity in the national system = 2.022 kWh/ $kWh_{e,g}$

Total primary energy requirement to deliver one unit of electricity From the national system **= 2.396 kWh/ $kWh_{e,d}$**

= 8.62 MJ/$_{kWhe,d}$

6.2 Embodied Energy in Cement

6.2.1 Level 1 Analysis

Total annual cement production = 509246 MT

Total annual electrical energy consumption of the factory = 592635527.3 kWh_d

Electrical energy consumption per MT of cement = **116 kWh_d/ MT cement**

Total annual furnace oil consumption = 42584 MT

Calorific value of furnace oil = 43.054 $\frac{MJ}{kg}$

∴ Annual heat energy consumption = 1833.4 $GJ_{th,d}$

Heat energy requirement per MT of cement = **3600 $\frac{MJ_{th,d}}{MT}$**

Annual diesel consumption for internal transport & machines = 275456 Lit

Calorific value of diesel = 38.388 MJ/Lit

Annual energy consumption for internal transport & machines = 10.57 $GJ_{th,d}$

Internal transport energy consumption per tone of cement = 0.18 $MJ_{th,d}$/ MT cement

Referring Delivered Energy in to Total Primary Energy

(a) Delivered electrical energy

Energy required to produce one kWh_d = 8.62 MJ

∴ Primary energy equivalent of delivered electricity = $\frac{0.116\ kWh_d}{kg} \times \frac{8.62\ MJ}{kWh_d}$

= **1004 $\frac{MJ}{MT\ of\ cement}$**

(b) Delivered furnace oil

Total energy requirement to travel

1 km for a fuel bowser = 7.8 $\frac{MJ}{km}$ (Ref : Table 6.4)

Distance between refinery to Puttlam Cement factory = 140 km

Bowser capacity = 6000 lit

= 230328 MJ_d

∴ Transport energy requirement to transport fuel oil to Puttlam cement factory $= \frac{7.8 \text{ MJ/km} \times 140 \text{ km}}{230328 \text{ MJ}_d}$

$= 0.005 \text{ MJ/MJ}_d$

National energy required to produce one fuel oil $= 0.045 \text{ MJ/MJ}_{gcv}$

$= 0.045 \text{ MJ/MJ}_d$

∴ Total energy content of delivered fuel oil $= (1+0.005+0.045) \text{ MJ}_{th}/\text{MJ}_d$

∴ Total primary energy content of heat energy = 3778 MJ/MT of cement

(c) Delivered diesel for internal transport

Transport energy requirement to transport Diesel to factory $= 0.005 \text{ MJ/MJ}_d$

National energy required to produce one fuel oil $= 0.017 \text{ MJ/MJ}_{gcv}$

∴ Total primary energy required for internal transport = 0.18 MJ/MT

LEVEL 1 ENERGY = 1004 +3778 +0.18 MJ/MT of Cement

= 4782 MJ/MT of Cement

6.2.2 Level 2 Analysis

In this level, energy consumption for ancillary inputs of cement production is considered.

6.2.2.1 Energy Consumption for Employee Transports

Total motor cycle - passenger km in year 2001 = 533,700 km.p

Total motor car - passenger km in year 2001 = 41250 km.p

Total bus – passenger km in year 2001 = 3,142,500 km.p

Total van-group passenger km = 231,200 km.p

∴ Total employees transport energy consumption = 533700 x 0.671 + 41250 x 3.349

3142500 x 0.163 + 231200 x 0.326

= **1082553 MJ**

6.2.2.2 Energy Consumption for Employees' Uniforms

Number of uniforms per person per annum = 2

Amount of clothing per person = 10 m

Number of employees = 567

∴ Annual clothing requirement = 5670 m

Energy consumption per meter = 29.3 MJ/m

∴ Total annual uniform energy consumption = **166072 MJ**

6.2.2.3 Energy Consumption for Safety Shoes

Number of shoes per person per year = 1

∴ Total annual shoes required = 567

Energy consumption per pair of shoe = 3.14 MJ/pair

∴ Total annual shoes energy consumption = 1783 MJ

6.2.2.4 Lubricant Oil Energy Consumption

Total lubricant oil consumption = 6610 lb

National energy embodied in lubricant oil = 0.315 MJ/lit

∴ Lubricant oil energy consumption = 6610 x 0.315 MJ

= 2080 MJ

Capacity of a lorry = 3.5 Tone

Number of lorries to transport lubricant oil = 2

Number of lorry km = 130 x 2 x 2

= 520 km.l

Energy consumption for lubricant oil transport = 520 x 6.5

= 3647 MJ

∴ Total energy consumption in lubricant oil = 2080 + 3647

= **5727 MJ**

∴ Total energy consumption for ancillary inputs = 1256135
= 1256135/509246 MJ/MT of cement
= 2.467 MJ/MTof cement

LEVEL 2 ENERGY CONSUMPTION = **2.47** $\frac{\textbf{MJ}}{\textbf{MT of cement}}$

6.2.3 Level 3 Analysis

In this level energy requirement to extract raw material and transport them to Puttlam factory are accounted.

Total annual lime stone extracted = 720143 MT
Annual electrical energy consumption at the quarry = 150900 kWh_d
= 543240 MJ_{ed}
Equivalent primary energy = **1301377 MJ**

Annual diesel consumption for internal
transport & Machinaries = 813397 Lit._d

GCV of diesel = 38.39 MJ/Lit
∴ Internal transport energy consumption = 813397 x 38.39 MJ_{GCV}
= 31224684 MJ_{GCV}
Total energy requirement to travel 1 km for
a fuel bowser = 7.82 MJ/km
Distance between Kolonnawa to Aruwarkaru quarry = 160 km
Bowser capacity = 6000 lit
= 230328 MJ_d
∴ Transport energy requirement to transport diesel from
Kolonnawa to Aruwakkaru quarry = $\frac{7.82 \times 2 \times 160}{230328}$ MJ/MJ_d
= 0.01086 MJ/MJ_d
National energy required to produce diesel = 0.0173 MJ/MJ_d

Total primary energy consumption for internal
transport & mechanisms = (1 + 0.01086 + 0.0173) x 31224684 MJ
= **31205230.8 MJ**

Annual diesel consumption for stand by generator = 29324 Lit.$_d$
= 1125689.7 MJ$_d$
Equivalent primary energy = (1+0.01086+0.0173) x 1125689.7 MJ
= **1157434.6 MJ**

Energy consumption for transport of explosive

Number of explosion during the year = 24 Nos.
Lorry km to transport Explosive = 24 x 160 x 2 km
= 7680 km
Light vehicle km = 7680 x 2 km
= 15360 km
Transport energy consumption for a lorry = 6.513 MJ/km
Transport energy consumption for a light vehicle = 3.908 MJ/km
∴ Total explosive transport energy = **110046.3 MJ**

Energy Consumption for External Water Supply
Annual external water supply = 15980000 Lit
= 2730 Bowsers
Water pumping energy = 0.08 kWh$_d$/ 1000 lit
= 1278.4 kWh$_d$
= 4602 MJ$_e$
Equivalent primary energy = 11025 MJ
Distance between water source and
Aruwakuma quarry = 15 km
Bowser energy consumption = 7.82 MJ/km
Water transport energy consumption = 15 x 2 x 7.82 x 2730 MJ
= 640093 MJ
Total energy consumption for external water supply = **651169.7 MJ**

Energy Consumption for Lubricant Oil

Annual lubricant oil consumption = 7166 Lit.
Transport mode = Lorry
Number of lorry per annum = 2 Nos.
Distance between Aruwakaru & Colombo = 160 km
Annual lorry-km for lubricant oil transport = 2 x 160 x 2
= 740 Lorry - km
Energy consumption of a lorry = 6.5 MJ/km
Energy consumption to transport oil = 4169 MJ
National energy consumption to produce lube oil = 0.328 MJ/lit
lube oil energy consumption = 7166 x 0.328
= 2349 MJ
Total lube oil energy consumption **= 6518 MJ**

Employee Transport Energy Consumption

All the staff except from the engineer come to work within 15 km range and they are provided with office transport. This is included in the annual diesel consumption.

Engineer's transport mode = Car - Gasoline
Distance = 125 km
Number of turns per week = 2 x 3
Annual car - km = 125 x 6 x 52
= 39000 car-km
Energy consumption per car-km = 3.349 MJ/km
∴ Total employee transport energy consumption = 3.349 x 39000
= 130609 MJ

National Energy Consumption for Employees Uniforms

Clothing per uniform = 5 m
No. of kit per employee = 2 per annum
No. of employees = 78
Total cloth required = 78 x 2 x 5

= 780 m per year

Specific energy consumption for cloth production = 29.29MJ/m (refer Annex 1)

∴ Total uniform energy consumption = 780 x 29.29

= **22846 MJ**

∴ Total annual direct & indirect energy consumption for Limestone extraction = 1301377+32105258+1157436+110067 +651170+6517+130609+22846

= 35485281 MJ

∴ Energy consumption per tone of limestone = 35485281/720143 MJ/MT

= 49.275 MJ/MT of lime stone

Energy Consumption for Transport of LS to the Factory

Annual diesel consumption for lime stone transport = 325312 lit

Equivalent primary energy = 12840260 MJ

Annual engine oil consumption for Loco engine = 1400 lit

Equivalent engine oil energy consumption = 1400 x 0.328

= 459 MJ

Total lime stone transport energy consumption = 12840719 MJ

Total amount of limestone transported = 639746 ton

∴ Lime stone transport energy consumption = 12840260/12840719 MJ/MT of LS

= 20.07 MJ/MT of LS

∴ Total limestone energy consumption = 49.28 + 20.07

= 69.35 MJ/MT of limestone

Total lime stone consumption in year 2001 = 639746 MT

Total energy consumption for lime stone = 69.35 x 639746 MJ

= 44364411 MJ

Total cement production = 509246 MT

∴ Total lime stone energy consumption = 44364411/509246 MJ/Tone

= **87.12 MJ/MT**

Laterite Energy Consumption

Energy Consumption for Laterite Transport to the Factory

Total amount of laterite consumption = 20427 MT

Capacity of a truck = 5 MT

Number of trucks = 4085

Distance between Anamaduwa and Cement factory = 35 km

Annual truck km = 285978 truck-km

Laterite transport energy consumption = 2793982 MJ

Energy Consumption for Laterite Excavation

Output of the excavator = 10 MT/hr

Diesel Consumption = 9.6 Lit/hr

Total excavator operating hours = 2043 hr

Total Diesel consumption = 19634 Lit

= 753716 MJ_d

Bowser Capacity = 6000 Lit

= 230328 MJ_d

Distance between Anamaduwa to Colombo = 150 km

Energy required to traval 1 km for a bowser = 7.8 MJ/km

Diesel transport energy consumption = 7.8 * 150*2/230328

= 0.0102 MJ/MJ_d

Diesel production energy = 0.017 MJ/MJ_d

Total Diesel energy consumption for laterite excavation = (1+0.010+0.017)x753716 MJ

= 774460 MJ

Total laterite energy consumption = 774460 + 2793982 MJ

= 3568442 MJ

= 7.00 MJ/MT of cement

National Energy Consumption for Gypsum

Annual Gypsum consumption = 14907 MT

Number of trucks = 2941 Nos

Distance between Colombo to Factory = 140 km

Gypsum transport energy = 8155851 MJ

= **16.02 MJ/MT of cement**

LEVEL 3 ENERGY CONSUMPTION = 16.02+7.00+ 87.12

= 110.14 MJ/ MT of cement

Table 6.9 below shows the summary of embodied energy of cement manufactures in Sri Lanka.

Table 6.9: Embodied Energy of Cement

Level	MJ/MT of Cement
Level 1	4782.00
Level 2	2.47
Level 3	110.14
Total	4894.54

Chapter 7
Discussion and Conclusion

The embodied energy in cement produced in Sri Lanka was carried out. National energy input within the Sri Lankan boundaries for the cement manufacturing was the main focus of this study and therefore any energy involvement out side Sri Lanka was not considered in this analysis. The total embodied energy content was analyzed in three levels. In level 1, direct energy consumption in manufacture of cement at Puttlam cement factory was analyzed and energy consumption for ancillary inputs was considered in the level 2. Energy consumption for raw material extraction and transport within the country was analyzed in the level 3. In this study energy embodied in capital equipment such as plants and machinery was not considered because these are imported items and therefore it is outside the system boundary of this study.

7.1 Embodied Energy in Cement

The total national energy requirement to produce one ton of cement in Sri Lanka is found to be 4895 MJ based on the present energy mix of electricity generation. This varies in between 4982 MJ/MT and 4732 MJ/MT according to the future energy mix of the electricity generation and loss reduction plan of Sri Lanka. When this is broken in to three levels as defined in pervious chapters, Level 1 dominates the result as shown in Fig 7.1 below. The effect of level 2 is negligible.

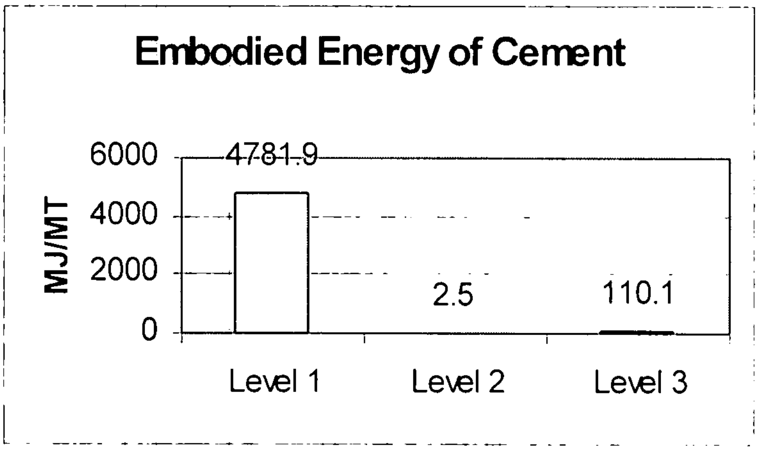


Fig. 7.1: Breakdown of Embodied Energy of Cement

7.1.1 Level 1- Energy

Level 1 energy comprises of electrical energy consumption, furnace oil consumption for kilns (thermal energy) and diesel consumption of earth moving machines and internal transport (M&IT). The share of this is shown in Fig 7.2 below.

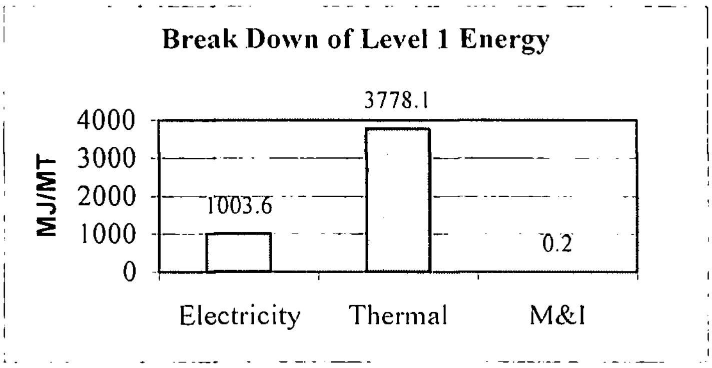


Fig 7.2 : Breakdown of level one energy

Hence, 79 % of level 1 energy is thermal energy obtained by burning furnace oil. The furnace oil energy comprises of

- The chemical energy content of furnace oil
- National energy involvement in refining and handling of furnace oil
- Transport energy requirement to transport furnace oil from Colombo to the Puttlam factory.

The share of these three components is shown in Fig 7.3.

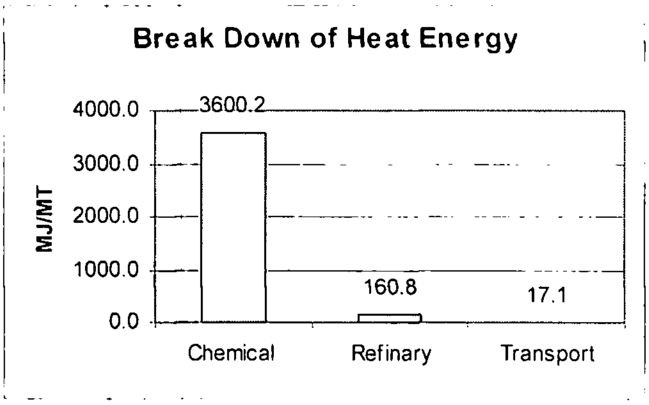


Fig 7.3 : Breakdown of Thermal Energy

7.1.2 Level 3 Energy

Level 3 energy comprises of energy consumption for limestone extraction & transport, laterite extraction & transport and gypsum transport. The share of this energy to one ton of cement is shown in Fig 7.4 below.

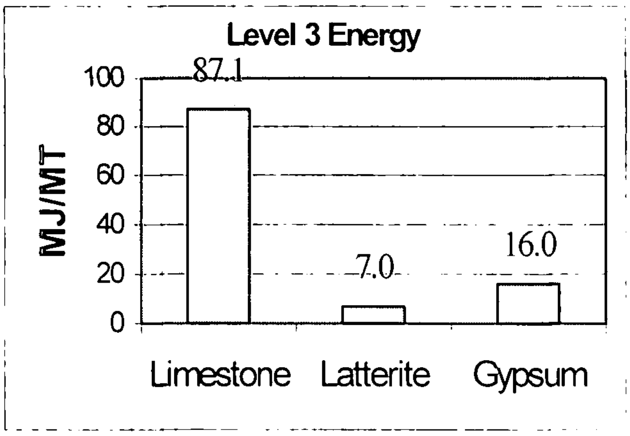


Fig. 7.4 : Breakdown of Level 3 Energy

Hence 74% of Level 3 energy is for limestone.

7.2 Sensitivity Analysis

According to the generation expansion plan for the electricity sector of Sri Lanka, thermal based power generation is expected to dominate the electricity generation in future and T&D losses in the electricity network is expected to be reduced [12] . Therefore it is very important to analyze sensitivity to the national electrical energy mix and to the reduction of T&D Losses in electricity network.

7.2.1 Sensitivity to National Electrical Energy Mix

The primary energy consumption for electricity generation depends on thermal and hydro mix of national electricity generating system, because in the hydro generation efficiency is taken as 100% whereas in thermal generation, plant efficiency is involved. According to the generation expansion plan [12] future mix of thermal energy is increased drastically as shown in Fig 7.5 below. This mix is based on the average rain fall conditions.

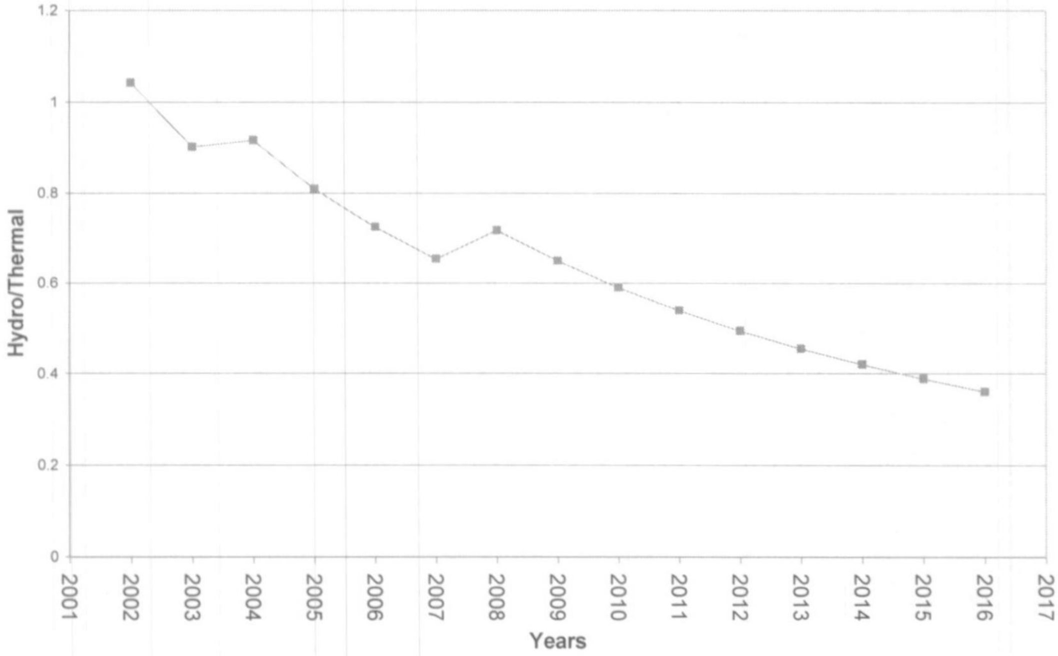


Fig 7.5 : Variation of Electrical Energy Mix

According to this trend one may expect that primary energy requirement to generate one unit of electricity will increase in coming years. A sensitivity analysis is carried out to see the effect of energy mix and Fig 7.6 below shows the variation of primary energy required to deliver one unit of electricity from the national grid.

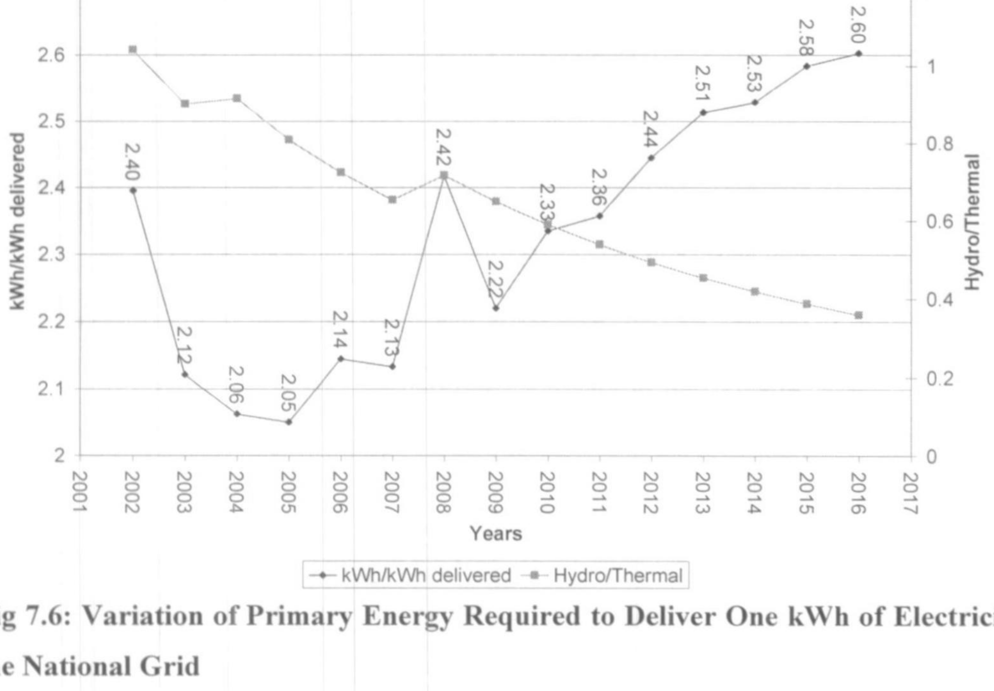


Fig 7.6: Variation of Primary Energy Required to Deliver One kWh of Electricity from the National Grid

In this analysis it is assumed that there will be no deviation from the future generation plan as given in the "generation expansion plan prepared by the Ceylon Electricity Board" [12].

The efficiency of future thermal power generation will be higher than the present operating efficiency of thermal power plants due to the introduction of combined cycle power plants. Therefore the rate of primary energy requirement is declining in the coming few years as seen in Figure 7.6.

Figure 7.7 shows the effect of electricity mix to the embodied energy content of the cement manufactured in Sri Lanka.

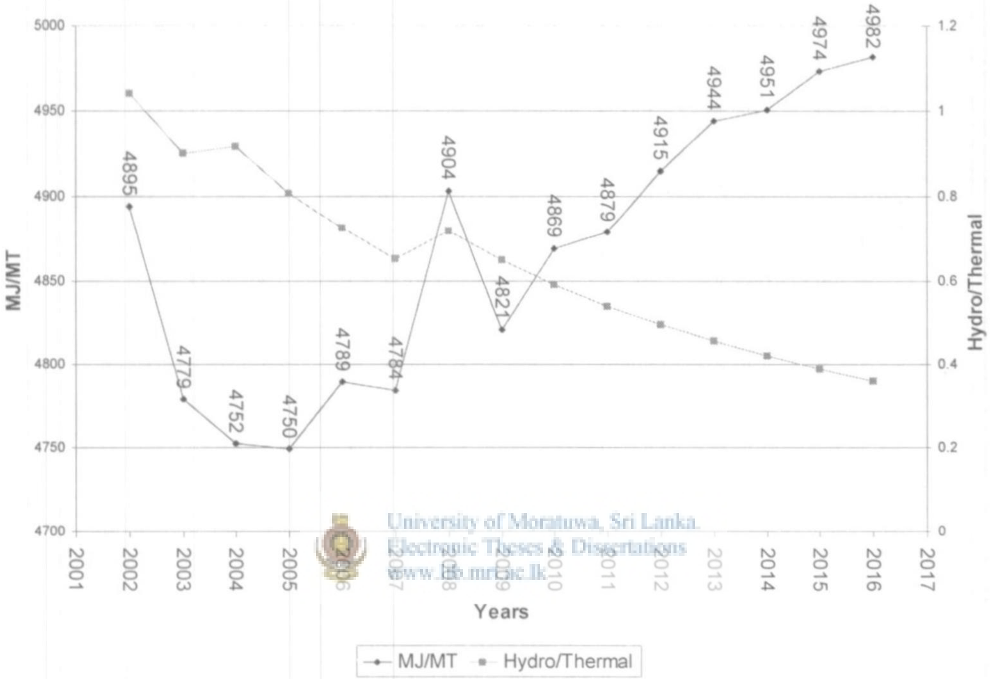


FIg. 7.7: Variation of Embodied Energy of Cement with Energy Mix in Electricity Generation

7.2.2 Sensitivity to Reduction of Transmission & Distribution Losses

The present (year 2002) transmission & distribution losses in the national grid is 18.5% and according to the generation expansion plan of the CEB, transmission & distribution losses will be reduced to 14.6% in year 2009 and it will maintain this value in the future years [12]. The variation of energy embodied in cement was analysed with this planned reduction of transmission & distribution losses and the variation is shown in Fig 7.8 below. In this analysis percentage of T and D losses in the national system is considered for the electricity delivered to the Puttlam cement factory. But in actual conditions, T and D losses in the transmission lines to Puttlam cement factory are less than the losses in the national system due to the high voltage transmission.

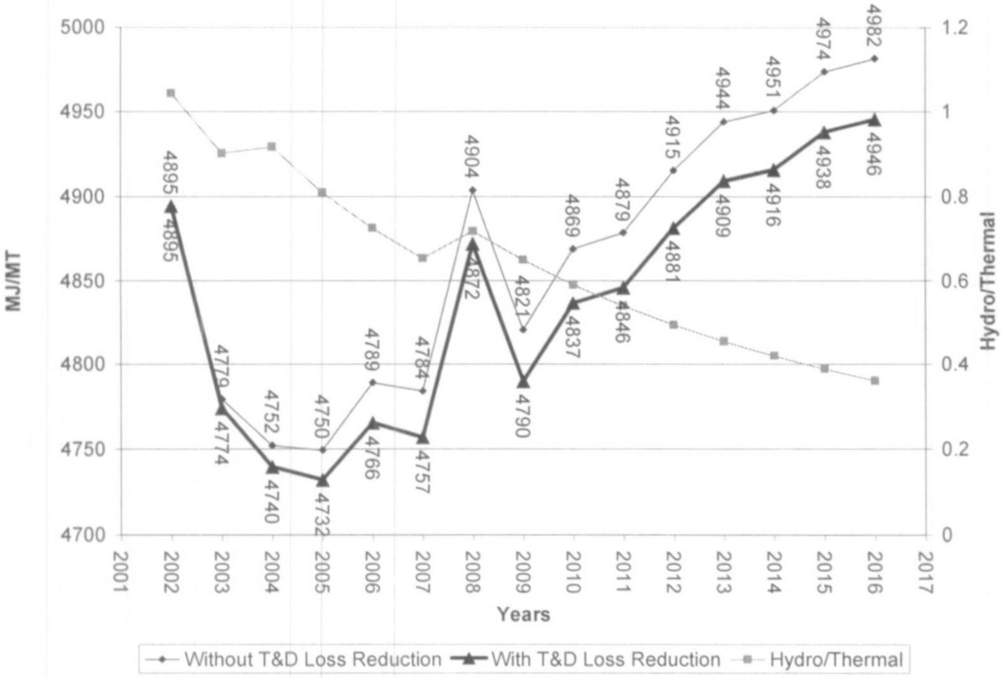


Fig. 7.8 : Variation of Embodied Energy of Cement with Energy Mix in Electricity Generation and Planned T&D Loss Reduction

7.3 Self Generation of Electricity

The share of energy corresponding to distribution & transmission losses is 0.16 MJ per kg of cement produced in Sri Lanka. By considering the annual cement production, this is equivalent to 11 Million kWh of electricity per annum. Hence, if the total electrical energy demand is met through self-generation by having a thermal power plant at Puttlam Cement Factory, 11 Million units of electricity can be saved to the country annually.

But this will slightly increase the embodied energy content of cement, because in order to generate one unit of electricity from a self-generation plant (based on diesel engine) at Puttlam, it is required 2.56 units of primary energy whereas if electricity is delivered from national grid, it needs only 2.40 units of electricity even considering the transmission & distribution losses. Hence if the self-generated electricity is used, the embodied energy content of cement will be 4960 MJ/MT which is corresponding to an increase of 1.2%.

7.4 Comparison of Embodied Energy for Cement found in Literature

The embodied energy value of cement found in literature varies between 4300 MJ/MT and 7800 MJ/MT as shown in Table 2.9 [4]. So the result of this study, i.e. 4895 MJ/MT of cement, falls to this range. This figure is closer to the lower limit of the value available in the literature. This may be due to thermal based electricity generation in the respective countries and due to the embodied energy in capital equipment & machinery, building & infrastructure, extraction of fuel & their processing and international transports of fuel & raw materials were not being accounted in the analysis.

7.5 Use of the Result

Sri Lanka is an energy scarce country from the point of view of indigenous energy recourses. Apart from the hydro and bio-mass all the other primary forms of energy are imported to Sri Lanka, expending millions of rupees of foreign exchange. Therefore energy has to be used carefully and it is very important to study what happens to the energy used. Part of the energy used is in materials and products that we use everyday. Therefore low national energy embodied materials and products have to be selected as far as possible. However, there is no much work done in Sri Lanka to find the amount of national energy embodied in materials and products used. This study can be used as a case study to conduct further research to find out embodied energy of other materials. The main outcome of this study is the amount of national energy embodied in cement manufactured in Sri Lanka. Cement is one of main materials used in built environment and there are alternatives available for cement based building martial. Clay bricks versus cement blocks, asbestos roofing sheets versus clay tiles, concrete versus timber for door and window frames can be considered as some examples. Embodied energy in materials can be used to select best out of them in terms of energy. The author strongly recommends that when selecting materials, the embodied energy should also be considered as one important factor.

In the formulation of energy conservation policies due consideration should be given to the embodied energy content of materials and products. For example, in the formulation of building code for construction of energy efficient buildings, the embodied energy value of cement is very useful.

Apart from the major output, i.e. embodied energy of cement, there are few other useful outputs in this work. They are

- The national energy requirement to produce one litre of petroleum fuel such as diesel, gasoline, furnace oil, etc.
- Transport energy requirement in various modes of transport.
- The primary energy requirement to produce one unit of electricity to the national grid based on the present & future generation mix.

These outcomes are very much useful in conducting further research in other areas of embodied energy and related policy formulation.

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ANNEX 1

Energy Requirement in Producing Lubricating Oil

Caltex Lubrication Lanka Ltd., produces 96% of the lubricant oil requirement in Sri Lanka. The balance 4% is imported. Accordingly 43000 MT of lubricant oil were produced in Year 2001. Table A – 1 below shows the energy consumption in Year 2001.

Table A – 1 : Energy Consumption Year 2001- Caltex Lubrication Lanka Ltd

Energy Type	Annual Energy of Consumption
Electricity	720 MWh
Diesel for stand by generator	51420 lit
Furnace oil	79200 lit
Diesel for internal transport	12600 lit

Source: Data collected at the preliminary energy audit

ANNEX 2

Energy Consumption for Shoe Manufacturing

The Ceylon Leather Products Ltd., is a shoe factory located at Mattakkuliya, Colombo. It meets its commercial energy requirement through electricity taken from the National Grid. Table A_ 2 below shows the monthly electrical energy consumption and corresponding production of shoes during the Year 2000.

Table A_ 2: Electrical Energy Consumption & Production [40]

Month	kWh	Production – Pair of Shoes
January	41480	31746
February	43340	35581
March	46240	43995
April	38630	20414
May	45040	35699
June	31650	27085
July	45320	34405
August	38880	34782
September	42500	26570
October	33130	25569
November	49940	38010
December	40030	24107
Total	**496090**	**377963**

Source : Energy Audit report of Ceylon Leather Products Ltd., by NERD Centre.

∴ Total electrical energy consumption of the factory = 496090 kWh
Equivalent primary energy = 1188425 MJ
Annual production = 377963 Pairs

∴ Energy consumption per pair = 3.14 MJ/Pair

ANNEX 3

Energy Consumption at Kabool Lanka Ltd.

Kabool Lanka (Pvt.) Ltd. manufactures cloths and located at Thulhiriya. It meets its electrical energy requirement through own generation & the national grid, where as thermal energy requirement is met by furnace oil & saw dust.

Table A_ 3 below shows the energy consumption and production during the Year 1999.

Table A_- 3: Energy Consumption & production – 1999 [46]

Month	kWh		Furnace Oil	Saw Dust	Production
	National Grid	Generation	(Lit)	(MT)	Yrds
January	33416	6276372	1160916	267	2114312
February	69076	6267850	1164399	262	2401744
March	30106	6777000	1237995	267	2855311
April	52330	5565350	862995	210	1857512
May	44060	6696540	958256	286	2282829
June	87310	6560490	955798	250	2317983
July	34940	7148590	1029711	276	2555154
August	46770	7129027	1010926	314	2636045
September	777570	7012770	980573	233	2443714
October	960640	6347491	1066874	295	2397178
November	428110	6624700	1167874	289	2809255
December	43500	7043750	1231553	357	2790191

Total National grid electricity consumption	=	2607828 kWh
Equivalent primary energy	=	22490172 MJ
Electrical energy generated	=	7934990 kWh
Plant electrical efficiency	=	40.2 %
Equivalent furnace oil energy	=	710596388 MJ
Furnace oil consumption for thermal energy	=	12827870 Lit
	=	519153648 MJ
Total furnace oil energy	=	1229750036 MJ
Bowser Capacity	=	6000 Lit
	=	242825 MJ

Fuel oil transport distance = 65 km

Fuel oil transport energy = 0.00418 MJ/MJ

Energy for fuel oil production = 0.04466 MJ/MJ

Total fuel oil energy = 1289815156 MJ

Saw dust energy = 74399000 MJ

Saw dust consumption = 3306 MT

Lorry capacity = 5 MT

Number of Lorries = 661 Nos

Transport distance = 50 km

Saw dust transport energy = 430626 MJ

Total energy consumption = 1387134955 MJ

Total production = 47359231 m

Specific energy consumption of cloth $= \frac{1387134955\ \text{MJ}}{47359231\ \text{m}}$

$= 29.3\ \text{MJ/m}$

ANNEX 4

1 Energy Consumption in Petroleum Fuel Filling Station

Energy consumption and corresponding petrol & diesel sales figures were obtained from few filling stations and details are given in Table A - 4 - 1 below.

Table A - 4 - 1 : Monthly Fuel Sales and Energy Consumption

Station ID	Fuel Sales			Energy Consumption (kWh)
	Diesel	Petrol	Kerosene Oil	
1	120000	30000	15000	397
2	170000	50000	25000	540
3	130000	40000	20000	440
Total	**420000**	**120000**	**60000**	**1377**
Average	**140000**	**40000**	**20000**	**459**

1 Energy Consumption in Vehicle service stations

Energy consumption figures were obtained from few service stations and details are given in Table A - 4 - 2 below.

Table A - 4 - 2: Monthly Energy Consumption and Vehicle Serviced

Station ID	Number of Vehicle	Energy Consumption (kWh)
1	375	175
2	400	165
3	350	140
Total	**1125**	**480**
Average	**375**	**160**

ANNEX 5

Table A - 5: Properties of Fuel

Fuel	Gross Calorific Value MJ/kg	Density kg/l
Auto diesel	45.7	0.84
Fuel oil	43.05	0.94
Gasoline	44.8	0.72
Kerosene	46.5	0.78
Naptha	47.07	0.68
Fuel gas	45.98	--
Coal	26.33	--

Source : 1 Ceylon Petroleum Corporation, 2 Generation Planning Branch, CEB