Limitierte Ökobilanz für Flüssiggas und Petroleum als Kochbrennstoffe in Indien

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Restricted Life Cycle Assessment for the Use of Liquefied Petroleum Gas and Kerosene as Cooking Fuels in India

Diplomarbeit

im Studiengang Technischer Umweltschutz

angefertigt von

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Contents

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Abbreviations

a	per annum
APM	Government administered pricing mechanism
ATF	Aviation turbine fuel
Aux.	Auxiliary
billion	Thousand million
Bm^3	Billion cubic metre
BOD	Biochemical oxygen demand
BPCL	Bharat Petroleum Corporation Ltd.
BRPL	Bongaigaon Refineries and Petrochemicals Ltd.
BSW	Bottom-sediment and water sludge
c. i. f.	Cost, insurance and freight
C2/C3	Liquefied ethane-propane mixture
CIS	Commonwealth of Independent States
CNG	Compressed natural gas
CO	Carbon oxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CPCB	Central Pollution Control Board
CRL	Cochin Refinery Ltd.
DIN	Deutsches Institut für Normung (German Institute for Standardisation)
DPD	Dew point depression
EM	Environmental Manual (computer program)
en.	Energy
EOR	Enhanced oil recovery
ESP	Electrostatic precipitator
eta	Thermal efficiency of a process (used in the computer program TEMIS)
ETP	Effluent treatment plant
FCC	Fluid catalytic cracking
FO	Fuel (furnace) oil
FTP	File transfer protocol
g	gram
GAIL	Gas Authority of India Ltd.
GEMIS	Gesamt-Emissions-Modell Integrierter Systeme
GER	Germany
GGS	Group gathering station
GJ	Giga joule = 10^9 joule
GNP	Gross national product

GOI	Government of India
h	per hour
HC	Hydrocarbons
HFO	Heavy fuel oil
HHV	Higher heating value
HPLC	Hindustan Petroleum Corporation Ltd.
HPS	Heavy petroleum stock
HSD	High speed diesel
IIP	Indian Institute of Petroleum
In	India
int	international
IOC	Indian Oil Corporation
IS	Indian standard
ISI	Indian Standards Institution
kgoe	Kilograms of oil equivalent
LCA	Life cycle assessment / analysis
LCI	Life cycle inventory
LCV	Light commercial vehicle
LDC	Low / Less / Least developed country
LDO	Light diesel oil
LHV	Lower heating value
LNG	Lean natural gas
LPG	Liquefied petroleum gas
LSHS	Low sulphur heavy stock
MINAS	Minimal national (Indian water) standards
MJ	Mega joule = 10^6 joule
Mm^3	Million metric cubic meters
MMSCMD	Million metric square cubic meters per day
MRL	Madras Refinery Ltd.
MT	Million tonnes (in some publications also for metric tonnes!)
Mtcr	Million tonnes of coal replacement
Mtoe	Million tonnes of oil equivalent
Mtpa	Million tonnes per annum
MW	Mega watt
n.a.	Not available
n.d.	No date
NEERI	National Environmental Engineering Research Institute
NGL	Natural gas liquid
Nm^3	Norm cubic meter
NMVOC	Non-methane volatile organic compounds
NO_X	Nitrogen oxides

O&M	Operating & maintaining
OCC	Oil Coordination Committee
OIL	Oil India Ltd.
ONGC	Oil & Natural Gas Corporation Ltd. (erstwhile Commission)
OPEC	Organisation of Oil Exporting Countries
pa	per annum
PAH	Polycyclic aromatic hydrocarbons
PDS	Public distribution system
PM	Particulate matter
POL	Petroleum, oil & lubricants
PP	Power plant
R&D	Research & development
Rs	Indian Rupees[1] (Currency)
SETAC	Society of Environmental Toxicology and Chemistry
SI	Système International (International system of units of measurement)
SKO	Superior kerosene oil
SO_2	Sulphur dioxide
SPM	Suspended particulate matter
SRU	Sulphur recovery unit
t	Metric tonnes (= 10^6 g)
TDS	Total dissolved solids
TEG	Triethylene glycol
TEMIS	Total Emission Model for Integrated Systems
TERI	TATA Energy Research Institute
TJ	Tera Joule = 10^{12} Joule
tkm	per tonne and kilometre
TNMOC	Total non-methane organic compounds
toe	Tonnes of oil equivalent
tpa	Tonnes per annum
TSP	Total suspended particulates
TSS	Total suspended solids
UBA	Umweltbundesamt (Environmental Protection Agency in Germany)
vol%	Volume percent
wt%	Weight percent

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[1] 31 Rs = US$ 1 = 1.50 DM (January 1995)

Tables

Figures

Zusammenfassung

In Indien hat der Energieverbrauch im Haushalt, und hier vor allem der Einsatz zum Kochen, einen Anteil von ca. 50% am gesamten Energieverbrauch. Traditionell werden überwiegend pflanzliche Materialien wie z.B. Holz, Erntereste und Dung zum Kochen verwendet. Zunehmend werden diese durch fossile Brennstoffe, vor allem Petroleum und Flüssiggas, ersetzt.

Die Verwendung der Biomasse-Brennstoffe führte in Indien zu einer Reihe von Problemen. Zur Deckung des Bedarfs wurden Teile des ursprünglichen Waldbestandes gerodet. Die brachliegenden Flächen wurden durch nachfolgende Erosion irreversibel geschädigt. Das Kochen ist durch die Verbrennungsgase mit gesundheitlichen Gefahren für die Hausfrau verbunden. Die Verwendung von fossilen Brennstoffen führt zu Umweltschädigungen bei der Produktion und beim Transport. Auch beim Kochen werden Schadstoffe, z.B. klimarelevante Gase freigesetzt.

In der vorliegenden Arbeit und in einer parallel durchgeführten Studie werden die Folgen des Kochens in Indien über den gesamten Lebensweg der Brennstoffe in einer Ökobilanz untersucht. Die vorliegende Studie beschränkt sich dabei auf das Kochen mit den fossilen Brennstoffen **Petroleum** und **Flüssiggas**. Lauterbach (n.d.) untersucht die Verwendung von Biomasse Brennstoffen. Endprodukt und Vergleichseinheit für die Untersuchungen ist die durch das Verbrennen bereitgestellte, zum Kochen nutzbare Wärme. Aufgrund der begrenzten Zeit und der eingeschränkten Datenlage ist die Ökobilanz hinsichtlich Anzahl der untersuchten Parameter und Tiefe der Untersuchung limitiert.

Ziel ist es, in einem Vergleich unterschiedlicher Kochmöglichkeiten ökologische Vor- und Nachteile der Varianten zu beleuchten und somit die Grundlage für eine ökologisch verträgliche Weichenstellung im Bereich des Kochens zu entwickeln.

Der Lebensweg der untersuchten fossilen Brennstoffe ist in vielen Punkten identisch. In der vorliegenden Studie wurden für folgenden Prozeßschritte in Indien **Sachbilanzen** erarbeitet: Erdöl und Erdgasförderung; Weiterverarbeitung von Öl in Raffinerien zu Petroleum, Flüssiggas und anderen Produkten; Produktion von Flüssiggas aus Erdgas in speziellen Anlagen; Umfüllung von Flüssiggas in Flaschen; Lagerung, Transport und Verkauf der Produkte; Kochen mit Gas und Petroleum. Umweltfolgen die mit den notwendigen Importen verknüpft sind, wurden durch Literaturangaben abgeschätzt

Die Untersuchung der umweltrelevanten Parameter Energieverwendung, Emissionen von Luft- und Wasserschadstoffen, Materialverbrauch und Flächeninanspruchnahme wurde ergänzt durch Untersuchungen zu den wirtschaftlichen Rahmenbedingungen und den sozialen Begleiterscheinungen des Kochens.

Die gefundenen Daten wurden in ein Format umgerechnet, das eine Weiterverarbeitung mit dem Computerprogramm TEMIS 2.0[2] (Total Emission Model of Integrated Systems) ermöglicht. Mit diesem Programm wurden die quantifizierbaren Größen für verschiedene Szenarien summiert. Diese sind auf den Gebrauch der Brennstoffe in Dhanawas, einem kleinen Ort 45 km von New Delhi entfernt, hin ausgerichtet. Dies ermöglicht einen Vergleich der errechneten Ökoprofile mit den Ergebnissen der parallelen Studie. Die gewonnen Ergebnisse lassen einige interessante Rückschlüsse zu den Umweltfolgen des Kochens mit fossilen Brennstoffen zu:

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[2] Diese Daten können von einem FTP-server abgerufen werden: telnet *itu106.ut.tu-berlin.de*, login *ftp*, Paßwort *ftp*, cd *india*, ls -l, ftp *eigener name*, login *eigener name*, Paßwort *eigenes*, put *.* *.*

Für die Bereitstellung wird ein Äquivalent von 18% des Energiegehalts der Brennstoffe aufgewendet. Bis zur Lieferung von 1 kg Brennstoff an die VerbraucherInnen werden Treibhausgase emittiert, die in ihrer Wirkung 740 g CO_2 entsprechen. Die Bereitstellung von Flüssiggas ist in vielen Punkten mit einer etwas niedrigeren Umweltbelastung als die Bereitstellung von Petroleum, verbunden. Wasserschadstoffe werden z.B. zu 10% bis 60% weniger für die Bereitstellung einer vergleichbaren Energiemenge emittiert. Die Umweltfolgen des Materialverbrauchs wurden nicht für Indien ermittelt. Da der Verbrauch an Stahl und Zement für Flüssiggas höher ist als für Petroleum, könnten einige der gefundenen Unterschiede in einer ausführlicheren Untersuchung relativiert werden.

Einer überraschend großen Anteil an der ökologischen Last tragen die notwendigen Transporte. Sie haben einen Anteil von um die 30% an den Schadgasemissionen bis zur Übergabe der Brennstoffe an die Haushalte. Begründet ist dies durch die weiten Entfernungen von den Produktionsstätten bis zu den VerbraucherInnen und durch die hohen Umweltbelastungen während des Transports von importierten Energieträgern in Tankschiffen.

Die ökologischen Vorteile von Flüssiggas werden deutlicher wenn der Kochvorgang in die Betrachtung einbezogen wird. Das Gas kann sauberer und effizienter in nutzbare Wärme umgewandelt werden. Die über den Lebensweg zusammengefaßte Energie Effizienz beträgt für Gas 54% wenn ein Kocher mit 64% Effizienz angenommen wird. Für Petroleum Kocher mit 54% Effizienz ist der Wert 46%. Die Ergebnisse der Sachbilanzen wurden für die Bereitstellung von 1 Gigajoule nutzbarer Wärme berechnet. Ungefähr 250 kg Wasser werden hierfür im Lebenszyklus von Gas verwendet. Der Wert für die Verwendung von Petroleum ist 420 kg. Die Emission von Öl wurde mit 6.2 g für Gas und 15 g für Petroleum errechnet.

Obwohl der Hauptverbrauch an Energie dem Kochen direkt zuzuordnen ist, zeigt die durchgeführte Ökobilanz, daß ein nicht unerheblicher Anteil der Umweltbelastungen mit der Herstellung und dem Transport der Brennstoffe verbunden ist. Wasserbelastungen z.B. fallen vor allem während der Ressourcengewinnung und in Raffinerien an. Auch hinsichtlich einige Luftschadstoffe ist der Lebensabschnitt bis zur Übergabe an die EndverbraucherInnen umweltbelastender als das eigentliche Kochen. Kohlenwasserstoffe werden nur zu etwa 20% - 30% und NO_X nur zu 45% während des Kochens emittiert. Die Emissionen von Staub und SO_2 im Lebenszyklus von Flüssiggas fallen zu über 90% vor der eigentlichen Verwendung an. Dies zeigt wie notwendig es ist, den gesamten Lebenslauf für einen ökologischen Vergleich von Kochmöglichkeiten zu betrachten.

Im Vergleich qualitativer Parameter spricht für Gas z.B. die leichtere Verwendung und die geringeren Gesundheitsrisiken. Petroleum ist geringer subventioniert. Der Preis für das Kochen hängt wesentlich von der Effizienz des benutzten Kochers ab. Kochen mit subventioniertem Petroleum ist billiger als das mit ebenfalls subventioniertem Gas oder frei erhältlichem Petroleum.

Die durch das Kochen insgesamt emittierte CO_2 Menge entspricht in etwa 3.8% der totalen Emissionen in Indien. Ein Vergleich der für Indien gültigen Ergebnisse mit Daten zum Kochen in Deutschland zeigt, daß das weitverbreitete elektrische Kochen in puncto Energieverbrauch und Emission von einigen Luftschadstoffen deutlich umweltbelastender ist als die in Indien gebräuchlichen Alternativen. Weitere interessante Ergebnisse sind durch den Vergleich mit der Ökobilanz für Biomasse Brennstoffe zu erwarten. Durch die vorliegende Arbeit wurden wohl erstmals Teile des Energiesektors in Indien in einer ökologischen Betrachtung untersucht. Die gewonnen Daten können als Grundlage für weitere Studien verwendet werden. Die Datengrundlage für den Bereich der Raffinerien und des Transports kann dabei als relativ gesichert gelten. Weitere Untersuchungen sind wünschenswert für den Bereich der Erdöl- und Gas- Gewinnung, für die Materialproduktion und über die Transportdistanzen.

Summary

The use of different fuels for cooking is one of the most important sectors for energy use in India. The residential use and here mainly the cooking has a share of about 50% of the total energy use. The main energy carriers for cooking are traditional fuels gained from biomass sources like wood, agricultural wastes and dung. But the customs are changing and commercial fuels like kerosene and liquefied petroleum gas (LPG) are used in a rising share.

The use of biomass fuels is linked with hazards for the Indian environment and with problems for the society. Parts of the former forests were rooted out for the use as firewood and the land was farther irreversibly destroyed by erosion. Due to the emission of air pollutants during the cooking, the use of biomass fuels is linked with health risks for the cooks. The use of alternative fossil fuels is not free from problems. The extraction, the processing and the necessary transports lead to environmental hazards before the use of the fuels. Emission of greenhouse gases and other pollutants due to the cooking also leads to risks for the environment.

The study in hand and a parallel executed work by LAUTERBACH (n.d.) investigate the use of different cooking fuels in a life cycle assessment. This study is limited on the use of **kerosene** and **liquefied petroleum gas** as cooking fuels. The parallel study looks on biomass fuels. End product for the assessment is the useful heat for cooking that is delivered by burning the fuels. The life cycle assessment is restricted regarding the number of investigated indicators and the depth of the survey.

The goal of these studies is to compare different types of cooking and their ecological advantages and disadvantages over the whole life cycle. This information can serve as a base for environmental sound policy decisions in India for the field of cooking.

The life cycle of the two fuels is identical in many points. This study investigates the situation in India in **life cycle inventories** for the following stages: Extraction of the resources crude oil and natural gas; processing of crude oil in refineries to LPG, kerosene and other products; extraction of LPG from natural gas in fractionating plants; bottling of LPG in bottling plants; distribution and transport of the fuels; cooking with LPG and kerosene. Environmental impacts caused by the necessary imports of products are considered in the inventory using literature data.

The environmental burdens are comprehended for a limited list of indicators in the categories energy use, emissions of air and water pollutants, use of materials and land. This is supplemented by a reflection on the economic conditions and the social consequences during the life cycle.

The data were compiled into a format that made it possible to calculate the overall impacts with the computer program TEMIS 2.0[3] (Total emission model of integrated systems). The results for different scenarios of fuel supply and cooking were calculated with this program. The environmental impacts are summarised in final calculated ecological profiles for the two fuels. These scenarios were adopted for a cooking session in Dhanawas, a little rural village 45 km away from New Delhi. This was necessary to compare the results of this study with the study on biomass fuels. The comparison of LPG and kerosene leads to some interesting results:

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[3] These data are available on a FTP-server: TELNET *itu106.ut.tu-berlin.de*, LOGIN *ftp*, PASS *ftp*, CD *india*, LS -L, FTP *own name*, LOGIN *own name*, PASS *own*, PUT **.* *.**

The production of the two fuels requires an energy input of about 18% of the energy content. The production and supply of 1 kg fuel is linked with an emission of greenhouse gases that is comparable to 740 g CO_2. The supply of LPG to the consumer is more environmentally sound than this of kerosene for the majority of investigated indicators. Effluents and water pollutants are emitted about 10% to 60% more for the supply of kerosene than for a comparable amount of LPG. The environmental impacts of material production were not investigated for India. Due to the higher demand of steel and cement for the production of LPG some differences between the two fuels might be lower than calculated in this study.

A surprisingly high share of the environmental burdens for the fuels is caused by the transport processes. One reason is the high distance in India between the points of resource exploitation and the final use of the end consumers. The other reason is the import of resources and products with tankers into the country. The transports have a share of about 30% for emissions of air pollutants until the delivery to the household.

The environmental advantage of LPG is more obvious if cooking is included in the environmental profile. Cooking with gas has a higher efficiency and causes fewer emissions of air pollutants. The total energy efficiency of the life cycle is 54% for an LPG cookstove with 64% efficiency. The comparable value for a kerosene stove with 54% efficiency is 46%. The total impacts of cooking were compared for 1 gigajoule output of useful heat. About 250 kg and 420 kg of water are used for this cooking heat output with LPG and kerosene respectively. This cooking scenario is linked with an emission of 6.2 g and 15 g oil & grease in the case of LPG and kerosene respectively.

Even if cooking consumes most of the necessary energy, some parts of the upper life cycle are responsible for a high share on the total environmental burden. Water pollutants for example are only emitted during the extraction and processing of the fuels. But also some air pollutants are emitted in high share before the consumption of the fuels. Cooking causes only 45% of NO_X and less than 25% of hydrocarbon emissions. Particulates and SO_2 are emitted in a share of over 90% of the total emissions due to the supply of LPG to the consumer. The results show that is necessary to consider the total emissions during the life cycle for an evaluation of the environmental impacts of kerosene and LPG.

Also the comparison of qualitative indicators shows some advantages for LPG. These are for example the easier product use and the lower health risks. Kerosene needs today less subsidies. The price of cooking depends on the efficiency of the used cookstoves. Cooking with subsidised kerosene is the cheapest possibility. Using LPG or non-subsidised kerosene is linked with comparable costs.

Cooking with the two possibilities in India emitted as much as 3.8% of the total carbon dioxide emissions in the country. A comparison of the results for India with common cooking possibilities in Germany points out another interesting fact. The widespread use of electricity for cooking has a higher energy intensity and higher emissions for most of the investigated air pollutants.

Further results can be expected after a comparison with the study on biomass fuels. The study in hand probably investigates for the first time parts of the Indian energy sector in a life cycle assessment. The found data are also useful as a base for other studies in the energy sector. The data for transports and refineries are reliable. More investigation would be useful for the petroleum extraction, the transport distances and the material production.

1 Introduction

This chapter contains some preliminary background for the study. Facts about Indian society and the energy sector are described. The methodology for the study is deduced and the advance is explained.

1.1 India's Society and Economy

Table 1.1 gives some important statistical factors concerning society and economy of India. With a per capita income of US $290[1] India belongs to the "Least Developed Countries". The industrial and service sectors shows disproportional fast growth rates, but this is not a solution for India's poverty problems. Due to the still high population growth rate the efforts to increase the GNP[2] have not led to higher per capita income. The devaluation of the Indian rupee in comparison to the US dollar has resulted in a decline in the GNP per capita. The economic and social circumstances present large differences in the living conditions of people of different classes (MANOMARA 1995; PAULUS 1992).

Table 1.1: Social and economic indicators for India

Area	3,287,263	km²
Population (mid 1994)	897	million
Annual population growth rate (1990 to 1995)	1.9	%
Urban population (1992)	26	%
Rural population (1992)	74	%
Population density	267	people/km²
Per capita GNP (1993)	290	US $
Growth of GNP (at 1980/81 prices)	5	%
Inflation rate (September 1994)	9.1	%
Fiscal deficit of the central government	7.3	% of GNP
Current account deficit	1.8	% of GNP
Per capita yearly consumption of commercial energy (1992)	235	kgoe[3]

Sources*: Manomara 1995; TEDDY 1994; Paulus 1992*

In terms of goods produced, India is one of the 10 leading nations in the world and manufactures satellites, computers and nuclear power plants. Statistics show that 40 million people (4.5% of the Indian population) live with a family income of more than US $30,000 a year. A middle class of 250 million people (27.9%) passes into a consumer-oriented life style. On the other hand a 60% majority of the Indian people are still living in traditional economic structures. For them consumption begins and ends with a daily meal, if they are lucky. They do not benefit from the new achievements. Today, about 360 million people live below the poverty line. The level of poverty rose to 40 per cent in 1992 from the 1989/90[4] figure of 34 per cent (INDIA TODAY 1995; MANOMARA 1995).

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[1] January 1995: US $1 = Rs 31 = DM 1.50 (German mark)

[2] GNP - Gross national product: The total monetary value of final goods and services produced in a country

[3] kgoe - kilogram of oil equivalent

[4] Statistical data in India are prepared yearly for the period April to March.

1.2 Energy Scene in India

About 55% of India's total energy requirement is supplied by *commercial* energy. That is electricity and fossil fuels that are bought by the consumer. The rest is contributed by *non-commercial* energy carriers. These are biomass fuels that are normally collected by the users themselves. The use of commercial energy at 235 kgoe per year and per capita is low in comparison to the developed countries with values of approximately 5,000 kgoe/a (TEDDY 1994).

The country has witnessed a rapid growth in energy needs owing to industrialisation and the changing demographic profile. A balance for the commercial energy availability and its consumption is shown in Table 1.2. In the years from 1981/82 to 1991/92 the commercial available energy increased from 101 Mtoe[5] to 194 Mtoe. One third of this available energy was lost during conversion and transmission. Thus the total energy consumption in 1991/92 was 131 Mtoe (TEDDY 1994; WSN 1994).

Table 1.2: Commercial energy balance (Mtoe) for 1991/92 (TEDDY 1994)

	Coal	Crude oil	Natural Gas	Electricity	Petroleum products	Total commercial energy	% Energy
Production	112.4	30.3	16	6.6	-	165.3	85.34%
Imports-(Exports + Stock changes)	-0.2	21.1	0	0	7.5	28.4	14.66%
Availability	112.2	51.4	16	6.6	7.5	193.7	100.00%
Conversion, Transmission, Distribution, etc.							32.83%
Consumption	50.7	0	5.9	17.5	56	**130.1**	67.17%

Figure 1.1 shows the energy balance in India for the main sectors taking into account the availability of commercial energy (194 Mtoe) and the estimated total energy use (350 Mtoe). Main users of commercial energy are the industrial and the transport sectors. The household sector is the largest consumer of energy in India if all energy carriers are considered. It accounts for 40% to 50% of total energy consumption; That is 10 per cent of the commercial energy consumed (TEDDY 1994).

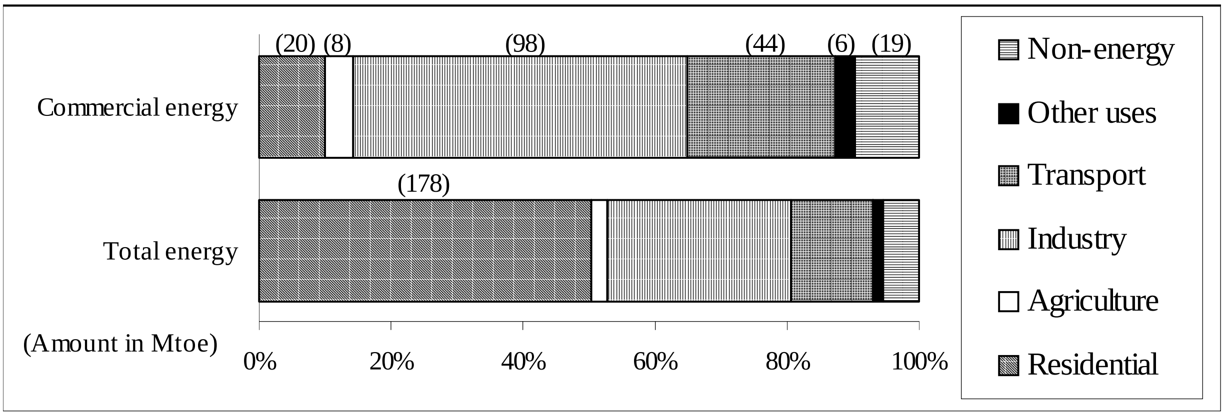

Figure 1.1: India's energy consumption and share by different sectors in percentages and Mtoe for 1991/92. Total energy estimated (TEDDY 1994; Paulus 1992)

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[5] Mtoe - Million tonnes of oil equivalent

The proportion of the total residential energy use for cooking (including water and space heating) is 90% in rural and about 80% in urban areas is the main purpose. Thus cooking consumes about 35% to 45% of the total energy used in India. In developed countries cooking consumes less than 10 per cent of total national fuel consumption (AGARWAL/NARAIN 1990; TEDDY 1994).

Figure 1.2 shows by proportion the use of the different household fuels in India. The bulk of energy consumption in households consists of biomass (non-commercial) fuels, such as firewood (59%), dung (20%) and agricultural residues (14%). The main commercial energy carriers for residential use are kerosene and LPG (liquefied petroleum gas). Together these two have a 5.2% share of the energy consumed in households. This amounts to 79% of the total commercial energy consumption of 13.1 Mtoe in 1991/92. LPG consumption grew at annual rate of over 16% and this of kerosene by 6% between 1984/85 and 1991/92 (TEDDY 1994).

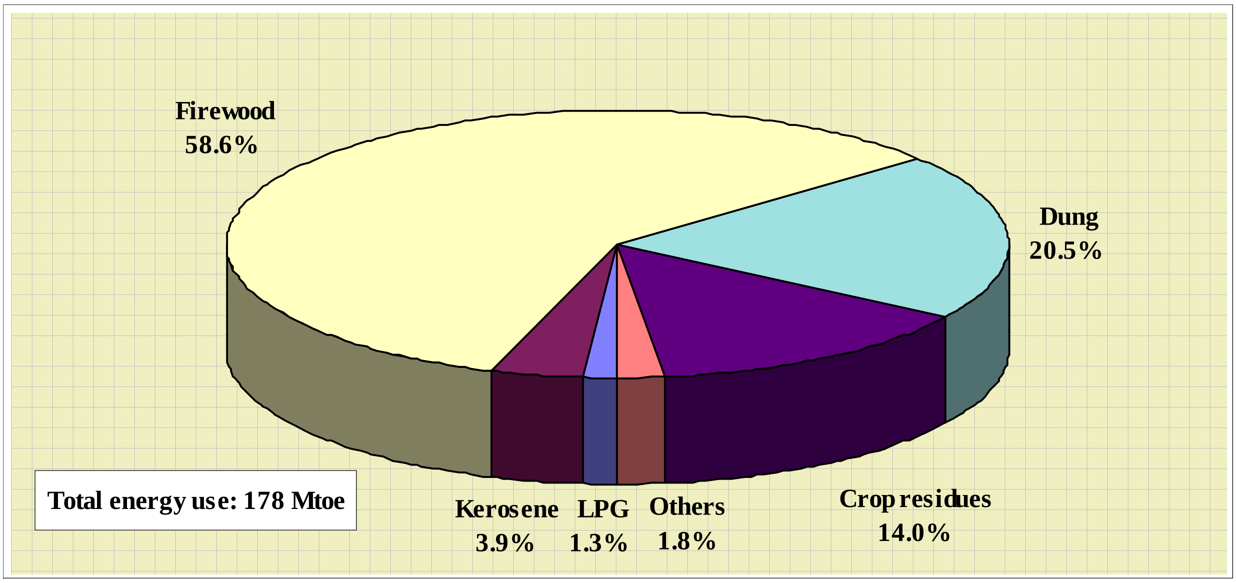

Figure 1.2: Use of household fuels in India (TEDDY 1994)

The main factors in the choice of fuels are family income and availability. TEDDY (1994) describes the situation for 1978/79. Low income households use mainly biomass fuels. Kerosene has the highest distribution in the lower-middle class group and LPG, which is not used by the lowest income group has a share of over 40% in the highest income group (TEDDY 1994).

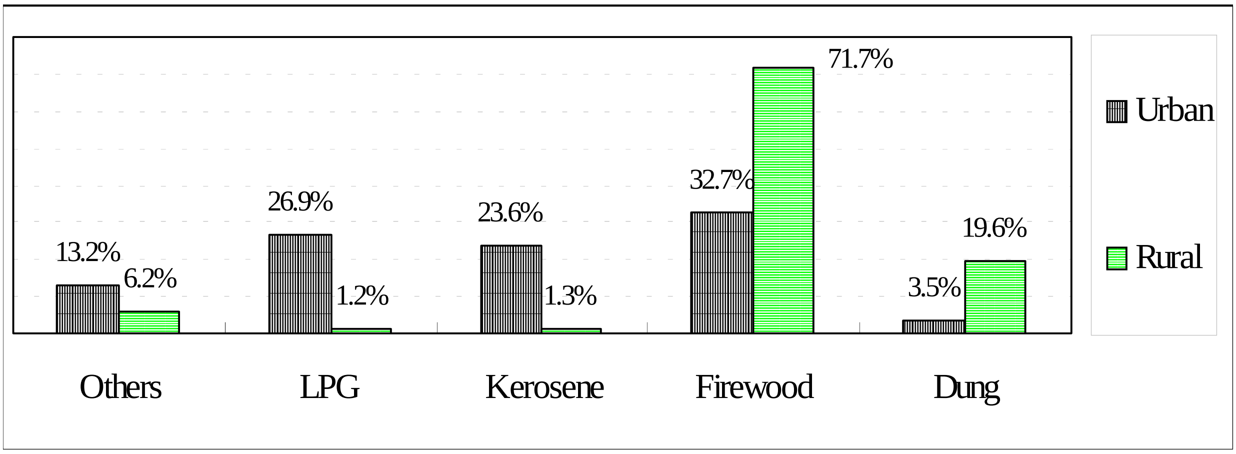

Figure 1.3: Percentage of household using a specific cooking fuel in urban and rural areas (MODAK 1995)

There is also a big difference between rural and urban energy users. The different distribution for the used cooking fuels is shown in Figure 1.3. Over 90% of the **rural** households use traditional fuels for cooking. In the low income rural households half of the commercial fuels are used for lighting. LPG is usually not available in these areas (MODAK 1995; TEDDY 1994).

In **urban** areas over 60% of the used energy is delivered by commercial fuels, but here also the share of traditional fuels is still high. Kerosene meets 24% and LPG 27% of the total requirement. Urban households use the LPG exclusively for cooking and water heating. Cooking with a share of 70% is also the main use of kerosene in urban areas. About 8% of the kerosene is burnt for lighting and 20% is used for water heating (MODAK 1995; TEDDY 1994).

The heavy dependence on biomass fuels has lead to several health- and ecological problems in India. The depletion of natural forest leads to soil erosion. Due to the depletion of traditional fuelwood resources, people burn more, and lower quality fuels such as twigs, crop residues and animal dung. The time taken by the women to search for fuelwood increases with the depletion of the resources. Emissions of the cookstove are hazardous for the cooking woman and their family (CFSAE 1985; TEDDY 1994).

The shift to the commercial household fuels brings many benefits to people. The use of modern fuels avoids some of the health risks of cooking, but result in higher environmental costs. The resources of these fuels are not renewable. The burning of fossil fuels contributes to the global warming due to the resultant emissions of carbon dioxide and other greenhouse gases. The import of these fuels adds greatly to the already heavy burden on scarce resources of capital and foreign exchange in India (CFSAE 1985; TEDDY 1994).

For India these facts lead to the statement (CFSAE 1982):

> *„Energy for cooking in households constitutes half of India’s total energy consumption. No other form of energy use has greater impact on the environment or is more crucial for human survival.“*

1.3 Life Cycle Assessment as an Analytical Instrument for Environmental Policy

Existing research work concentrates on particular aspects of cooking, for example deforestation or health risks. The broad differences of the existing cooking possibilities and the discussion about their advantages and disadvantages led to the idea to compare their environmental effects over the whole life-cycle. An investigation of the environmental effects during the production and the use of the fuels can contribute discussions about the direction of future developments.

The methodological technique adopted for the investigation is a **life cycle assessment**[6] (**LCA**). It has been developed in recent years to analyse and understand the full natural resource and environmental effects of using a product. The LCA is defined by the Society of Environmental Toxicology and Chemistry (SETAC) as „*... an objective process to evaluate the environmental burdens associated with a product, package, process or activity*“ (POSTLETHWAITE 1994). The process involves:

- Identifying and quantifying energy consumed, material used and waste discharged to the environment
- Assessing the impact on the environment of those energy and material uses and waste releases
- Identifying ways to reduce the environmental impacts (*additional in some studies*)

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[6] Some authors use also the term life cycle analysis.

This methodology is a further development of the product related environmental policy of the Nineteen Seventies and Eighties in the industrialised countries. The policy of looking on single aspects of a product was replaced by a global view on all environmental effects (UBA 1992/07).

LCA's and similar studies have possessed a more diverse set of goals: Scientists tried to identify all the environmental impacts of a product. Manufacturers tried to prove that their products are the most environmental friendly ones. They used the results for advertising and to improve their production processes. Governmental organisations used it as a tool for environmental policy.

Subjects of former LCA's were packing materials, chemical products, construction materials or energy systems. Different formal names are given for LCA's and they employ different methodologies. Results for a product often vary considerably depending on the investigated indicators, the modules of the life cycle and the weighing given to the effects.

Various national and international organisations are making attempts to standardise and harmonise the concepts[7] without final results (WEIDEMA/CHRISTIANSEN 1994). Essential parts of an LCA as defined by most of them are *goal definition, life cycle inventory (LCI), environmental impact assessment* and *evaluation of the results* (BERG ET AL. 1994; DIN 1994; POSTLETHWAITE 1994; UBA 1992/07).

The **goal definition** is a basic requirement to clearly define the exact investigatory purpose of the LCA. Objectives and the target group of the study are named. The underlying necessity is described and a definition for a functional unit of the product is made. The system is described. The investigated life cycle should include all necessary modules for resource extraction, production, distribution, consumption or use and waste management. The necessary transport of goods and materials are also subject of the investigation. A list of indicators that should be investigated is set up. Indicators are mainly quantifiable values for environmental pollution. Qualitative indicators, for example noise, are not considered in all studies because it is difficult to summarise them over the life cycle. Only the methodology of *Produktlinienanalyse* or *„product line assessment*“ (ÖKO 1987) examines economic and social indicators. Definitions are made for the system boundaries: **time, location, depth** and **cut-off criteria**.

A balance sheet is made in the **life cycle inventory (LCI)** of all in- and outputs in the various stages of the life cycle. The flow of energy and materials between the environment and the examined system is compiled. The effects to the environment are described for all modules. This is described as the *vertical analysis*. The values for the indicators are calculated or compiled to give the following *horizontal analysis*. This step takes into account life cycle criteria like recycling or life time.

The **environmental impact assessment** is the next step. The possible effects are described and assessed by the list of indicators. These include all local and global effects on different aspects of the environment for example water and air pollution, global warming or resource depletion.

An **evaluation of the results** of the life cycle inventory and the assessed impacts is the final part of the LCA. Criteria for the valuation must be described. They should be generally accepted. The single indicators are weighed and ranked with the end goal to decide which product has the least overall adverse impact on the environment. Political decisions are prepared.

The process of **valuation** is the most discussed and the least standardised stage of the LCA. Some authors tried to comprehend all resulting effects in a single value by standardisation of the effects. Other authors give weigh to the effects in a verbal discussion. However, the relative

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[7] These are e.g. ISO-SAGE (The International Standards Organisation Strategic Advisory Group), CEN (Comité Européen de Normalisation), SETAC (Society of Environmental Toxicology and Chemistry) and the German Institute for Standardisation (DIN).

importance of one impact category to another is a matter of value judgement, reflecting social values and preferences. Consensus has not yet been established any common basis for achieving or rationalising such judgements. And it seems difficult establishing such consensus in the future because the judgement depends on the personal value system of the researcher.

SETAC suggests an evaluation of the weak points of the life cycle and potentials for further improvements as an other essential part defined as *improvement assessment*. The effect of further developments or the influx of specific unsure data is evaluated in a *sensitivity analysis*.

The parts of the LCA are not executed in a straight succession. An LCA is a process with the necessity for an evaluation of the done parts at a given time. For the iterative process a continuously forward and backward move between preceding and following modules is essential (BERG ET AL. 1994; DIN 1994).

1.4 Use of the Computer Program TEMIS as a Tool for the Assessment

For the life cycle assessment all information about energy use, waste, emissions of air and water pollutants as well as material demands are collected. To compare different products, the investigated environmental impacts are calculated in a comparable way, in relation to a finished product. For this survey the computer program **TEMIS 2.0** (Total Emissions Model for Integrated Systems) was used as a tool to do the necessary calculations (TEMIS 2.0, 2.1).

This program was developed by the German non-governmental *Öko-Institut* and the *Environmental Systems Research Group at the University of Kassel*. The Öko-Institute has collected available comparative information on environmental aspects for Germany[8]. Due to the cross boundary interdependence of national energy systems, parts of the original database reflect processes in other countries. The program and database should offer an analytic tool for decision makers in energy policy (FRITSCHE 1991/11; GEMIS 2.0).

It is possible to calculate the environmental effects of different energy scenarios with TEMIS. These scenarios consist of a certain amount of energy to be delivered by a mix of energy systems. The user can define and adapt the scenarios to different needs (FRITSCHE 1991/11).

The model does not only include emissions from the operation of energy facilities, but considers all ”upstream” activities. Beside the emissions of pollutants, other aspects like land use, costs, materials used, residuals, etc. are included in the program. The emissions of greenhouse gases are compiled to CO_2-equivalents. The TEMIS version 2.0 is available as public domain software in both English and German[9] (FRITSCHE 1991/11; GEMIS 2.0; ÖKO 1993/3, 1993/12, 1994/12; TEMIS 2.0, 2.1).

To run the program data on the fuels used and the processes involved are required. The energy carriers are described with their contents of elements. TEMIS calculates the heating values from this information. Figure 1.4 shows all information that must be collected for each process in order to calculate the emissions and impacts of the process. The life cycle system is broken down into a series of inter-linked operations. Each of these **processes** is connected through in- and output products or through the auxiliary fuels and materials. The impacts are handled over as a burden of the output product to the following module in the life cycle. All calculations for environmental impacts are related to the energy content (lower heating value) of the specific

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[8] These were first used in GEMIS 2.0 (Gesamt-Emissions-Modell Integrierter Systeme) and then translated for the English version TEMIS.

[9] TEMIS 2.0 can be received with an FTP (file transfer protocol) server via the INTERNET in the following way: *open ftp.hrz.uni-kassel.de,* Login: *anonymous,* Password: (email address), *cd /pub/envsys/temis, get* (all files). These data are available on a FTP-server: TELNET *itu106.ut.tu-berlin.de,* LOGIN *ftp,* PASS *ftp,* CD *india,* LS -L, FTP *own name,* LOGIN *own name,* PASS *own,* PUT **.* *.** Use *pkunzip.exe* for extracting the files

product. The calculations made for auxiliary materials are related to the weight (TEMIS 2.0; ÖKO 1993/3, 1993/12, 1994/12).

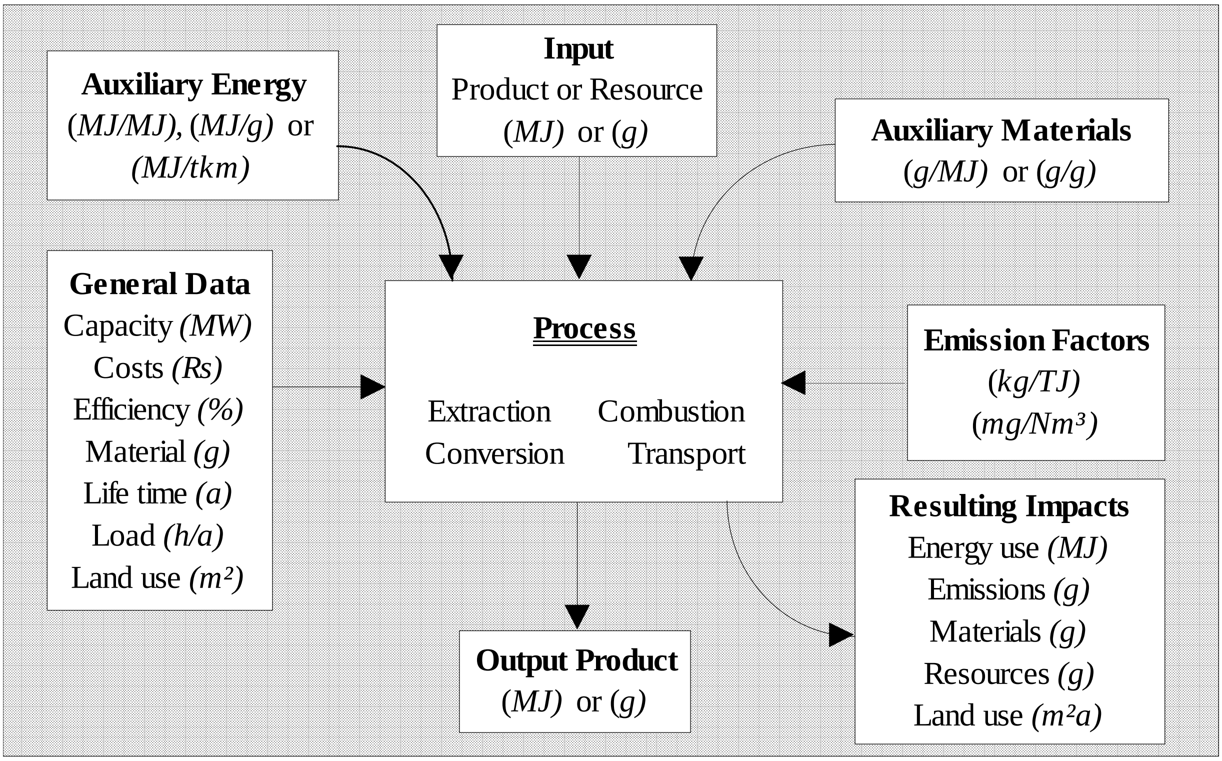

Figure 1.4: Structure of a process module in TEMIS 2.0. The necessary information data inputs and the results calculated by the program are shown. The obligatory unit is given in brackets

Nm³ - Norm cubic metres (used for standardised values of emission data)

1.5 Collecting of Data and Participating Organisations

The information necessary to prepare the life cycle inventory was gathered during a five-months stay (November 1994 to April 1995) in the **TATA Energy Research Institute** (TERI), New Delhi, India. This non-governmental institute was set up in 1974 to tackle the problems that humankind is likely to face because of the gradual depletion of the earth's finite energy resources and the existing methods of their use.

The work in India included:

- Screening of the available information from reports prepared by the Institute
- Interviews with people of the institute concerned with this subject
- Visits to the laboratory, the library and field research sites
- Visit to the INTERNATIONAL CONFERENCE ON ENERGY and the PETROTECH conference and exhibition held in New Delhi
- Visits to other Research Institutes
- Interviews with experts from governmental bodies and public enterprises

2 Goal Definition for the Life Cycle Assessment

This chapter contains definitions needed for the carrying out of the life cycle inventory (LCI). The systematic manner follows the proposals made by BERG ET AL. (1994), DIN (1994), UBA (1992/7), POSTLETHWAITE (1994) and FLEISCHER/RINGE (1992).

2.1 Target Group and Objectives of the Study

The purpose of this study is to discuss environmental advantages and disadvantages of different cooking possibilities typically used in India. Cooking is an interesting field to apply the instrument of an LCA in India because of its great significance to the energy balance. The suggestions made for an LCA by SETAC or other organisations represent a high demand. To satisfy these demands scientists normally require several years of time, even if they work in countries with an easier access to compiled data than in India. Thus, only a **restricted life cycle assessment** is proposed here. It will look at all stages from the resource extraction down to the consumption of the fuels. The main subject of investigation is the life cycle inventory. Many criteria are cut off because it was not possible to investigate them sufficiently during the limited time in India.

The purpose of the study is to provide arguments for discussions about the advantages and disadvantages of different means of cooking. This study is addressed to people who are interested in the environmental impacts but also the economic and social aspects of cooking. Policymakers in both energy policy and the environmental policy should gain from this study. Further on, the study might be interesting for people who deal with the environmental impacts of the energy sector and especially the petroleum sector. The focus of the study is India but the situation in other developing countries might be comparable and therefore the investigation might also be found helpful.

2.2 Description of the Underlying Necessity

The subject of this investigation is the activity of cooking food and heating water on cookstoves in Indian households. The investigation is focused on all the environmental impacts that are connected with this activity. The underlying requirement for this activity is the heating of food and drinks for the preparation of meals. All over the world, cooking is an old practice. The reasons are many. Some fruit, vegetables, cereals and meat must be cooked to make them edible or to improve their taste. Water and other foods are cooked for hygienic reasons, i.e. to kill germs. Both cooking and eating together are social acts, influenced by traditions and religious practices.

The cooking practices in India are not uniform. It varies from place to place according to different traditions. The practices also depend on the living conditions of the family, for example working hours, age of children and available income. Here are two examples: Farmer families in Guntur district, Andhra Pradesh, followed the meal pattern: coffee - early lunch - snack & tea - dinner meal. After the early meal they work in the fields. For the lower income status the most popular practice is early lunch - mid-day meal - dinner meal. These people carry their mid-day dish to the workplace (NEERAJA/VENKATA 1991).

For most of the meals some form of cooking is necessary. This is in contrast to the „continental“ or „western“ style of meals, in which one or two meals mainly consist of cold food. For practical reasons, they are sometimes cooked with an earlier meal and than subsequently eaten cold.

2.3 Selection of Product Variants for the Investigation

Before starting an LCA the product variants to be investigated are defined. A neutral or **zero option** should be investigated for every LCA. In this case a scenario with no cooking might be theoretically possible, but due to strong traditions this does not appear to be a practical means of meeting the demand for food in India. Thus the investigation is restricted to several possibilities which deliver heat for cooking. They can be broadly divided into three variants:

- Cooking in a traditional way with **biomass fuels**. These are fuelwood, charcoal, animal dung, agricultural wastes, etc. In most cases they are collected by the users. This has led to the expression *non-commercial fuels*. A new possibility in this field is the cooking with biogas or *gobargas* (Indian expression) produced in plants from animal dung or agricultural wastes. Cooking with vegetable oil belongs also to this category.
- Cooking with the **commercial fuels** LPG, kerosene and coal. They are based on non-renewable resources. The fuels are bought by the user. Another possibility, that is seldom utilised in India, is cooking with electricity.
- Cooking with **new technologies.** These possibilities do not burn a fuel and they are based on renewable energy. In the main this is cooking with *solar cookers*. Other possibilities might be the use of electricity generated by wind, solar power or hydropower.

The life cycle assessment for cooking fuels in India is divided into two parts, undertaken at the same time by two researchers. This study is focused on the most important *commercial fuels*. A second study, undertaken by LAUTERBACH (n.d.), looks at the *biomass fuels*. The results of the life cycle inventory for both types of fuels shall be compared in the report of LAUTERBACH.

The investigation for commercial fuels is restricted to **LPG** (liquefied petroleum gas) and **SKO** (superior **kerosene** oil). These two are the most used commercial fuels. It is relatively easy to handle them in one study because the life cycle is analogous at several stages. Due to the limited time available for the investigation the assessment could not be extended to other fuels like coal or electricity. Most surveys in the field of cooking describe LPG and kerosene (to a lesser degree) as the least polluting fuels[1] (EPA 1992; KULKARNI ET AL. 1994; RAIYANI ET AL. 1993; REDDY/REDDY 1994; SMITH n.d.; SMITH ET AL. 1994). This statement is based on the ambient air situation in the kitchen and the emission of greenhouse gases due to the cooking. Thus, these commercial fuels are the most important ones for an LCA.

2.4 Definition of the Functional Unit

To serve the necessity of a cooked meal heating energy is required. The energy demanded to cook one dish depends not only on the type and energy content of the fuel, but also on the **efficiency** (eta) of the cookstove used. The efficiency states the ratio between the energy that is useful for cooking and the *theoretical energy* delivered by the fuel. This leads to the definition of the functional unit as **effective heating energy** delivered by burning the fuel. The SI[2] unit to measure energy is **Joule[3] (J).** The purpose of the LCI is to calculate environmental impacts in relation to a specific amount of effective heating energy delivered by burning the investigated fuel.

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[1] This statement is limited to the field of fired appliances. Solar heaters have no direct emissions of air pollutants in the kitchen.

[2] SI - Système International, International system of units of measurement. This study uses SI units.

[3] The meaning of this abstract unit can be described with an example: To heat one kg (one litre) of water from 20°C to 100°C a useful heating energy of 334 kJ is required.

2.5 Life Cycle of Liquefied Petroleum Gas (LPG) and Kerosene

The life cycles for the two fuels LPG and kerosene are shown in Figure 2.1. Boxes that compile different streams to one are virtual processes to explain the origin of the available **amount** of a product.

The original resource for the production of kerosene and LPG is crude oil. LPG is also derived from natural gas. These resources are extracted in India from onshore and offshore sources. The investigation concentrates on both the exploration activities and on the following exploitation of the resources. Crude oil is also imported with tankers into the country. All these aspects of the life cycle are termed the *upstream sector*.

The resources are transported by pipeline or with tankers to the processing facilities. The *transportation* and connected aspects of the life cycle are investigated for the LCI in a separate chapter.

The crude oil is processed in refineries. LPG and kerosene are two of the possible products. In gas processing plants LPG and other gases are extracted from the natural gas. LPG and kerosene are also imported in bulk by means of tankers from foreign refineries and processing plants. For cooking purposes the LPG is filled into steel-cylinders at bottling plants. These plants receive the product by rail or road tanker trucks. All the processing steps are summarised in the *downstream sector*.

The LPG-bottles are delivered to the retailers of the marketing organisations by road trucks. From the retailers they are transported to the end user by a variety of vehicles. The gas is burnt for cooking or lighting. The empty bottles are returned in the same way to the bottling plant by employees of the marketing organisations to be used again.

Kerosene is brought to the wholesaler by train or road tanker trucks. The latter are also used to transport the fuel from the storage of the wholesaler to the retailer. The retailer stores it in barrels. The product is refilled into containers brought by the customers. They use it for cooking or other purposes (e.g. lighting).

The *waste management* is not considered in this main life cycle because the product is burnt. There is no direct waste left following consumption. Waste is produced at some stages of the life cycle and the waste management is accordingly described there.

2.6 Investigated Indicators and their Meaning

Environmental pollution can be identified by many analytical indicators. Some of these indicators can be **quantified** and added over the life cycle, e.g. the amount of effluent. This is not possible for indicators like noise, because they must be seen in the context of a particular location. Investigations on social or economic impacts describe the **quality** of a certain situation in words. They cannot be the subject of a calculation.

The investigation for an LCA should be focused on a list of indicators that describe an important impact. Data should be available for the whole life-cycle of the compared processes in a comparable accuracy. A proposed list of indicators is given by HUNT (n.d.). The choice of indicators for this report was influenced by regulations for emissions from production sites in India. To make general estimations, enough data were available only for pollutants that are subject of these regulations.

The following **indicators** are investigated in the study. They are necessary for the structure of TEMIS as shown in figure 1.4. The indicators are considered in TEMIS as products. The description starts with **quantifiable** impacts:

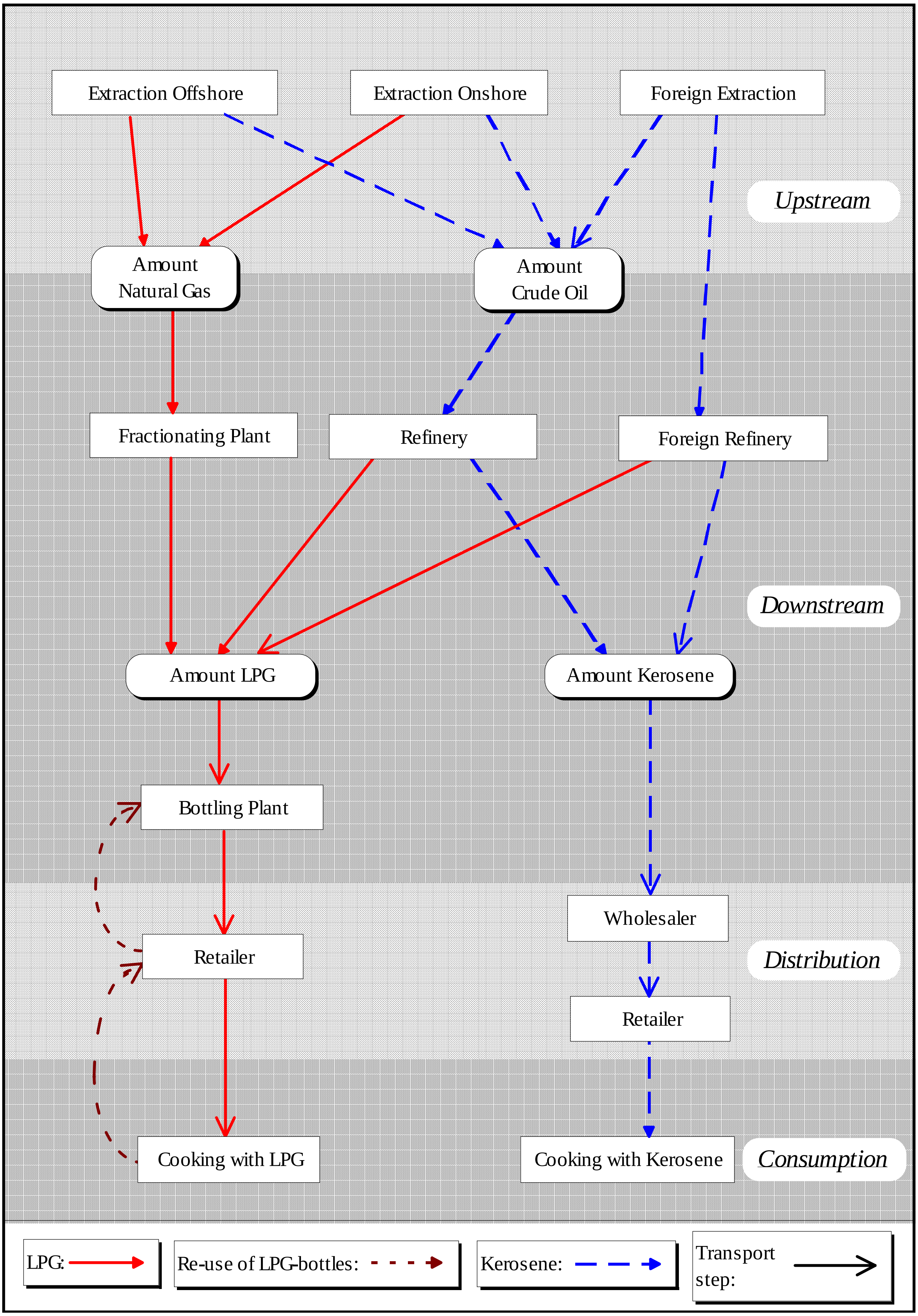

Figure 2.1: Stages in the life cycle for liquefied petroleum gas and kerosene in India. The arrow has a special head (as shown in the right bottom edge) if transportation is investigated between two stages

Energy use is classified by the quantity and type of the burnt fuels or the *electricity* used. Main categories of the fuels are *solid, gaseous and liquid*. They are described in chapter 3.2. For the calculations, assumptions are made about the average composition and type of the used fuels. The use of *human power* is also investigated but this energy use is not summed up for the LCI.

Materials are an input in the life cycle. Investigated materials are *water, chemicals, steel* and *cement*. The indicator *water* describes the use of ground, river, lake and sea water for production, cleaning and cooling. It does not include formation water, that is lifted up with the crude oil and natural gas and that is re-injected in the same production step. The generic indicator *chemicals* describes the use of chemical substances in the processes. The chemicals vary considerably in their attributes, e.g. energy requirement for their production or hazards for the environment. It was not possible to specify the chemicals further, due to the high number of different categories. *Steel* and *cement* are used as construction materials for the processing facilities, transport devices and as materials for the cookstoves. Other materials used in these production facilities are not considered in the LCI.

Water pollution is one sector to describe the environmental impacts of an activity. One indicator in this study is the discharged *effluent*. This includes the discharge of cooling water. Effluents are only evaluated if they are discharged into rivers and sea or irrigation schemes. Evaporated or re-injected effluents are not considered. The pollution is described by the indicators *BOD (biochemical oxygen demand* usually in 5 days*)* and *COD (chemical oxygen demand)* to give the impact on the oxygen balance in the receiving water body. *Total dissolved solids (TDS)* and *total suspended solids (TSS)* are sum indicators for solids discharged in the effluent. *Phenol* and *oil & grease* are measurements of toxic substances. The choice of these indicators considers the regulations made in MINAS (Minimal National Standards, CBWP 1985/07). Sulphides and sulphates effluents are not calculated because the available data was not adequate.

Air pollution mainly consists of flue gases emitted from combustion devices. *Sulphur dioxide (SO_2), Nitrogen oxides (NO_x)* and *Carbon monoxide (CO)* are hazardous substances for human beings, animals and plants. They are also destructive to buildings if they are dissolved in water and become acid rain. *Particulate matter (PM)* describes the emissions of particles[4] into the atmosphere which contain toxic chemicals and thus they are also hazardous to living beings.

A group of gases contributing to the global warming is summarised under the category *greenhouse gases*. These are CO, CO_2, NO_X, methane, NMVOC (non-methane volatile organic compounds) and N_2O. The CO_2 equivalents (CO2 eq) are calculated with factors given by ÖKO (1993/12). Table 2.1 gives the used factors. The amount of emitted gases is multiplied by these factors. These factors aggregate the climatic impacts of different greenhouse gases for a period of 100 years. The results are expressed in the mass of *CO2 eq* in grams.

Table 2.1: CO_2 equivalent factors for a period of 100 years (ÖKO 1993/12)

	CH_4	CO	NO_X	NMVOC	N_2O	CO_2
Equivalent factor	25	3	8	11	270	1

TEMIS requires the concentration of the pollutants in the flue gases of the combustion devices to calculate the emissions. The indicators SO_2 and CO_2 are computed by TEMIS with information about the burnt fuel. Only the emissions of SO_2 and particulate matter are regulated in In-

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[4] The emission of particles is described in Indian publications with different terms. The expressions *particulate matter (PM)* and *particulates* are used in the National standards. The expression *suspended particulates* is used in the ambient air quality guidelines. Other authors use also *suspended particulate matter* (SPM) or *total suspended particulates* (TSP) for emissions and ambient air concentrations. TEMIS uses *particulates* for the emission values.

dia. Other air pollutants are controlled by the ambient air concentration. The latter data cannot be used for an LCA because it is not possible to link the information to a particular product. Information about other air pollutants as indicators was not available for India.

Wastes take different forms and require various forms of management. In this study two types of wastes are classified. One type is *cuttings*. These are mainly geologically based materials from drilling activities with related impurities from the drilling chemicals. Normally they are not dumped on landfills. The rest of possible *wastes* are for example sludge from effluent treatment plants, used drilling mud and oily sludge from storage facilities. These wastes are more hazardous.

The *land use* required for the production facilities is investigated as another qualitative indicator. Other investigated environmental impacts are the effects on *flora and fauna*, local influences on *temperature* and emissions of *noise*. All these and the following indicators belong to the category of **qualitative** impacts.

The following aspects of enquiry are investigated in the category **society**. The possibilities of *accidents* and *health risks* are described. Investigations about *time budgets, gender specific shares, product use* and *cultural plurality* are interesting mainly for the product use. The investigation of these and other social indicators was proposed by the Öko-Institut for the instrument of „Produktlinienanalyse“ (ÖKO 1987). Other authors often do not consider these factors. The investigations in these areas should supplement the LCA.

Economic indicators are also not surveyed in all LCA’s. In this study economic variables on the system such as *subsidies, market concentration, international co-operation and dependence* are described. The policy of subsidies to petroleum products made it (for example) impossible to allocate impacts by their product value. Another example is the market concentration in the petroleum sectors that limits a competition between the companies. *Individual costs* to the customer are calculated for the product variants. National costs are also outlined. Investigations concerning *couple products* are necessary to understand some processes and to allocate their impacts. Looking at the economic parameters is required to understand some restrictions to the system. They are less important for the comparison than the investigation on environmental indicators.

2.7 Matrix for the Life Cycle Assessment

Not all indicators stated in chapter 2.6 are investigated at every stage in the life cycle because sometimes they do not have a significant impact. Stages in the product life and investigated indicators are mapped in a matrix that is shown in Table 2.2.

The different stages of the life-cycle are shown as explained in chapter 2.5. These stages are numbered with I to X. Each indicator is also labelled with a specific expression. Thus every field of the shown matrix has a specific number. This number is quoted if the field is investigated in one of the following chapters. Field *{III-B-1}* stands for example for the water use in refineries. These labels make it possible to use the matrix in parallel with a reading of the following chapters. It enables one to ascertain the exact point of transformation at every stage in the investigation.

The fields of energy use, materials, waste water, air pollution and wastes represent **quantifiable impacts**. The LCI tries to find values that give the effect of each specific process step.

Table 2.2: Matrix of life stages and investigated indicators for the restricted LCA of commercial cooking fuels

I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*	*X*			
◆	◆	◆	-	-	-	◆	◆	◆	◆	*A-1*	Liquid fuels	Energy use
◆	◆	◆	◆	-	-	◆	-	-	-	*A-2*	Gaseous fuels	
-	-	◆	-	-	-	-	-	◆	-	*A-3*	Solid fuels	
-	?	◆	-	◆	-	-	-	◆	-	*A-4*	Electricity	
◆	◆	◆	◆	?	?	◆	?	?	◆	*A-5*	Human power	
◆	◆	◆	?	◆	-	?	-	-	-	*B-1*	Water	Materials
-	◆	◆	◆	◆	◆	◆	◆	◆	◆	*B-2*	Steel	
◆	-	◆	◆	◆	◆	-	-	?	?	*B-3*	Cement	
◆	◆	?	-	-	-	-	-	-	-	*B-4*	Chemicals	
◆	◆	◆	◆	◆	-	?	?	-	-	*C-1*	Effluents	Water pollution
◆	◆	◆	?	?	-	?	?	?	?	*C-2*	BOD	
◆	◆	◆	?	?	-	?	?	?	?	*C-3*	COD	
-	-	◆	?	?	-	-	?	-	-	*C-4*	Phenol	
◆	◆	?	?	?	-	-	-	-	-	*C-5*	TDS	
◆	◆	◆	?	?	-	-	-	-	-	*C-6*	TSS	
◆	◆	◆	?	-	?	-	◆	?	?	*C-7*	Oil & grease	
◆	◆	◆	◆	-	-	◆	◆	◆	◆	*D-1*	SO_2	Air pollution
◆	◆	◆	○	-	-	◆	○	○	◆	*D-2*	NO_X	
◆	◆	◆	○	-	-	◆	○	○	◆	*D-3*	CO	
◆	◆	◆	○	-	-	◆	○	○	◆	*D-4*	PM	
◆	◆	○	○	◆	◆	◆	○	○	◆	*D-5*	Greenhouse gases	
◆	-	-	-	-	-	-	-	-	-	*E-1*	Cuttings	Waste
◆	◆	◆	?	-	-	-	◆	-	-	*E-2*	Waste (others)	
?	◆	◆	◆	◆	◆	◆	◆	◆	◆	*F-1*	Land use	Other impacts
?	◆	◆	?	-	-	-	○	?	?	*F-2*	Flora and fauna	
◆	◆	?	?	-	-	◆	-	○	○	*F-3*	Noise	
◆	◆	?	-	-	-	-	-	-	-	*F-4*	Temperature	
◆	◆	?	?	?	◆	◆	?	?	◆	*G-1*	Health risks	Society
-	-	-	-	-	-	◆	-	-	-	*G-2*	Gender specific shares	
-	-	-	-	-	?	◆	-	-	-	*G-3*	Time budget	
-	-	-	-	-	◆	◆	-	-	-	*G-4*	Product use	
-	-	-	-	-	-	◆	-	-	-	*G-5*	Cultural plurality	
◆	◆	?	?	?	-	◆	◆	?	◆	*G-6*	Accidents	
?	◆	◆	?	?	?	◆	?	?	?	*H-1*	Costs	Economy
-	-	◆	◆	-	◆	◆	?	?	?	*H-2*	Subsidies	
◆	◆	◆	◆	◆	-	-	◆	-	-	*H-3*	International co-operation, dependence	
◆	◆	◆	◆	◆	◆	◆	-	-	◆	*H-4*	Market concentration	
-	◆	◆	◆	-	-	-	-	-	-	*H-5*	Couple products	

I	Exploration	Upstream (Resource Extraction)
II	Exploitation	
III	Refinery	
IV	Gas processing plant	Downstream (Production)
V	Bottling plant	
VI	Wholesaler, Retailer	Distribution
VII	Cooking	Consumption
VIII	Sea	
IX	Rail	Transport
X	Road	

◆	This field is investigated in the LCI for the situation in India and/or for imports
○	Estimations are made for this field in the LCI
?	Effect might be possible but the indicator was not investigated in the LCI
-	No effect or negligible effect

The fields in the second half of the matrix (except the costs and subsidies), starting with field *F-2* describe **qualitative impacts**. These effects are given in words. Naturally it is not possible to add these qualitative effects or to calculate them over the whole life cycle. Note that noise emissions also belong to this category, even if measurable, they can not be aggregated over the life cycle.

Every field is marked with a sign that indicates the nature of the investigation in the LCI. This anticipates some of the results in following chapters. The fields of the matrix investigated for India are marked with a „◆“. The fields that were estimated for the inventory are labelled with a „○“. Other fields that might be of interest but where no information was available are marked with a „**?**“. Fields without any effect or with negligible effects are filled with a „-“.

2.8 Definition of the Balance Room

The LCI and the calculations of the impacts are made for a cooking session in Dhanawas, a small village in a rural region near New Delhi. This is necessary to compare the results with the study of LAUTERBACH (n.d.). Figure 2.2 shows the location of this village in India. Dhanawas is in the district of Gurgaon, 15 km from Gurgaon, in the state of Haryana. It is approximately 7 km from the neighbouring Faroukhnagar and about 45 km from Delhi (TERI 1994).

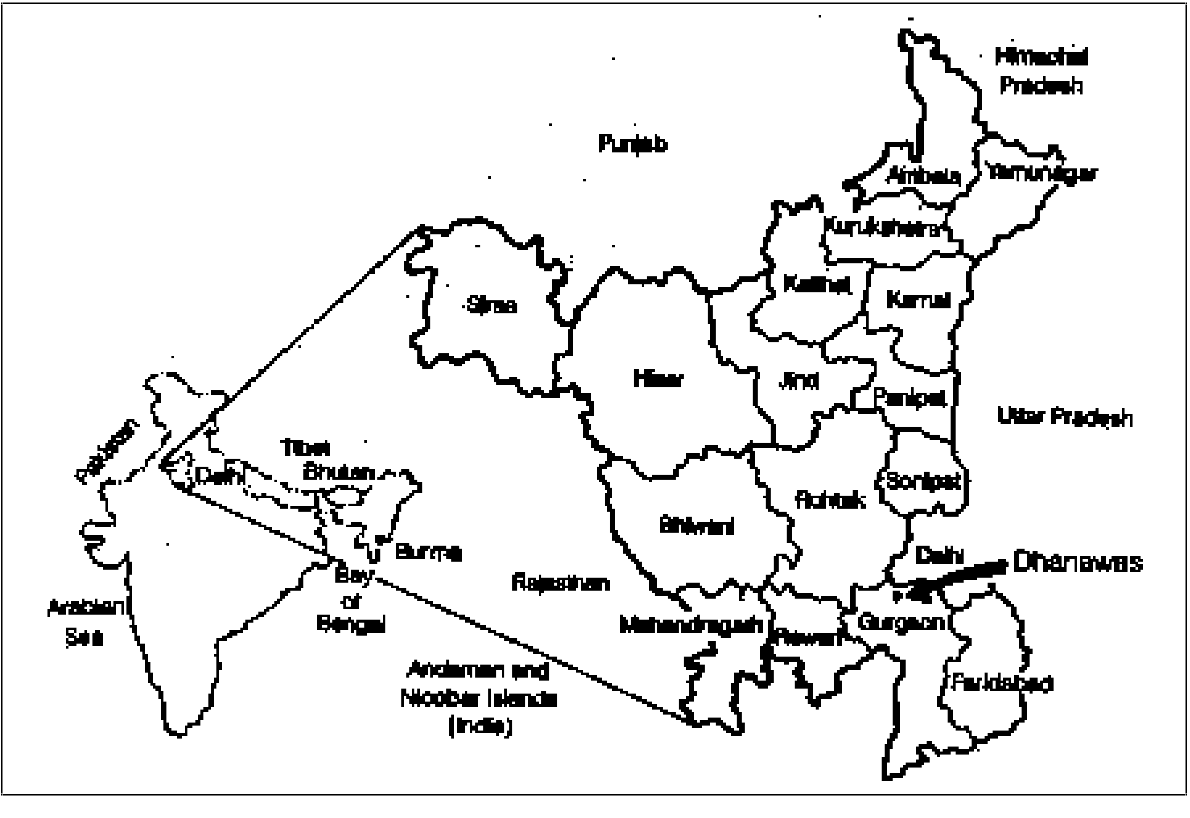

Figure 2.2: The location of Dhanawas (TERI 1994)

The LCI investigates the environmental impacts of the production in India. This includes a scenario for the average production and transports in India. Environmental effects caused outside the country by imported products are considered in this scenario. Thus the set of **investigation boundaries** varies in each stages of the life cycle. The investigation boundaries for the effects depend also on the nature of the pollutants. Greenhouse gases have a global effect. Effects from the discharge of effluents are restricted to the rivers and oceans in India. The effects of the air pollutant emissions during the actual cooking are mainly of local concern inside the kitchen. In TEMIS the emissions of the cookstove are defined as *local* to distinguish these effects from the average *global* emissions of foregoing processes. Further definitions of the boundaries are made in the inventory of each process.

2.9 Depth of the Balance

The definition and description of the **depth of the balance** are necessary to have comparable results within the study and against other studies. It is neither possible nor necessary to consider all impacts that are linked with the life cycle. At a certain point the investigation is **cut-off** because the additional impacts are considered very small in comparison to the impacts investigated[5].

For this study, only **auxiliary materials** (as described in chapter 2.6) are considered. Because of limited time it was not possible to estimate the energy use and environmental impact of the production of these materials in India. So only the amount of used materials is calculated. The additional environmental impacts are estimated using an assessment made for German material processing facilities. Lubricants, additives for the fuels and their production were not investigated.

The amount of produced wastes is calculated. But the **waste-management** with its impacts and energy requirement is not taken into account. For some data used in the inventory the demarcation line was not clear. Further information about the investigated depth of balance is given in the inventory for the specific process.

For the **computation** in this study the following method is used: The energy flow is computed **iterative** by TEMIS[6]. This is required because outputs of a process are also possible inputs for the same process (e.g. refinery needs diesel oil as an energy carrier). This input causes an additional impact on the specific process. This impacts must be considered for all processes using the specified product (the impact of diesel oil production must be considered for the refinery). The accuracy for the iterative (looped) computation was set to 0.001. This is a standard value used in most of the cases. This value stops the iterative computation, if the variation between two steps of computation (= maximum possible mistake due to the computation) is less than 1% (ÖKO 1993/12, 1994/12).

2.10 Balance Time for the Investigation

The purpose of the investigation is to describe the situation in India in the year 1993/94. It was not possible to find the information required for this year. Thus sources from 1984 to April 1995 were used to maintain sufficient data. In some areas possible changes in the future are outlined. Some effects are not linked to one year, e.g. the efforts to explore new sources of crude oil or raw materials used to construct a plant. These impacts are depreciated over the estimated life span of the process.

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[5] For example: For cooking a stove is used. The steel for it has to be produced. For the construction of the steel plant again materials are necessary. It is not possible to find an end in this tree of impacts.

[6] This is described by ÖKO (1993/12, 1994/12).

3 Product Data for the Life Cycle Inventory

This chapter contains some information about the products used in the life cycle inventory. The definition of *products*, these are resources, materials, fuels and residuals, is essential for the application of TEMIS. Residuals and materials are described as indicators in chapter 2.6. Most of the product definitions use the *generic* data sets of GEMIS 2.0 and TEMIS 2.0. These data sets describe the situation in Germany. Data diverging from this data set is laid out for India in this chapter. Some new products are also defined here (ÖKO 1993/12, 1994/12).

3.1 Resources

Resources describes primary forms of energy and raw materials. The definitions include qualitative environmental aspects. They are considered with an assessment factor. Descriptions for all resources except water adopt the *generic* data set. The new resource ***water*** describes the use of ground, river, lake and sea water as a resource for processes. The extraction of ground water can lead to groundwater depletion. Water extracted from surface sources is no longer available for other purposes such as biological demands or irrigation. The water extraction also causes disadvantages to the micro-ecology. The influences to the indicators solid waste, accidents and land use are not significant (ÖKO 1993/12).

3.2 Investigation of Energy Carriers Used in India

Detailed information is given in this chapter for the two investigated fuels, LPG and kerosene and the resources natural gas and crude oil. For other fuels only brief information is given. The fuels are described first in alphabetical order. The **ultimate analysis** for all **solid** and **liquid fuels** is given in Table 3.3 (at the end of this chapter). The assessed **analysis of gases** is given in Table 3.4. The values given in these tables are used for all further calculations.

For every solid or liquid fuel TEMIS requires the contents of elements as weight percentage (wt%). For gaseous fuels a content analysis of the gases in volume percentage (vol%) is necessary. TEMIS uses the data for calculating the following (ÖKO 1993/12, 1994/12):

- **Lower** and **higher heating value**. The lower heating value (LHV) shows the useful energy content of a fuel. The higher heating value (HHV) stands for the theoretical energy content.
- **Air demand** and **flue gas rate** for combustion. These values are necessary to calculate the total emissions of a pollutant if the concentration in the flue gases is known.
- Theoretical emissions of **SO_2, CO_2, halogens** and **ashes**. The results are used in the life cycle inventory.

Coke

Coke is a by-product of some processes in the refinery. It is burned as a solid fuel for heating purposes in the refinery. Coke has a lower heating value of 39.8 MJ/kg (CFHT 1995).

Crude Oil (or **Crude**)

21 million tonnes of crude oil are imported from OPEC countries of the Gulf region: i.e. Iran, Saudi-Arabia, Dubai, Abu-Dhabi, and from Malaysia, Nigeria and in small amounts from Australia. In 1993/94, India produced 34 million tonnes domestically of the total crude oil processed(IOC 1995; OOC 1995).

The crude oil extracted in India contains small amounts of sulphur in the range of 0.2 to 0.4 wt%. The crude oil imported from the OPEC, except the 1 million tonnes low sulphur crude from Nigeria, contains between 2 and 2.5 wt% of sulphur. The sulphur content of the feed stock for refineries on average lies between 1.2 to 1.5 wt% (IOC 1995; OCC 1995). The content of water in the crude oil for the processing in the refinery should not exceed 1 wt%(CBWP 1985/12). In most cases, the content of nitrogen compounds does not exceed 0.3 wt% (SHARMA/AGNIHORTI 1992). Data for Indian, imported and processed crude oil are given in Table 3.3.

Diesel Oil (**High Speed Diesel** or **Light Diesel Oil**)

Motor vehicles require **HSD** (high speed diesel) as their source of fuel. **LDO** (light diesel oil) is used in small amounts for agriculture. Six times more diesel is used than gasoline in India. The price is set at 8 Rs per litre and it is subsidised. The product specification of Indian diesel is given in (ISI 1974a).

The content of sulphur in Indian diesel ranges between 0.3 and 0.7 wt% (in two refineries) with an average of 0.5 wt%. This is less than the legal specification of 1 wt%. For metropolitan cities this maximum will be reduced on April 1, 1996, to 0.5 wt%. The content of sulphur in diesel will be reduced to 0.25 wt% by the year 2000 (IIP 1994/12; HINDUSTAN TIMES 1994; IOC 1995). The carbon content of HSD and LDO is 86.1 wt% and 87.4 wt% respectively. Estimated data for Indian diesel oil is given in Table 3.3 (SHARMA/SHARMA 1994/04).

Fuel gas

Fuel gas is a waste gas from the rectification unit. It basically contains methane and is a low grade fuel. It has a lower heating value of 46.9 MJ/m³ and is used in refineries (ALUER 1994; CFHT 1995).

Fuel Oil (also **Furnace Oil** or **F.O.**)

The sulphur content of fuel oil ranges between 0.5 wt% and the maximum of 4.5 wt% prescribed by the standard. Refineries normally use fuel oil with a sulphur content of 1 wt% to reduce the emissions of sulphur dioxide. The specified ash content is less than 0.1 wt% and the water content is less than 1 wt%. The carbon content of fuel oil is 88 wt%. It has a lower heating value of 41.72 MJ/kg (CFHT 1995; ISI 1988; IOC 1995; OCC 1995; SHARMA/SHARMA 1994/04).

Hardcoal

Hardcoal extracted in India and used for steam trains has a lower heating value of 20.93 MJ/kg. The ash content of this coal is 23 wt% and the moisture content is estimated to be 10 wt% (IPNGS 1992; TEDDY 1994). Hardcoal is used for power plants and has a relatively high ash content of 40 wt% and a moisture content of 10 wt%. The LHV estimated at 11.8 MJ/kg (HARANT ET AL. 1993; TEDDY 1994). Table 3.3 shows the estimations for the ultimate analysis.

Kerosene (also **SKO** (Superior Kerosene Oil) or **Kerosine**)

Kerosene is a highly refined transparent fuel with a distinctive odour. It has clean and efficient burning qualities. Kerosene has many applications (BPCL 1994; BHANDARI/THUKRAL 1994):

- A fuel for wick fed lamps and pressure burner type lamps
- A fuel in cooking stoves, ranges, ovens, standby electricity generators and blow lamps
- Miscellaneous as a cleaning fluid, a solvent in paints or a raw material for the manufacture of printing inks
- Substitute to gasoline or diesel oil in the combustion motors of transport vehicles[1]

Kerosene mainly consists of saturated hydrocarbons with the molecule length of ten carbon atoms (C_{10}). Due to the flash point of 50°C, it is possible to handle it at room temperature without danger. Its low viscosity makes it easily possible to pump or to transport it by the capillary action of a wick (LAUTERBACH/SCHNAITER 1995).

The specifications for kerosene are given in the Indian standard 1459-1974. The fuel should be free of visible water, sediment and suspended matter. The char value shall not exceed 20 mg/kg of consumed oil. The minimum flash point (Abel) is 35°C. The total sulphur content shall not exceed 0.25 wt%. The lower heating value of kerosene is 40.8 to 43.5 MJ/kg (ISI 1974). Table 3.1 records the composition of kerosene investigated by different authors.

Table 3.1: Analysis of elements in kerosene (wt%)

	India	*India*	*Germany*	*Estimation for the LCI*
Carbon	86.15	85.7	84.36	**85.9**
Hydrogen		14.0	15.09	**13.8**
Oxygen		-	0.45	**0.05**
Nitrogen		-	0.10	**0.05**
Sulphur		0.5	(0.25)	**0.2**
Source:	SHARMA/ SHARMA 1994	PCRA 1994/12	LAUTERBACH/ SCHNAITER 1995[a]	

[a] This analysis was made for German kerosene. The sulphur content is additional to 100%. It was estimated by using literature data.

LPG (Liquefied Petroleum Gas)

The history of LPG is connected to the wider production history of the petroleum industry. The production of gasoline was disturbed by the presence of unstable materials in the fuel. These substances at first could not be kept easily in a liquid state and they boiled away at atmospheric pressure. The result being it was not possible to use them practically, and they were released into the atmosphere or burned as flares. In 1910 a process was developed to convert some of the gases into a liquid at a moderate pressure of 4,900 hPa. It was then possible to vaporise them again by reducing the pressure. This new fuel had both the compactness and portability of a liquid, yet it could be burned as a gas (MODAK 1995).

It is possible to convert 240 volumes of gas into one volume of liquid. The ability to compress LPG is a distinct advantage over natural gas where a relatively high pressure is required. This

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[1] Some drivers and gasoline retailers profit illegally from the highly subsidised price. The price of gasoline is five times higher than this of kerosene. It is estimated that about 15% of the total kerosene consumption in India is diverted for use as transport fuel (BHANDARI/THUKRAL 1994).

property makes it easy to store large volumes in small containers. In India LPG is produced in 12 refineries and 5 natural gas fractionating plants (MODAK 1995).

LPG is a basic mixture of propane (C_3H_8), n-butane, i-butane (C_4H_{10}) plus small parts of propene (C_3H_6) and butene (C_4H_8). Requirements for LPG are prescribed in the Indian standard 4576-1978. The contents of volatile sulphur should be below 0.02 wt%. Commercial butane-propane mixture should have a maximum vapour pressure of 16,500 hPa (ISI 1978).

LPG that is produced in Indian refineries is butane rich (ratio butane/propane = 65:35) in comparison to other countries because of the lower demand for light distillates. Butane in other countries is an important resource for the petrochemical industry. The LPG produced from natural gas in fractionating plants has a high content of propane (50:50) (IIP 1994/12; MODAK 1995; TERI 1989/03). Gaseous LPG is estimated as a mixture of 45 vol% propane and 55 vol% butane. For the calculations it is treated as a liquid fuel (**LPG**) with 0.01 wt% of sulphur, 17.7 wt% of hydrogen and 82.29 wt% of carbon. Table 3.3 shows all data for the following calculations.

Natural Gas

Natural gas is a mixture of hydrocarbon and non-hydrocarbon gases. It is found in the porous formations beneath the earth surface, either in association with crude oil or as free gas. The heating values vary from 33 MJ/m³ to 45 MJ/m³ depending on the composition. It is used as a resource for fractionating plants and as a fuel in production (JAGGI 1994). Different analysis's of the components in Indian natural gases are shown in Table 3.2.

Table 3.2: Composition of Natural Gas in India. The tables gives also minimum and maximum contents with different analysis's

						Estimation
	Vol%	***Mol% min - max.***		***Mol% min - max.***		***Vol%***
N_2	0.1	0.01	n.a.	0.4	10.3	**0.1**
H_2S	n.a.	0	0.0006	n.a.	n.a.	**0.0005**
CO_2	0.9	4.76	5.12	0.03	0.25	**1.0**
O_2	n.a.	n.a.	n.a.	0.02	1.24	**0.0**
CH_4	85.8	79	92	76.1	83.5	**86.8**
C_2H_6	7.2	5.12	7.7	2.6	10.1	**7.0**
C_3H_8	3.2	1.18	4.7	2.3	6.1	**3.0**
C_4H_{10}	1.8	0.1	2	1.4	2.4	**1.8**
C_4H_8	n.a.	n.a.	n.a.	n.a.	n.a.	**0.3**
C_5H_{12}	0.7	0	0.5	0.1	1.6	**-**
C_6+	0.3	0	0.03	0.1	1.3	**-**
Sources:	JAGGI 1994	PETROTECH 1995		SHARMA/CHAUDHARY 1992		

n.a. - data not available

Data for Products in TEMIS

Products that are marked with (GEMIS) were used without modifications from the data of GEMIS 2.0 or TEMIS 2.0. Other products are estimated with the previously presented information. Table 3.3 and Table 3.4 show the data for the calculation with TEMIS. The following abbreviations are used for the comments:

CIS	Commonwealth of independent states
In	India
int	international
OPEC	Organisation of Oil Exporting Countries
PP	Power plant

Table 3.3: Ultimate analysis of solid and liquid fuels

Fuel and comment	***LHV (MJ/kg)***	***HHV (MJ/kg)***	***Spec. weight (kg/MJ)***	***C (wt%)***	***H (wt%)***	***N (wt%)***	***O (wt%)***	***S (wt%)***	***Cl (wt%)***	***F (wt%)***	***H_2O (wt%)***	***Ash (wt%)***
C2-C3-In	44.80	48.61	0.02232	83.05	16.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Liquefied ethane-propane mixture, raw material produced in fractionating plants for petrochemical products												
Coke-In	39.75	41.93	0.02515	88.00	9.65	0.50	0.10	0.60	0.00	0.00	0.20	0.95
Coke produced in the FCC of the refinery and burnt in furnaces												
Crude-CIS	40.00	40.86	0.025	85.00	10.10	1.00	1.00	1.90	0.00	0.00	1.00	0.00
Crude oil from Commonwealth of Independent States (GEMIS)												
Crude-In	39.69	42.09	0.0252	85.70	10.60	0.30	1.00	0.30	0.00	0.00	0.80	1.30
Crude oil extracted in India												
Crude-OPEC	38.78	41.05	0.02579	84.00	10.00	1.00	1.00	2.25	0.00	0.00	1.00	0.75
Average crude oil imported to India mainly from OPEC countries (GEMIS)												
Crude-proc-In	39.26	41.58	0.02547	85.20	10.20	0.50	1.00	1.35	0.00	0.00	0.80	0.95
Average crude oil processed in Indian refineries												
HSD-In	42.46	45.45	0.02355	86.10	13.27	0.02	0.00	0.50	0.00	0.00	0.10	0.01
High speed diesel oil used for vehicles, trains and technical equipment (generators) in India												
LDO-In	41.78	44.49	0.02393	87.40	12.06	0.02	0.00	0.50	0.00	0.00	0.00	0.02
Light diesel oil used in small amounts for agriculture in India												
Fuel-oil-(HPS)-In	39.74	42.17	0.02517	84.00	10.80	0.30	0.50	4.00	0.00	0.00	0.30	0.10
Fuel oil or heavy petroleum stock (HPS) in India												
Fuel-oil-low-S-In	41.69	44.57	0.02398	85.25	12.75	0.20	0.40	1.00	0.00	0.00	0.30	0.10
Low sulphur fuel oil or (HPS) used in refineries												
Hardcoal-CIS	25.60	26.25	0.03906	70.43	2.00	1.30	7.00	1.00	0.25	0.02	8.00	10.00
Imported hardcoal from CIS (GEMIS)												
Hardcoal/PP-In	11.76	13.64	0.08503	29	4.00	1.50	15.00	0.50	0.004	0.001	10.00	40.00
Estimation for hardcoal as a fuel for power-plants												

Table 3.3: Ultimate analysis of solid and liquid fuels (continuation)

Fuel and comment	LHV	HHV	Spec. weight	C	H	N	O	S	Cl	F	H_2O	Ash
	(MJ/kg)	(MJ/kg)	(kg/MJ)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)
Hardcoal/train-In	20.93	23.40	0.04778	51.00	5.00	1.30	9.00	0.50	0.20	0.01	10.00	23.00
Estimation for hardcoal as a fuel for steam trains in India												
Kerosene	42.86	45.96	0.02333	85.90	13.80	0.05	0.05	0.20	0.00	0.00	0.00	0.00
Superior kerosene oil for cooking and lightning in India												
LPG	45.24	49.22	0.0221	82.29	17.70	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Liquefied petroleum gas for residential use in India 45% propane and 55% butane												
NGL-In	48.96	54.36	0.02042	76.00	24.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural gas liquefied												
Oil-H-CIS	40.70	42.99	0.02457	87.00	10.75	0.45	0.00	1.80	0.00	0.00	0.00	0.00
Heavy-fuel oil, data based on German HFO (GEMIS)												
Oil-H-OPEC	40.70	42.99	0.02457	87.00	10.75	0.45	0.00	1.80	0.00	0.00	0.00	0.00
Heavy-fuel oil, data based on German HFO (GEMIS)												

Table 3.4: Analysis of gases

Gas	spec. weight	LHV	HHV	CH_4	C_2H_6	C_2H_4	C_3H_8	C_3H_6	$n\text{-}C_4H_{10}$	$i\text{-}C_4H_{10}$	C_4H_8	CO_2	N_2	H_2S
	(kg/MJ)	(MJ/m³)							(vol%)					
Fuel-gas-ref-In	0.02084	46.85	51.52	59.80	37.59	1.76	0.10	0.00	0.05	0.00	0.00	0.50	0.20	0.01
Fuel-gas used for internal energy demand in refineries														
LNG-fra-In	0.02015	36.40	40.37	97.85	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00
Lean natural gas, used as a fuel in gas fractionating plants														
LPG-g	0.02176	110.06	119.30	0.00	0.00	0.00	45.00	0.00	54.98	0.00	0.00	0.00	0.00	0.02
„gaseous“ LPG														
Natural-gas-CIS	0.02050	36.00	39.93	97.71	0.80	0.00	0.26	0.00	0.05	0.05	0.05	0.15	0.93	0.00
Natural gas from CIS (Siberia) (GEMIS)														
Natural-gas-In	0.02090	41.03	45.31	86.80	7.00	0.00	3.00	0.00	1.00	0.80	0.30	1.00	0.10	0.00
Estimation for typical natural gas in India, used as fuel for extraction, flaring and as a resource														

4 Life Cycle Inventory for the Upstream Sector

This chapter contains the life cycle inventory for the production of natural gas and crude oil in India.

4.1 Economical Background and Statistics for the Supply of Natural Gas and Crude Oil in India

The first production of oil in commercial quantities began in India over a hundred years ago with the discovery and subsequent development of the Digboi field. Gas and oil production in the western offshore area began in 1976 in the Bombay High field with the installation of the „NA“ platform(BATRA 1995).

In India there are two state controlled enterprises, the **Oil & Natural Gas Corporation Ltd.** (**ONGC**) and **Oil India Ltd.** (**OIL**) that undertake exploration, drilling and exploitation activities of crude oil and natural gas in the country in these days *{I-H-4,II-H-4}*[1]. A major initiative has been recently undertaken to form a new company through a consortium of three major downstream enterprises. The plan for the future is to open this field up to foreign companies *{II-H-3}*. They will be invited to work in joint ventures with the Indian companies (SHARMA 1995).

The ONGC is the major company in India and among the world's top 15 profit-making companies. The erstwhile Oil & Natural Gas **Commission** was established in August 1956 and renamed at 1 February 1994. The ONGC was incorporated in June 1993 as a public limited company. Today it has a working staff of 48,000 people *{I,II-A-5}*. Its activities are spread over 20 sedimentary basins, accounting for over 100 oil and gas fields. In 1988 it did 92.4% of drilling, and in 1991/92 the ONGC produced 92% of the total crude oil and natural gas produced in the country (ONGC 1994; PETROTECH 1995).

The formation of OIL dates back to 1959. On 14 October 1981 OIL was fully nationalised. OIL has its headquarters in Assam and is engaged in exploration, drilling and production from onshore areas in Assam, Rajasthan and Arunchal Pradesh. Nowadays OIL explores offshore basins in the Bay of Bengal and near the Andamans. It also runs a fractionating plant in Duljan. Today 9,000 persons are working for the company *{I,II-A-5}*. OIL has a preferential recruitment policy favouring unskilled labour that ensures a high proportion of employees are local people (JAGGI 1995; OIL 1989, 1995).

The Indian policy in the early years followed the motif of self-reliance as the foundation stone of economic activity. Core activities, like oil production, were turned into the exclusive responsibility of the India State. Since 1991 reforms have taken place and many sectors have been opened up to private enterprises. The oil price shock and the high bill for imports led the government to retract from its prior policy and to invite private enterprises (RAMAN/UPADHYAY 1995).

India is a net oil importing country and the annual bill for oil imports is increasing every year *{II-H-1}*. The oil sector assumes a particular importance in the economy, as it accounts for more than 40% of the commercial energy consumed. It is primarily responsible for the capital exchange outflow which constitutes one half of the entire foreign trades bill over a year (RAMAN/UPADHYAY 1995; TEDDY 1994).

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[1] The expression in brackets is reference to the investigated indicator and the stage of the life cycle as shown in table 2.2. This advance is explained in chapter 2.7.

All the statistical data given in the next section for 1992/93 is provisional. The calculations for the LCA are based on this data. The structure for crude oil and natural gas is shown in Table 4.1. For the following calculations the products are converted into MJ because the calculations are based on their specific energy content. During the year 29 million tonnes (MT) of crude oil was imported[2], 16 MT was produced at the offshore basin Bombay High and 11 MT was produced at onshore fields. Natural gas extraction accompanies the oil exploitation. The large share of the total 18 billion cubic metres (Bm^3) is produced at the offshore fields (13 Bm^3). Today nearly 2 billion cubic metres of the natural gas is flared[3] without any usage. A small part of the gas is re-injected for storage and pressure maintenance. Accordingly the net production is 16 billion cubic metres (TEDDY 1994).

Table 4.1: Structure and total supply of natural gas and crude oil in 1992/93 (TEDDY 1994)

	Crude oil	*Crude oil (10^9 MJ)*	*Natural gas*	*Natural gas (10^9 MJ)*	*Supply (10^9 MJ)*
Import	53%	1,160	-	-	1,160
Production onshore net	20%	445	23%	189	637
Production offshore net	27%	625	77%	548	1,170
Flaring	**-**	**-**	1.85 Bm^3	76	**-**
Available amount	**57.8 MT**	**2,230**	**16.10 Bm^3**	**737**	**2,970**

The data for the year 1993/94 was not yet fully available[4], but it is possible to give a few general trends. In this year 30.8 million tonnes of crude, with a value of 101 billion Rs, was imported. OIL produced 2.8 MT of crude out of the total production of 27 MT. The over all production of natural gas during 1993/94 was 18.3 billion m^3. The western offshore fields share of total gas production was 73%. The production for the next year is projected to be 20.1 billion m^3. Of this 78% is net production after flaring, internal use and shrinkage. Several projects are going on to increase the proportion gas used (ONGC 1994; Jaggi 1995; WSN 1994).

The production of crude oil in the country shows a declining trend from 1990/91 to 1992/93. The main reasons for a significant shortfall in production vis-à-vis targets was frequent power shutdowns and environmental constraints in the eastern region. The government has initiated a number of measures that should lead to an increase in production for the following years (WSN 1994).

To meet the demand in India, steps are being taken to import natural gas. A pre-feasibility study for transporting 56 MMSCMD (million metric square cubic metres per day) gas through a submarine pipeline from the Middle-East has been completed. A planned pipeline from Iran to India with a capacity of 50 to 70 MMSCMD is also proposed (WSN 1994).

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[2] In recent years there were also exports, beside the imports. The reason is that the Indian crude oil has a low sulphur content. The net profit for this *sweet* crude is higher than the price paid for imported *sour* crude that contains hydrogen sulphide or sulphur hydrocarbons. In refineries the two types are sometimes mixed (ONGC 1994/12).

[3] Since several years one aim of the oil exploiting companies is to increase the ratio between net and gross natural gas production. The main reasons that flaring could not be eliminated until now, are delays in commissioning downstream gas utilisation facilities and the little flexibility in reducing the production of associated gases (TEDDY 1994).

[4] Data for the offshore crude production, but also other necessary statistical data e.g. about drilling activities were not available.

4.2 Exploration and Exploitation of Crude Oil and Natural Gas in India

The impact of the resource extraction in India is investigated in this chapter. Petroleum was formed from dead plant and animal life in the seas. The material rots away in the sea-bed until finally only fatty and oily substances were left. The substances become buried under a compact layer of mud. Through the activities of oxygen-removing bacteria the substances are transferred into crude oil and gas. The oil seldom remains in the rock where it was formed. Sometimes it travels through pores until it reaches the surface. The reason for the migration is the compacting or squeezing of the source rock. Usually above the oil there is a layer of natural gas and beneath it there is salt water from the ancient sea (OIL 1989).

In India there are 26 large sedimentary territories that cover a total area of about 1.7 million km^2, including 700,000 km^2 in offshore area. Figure 4.1 shows the sedimentary basins in India. To date in one quarter of this area reserves of hydrocarbons have been discovered but half of the basins are virtually unexplored. There is certainly a good possibility of discovering much more commercial oil and gas in the remaining sedimentary basins. Much effort is being made towards this end (PETROTECH 1995).

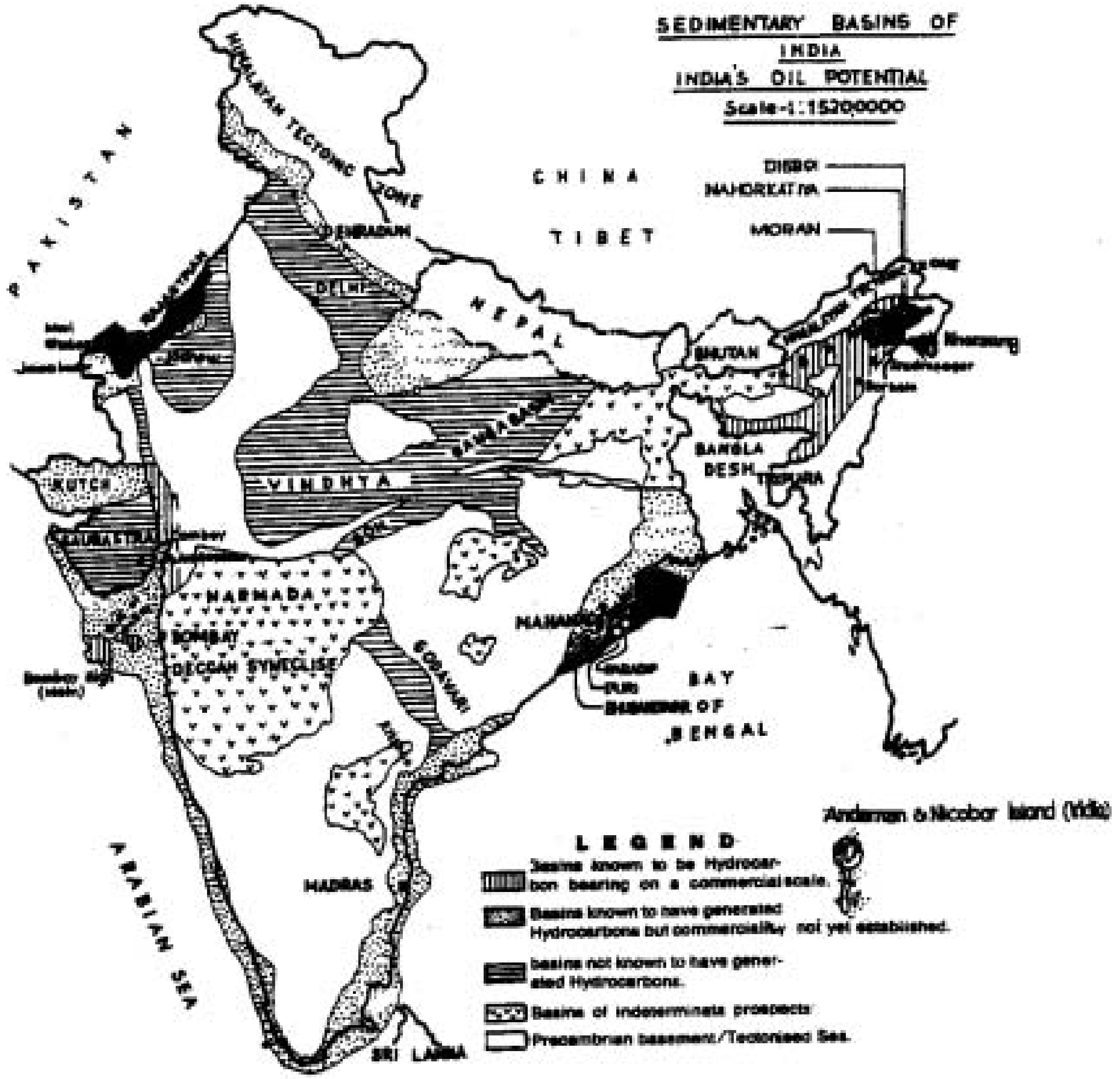

Figure 4.1: Map of India's potential sedimentary oil basins (OIL 1989)

The extraction and production of natural gas and crude oil can be divided into the following phases:

- Geographical and geophysical survey, seismic field studies
- Exploratory drilling with discovery wells
- Development drilling
- Well testing
- Construction of the processing facilities
- Production of natural gas and crude oil
- Dismantling and reclaiming of the production site

The production of crude oil and natural gas is investigated together in the following sections *{II-H-5}*. The allocation of the impacts is described in chapter 4.2.3.1. Most of the natural gas is produced in association with the crude oil. This makes it impossible to treat the two resources separated. Offshore and onshore productions are described together. Differences in the activities are stated and the environmental calculations are made separately.

4.2.1 Exploration of Petroleum Resources

4.2.1.1 Pre-surveys for the Exploration

The environmental impacts of the pre-surveys are relatively negligible. Main aspects are land use, energy use for the activities and artificial explosions for the seismic field parties. Steps for the discovery of oil fields are the following ones (OIL 1989; ONGC 1994/12):

- Geological survey: Source rock, a reservoir rock and a seal rock are necessary for the development of petroleum resources
- Geophysical survey: Energy waves from dynamite blast are reflected by rock formations to sensitive detectors. The sound reflection, sonar and seismic methods are used since 1930
- Geochemical survey: In use since 1950
- Remote sensing
- Microbiology survey of the fauna one metre below the earth surface. It is surveyed whether there are micro-organisms that are adapted to higher hydrocarbon concentrations. This could be a hint on petroleum resources

It was not possible to investigate the impacts of the pre-surveys separately for India. In ÖKO (1994/12) the amount of energy used for pre-surveys including the exploratory drilling is estimated to be less than 0.05% of the finally exploited energy resources. A few impacts of the pre-surveys are considered in the calculations of the next chapter.

4.2.1.2 Exploratory and Developmental Drilling and Well Testing

The drilling done in India during the last three years is shown Table 4.2. The average activity of these years is used for the following calculations. The specific drilling activity is 41 mm per tonne of exploited crude oil. This is considerably more than the average value of 13 mm/t found by FRISCHKNECHT ET AL. (1995) for average crude oil imported to Europe.

Table 4.2: Number of exploratory and development wells and the drilled metreage in India during the years 1990/91 to 1992/93(TEDDY 1994)

	Exploratory Onshore		**Development Onshore**		**Exploratory Offshore**		**Development Offshore**		**Total**	
	(km)	***(No.)***	***(km)***	***(No.)***	***(km)***	***(No.)***	***(km)***	***(No.)***	***(km)***	***(No.)***
1990/91	434	176	455	220	184	73	92	66	1,165	535
1991/92	454	176	401	193	167	61	41	22	1,063	452
1992/93	413	172	441	196	176	69	75	31	1,105	468
Average	**434**	**175**	**432**	**203**	**176**	**68**	**69**	**40**	**1,111**	**485**

Discovery (or exploratory) wells are drilled to estimate the size of a reservoir. If the reservoir is found to be of value, the next step is the developmental drilling. Onshore discovery wells are used for the construction of development wells. For a long time this was a problem for offshore wells, but today they are sometimes used too. Over 130 onshore and offshore drilling rigs for exploration and development drilling are in ONGC operation(GOEL 1995; ONGC 1994/12; TEDDY 1994).

Figure 4.2 shows the plan of a drilling site. Today oil wells are bored with a revolving bit that is fixed to lengths of drill-pipe slung by wire-cables from a tall tower called a derrick. This pipe is rotated by machinery driven either by a diesel engine or electricity.

Artificial **drilling mud** is pumped down the drill-pipe and circulated continuously through holes in the bit and then back up at the sides of the hole. With the upcoming mud, rocky materials are brought to the surface. These **cuttings** are washed and separated from the drilling mud on the vibrating screens of the shale shaker. The mud is reused for drilling. Near the drilling site there are waste pits located to store the produced effluents and the cuttings (OIL 1989).

Today most of the activities in Indian offshore areas are run by the ONGC *{I-H-4}*. The western offshore area is situated about 160 km from Bombay and includes the fields Bombay High, Heera, Basin, Neelam, Panna, Ratna and Mukta. The first platforms for oil exploitation in the western offshore area were established by ONGC in 1976. OIL explores gas and oil offshore in the Bay of Bengal and the Andamans. The offshore drilling is done from ships or drilling platforms. Normally six to nine wells are drilled for one production platform. If the effluents and wastes are not brought on land they are discarded into the sea (PETROTECH 1995; OIL 1989; ONGC 1995/01).

Environmental impacts on land, water and air are linked from the beginning of drilling activities. These impacts are not directly related to the amount of products. They occur only at the beginning of a new production. To consider them correctly, they should be spread over the life time of the production facility. It seems to be reliable to assume, for the calculations, the mean for the last 3 years (as shown in Table 4.2) because the activities of drilling and the production of crude oil and gas have not changed markedly over this time. To simplify the inventory these average drilling impacts are related to the amount of natural gas and crude oil produced in the year 1992/93.

4.2.1.3 Use of Materials and Chemicals

During drilling the upcoming sub-surface bottom pressure is counteracted by a column of fluid. This is known as **drilling mud**. It contains various **chemicals** and has a high specific gravity. It is pumped into the well and then the cuttings (rock pieces) are brought up to the surface together with the mud. This mud also cools and lubricates the bit, builds up a „cake“ on the wall and prevents the hole from caving in (OIL 1989).

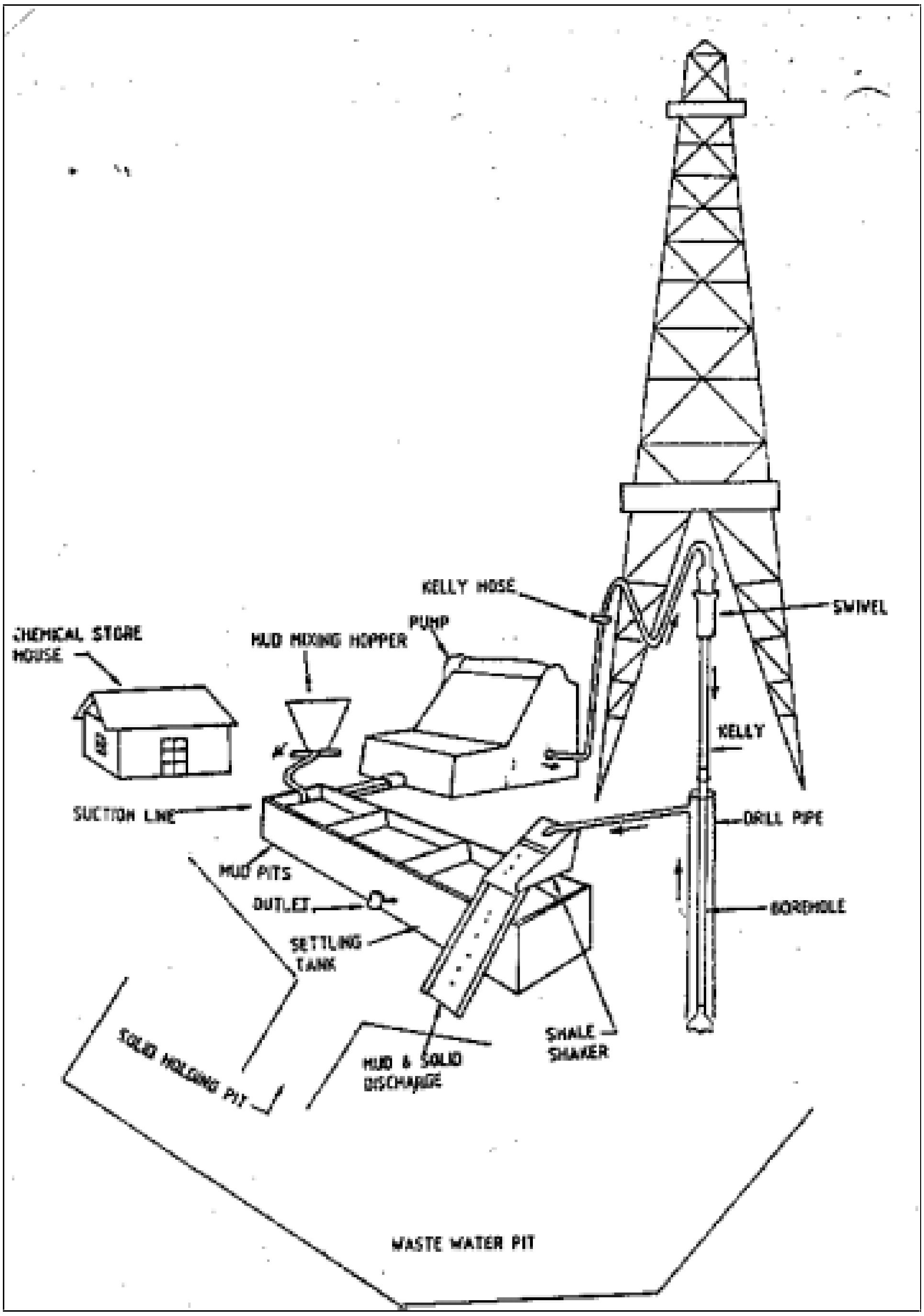

Figure 4.2: Drilling fluid circulation system and solid holding mechanism at an onshore drilling site (VELCHAMY/SINGH/NEGI 1992)

Water based mud contains 2 to 3% diesel oil. It can be used down to a depth of 1.5 km. Inside the reservoir the more expensive oil based mud is used. Diesel oil is a major constituent of this fluid. Drilling mud is adapted to the special needs of each drilling site. To gather the desired properties, various chemicals are steadily added (ASTHA 1995; OIL 1995; SHARMA/SHARMA 1994/04; PETROTECH 1995).

The chemicals used to prepare the mud vary considerably according to the different fluid systems. Figure 4.3 shows the composition of drilling fluid additives used in the western region of ONGC. The main ingredients of the fluids are fine solids like barite, bentonite clays, lignite or mica. They serve as lubricating, sealing and weighting materials. Other chemical additives like ferrochrome-lignosulfonate, polymers or thinners are used to give other properties. Some of the chemicals contain heavy metals. OIL uses low wax crude oil from the own oil production as a mud additive (ASTHA 1995; OIL 1995; SHARMA/SHARMA 1994/04; PETROTECH 1995).

About 250 to 350 tonnes of chemicals are used for one well *{I-B-4}*. An average of five parts water is mixed with the chemicals to prepare the drilling mud. Drilling fluids are sometimes lost into the formation (GOEL 1995; SHARMA/SHARMA 1994/04; PETROTECH 1995).

The amount of drilling mud used depends on the particular circumstances of the drilling and the depth of the well. Between 250 and 2,218 tonnes of drilling mud is used for one well. A volume of 100 to 4,800 cubic metres of liquid mud is discharged. The total amount of chemicals used by ONGC in 1993/94 was about 20,000 tonnes. The total HSD consumption in ONGC’s drilling operations has been reduced from a level of 8 million litres to 2.2 million litres per year by using alternative lubricating chemicals (ONGC 1994/04, 1995/01; PETROTECH 1995; SINGH 1992).

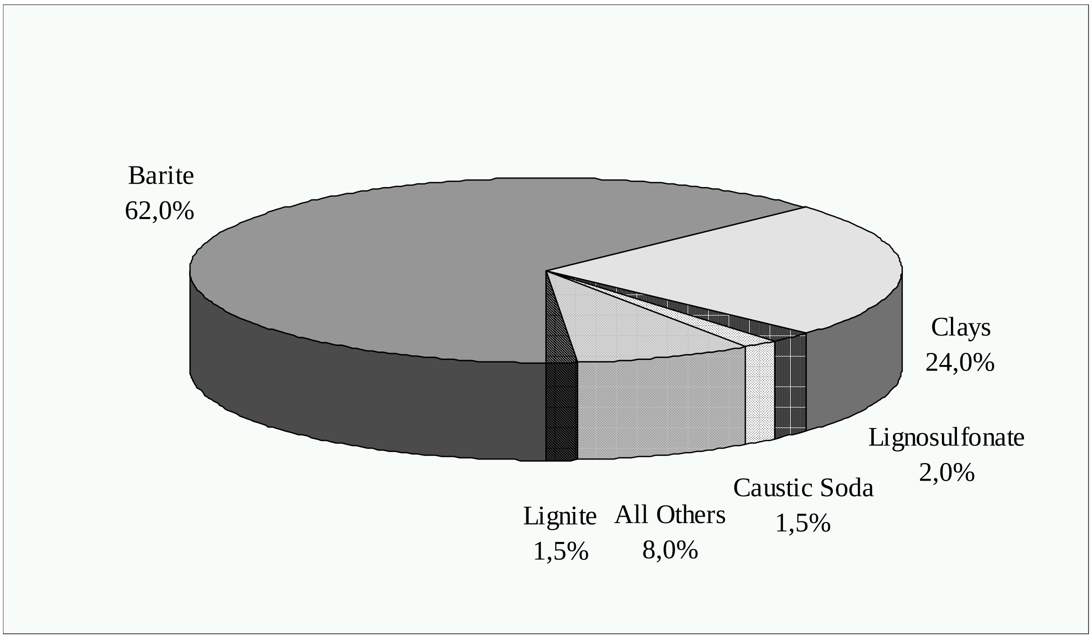

Figure 4.3: Share of the consumption rate for drilling fluid additives in the western region of ONGC (VELCHAMY/SINGH/NEGI 1992)

After the completion of the drilling, samples of each oil well are taken for various production and reservoir studies. To extract oil from the bottom of the well, the heavy mud is displaced by light weight diesel oil. The resulting flow of diesel oil reveals various required parameters and information about the well (ASTHA 1995; ONGC 1994/12).

To stabilise the well, its inner wall is cemented. One well is cemented with 100 to 120 tonnes of **special cement** *{I-B-3}*. For the activities of ONGC, this aggregates to a total of about 100 thousand tonnes of cement used every year. This cement needs a number of chemical additives to ensure certain properties. The cement should maintain for example a constant consistency before it hardens (ONGC 1994/12; PETROTECH 1995).

The amount of chemicals and cement used in India is estimated in Table 4.3 *{I-B-3, 4}*. These values are a calculation based on an average of different sources (ONGC 1995/01; TERI 1992/07; PETROTECH 1995).

Table 4.3: Materials used for the exploration activities in India (1,000 t/a)

	Offshore	***Onshore***
Chemicals	20.3	72.6
Cement	16.5	99.2

4.2.1.4 Energy Use and Emissions of Air Pollutants

During drilling, the following gaseous emissions are encountered (DINESH 1994/04; ONGC 1994/12):

- Mainly exhaust gases from burners, engines and power generation sets powered by diesel oil
- Products of combustion due to burning of natural gas and diesel oil at the time of well testing
- Emissions of hydrocarbons from *cold flaring* (release into the atmosphere without burning) during the testing period
- Smoke from the derrick (the framework over the oil well)
- Fumes, odours and cement dust from cementing and mud preparation operations

Due to the energy use emissions of air pollutants are encountered. For the drilling activities diesel oil is used. A share of about 58% of ONGC's total consumption of liquid petroleum products is used for drilling. The ONGC consumes 128 million litres of HSD and 24 million litres of lubricating oils[5] in its drilling operations. 6.5% share of the drilling costs is spent on petroleum products used as fuel. For one meter of drilling, among 102 (onshore) and 166 (offshore) litres of diesel oil and 1.8 to 3.1 litres of lubricating oils are used. After the various measurements for well testing, an amount of 50,000 litres per well is burnt off[6]. After calculations using these different sources for the HSD use, the average is 20.3 thousand tonnes for offshore and 56.4 thousand tonnes for onshore drilling *{I-A-1}*. The emission of air pollutants due to the burning of the HSD is calculated in chapter 4.2.2.7 (ASTHA 1995; GOEL 1995; ONGC 1994/12).

4.2.1.5 Use of Water and Discharge of Effluents

During drilling operations, an enormous quantity of water is handled for operational purposes. The water is used in the preparation of drilling mud, cooling and the cleaning of equipment.

The drilling mud can be reused in another well if transportation costs are not too expensive, otherwise it is treated with the other effluents of the drilling site. A widely used and simple method to get rid of water based drilling fluids from onshore sites, is to spread them thinly over the surrounding agricultural fields. BHARDWAJ (1994/04) claims that the material is a good fertiliser providing as organic chemicals such as diesel oil, corrosion inhibitors and biocides are kept to a minimum. The origin of different effluents at a drilling site is given in Table 4.4. Normally they are stored for some time in pits at the drilling site. If these pits are unlined, the probability of contamination of ground water increases with the higher permeability of the surface soil and a high ground-water table (AGNIHORTI ET AL. 1992).

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[5] The potential for reduction in the energy consumption in this area could be up to 10%. The savings possibilities are described by GOEL (1995).

[6] Approaches on how to reduce this type of consumption and how to reuse the diesel, were given by ASTHA (1995).

Table 4.4: Discharge of fluids during drilling (NEERI 1991/04)

Source of effluents	*Amount (l/h)*	*Frequency*
Shale shaker	160 - 320	continuous
Desander	480	2 - 3 h/d
Desilter	2,445 - 2,700	2 - 3 h/d
Centrifuge	4,720	1 - 3 h every 2 - 3 d
Sand trap	87,500 - 420,000	2 - 10 min every 2 - 3 d
Sample trap	240 - 480	5 - 10 min every 2 - 3 d
Total discharge of fluids for one well:		**420 - 4,800 m³**

The major pollutants in the effluents are soluble chemicals used with the drilling mud. Salt, hydrocarbons and heavy metals, found in the additives, accumulate in the waste pit (SINGH 1992). For the treatment of these effluents, mobile effluent treatment plants are used[7]. If the water is treated properly, it is possible to reuse it for the drilling operations, and thus save fresh water. If the water is not reused, the effluents are discharged into the environment whether they have been treated or not. A lack of proper wastewater management is likely to result in water pollution (PAUL ET AL. 1995; PETROTECH 1995; DINESH 1994/04).

At offshore drilling rigs, fluids that do not contain oil are discharged into the sea through pipelines that descend 50 m below the sea level. Otherwise the pot and drill water, in an amount of 23 to 45 tonnes, are transported to shore for treatment and disposal. The use of water recycling plants would potentially provide a large saving potential (GOEL 1995; NEERI 1990/03).

The onshore effluents are collected in pits with a capacity of 5,000 to 6,500 m³. On an average drilling site, 30 to 40 m³ of water is discharged daily. During the monsoon season these effluents are mixed with huge amounts of rain (PAUL ET AL. 1995; PETROTECH 1995; ONGC 1994/04).

The amount of **total effluent** is estimated as an average calculation based on three sources as shown in Table 4.5 *{I-B-1, I-C-1}*. The *water in mud* row gives the theoretical amount of water used to prepare the mud. Data about the *water use* was not available. The **water use** is estimated as the average of the water in mud value and the discharged effluent.

Table 4.5: Water balance for drilling (1,000 t/a)

	Offshore	*Onshore*
Water in mud	55	138
Total effluent	103	1,050
Water use	79	594

***Sources:** Calculation based on information given by SUYAN 1994/04; SHARMA/SHARMA 1994/04 and ONGC 1995*

Values for water pollutants in the treated effluents of drilling sites were available only for single wells. Thus these water pollutants are estimated together with the production effluents in chapter 4.2.2.8 *{I-C-2..C-7}*.

4.2.1.6 Cuttings and Waste

During drilling, different types of wastes are generated. The ratios as calculated by VELCHAMY/SINGH/NEGI (1992) are shown in Figure 4.4. Settlelates are residues of the settling tanks. The waste produce accompanying the treatment of effluents in ETP (Effluent treatment plants) is considered in chapter 4.2.2.8. Other types of waste arising from drilling are the left

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[7] OIL uses movable effluent treatment plants for all drilling sides. It is not clear if the ONGC has the same possibilities (JAGGI 1995).

additives in the cement, well treatment fluids and flow enhancers for stimulating production (TERI 1993/01).

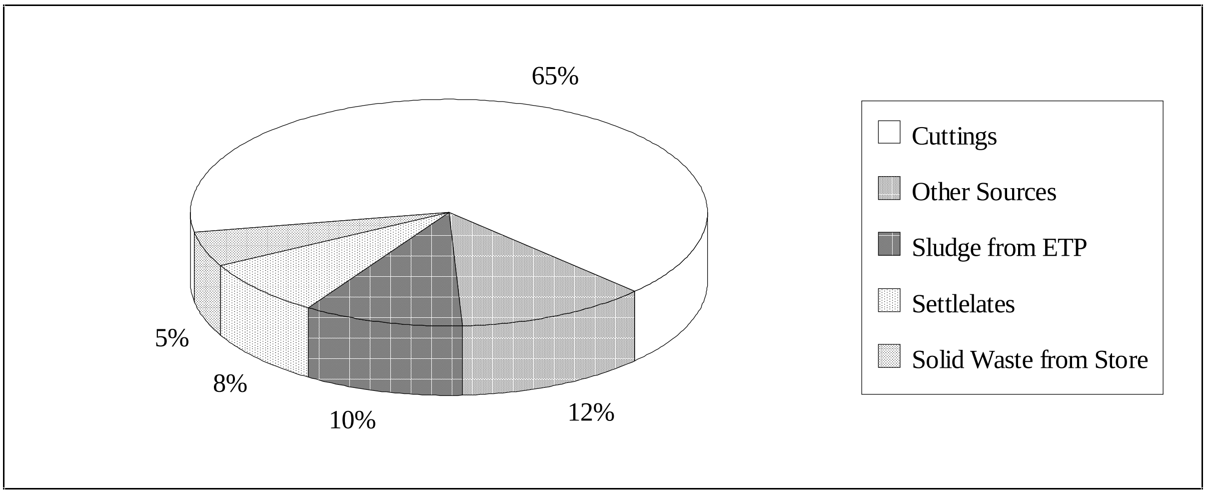

Figure 4.4: Solids generated and their distribution ratio (VELCHAMY/SINGH/NEGI 1992)

One of the environmental aspects of the drilling is the quantity and the characteristics of the produced drilling **cuttings**. This depends upon the nature of the formation, as well as upon the diameter and depth of the well. Cuttings generated average 10 tonnes per day at a drill site. The cuttings are inert rock materials with no toxicity. Problems are only assumed if heavy metals are washed out of the material. Similarly if remains of the drilling mud or traces of oil are discharged together with the cuttings. Onshore, the cuttings are used in agriculture, road construction or they are discarded in landfills. The cuttings from offshore platforms are discharged into the sea (BHARDWAJ 1994/04; CHAND 1992; TERI 1992/07).

It is difficult to quantify the magnitude of the impact from such discharges into the sea because the dispersion and dilution of such discharges will vary according to the ambient water condition, composition of drilling fluid and cutting discharges. The impact of the discharges into the sea also depends on the distance from the coast. At *Bombay High*, most of the activities are at a distance of 66 km from the coast and hence little impact would be expected at the coast. Adverse impacts on free water organisms are expected to be minor and of short duration. Effects on sessile organisms are limited to a short distance around the discharge point. If drilling activity is closer to the coast as for example in *Palk Bay,* or is close to major estuaries and deltas then the impacts will tend to be more significant as the possibility of dispersion and dilution of the discharges will be limited (TERI 1992/07; ONGC 1994/04). A governmental guideline will soon be in place for these wastes which will prescribe a secure storage in landfills (HAWK 1995).

Water pollutants are emitted due to the discharge of cuttings into the sea. FRISCHKNECHT ET AL. (1995) estimated an average of 100 g oil & grease per kg of cuttings from drilling with oil based mud. This type of mud is used for 20% of the drilling activities. The additional emission of oil & grease due to the discharge of cuttings from Indian offshore platforms is estimated to be 2 kg/TJ.

Table 4.6 shows categories of major waste discharges from offshore and onshore drilling. Under account of the typical quantities of cuttings, the total amount of waste due to the drilling activities can be estimated for one year. The amount of cuttings produced in one year is assessed with 171 thousand tonnes from offshore and 405 thousand tonnes from onshore drilling sites with the shown values *{I-E-1}*. TERI (1992/07) estimated the total amount of cuttings in 1990/91 to be about 38 - 60 thousand tonnes. Other wastes are estimated at an additional 100 tonnes per well

(VELCHAMY/SINGH/NEGI 1992). This adds up to 11 thousand tonnes of waste from offshore and 38 thousand tonnes of waste from onshore drilling activities *{I-E-2}*.

Table 4.6: Amounts of cuttings discharge from offshore and onshore drilling sites (tonnes)

	Exploration	***Development***
Total discharge of cuttings	836 - 1,305 per well	9,150 - 27,400 per platform [a]
Estimation for offshore wells	1,000 per well	2,570 per well
Estimation for onshore wells	1,070 per well	1,070 per well

[a] one platform = 6 to 9 wells

Sources: *Own calculation with SHARMA/SHARMA 1994/04; VELCHAMY/SINGH/NEGI 1992*

4.2.1.7 Other Environmental Impacts

Sources of noise at the drilling site are equipment like generators, pumps, etc., and transport vehicles *{I-F-3}*. Thermal pollution at drilling sites is caused by heat and light emitted from engines or due to the flaring of gas during well testing. This might have an impact on nearby standing plants *{I-F-2, 4}* (DINESH 1994/04).

4.2.2 Exploitation of Petroleum Resources in India

4.2.2.1 Exploitation from Onshore Areas

At the zone of interest, i.e. where petroleum is expected, the new drilled wells are perforated. The production of oil and gas from the well is initiated through newly created holes. The natural pressure forces the resources out of the well. A system of safety valves called a Christmas Tree ensures an even and controllable flow (OIL 1989).

Natural gas is found in the porous formations beneath the earth surface either in association with crude oil or as free gas. Depending on the reservoir-pressure and temperature, certain quantities of gas are either in a dissolved state or in free state above the oil column. The production of the so-called **associated gas** is dependent on the extraction of crude oil. This leads to gas flaring in case of low market demand for the gas. Most of the explored gas is associated (WSN 1994).

Natural gas can also be produced from gas reservoirs. The gas in the reservoir is under pressure. To avoid the formation of ice due to the expansion at the surface, the gas is preheated prior to expansion. The production of **free natural gas** is not related to a crude oil exploitation and thus controllable (WSN 1994).

Onshore 30 to 40% of the crude oil can be recovered by means of natural pressure. Most of the crude oil in India is produced by means of this **primary recovery**. After 2 to 3 years the **secondary recovery** starts. To get up to 50 to 60% of the crude oil, pressure water or gas is pumped into the reservoir to support the natural pressure. If the crude oil is liquefied under help of heat, chemicals or biological additives the exploitation is termed as **tertiary recovery**. This has advantages for the recovery of very viscous oils and is called Enhanced Oil Recovery (EOR). The secondary and tertiary recovery methods are more energy intensive and they will be extended in India in the next years. To reduce the possibility of subsidence, the optimum oil recovery should normally not exceed 50% of the total stored amount (AGNIHORTI ET AL. 1992; ONGC 1994/12; WSN 1994).

Gas lifting is universally used for the production of crude oil from depleted reservoirs. In this system high pressure gas is injected into the production string to assist lifting of well fluids to the surface. Presently about 60% of OIL’s crude production is achieved through this technique. Instead of pumping gas into the reservoir, it is also possible to achieve a high pressure by pumping water through injection wells into the earth. In both cases extra power is needed: to run gas compressing units or to run pumps on water wells and in the re-injection wells. The technique of water injection is used frequently in the offshore areas (WSN 1994).

The gas balance for the production of OIL is shown in Table 4.7. About 23% of the produced gas is re-injected into the reservoir. The re-injected gas is not considered as a product. The calculation if the final raw was used as the basis for the further investigation.

Table 4.7: Gas balance for the production of OIL in 1993/94 (million m³) (OIL 1995)

Total production of natural gas	**1,520**	**100.00%**
Internal consumption for gas injection	*255*	*16.74%*
Returned to reservoir	*97*	*6.40%*
Total re-injection	352	23.15%
Flaring	*459*	*30.19%*
Internal consumption as fuel	*67*	*4.42%*
Supplied to consumers	*642*	*42.24%*
Net production including flaring	**1,170**	**76.85%**

The **thermal method** includes the injection of hot steam, water or air. The following facilities are necessary for the EOR with a continuous steam injection process (AGNIHORTI ET AL. 1992):

- Surface facilities: Steam generators, fuel oil tanks, gas-fired heaters to reduce the viscosity of fuel oil in tanks
- Pipelines: To bring water to the generators after softening, to carry steam from generators to wells and to take oil from the production wells
- Off-site facilities: Pumps for water supply, ion exchange water softeners
- Transitory facilities for delivery of fuel oil

Over time the productivity of a well falls. The water cut tents to increasing and this can be a reason to cease exploitation of the well. The time of productivity can be lengthened with **work-over** activities. This process is similar to the activity of drilling. A new cementing is followed by a selective perforation (PETROTECH 1995).

The oil wells are connected by pipelines to a **Group Gathering Station**[8] (GGS) which is located centrally in respect to a cluster of wells. These GGS facilities are set up for the processing the incoming well fluid that is usually a mixture of crude oil, associated natural gas and sometimes formation water. For the treatment in the GGS, additives are necessary. Crude oil containing water is called *wet crude*, otherwise it is termed *dry crude*. These types are processed individually in the GGS (ONGC 1994/12; WSN 1994).

In the GGS the gas, oil and water are separated. The crude oil is collected in a storage tank and then dispatched to the central tank farm for onward delivery to refineries. The separated gas is fed directly into the gas distribution network: For extraction of LPG, for generation of power, internal consumption and to supply the market demand. Free natural gas is fed into the distribution network after dehydration and removal of sulphur (WSN 1994).

This chapter investigates the production of natural gas and crude oil in India. It is not possible to elaborate any further the different production possibilities. The allocation of the impacts to both resources is explained in chapter 4.2.3.1.

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[8] Another name for this facility, used in the publications of OIL is Oil Collecting Station (OCS).

4.2.2.2 Exploitation from Offshore Areas

In the western offshore area, there are 125 well platforms, each with 6 to 9 working wells that spread under the seabed. Since 1984 water has been injected for pressure maintenance. The majority of the wells are under secondary recovery. Presently 45% of the wells use production with gas lift. There are 6 water injection/process platforms to support the secondary recovery. Seventy to a hundred people live on each of the platforms (PETROTECH-ABSTRACTS 1995:249; ONGC 1995/01).

The crude and natural gas is transported from the well platforms to 28 process platforms. For this purpose 2,240 km of infield sub-sea pipelines and 875 km of trunk pipelines are used. On the process platforms the well fluid is separated into oil, gas and water (PETROTECH 1995).

The crude oil is sent By pipeline to the processing facilities in Uran. A share of 15% is transported directly to refineries by tankers. In Uran, the crude oil is processed in crude stabilisation units, stored in tanks and supplied to the refineries in Bombay. Other coastal refineries receive crude through sea tankers (BATRA 1995; PETROTECH 1995).

The associated natural gas is compressed and dehydrated before putting it into the trunk sub-sea pipelines to the two terminals in Uran and Hazira. Because of its H_2S concentrations of 100 to 120 ppm the free natural gas (*sour gas)* is also dehydrated. The present reservoir pressure of the field is adequate to transport this gas directly to Hazira by pipeline. After meeting the local requirements, the remaining gas is fed into a pipeline at Hazira for delivery to other consumers. At Uran and Hazira, there are gas fractionating plants for the production of LPG (BATRA 1995; WSN 1994).

4.2.2.3 Materials and Land Use of the Onshore Production Facilities

The area of land use for the production activities is difficult to estimate because of the onshore facilities are often spread over large areas and the land in-between is used for other purposes. An estimation of the land area used for the activities of OIL is made in Table 4.8.

Table 4.8: Land use of Oil India Ltd. for oil and gas production (JAGGI 1995)

Facilities	*Number*	*Land use per unit (acres)*	*Total land use (1,000 m²)*
Group gathering station	15	5.0	20.2
Gas compressor station	12	5.0	20.2
Water injection well	10	2.5	10.1
Well	500	7.0	28.3
Effluent treatment plant (ETP)	2	8.0	32.4
Total land use (Oil India Ltd.)			**111.2**

It can be said that the pattern of land has changed, especially if the area was mainly agricultural before (AGNIHORTI ET AL. 1992). The total land use for both oil companies is estimated to be about 2.86 million m² *{II.F-1}* considering the information given by CBWP (1985/12); ÖKO (1994/12); JAGGI (1995) and VELCHAMY (1992). The amount of **steel,** used to construct the facilities, is estimated at 532 thousand tonnes *{II-B-2}* considering the information given by ÖKO (1994/12).

4.2.2.4 Materials and Land Use of the Offshore Production Facilities

The data for the offshore production installations are given in Table 4.9. Over the years, well platform decks have increased in size, weight and complexity due to the addition of new facilities. The total weight of all necessary installations, most of it **steel**, is in the range of 400 to 500 thousand tonnes *{II-B-2}*. The average size nowadays is 1,000 m². The total area covered with processing facilities can thus be estimated to be about 180,000 m². NEERI (1990/03) gives the area with 902,500 m². The mean of these values is 541,250 m² *{II-F-1}*. The life expectancy of these facilities is estimated at 10 to 20 years (PETROTECH 1995; ONGC 1995/01).

Table 4.9: Number and weight of the production facilities in the offshore basin Bombay High (PETROTECH 1995)

	Number of installations	*Weight in tonnes (Maximum weight)*
Well platforms	125	850 - 1,500 (10,000)
Process platforms	28	2,100 - 2,200 (22,000)
Water injection platform	6	4,700
Living quarter platforms	5	ca. 5,000
Flaring structures	20	ca. 1,000
Pipelines	3,115 km	n.a.
Barges	ca. 40	500 - 10,000
Total estimated weight	**-**	**400,000 - 500,000**

n.a. - not available

The aim at the VIII five-year plan[9] is the construction of 31 new well platforms, 5 process platforms, 700 km pipeline with a structural tonnage of 110 thousand tonnes by April 1997. For this work, 25 barges are deployed (PETROTECH 1995; ONGC 1995/01).

4.2.2.5 Onshore Energy Use and Flaring

Energy is used for the following facilities:

- Steam and electricity generators
- Pump engines for oil, water and gas
- Gas compressors driven by diesel engines or electricity
- Fuel oil heaters used to reduce the viscosity of fuel oil in tanks
- Hot and cold flaring of natural gas
- Burning of natural gas to evaporate effluents in evaporation pits

The energy demand is met mainly by burning fossil fuels for power and steam generation. A small share of the energy needs is also met by other sources, for example solar panels *{II-A-4}*. The combustion devices are fired with crude oil, fuel oil, diesel oil, natural gas or fuel gas. OIL meets 95% of the energy demand for its activities with natural gas. The rest is delivered by other petroleum products like diesel oil and petrol. To reduce the emissions of SO_2 and particles, flue gas scrubbers are sometimes installed (AGNIHORTI ET AL. 1992; JAGGI 1995; ONGC 1994/12).

The total use of natural gas is calculated with 4.88E+08 m³ per year *{II-A-2}*. This is based on the data given by JAGGI (1995) and ONGC (1994/12).The amount of HSD used for onshore production is estimated to be about 5.20E+07 kg *{II-A-1}* according to the available data for the ONGC (GOEL 1995; PETROTECH 1995) and OIL (JAGGI 1995).

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[9] Goals for the governmental owned companies in India are normally planned in five year periods. The VIII plan is running from 1992 to 1997.

At the beginning of the production gas from a well is flared due to the lack of using facilities. This is called technical flaring. During the production period, there should be no flaring. The gas can be delivered to users. Because of variation in demand or stoppages, there are short flaring periods of surplus natural gas. Gas with a low natural pressure, which is difficult to transport, is always flared (ONGC 1994/12).

There are different types of flaring[10]. The burning of gas is called *hot flaring*. It can be done by releasing the gas through a burner. Steam is injected to the flame to prevent the development of smoke and to lower the temperature of the flame. Gas is discharged also through submerged vents placed in pits that are filled up with effluent. Due to this, the effluent evaporates. Sometimes the gas is released unburned through 90 to 120 m high pipes into the atmosphere[11]. For 30 to 90 days the *cold flaring* leads to direct emissions of methane that has a high greenhouse gas potential (SHARMA 1992; JAGGI 1995).

4.2.2.6 Offshore Energy Use and Flaring

The energy needs for the offshore fields are met by three power units, installed on processing platforms, with a capacity of 4 to 5 MW[12] each. The plants have dual fuel burners for both gas and fuel oil, but they use gas most of the time. One of the units lies idle as a reserve. At present two working units possess an energy over-capacity, so there is no incentive to adopt energy savings. The offshore platforms use 7.8% of the natural gas *{II-A-2}* for their requirements[13] (ONGC 1994/12; PETROTECH 1995).

HSD is also used offshore in the production facilities. The average use is given by SHARMA/SHARMA (1994/04) and GOEL (1995) and is estimated at 70.9 thousand tonnes *{II-A-1}*. For electricity demand *{II-A-4}*, there are solar panels installed on a small number of platforms (ONGC 1994/12).

4.2.2.7 Emissions of Air Pollutants during Exploration and Exploitation

Table 4.10 shows the amount of different energy carriers used for the production facilities and for the drilling activities *{I-A.1, 2, II-A1, 2}*. The data source of the values stated are given in the chapters 4.2.1.4, 4.2.2.5 and 4.2.2.6.

Table 4.10: Total quantity of energy carriers used for the oil and gas production including the exploration activities during one year

	Offshore	Offshore (GJ)	Onshore	Onshore (GJ)
Flared gas	899 Mm³	36.9	955 Mm³	39.2
Fuel gas	532 Mm³	21.8	488 Mm³	20.0
HSD	91,200 t	3.01	60,700 t	2.21

Data about emissions of the combustion devices like generators, etc., was available only for single facilities. TEMIS requires for its calculations, concentrations of the pollutants in the flue gases. The combustion of the fuel is estimated with **generic** devices. The **eta** (= efficiency) of

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[10] Types of flaring are described by SHARMA (1992). He shows advantages and disadvantages of different systems.

[11] This is done for example near tea-gardens and agriculture in the 3 - 4 month period of flowering. See also under chapter 4.2.2.13.

[12] An amount of 8,000 - 10,000 m³ fuel gas per day is burnt to produce 1 MW.

[13] In WSN (1994) it is stated that the ONGC uses 7.74% of the produced gas for internal needs in 1993/94 and that a part of 11.9% was flared. In ONGC (1994) the gas utilisation is given with 91% for the same period.

these virtual devices is taken to be 1. The combustion devices deliver **energy-virtual** for the extraction process in an amount as given in Table 4.10 [14]. In this study it is assumed that natural gas is used as the normal fuel to meet the energy demands.

Table 4.11 shows the data for the combustion devices *{I-D-1..5, II-D-1..5}*. The values for the flue gas concentrations of pollutants are estimated with the help of the data given by ÖKO (1994/12), FRISCHKNECHT ET AL. (1994) and the available emission data for India. The values investigated by FRISCHKNECHT ET AL. (1994) for diesel generators are considerably higher than the values in TEMIS. The estimation considers the available information.

Table 4.11: Combustion devices for diesel oil and gas. Analysis of the literature values, data from Hazira and estimation for the inventory (mg/Nm³)

	NO_X	PM	CO	CH_4	NMVOC	N_2O
HSD minimum	175	5	100	0	21	0.0
HSD maximum	3,500	500	1,000	10	250	5.0
HSD mean	1,568	209	409	2	126	1.2
HSD†	4,800	530	2,000	84	220	18.6
HSD estimation	**4,000**	**500**	**1,500**	**40**	**200**	**5.0**
Gas minimum	143	0.5	80	5	10	0.1
Gas maximum	500	10.0	322	100	50	5.0
Gas mean	273	3.0	165	16	31	1.3
Gas combustion estimation	**300**	**4.0**	**250**	**15**	**30**	**1.0**
Flaring †	1,200	-	-	3,000	450	-
Hazira flaring ‡	133	44	9	-	-	-
Gas flaring estimation	**1,200**	**40**	**80**	**3,000**	**450**	**4.0**

Sources: *† FRISCHKNECHT ET AL. 1995 ‡ SHARMA 1992 All others ÖKO 1994/12*

The type of flares operated has a considerable influence on the combustion conditions. Data about the flares used in India was not available. FRISCHKNECHT ET AL. (1994) assumed the efficiency of flares in different regions of the world to be 94% to 99%. The efficiency is estimated for India to be about 96%. The unburned rest of the natural gas is released as methane and NMVOC. The value for NO_X emissions is estimated with the data given by FRISCHKNECHT ET AL. (1994).

For flaring, there is no standard prescribed, and no quantitative limit on glare and smoke has been specified. It is assumed that on average 4% of onshore and 0.5% of offshore flaring is cold flaring. The emissions of methane and NMVOC are shown in Table 4.12 *{I, II-D-5}* (OIL 1995).

Table 4.12: Release of greenhouse gases during cold flaring and emission of SO_2 in evaporation pits (kg/TJ)

	Offshore	Onshore
SO_2	-	19.40
CH_4	2.74	43.00
NMVOC	0.45	7.07

Table 4.12 also gives the value for the SO_2 from evaporation pits *{II-D-1}*. About 240 thousand tonnes of formation water produced during the activities of OIL is evaporated accompanying the gas flaring in evaporation pits. Due to this evaporation additional amounts of sulphur, that is

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[14] TEMIS uses normally the real efficiency of combustion devices for the transformation of fuels into process heat or mechanical power. These types of energies are delivered to the process. The necessary information like types of energy demand or the real efficiency of Indian combustion devices were not available. Only the known amount of used fuels was available for the calculations.

solved in the effluents, are emitted. The amount from this source is estimated to be about 5.81 kg sulphur per cubic meter of evaporated water. This is the mean of information given by AGNIHORTI ET AL. (1992), JAGGI (1995) and SURRENDER ET AL. (1992).

4.2.2.8 Onshore Use of Water and Discharge of Effluents

Onshore sites, there is a need for injection water. A large part of this demand is met by purified water from the crude oil production. In smaller amount, **water** is used for other purposes such as cleaning of equipment or sanitary water. The amount of used ground and surface water is calculated at 40% of the treated effluent with 4.71E+12 g *{II-B-1}*. This value is in the same range as the data available for the production of OIL (JAGGI 1995).

Effluents are produced mainly from the GGS during the separation of crude oil, associated gases and the so-called **formation water**. The water contains dissolved mineral salts and in small concentrations dissolved petroleum products. The quantity of formation water involved varies from well to well according to the water content of the crude. It can range from almost zero to 90%. The older the well, the more formation water will be in the crude oil. Due to the water injection, the crude in the formation is mixed with the injected water. With the crude oil production of OIL today an average of 70% of formation water is connected. This adds up to 1.9 million tonnes annually (JAGGI 1995; PETROTECH 1995; TERI 1993/01).

Effluents are produced also by other production activities, for example by the cleaning of equipment. With rainfalls there is increased amounts of effluents. During the activities of OIL, about 2.9 million tonnes effluents are produced annually and it is expected that due to new techniques the water quantity will double in the next few years (OIL 1995).

The effluent (formation water) from the GGS is the object of de-oilier treatment and is passed through a series of tanks where the free oil & grease (1 to 2%) is recovered by skimming[15]. The remaining water then passes through a water-oil clarification plant for further recovery of residual oil. Demulsifier and de-oilier chemicals are used for reducing the oil content. The oil content of the water following the treatment process is 0.2 to 0.3% (WSN 1994).

In the western region there are nine ONGC effluent treatment plants. The capacity should be enhanced to 6.2 million m³ per annum with seven more plants in the next few years. OIL has four formation water clarification plants for the onshore fields, with a total annual capacity of 1.98 million m³. The ratio between crude oil and the total amount of treated water ranges among 0.23 and 1.1 at different sites. The average ratio for the *specific water production* in India is assumed at 1.05. The estimation was necessary because overall data for India was not available. FRISCHKNECHT ET AL. (1995) estimated the value to be 1 for the situation in Europe. The total amount of treated water is calculated at 11.8 million tonnes per annum (Mtpa) *{I, II-C-2}*. This is the starting point for the estimates made in Table 4.13 (OIL 1995; ONGC 1995/03; PETROTECH 1995).

Producers of oil and gas have several options for the disposal of the produced water:

- The treated water can be disposed into deep horizons of the formation through specially drilled **disposal wells**
- Thermal **evaporation** in pits. The heat required is delivered by burning natural gas. Another possibility is surface evaporation

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[15] A new possibility for the treatment of wastewater from GGS is the purification by electroflotation. It seems possible to reduce the oil content to 10 ppm. For electroflotation no chemicals are needed and no sludge is produced because the oily overflow can be recycled in the GGS (ONGC 1994/12).

- **Discharge** of the treated water into rivers or the sea
- The water can be used instead of tube well water for the secondary recovery. It is pumped into the oil bearing reservoirs through **deep injection wells**. An advantage of this method is that the possibility of subsidence is reduced
- **Recycling** of the water for use in the production facilities
- Use of the water for **irrigation**

About 60% of the wastewater from the production sites of OIL is re-injected, 20% is evaporated and 20% is discharged into rivers. The water balances of both ONGC (western region) and of OIL are shown in Table 4.13. The last column gives the estimated split of the disposed treated water in percentages (JAGGI 1995; PETROTECH 1995; WSN 1994).

Table 4.13: Water Balances for the western region of ONGC and for the production of OIL and estimates for the inventory

	Western Region ONGC		***Oil India Ltd.***		***Estimation for the LCI***
Total water	**7,020 t/a**	**100.0%**	**3.86 Mtpa**	**100.0%**	**11.8 Mtpa**
Formation water	*n.a.*	*n.a.*	1.93 Mtpa	50.0%	**60%**
Well water	*n.a.*	*n.a.*	1.93 Mtpa	50.0%	**40%**
Disposal in wells	1,860 t/a	26.6%	1.11 Mtpa	28.8%	**16%**
Injection water	3,540 t/a	50.4%	1.58 Mtpa	40.9%	**50%**
Evaporated	1,620 t/a	23.0%	0.584 Mtpa	15.1%	**18%**
Discharged	*n.a.*	*n.a.*	0.584 Mtpa	15.1%	**16%**
ETP capacity	*n.a.*	*n.a.*	2.92 Mtpa	75.6%	**-**

n.a. - not available
Sources: *ONGC 1995/03; JAGGI 1995*

The environmental impacts of evaporation are considered in chapter 4.2.2.7 (concerning air pollution). The injection and disposal of water through wells is not evaluated as an environmental impact because it occurs inside the boundaries of the production process. This reflects that extracted water is simply re-injected. Nevertheless this action might affect the groundwater in the concerned area.

4.2.2.9 Offshore Use of Water and Discharge of Effluents

Today there are 164 injectors at 35 different well platforms. The **water** requirement is met by three water-processing platforms with a total capacity of 180 thousand m^3 per day (= 65.4 Mtpa) *{II-B-1}*. Sea water is lifted up and purified by adding chemicals like hypochloride for disinfection, coagulants and defoamers. The high pressure injection water is distributed through a network of pipelines (PETROTECH-ABSTRACTS 1995:233).

A share of the wastewater from offshore platforms is discharged after treatment directly into the sea. The remaining effluents are treated onshore at the processing terminals of Uran and Hazira (PETROTECH 1995). The total amount of effluents discharged from onshore production is estimated at 5.13 Mtpa *{II-C-2}*. This average is based on the assumptions of NEERI (1990/03) and RANA (1992).

4.2.2.10 Emission of Water Pollutants with the Effluents

The discharge of the effluents is regulated by the State Pollution Control Board. Normally the standards of the CPCB (Central Pollution Control Board) are prescribed. A new guideline for the quality of the effluents from drilling sites is expected to be issued in the next future. Additional limits now set values for seven heavy-metals will be prescribed (HAWK 1995). The planned standards for onshore drilling sites and the general standards for effluents are given in Table 4.14.

Table 4.14: Tolerance limits according to IS 2490-1981 for the discharge of effluents into different environments (mg/l) and planned Indian standard for onshore and offshore drilling as presented by HAWK (1995)

	Onland Surface	*Public Sewer*	*Onland Irrigation*	*Onshore Drilling*	*Offshore Drilling*	*Coastal area*
BOD	30	350	100	30	-	100
COD	250	-	-	-	-	250
TDS	2,100	2,100	2,100	-	-	-
TSS	100	600	200	100	-	100
Oil & grease	10	20	10	10	100	20
Phenol	1	5	-	-	-	5

Table 4.15 shows the range of measured values for water pollutants in the effluents. The available information was not sufficient to calculate average concentrations describing the situation in India. The available data (CBWP 1985/12; ONGC 1994/04:44; PAUL 1995; SHARMA/CHAUDHARI 1992; SURRENDER ET AL. 1992) and the limits shown above were used to give estimates of the emissions of water pollutants originating from drilling and production sites effluents *{I, II-C2..C-7}*.

Table 4.15: Minimum and maximum concentrations of water pollutants in the effluents of drilling and production sites and estimates for the LCI (mg/l)

	Minimum	*Maximum*	*Offshore estimation*	*Onshore estimation*
BOD	20	70	**50**	**30**
COD	46	200	**200**	**70**
TDS	400	10,000	**1,500**	**1,200**
TSS	nil	4,000	**100**	**90**
Oil & grease	nil	1,000	**20**	**10**
Phenol	n.a.	n.a.	**0**	**0**

4.2.2.11 On- and Offshore Wastes

The chemical and biological treatment of effluents produces sludge. Normally this sludge is dumped at landfills or it is burnt (ONGC 1994/12). The ratio between sludge and treated water is assumed to be 0.1%. This reflects the data found for refineries (0.03%) and the information given by SURRENDER ET AL. (1992) and CHAND (1992), 5% and 0.11% respectively. Thus the total amount of sludge is 12.8 Mtpa onshore and 5.23 Mtpa offshore *{II-E-2}*. The oil content in sludge varies between 17 and 25 per cent (VELCHAMY/SINGH/NEGI 1992).

One type of waste is called **BSW**, for *bottom-sediment and water sludge*. This is a complex mixture of heavy, solid-like paraffin-components, with occluded water and oil. These solidified fractions are either entrained with the crude or else precipitated out when the temperature and pressure are lowered in production. This is the case when the crude oil is stored. The composition of tank bottom sludge is given in Table 4.16. The sludge rate is estimated to be about 0.2% of the stored crude oil *{II-E-2}*. The development of BSW is only linked with the production of crude oil and not with the production of natural gas. In Uran for example with processing facilities for 20 million tonnes per annum, 40,000 tonnes of sludge are accumulated every year (PETROTECH-ABSTRACTS 1995:259; TERI 1993/01).

Table 4.16: Composition of tank bottom sludge in Uran (PETROTECH-ABSTRACTS 1995:259)

Asphaltene	30%
Resins	10%
Wax	17%
Oil	32%
Other components	11%

Today the domestic waste from offshore platforms is dumped in polyethylene bags into the sea. For new installations treatment of the biodegradable parts with a shredder is recommended. Non-biodegradable wastes should be brought on land (NEERI 1990/03).

4.2.2.12 Dismantling and Reclaiming of the Production Facilities

The environmental impacts of production do not end with the extraction of the crude oil and natural gas. The production facilities must be dismantled after the plant ceases production. For offshore production this creates big problems as was demonstrated by the North Sea platform „*Brent Spar*“ in June 1995. Some experts claimed that the most environmentally friendly solution was to send the platform to the bottom of the sea. This would result in tonnes of hazardous wastes, stored on the platform, being dumped into the north sea. Bringing the platform onshore for dismantling is claimed to be too expensive by the owners *SHELL*. Protests initiated by *GREENPEACE* finally prevented the dumping of the platform. Other companies plan to blow up their facilities. A future problem is what to do with the pipelines laid in the North Sea once production in the North Sea ceases (TAZ 1995). These problems need to be addressed in India soon because platforms and onshore production facilities are reaching the end off their 20 years production life span *{II-E-2}*. Information regarding these problems could not be found.

4.2.2.13 Other Environmental and Social Impacts

A glimpse at the impacts of crude oil and natural gas production, which are not easy to quantify is given in the following section.

Social impacts are encountered with the resettlement of people on account of the establishment of production facilities in one area. The Naga Students Federation have demanded a re-negotiation of the system of royalties for oil exploration activities in Nagaland. The students' protests should lead to increased sums of compensation for owners of mining land and greater benefits in general to the Naga people (WSN 1994).

Noise levels during the construction period may be as great as 85 to 95 dB (A) at a distance of 50 ft (15,24 m) *{II-F-3}*. Sources of noise are construction equipment like scrapers, graders, trucks and pavers. Operational noises are generally less than those of either the construction or drilling project phases. Generators for steam production however may produce noise levels at 69 to 75 dBA at 50ft *{II-F-3}*. Workers are exposed to this hazard during the operation phase (AGNIHORTI ET AL. 1992).

The hot gas flaring produces a special impact on **plants** surrounding a production site with the influence of light and heat *{II-F-2}*. Darkness is essential for some plants such as rice crops and tea during their period flowering. Thus plant cultivation should be at least 65 metres from the flares. To avoid this negative impact, the natural gas is released for the period of flowering without being burnt. This type of flaring to prevent damage from cultivated plants can extend 3 to 4 months. C*old flaring* is restricted to production neighbouring of plantations. The problem with it is that it will lead to a high emission of the greenhouse gas methane (JAGGI 1995; OIL 1995).

Hydrocarbon emissions into the sea are caused by 24% from tankers and by 2% from offshore platforms *{II-C-7}*. The appearance of tar balls along the beaches of west coast India, due to tankers plying the shipping lanes of the Indian seas, is a routine phenomenon. It is estimated that around 1,000 tonnes of tar balls are received per year (PETROTECH-ABSTRACTS 1995).

Accidents bring their own environmental impacts *{II-G-6}*. A few examples are quoted. In May 1993, a rupture occurred at the riser of the Bombay High-Uran trunk pipeline, about 2,000 m³ (1,600 tonnes) of oil spilled into the sea. Approximately 40% of the oil evaporated. This accident has resulted in an estimated loss in crude oil production of 282 thousand tonnes (WSN 1994; PETROTECH 1995).

A **Blow-Out** is another form of accident associated with the production of crude and natural gas, and occurs once in every few years in the country. The last one started at January 8, 1995 during the drilling of an oil well in Andhra Pradesh, because insufficient drilling mud was used to neutralise the formation pressure *{I-G-6}*. The flames of the fire were 100 to 200 m high and could be seen at a distance of 40 km. The fire consumed 1 to 1.3 million cubic metres of gas per day and caused a financial loss of 1.7 million Rupees per day. More than 5,000 villagers in the surrounding area were evacuated *{I-G-1}*. After one month the well started spilling out a shower of crude oil affecting an area of 5 km². Thick black smoke accompanied the flames (BLOW-OUT 1995).

Several attempts were made to control the fire with plastic explosives. These actions were executed in co-operation with foreign fire fighting experts. Their high financial demands and the lack of planning on the part of ONGC led to several differences and delays. It took 61 days to finally put the fire out. It was reported as the biggest blaze in the history of the Indian petroleum industry. The costs to date are 411 million Rupees (US$ 13.3 million) for fire-control expenses and damage to equipment. A few years prior a blow out occurred in the western region of ONGC (BLOW-OUT 1995; ONGC 1995/03).

4.2.3 Quantitative Aspects of Oil and Natural Gas Extraction

4.2.3.1 Allocation of the Investigated Impacts on the two Resources

The allocation of environmental burdens to different outputs in a multi-output system is a problem often met in the practice of LCA. The environmental burdens investigated in the previous chapter for the gas and oil production must be related to an amount of product. This makes it necessary to allocate the impacts between oil and gas. Both are products of the same processes. Sometimes the necessary steps are different for both resources, but it was not possible to investigate these differences in the limited time available. Possible **general** criteria for the allocation are:

- Energy content
- Mass of the outputs
- Economic value of the products
- Volume of the outputs

- Molar content of the outputs
- Exergy content[16]

FEYTER (1994) compared a few methods for the petroleum sector and showed that there are relative small differences. He compared the ratio of natural gas to crude oil if different units are used to express the amount. The allocation ratio between crude and gas varies from 31:69 (by mass), 35:65 (by heating value) to 37:63 (by prices). The impacts in this study are allocated by the energy content of the products. This makes it possible to use processes in TEMIS with the same specifications for both resources.

KNOEPFEL (1994) compared the *general allocation* and a more specific combination of general and *direct allocation* for the case of North Sea offshore production. He investigated the specific differences in the production of natural gas and crude oil. Therefore basic engineering knowledge of the system is necessary to determine if impacts of single processes can be allocated directly to one of the products. The environmental burdens of gas treatment are for example directly allocated to the gas exploitation.

KNOEPFEL (1994) showed that, for the indicator *oil emissions into water*, the general allocation leads to higher values for the gas and lower values for the oil production than a combined allocation that considers different ways of production. The share allocated to the production of oil increased from 87% to 98%.

The impacts of crude oil and natural gas production were allocated in this study by the lower heating value of the products. This assumes for both products the same impacts. It is likely that a more specific allocation could change some of the results for the LCI. The gas production is linked with fewer impacts in the case of water pollutants than assumed in the LCI for India because some gas is explored as free gas. This causes smaller quantities of effluents. For the exploitation of free gas less auxiliary energy is necessary because the efforts for pressure maintenance are smaller (KNOEPFEL 1994). The impacts of crude oil exploitation might turn to be higher in a more specified inventory of the Indian situation. BUWAL (1995) found on the other side higher values in the case of gas exploitation for some indicators. The reasons for the differences are not quoted. FRISCHKNECHT ET AL. (1995) used also a general allocation with the LHV for a comparable study about the petroleum sector in Europe.

4.2.3.2 Final Inventory for the Petroleum Exploitation

Table 4.17 shows the final life cycle inventory for the supply of natural gas and crude oil in India for **all quantitative indicators**. To estimate the environmental impacts of the drilling activities, the impacts of one year are related to the amount of natural gas and crude oil produced in this year. Normally these impacts should be spread over the life time of the constructed production facility. For a broad estimation, the chosen way seems to be reliable because the activities of drilling and the production of crude and gas has not changed essentially in the last years. The burdens of the production were investigated in the previous chapter. They are related to the amount of **total products** (gas and crude) in one year expressed in MJ or TJ. The specific values (MJ/MJ, g/MJ or kg/TJ) are shown in Table 4.17. They are used for the calculations with TEMIS 2.0.

The data estimates for the exploitation of imported crude oil are shown in Table 4.17. These data are used also for crude oil throughput to *international* refineries and to calculate the impacts of crude oil imports to India. It was not possible to make an inventory for the world-wide crude oil exploitation and the specific throughput to the Indian market. The international refiner-

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[16] The exergy concept takes into account both the quality and the quantity of energy carriers. It uses the work content instead of the heat content of a fuel (ENGELENBURG/NIEUWLAAR 1994).

ies are described in chapter 5. These data are used to calculate the impacts of petroleum-product imports.

The two last columns in the table show data as investigated by FRISCHKNECHT ET AL. (1995), BUWAL (1995) and ÖKO (1994/12). The values of FRISCHKNECHT ET AL. are calculated for an average import of crude oil to Europe with a share of 50:50 for on- and offshore exploitation. The values found by ÖKO (1994/12) for the energy use consider the efficiency of the used combustion processes like boilers or generators. These processes have an efficiency *(eta)* of less than 1. The original values of ÖKO are divided by the efficiencies to compare the data with the Indian values.

Data for the import of crude oil are estimated using these three sources and the Indian values. To avoid a bias in the calculation, values for the import are chosen in a way that they do not differ strongly from the values investigated for India. This does not totally reflect the true values but otherwise the results of the LCI would be influenced mainly by the different share of imports for the two fuels LPG and kerosene. The values for kerosene are influenced more by the estimation for imports than the results for LPG.

The **capacity** of the Indian extraction processes is calculated for the present situation. This value has an influence on the steel, cement and land use of the process module. All other values are comparable with the data for a 1,000 MW process in TEMIS.

The Indian data for the **energy use** are in the range of the values found by the Öko-Institute and FRISCHKNECHT ET AL. But the Öko values do not consider the flaring of natural gas. The Indian values might turn out to be higher in a more specific inventory where more uses of energy were investigated. Energy use will rise in the future due to greater efforts for secondary and tertiary recovery. Flaring consumes about 3 to 6 per cent of the produced energy carriers. The necessary energy use for the extraction is 2 to 3 per cent. Additional emissions of sulphur dioxide from non-combustion sources are not investigated in the ÖKO study. The investigated emission of hydrocarbons is also in the range of the values as investigated by BUWAL and ÖKO. The values found by FRISCHKNECHT ET AL. are higher than the values found for India but they consider emissions due to the flaring that are not shown directly for the Indian situation. These emissions are considered in the combustion process.

The comparison of the data for discharged **drilling mud** shows much smaller values in the study of ÖKO than in the LCI for India. The origin of the value is not quoted in the ÖKO study. Thus it is not possible to give an explanation of the differences. In India between 150 and 640 kg of **cuttings** are discharged for the production of 1 TJ petroleum resources. The value found by FRISCHKNECHT ET AL. is nearly the same. The values for **wastes** are of a comparable figure.

The use of **water** investigated by BUWAL and FRISCHKNECHT ET AL. is considerably smaller than that found for India. Different definitions of water use make an explanation difficult. About 4,500 litres of **effluents** are discharged in India for the production of 1 TJ crude oil or natural gas. FRISCHKNECHT ET AL. found a higher value for the discharge of effluents. One reason might be that re-injection of water is not considered in this value. The values found by BUWAL for the emission of **water pollutants** are approximately in the range of the values investigated for India. Even with the higher amount of effluents FRISCHKNECHT ET AL. found smaller values for some water pollutants.

It is difficult to assess the overall reliability of the Indian data. The environmental impacts of petroleum extraction vary considerably from place to place. Thus large variations from investigated indicators are normal. The LCI is based on some unreliable estimations. A large deviation from the stated figure for water pollutants is probable. Comparison with other studies however indicates the values found lie within a possible range.

Table 4.17: Final data for the LCI, data for international extraction and comparison with the range of values found by other authors

	Unit	Offshore (India)	Onshore (India)	Import (international)	Imports to Europe[a]	Imports to Europe[b]
Capacity	MW	39,348	21,277	1,000	1,000	1,000
Product crude	t/a	1.57E+07	1.12E+07	-	-	7.12E+05
Crude	MJ/a	6.25E+11	4.45E+11	-	2.84E+10	2.83E+10
Natural gas	m^3/a	1.34E+10	4.62E+09	-	-	3.92E+06
Natural gas	MJ/a	5.48E+11	1.89E+11	-	-	1.61E+08
Total products	MJ/a	1.17E+12	6.34E+11	-	2.84E+10	2.84E+10
Supplied gas	MJ/a	5.11E+11	1.50E+11	-	-	-
Flared gas	m^3/a	8.99E+08	9.55E+08	-	-	3.16E+07
Flared gas	MJ/MJ	0.0315	0.0618	0.046	-	0.046
Fuel gas	MJ/a	2.18E+10	2.00E+10	-	-	-
Fuel gas	MJ/MJ	0.0186	0.0316	-	0.0012 to 0.01	-
HSD use	kg	9.12E+07	6.07E+07	-	-	-
HSD use	MJ/MJ	4.04E-03	4.06E-03	0.02	0.003 to 0.85	0.018
Total auxiliary energy	MJ/MJ	0.0226	0.0357	0.02	0.003 to 0.85	0.018
SO_2	kg/TJ	-	19.4	-	-	-
CH_4	kg/TJ	2.7	43.0	30	2 to 137 (40/46)	51
NMVOC	kg/TJ	0.4	7.1	10	0 to 36	166
Drilling mud	g/a	7.52E+10	3.18E+11	-	-	-
(no indicator)	g/MJ	0.064	0.501	-	1.00E-09	-
Chemicals	g/a	2.03E+10	7.26E+10	-	-	-
Chemicals	g/MJ	0.017	0.115	0.12	-	0.12
Steel	g	4.50E+11	5.32E+11	1.0E+10	2.50E+10	2.24E+09
Cement	g	1.65E+11	9.92E+11	4.0E+09	8.00E+09	2.14E+09
Raw water	g/a	6.54E+13	5.30E+12	-	-	-
Raw water	g/MJ	55.7	8.4	10	0.67/?	0.98
Effluent total	kg	5.23E+09	1.28E+10	-	-	-
Effluent discharged	kg	5.23E+09	2.93E+09	-	-	-
Effluent evaporated	kg	-	2.12E+09	-	-	-
Effluent discharged	kg/TJ	4,458	4,622	4,500	-	13,000
BOD	mg/l	50	30	-	-	-
BOD	kg/TJ	0.223	0.139	0.14	< 0.10/ < 0.09	0.0049
COD	mg/l	200	70	-	-	-
COD	kg/TJ	0.892	0.324	0.32	< 0.10/ < 0.09	0.0489
TDS	mg/l	1,500	1,200	-	-	-
TDS	kg/TJ	6.69	5.55	5.6	< 0.10/1.29	-
TSS	mg/l	100	90	-	-	-
TSS	kg/TJ	0.446	0.416	0.42	1.56/1.48	-
Oil & grease	mg/l	20	10	-	-	-
Oil & grease	kg/TJ	2.09	0.0462	1.5	0.67/1.56	3.12
Cuttings	kg/a	1.71E+08	4.05E+08	-	-	-
Cuttings	kg/TJ	146	639	470	-	472
Waste	kg/a	5.23E+06	1.28E+07	-	-	-
Waste	kg/TJ	14	80	40	32.7/88.2	20
BSM (only for crude)	kg/TJ	0.05	0.05	-	-	
Load	h/a	8,280	8,280	7,900	7,900	7,900
Life time	a	10	15	20	25	25
Land use	m^2	541,250	2,855,536	200,000	200,000	1.70E+09

[a] *Values for petroleum extraction for OPEC, Northern Europe, North Sea and CIS as investigated by ÖKO (1994/12). The data for water use, water pollutants, HC emissions and wastes in this column were investigated by BUWAL (1995) for the situation of crude oil and natural gas exploitation (oil/gas) for the demand in Europe.*

[b] *The last column shows the values as investigated by* Frischknecht et al. *(1995) for the import of crude oil to Europe (1:1 - onshore/offshore).*

5 Life Cycle Inventory for the Downstream Sector

This chapter deals with the life cycle inventory for the downstream petroleum sector. The first section describes the production of this sector in India. It is followed by an explanation of the pricing system for petroleum products. After that the three sections of the downstream sector - *refineries, fractionating plants* and *bottling plants* - are investigated. At the end of the chapter an inventory for the electricity generation is estimated.

5.1 The Petroleum Downstream Sector in India

The petroleum refining industry is an old industry in the country. It started with a capacity of 0.3 Mtpa (million metric tonnes per annum) after the Declaration of Independence in 1947. The Digboi refinery is one of the oldest operating refineries in the world, established in 1901 and rebuilt in 1923. The refineries and the companies who own them *{III-H-4}* are given in Table 5.1. At present this industry consists of 12 operating refineries with a capacity of 54 Mtpa (IOC 1994/12a).

Table 5.1: Downstream companies and refineries

	Company	*Refineries*
BPCL	Bharat Petroleum Corporation Ltd.	Bombay
BRPL	Bongaigaon Refineries and Petrochemicals Ltd.	Bongaigaon
CRL	Cochin Refinery Ltd.	Cochin
HPCL	Hindustan Petroleum Corporation Ltd.	Visag (Vishakhapatnam), Bombay
IOC	Indian Oil Corporation	Barauni, Digboi, Gujarat, Guwahati, Haldia, Mathura
MRL	Madras Refinery Ltd.	Madras

In refineries, the crude oil is processed to LPG, kerosene and other products. The first plant for the production of LPG was set up in Delhi in 1960. During the 1970s, LPG was obtained solely from refinery flue gases. As LPG is a clean fuel that can be used for domestic cooking, the government made plans to considerably increase the supply. The commissioning of LPG extraction plants in Bombay in 1981 and Duliajan in Assam (OIL) in 1982 allowed LPG to be extracted from natural gas. The lean gas is fed to fertiliser plants or is used for other purposes. To process all the natural gas from the offshore region, the ONGC set up two other gas-processing plants, at Hazira and Uran near Bombay. The Gas Authority of India Ltd. (GAIL) runs two plants in Vizapur and near Baroda. All eight plants in India are situated near the point of exploitation or along the pipelines (ARORA 1994; SHAMSUNDAR 1995).

The total petroleum sector was nationalised between 1965 and the early 1970s. Multinational companies were taken over in order to enable the government to control this sector. The refineries became public sector enterprises under the administrative control of the Ministry of Petroleum and Natural Gas. Today the policy has changed and company shares are sold on the free market. In the future the market will be opened up to foreign investors *{III-H-3}*. The government will retain only 51 per cent of the shares (BUSINESS INDIA 1994).

One future project is the construction of a grassroots refinery in Daitari by the IOC in a joint venture with the Kuwait Petroleum Corporation who hold 26% the equity. This refinery is planned to have a capacity of 6 Mtpa. The HPCL plans to construct refineries in collaboration with foreign enterprises with capacities of 6 Mtpa in Mangalore and Dabhol. Similarly BPCL is setting up refineries of the same size in Bina and Jamnagar. Other projects are the Numaligarh Refinery in Assam with a planned capacity of 3 Mtpa, the Pannipat refinery (6 Mtpa), a refinery in Orissa (6 Mtpa) and the modernisation of existing refineries (BUSINESS INDIA 1994; IOC 1994/12a; NRL 1994; OCC 1995; THE PIONEER 1995/1/15).

Table 5.2 shows the number of persons employed in the different categories of the petroleum industry *{I..VI-A-5}* (IPNGS 1993).

Table 5.2: Employed persons in different sectors of the petroleum industry (IPNGS 1993)

Exploration & Production	58,864
Refining	23,386
Marketing	38,414
Pipelines	3,312
Research & development	3,035
Others	14,340
Grand Total	141,351

The amount and share of refinery products are centrally controlled by the governmental Oil Co-ordination Committee (OCC). The committee members are employees of the companies running the refineries or ministry officials. The Committee also controls the crude oil allocation and any expansion plans for the refineries. The retail prices for the products are fixed by this committee. This includes a cross subsidy system as described in chapter 5.2 (BUSINESS INDIA 1994, OCC 1995).

Production in the refineries and fractionating plants is not sufficient to meet the demand in India. First priority has the production of diesel oil, because of its importance in the transportation sector as a fuel for trains and trucks. Kerosene is similar to diesel oil so that, if the priority would change, the ratio between kerosene and diesel oil could be varied by a margin of 30% *{III-H-5}*. At present, apart from being used for cooking and lighting by poor people, kerosene is not important for the Indian economy. Five to six times more diesel oil is produced than petrol, the world-wide average is two to three times. For the production of LPG in the refinery, there are no competing products, except the lean gas *{III-H-5}* used for the refinery’s own energy demand (IOC 1994/12).

The refinery production has increased from 17 million tonnes in 1970/71 to over 48 million tonnes in 1990/91. In 1993/94 the Indian refineries had a crude throughput of 54.3 million tonnes. Final production amounted to 53.8 million tonnes. The net production excluding internal demand by the refineries amounted to 51.3 million tonnes. The refining capacity is expected to increase to approximately 73 Mtpa by the early part of ninth five-year-plan (CFHT 1995; TERI 1993/01).

The refinery output-mix in recent years was 20% light distillates (LPG, petrol, motor gasoline), 54% middle distillates (diesel oil, kerosene, aviation turbine fuel) and 26% heavy ends (fuel oils, lube oils, bitumen, coke). This represents a recent shift in output mix away from heavy ends to light and middle distillates. It is notable that the capacity utilisation in Indian refineries, ranging from 75% to 164%, is remarkably high (TEDDY 1994; TERI 1993/01).

LPG and kerosene are also imported into the country. LPG is bought from companies in USA, Japan, Greece and a few Middle-East countries. There are two ports with the necessary facilities that have a capacity of 6 Mtpa *{III-H-3}*. It is planned to set up new infrastructure facilities at ports throughout the country in order to import LPG. The total sales of petroleum products during 1993/94 in India amount to 60.3 million tonnes. The consumption of petroleum products is presently growing at a rate of 6% to 7% per year and is expected to reach a level of 150 million tonnes by the year 2010. The structure of the Indian market is shown in Table 5.3. It is unclear why in 1992/93 there is such a large discrepancy between sales and actual availability of kerosene. This discrepancy was not apart in previous years (MODAK 1995; SHARMA 1995; TEDDY 1994).

Table 5.3: Origin of LPG and kerosene in India in 1992/93 (TEDDY 1994)

	LPG	*Kerosene*
Import	11%	40%
Production Refineries	44%	60%
Production Gas Processing	45%	-
Availability (thousand tonnes)	2,940	8,750
Sales (thousand tonnes)	2,870	3,580

The LPG is filled into cylinders at a **bottling plant**. In the plant, the cylinders are also maintained and repaired in case of defects. The bottling plants are run by the oil marketing companies. Two types of bottling plants are common. Small plants with a capacity of 5,000 to 10,000 tonnes per annum (tpa) or large bottling plants with an installed capacity from 25,000 up to 130,000 tpa. The small plant meets the demand for LPG cylinders only in the town or city where it is located. The large bottling plant may also feed the demand within a radius of up to 400 km (TERI 1989/03).

In India there are at present 83 existing LPG bottling plants and over 30 plants have been envisaged *{V-H-4}*. Among the running facilities are 16 rail-fed bottling plants. They bottle one million tonnes of LPG every year. Due to the lack of rail-tank-wagons, part of the LPG has to be delivered with road trucks to these plants. All over the country 65 bottling plants are road-fed. Every year they bottle 1.9 million tonnes LPG. LPG is filled into cylinders at 11 out of 12 existing refineries. Likewise in the 8 fractionating plants for natural gas, most of which are located near the gas fields or pipelines. It is expected that more than 100 new plants will come into production in the private sector. At present four to six companies have begun bottling activities (ARORA 1994; MODAK 1995).

5.2 Energy Pricing Policy in India

Energy prices in India are administered[1] with the goal of pursuing certain social objectives. They do not reflect the production costs. A **key concern** of this policy is the provision of cheap fuels in the domestic sector, for poorer sections of society and for fertiliser plants. The subsidy on kerosene is ostensibly to make a relatively clean and efficient fuel available to low income urban and rural households. The primary reason for the subsidy is to make lighting available the majority of the population *{III, IV-H-2}*. For LPG the primary objective in the 1960s and 1970s was to promote its use, particularly in urban areas (BHANDARI/THUKRAL 1994).

Table 5.4 illustrates the costs of production and the selling prices for energy in India. The subsidisation for LPG and kerosene is 90 Rs and 70 Rs per GJ of energy content respectively *{III, IV-H-1}*. A rational energy pricing policy is very important for the purposes of long-term energy planning. The petroleum products are divided into two main categories: the *price administered* products and *free trade* products. The major products (for example kerosene, diesel oil, LPG and naphtha) belong to the price-administered category *{III, IV-H-2}*. The government fixes the ex-storage point prices for them. These prices are beneath the level of the world market. About 90% of the total volume of petroleum products sold and 95% of the petroleum products refined fall under the price-administered category (TEDDY 1994; WSC 1994).

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[1] Government administered pricing mechanism (APM)

Table 5.4: Costs of production and selling prices for energy in 1993/94 (INDIA TODAY 1995)

	LPG	*Kerosene*	*Domestic electricity*	*Irrigation electricity*
Unit	*Rs per 14.5 kg cylinder*	*Rs per litre*	*Rs per kWh*	*Rs per kWh*
Costs of production	142.30	5.03	1.48	1.36
Selling price	83.20	2.4	0.79	0.15
Total annual subsidies (million Rs)	9,260	24,010	27,660	81,980

To compensate for the loss to the refinery, the prices for other products, for example petrol or turbine fuel, are raised to make for an overall balance. The prices are calculated in such a way that the refinery gets a return on their investment of 12% after tax. If the refinery meets the production plan target, it achieves a sufficient income (OCC 1995).

Since the liberalisation of the petroleum sector a large number of the products with intentionally high prices were taken out of the control of the pricing mechanisms. They have been made free for marketing. The volume of subsidised products has also been increasing due to growing demand. This has led to an increasing subsidy paid by the government to meet the balance for the petroleum sector *{III, IV-H-1}*. The subsidy, paid for major petroleum products, is shown in Table 5.5. The reason for the difference in comparison with the figures in Table 5.4 for the paid subsidies is not clear (THE ECONOMIC TIMES 1995/01).

Table 5.5: Subsidies in billion Rs on major petroleum products (THE ECONOMIC TIMES 1995/01)

	1992/93	*1993/94*	*1994/95*
Kerosene (Domestic)	33.04	37.85	41.01
LPG (Domestic)	11.75	12.57	11.91
Naphtha (Fertiliser)	5.32	5.03	5.39
FO + LSHS (Fertiliser)	2.83	2.69	2.96
Bitumen Packed	1.53	1.25	1.27
Paraffin Wax	1.19	0.89	0.20
HSD	1.20	3.45	22.05
Total	**56.86**	**63.73**	**84.79**

It can be expected that this burden on the petroleum pool account will lead to new raises in the prices for petroleum products. The first attempts to reduce the oil pool account deficit were made with the petrol and diesel oil price increases in February 1994 of about 7 per cent and 13 per cent respectively. Kerosene, which enjoys the greatest subsidy, will be the last to be decontrolled owing to its status as a mass consumption item and potential political resistance (BUSINESS INDIA 1994).

The prices of LPG and SKO are normally cheaper than the biomass fuels. The comparative costs of cooking fuels are shown in Table 5.6 *{III, IV-H-1}*. The prices are related to the useful energy of the different fuels. This takes into account the efficiency of the cookstove. The last increase in the price of LPG of Rs 15 was followed from protests of urban communities and the increase was swiftly reduced to 10 Rs. The increase was not without justification because between 1984/85 and 1993/94 the cost advantage of LPG has actually gone up. Cooking food with LPG costs less than one-tenth the price of cooking with firewood and half that of kerosene. LPG is used mostly by the urban middle class and the rich (as described in chapter 1.2). In the poor rural areas it is not available and under these circumstances the subsidising policy is not compatible with its stated objects (DOWN TO EARTH 1995/02).

Table 5.6: Comparative costs of cooking fuels (CFSAE 1985; DOWN TO EARTH 1995/02)

Energy source	***Unit***	***Unit price (Rs)***		***Cost of useful energy (Rs/GJ)***		***Ratio of fuel cost to LPG***	
	Year	*84/85*	*93/94*	*84/85*	*93/94*	*84/85*	*93/94*
Firewood	1 kg	0.65	2.00	542	1,667	6.03	11.34
Kerosene (PDS[a])	1 litre	1.90	2.70	107	135	1.19	0.92
Kerosene (open market)	1 litre	4.00	6.00	225	299	2.50	2.03
LPG	1 kg	3.60	6.50	90	147	1.00	1.00

[a] *PDS - Public distribution system (subsidised products)*

Although the need to promote LPG no longer remains, the subsidisation scheme still continues. A dual pricing mechanism for LPG and kerosene is planned by the government and could lead to an increasing bias in the subsidy policy. It implies that upper middle and high income households in urban areas, who already have access to subsidised LPG, will continue to receive the subsidy, while lower middle and low income households will be increasingly forced to go for the more expensive fuels sold on the private parallel market[2] (BHANDARI/THUKRAL 1994).

5.3 Production of LPG, Kerosene and other Petroleum Products from Crude Oil in Indian Refineries

The incoming crude oil is processed in different refinery units. The processes adopted in Indian refineries can broadly be classified as follows (CBWP 1982):

- **Fractionation and stabilisation** are the basic refining processes for forming intermediate fractions of specified boiling point ranges.
- **Reforming** is a process in which low octane naphtha, heavy gasoline and naphthalene rich stocks are converted to high octane gasoline blending stocks, aromatics and isobutane.
- **Thermal and catalytic cracking** are processes in which heavy oil fractions are broken down into lower molecular weight fractions. The cracking can be done with the help of heat or by using catalysts. The catalytic cracking is the key process in the production of large volumes of high octane gasoline stocks, furnace oil and other useful middle molecular weight distillates. In the Indian refineries there is a total FCC (Fluid Catalytic Cracking) capacity of 1 million tonnes per day. These units consume 1,000 tonnes of catalysts per day. The production of coke in this process amounts to 0.7% to 0.9% of the throughput. To regenerate the catalyst, this coke is also burnt in furnaces (IOC 1995; PETROTECH 1995).
- **Hydrocracker** units produce cleaner fuels, and can upgrade heavier fractions of crude oil into more valuable middle distillates. In the hydrocracker process C-C bonds are broken down and simultaneously hydrogenated in the presence of catalysts.
- **Desulphurization** is necessary to minimise the sulphur content of the products. Sulphur is by far the most predominant impurity in crude oil. It exists in the form of sulphides, polysulphides and thiophenes. Crude oil varies significantly in sulphur content and therefore the processing scheme must be able to handle the crude oil of the maximum sulphur content that can occur (TERI 1993/01).

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[2] BHANDARI/THUKRAL (1994) gave alternative proposals for subsidy reduction.

- **Hydrofinishing** is the process that removes sulphur and nitrogen compounds, odour, colour and gum-forming materials as well as saturates olefins by catalytic actions.
- **Coking** is an operation to produce coke with the help of thermal cracking from heavy residuals of the fuel oil distilled (FRISCHKNECHT ET AL. 1995).
- **Utility** functions are for example the supply of steam, heat, electricity and cooling water.

These processes are connected in different ways in the refinery. The process flow depends on the type of crude, the age of the refinery and the palette of products. A process flow diagram for a newly planned refinery in Numaligarh, Assam, is shown in Figure 5.1.

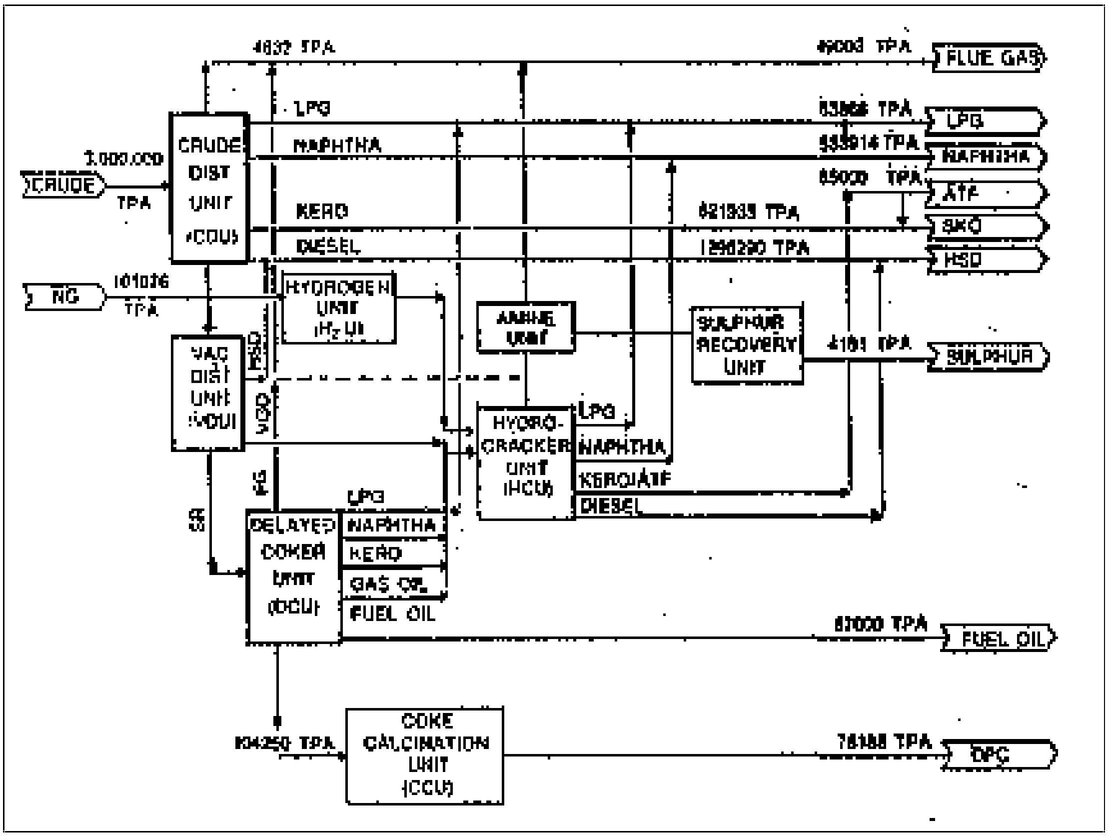

Figure 5.1: Simplified process flow diagram for the Numaligarh refinery (NRL 1994)

LPG is a by-product arising during the extraction and refining of crude oil. The quantity amounts to approximately 10 to 15% of the amount of petrol produced. The share of the refinery output is 2.5 wt% for LPG and 11.2 wt% for kerosene (DAS 1994; UBA 1992).

One parameter to measure the state of the art of refineries is the amount of **fuel and loss**. This is the weight balance between the crude oil throughput of the refinery less the water content of the crude and the output of products. The energy use includes the use for pipe inlets (OCC 1995; IOC 1994/12).

5.3.1 Energy Use

Oil refineries are one of the most energy consuming sectors. The energy intensity depends upon crude oil characteristics, adopted processes and the finished product mix. The energy use in a refinery rises with the complexity of the processes. These are simple distillation, cracking, FCC (fluid catalytic cracking), hydrocracking. All Indian refineries, except one in Mathura, were constructed in the 1970s or earlier. At this time the crude oil prices were low and so their energy efficiency was sub-optimal. All Indian refineries have FCC and there is one hydrocracker under construction. This is comparable to the state of the art in 1980's US refineries. For 1993/94, the fuel consumption ranges from 4.08% to 12.11% with an average of 5.1% of the output. The average for US refineries is about 4%. A reduction in energy consumption seems to be possible. The potential scope for saving in refineries was identified at 10.9% in 1988/89. It could be achieved by improving the furnace efficiency, installation of co-generation gas turbines, process optimisation and waste heat recovery (CFHT 1995; OCC 1995; IOC 1994/12, 1995; TERI 1993/01).

The energy balance for an average 4.5 Mtpa refinery is shown in Table 5.7. The energy demand of the refinery is met with the following fuels: fuel gas, natural gas, dump gas, fuel oil, low sulphur heavy stock (LSHS), naphtha, diesel oil (HSD), asphalt and coke from the FCC. Electricity is normally produced in co-generation with steam. Usually refineries use boilers with a capacity in excess of 200 kg fuel oil per hour (IIP 1994/12).

Table 5.7: Energy balance for a 4.5 Mtpa refinery with an energy demand of 364 MW (NEERI 1995)

Input	***Share***	***Output***	***Share***
Fuel	81.19%	Products	1.66%
Coke	18.62%	Flue gas	7.26%
Crude	0.19%	Sea water (for cooling)	57.71%
		Frictional loss	3.68%
		Radiation	7.90%
		Effluent water	0.96%
		Heat of reaction	4.45%
		Steam leaks	1.60%
		Steam tracking	5.53%
		Miscellaneous steam	2.62%
		Unaccounted	6.62%

Data for the energy use was available for the twelve running units. The average consumption of electricity, fuel oil, fuel gas and coke was calculated with these data. The data for the energy use are shown in Table 5.8 *{III-A-1..4}*. The refineries used fuels with a variety of lower heating values. These are standardised for the inventory. A few refineries sell electricity of their co-generation plants to the state electricity boards. These quantities are subtracted from the total amount. The production of electricity in India is investigated in chapter 5.6. The main energy for the refineries is fuel oil with a share of 58% followed by fuel gas with a share of 27%.

Table 5.8: Use of auxiliary energy and flaring in the 12 running Indian refineries and the average use of energy in 1993/94 (CFHT 1995)

		Sum of Indian refineries	***Average of all refineries***	***Total (TJ)***	***Share***
Electricity	**(MWh)**	123,241	10,270	444	0.38%
Fuel gas	**(m³)**	664,497	55,375	31,132	26.87%
Fuel oil	**(t)**	1,623,517	135,293	67,684	58.43%
Coke	**(t)**	262,905	21,909	10,450	9.02%
Flaring of gas	**(m³)**	130,878	10,907	6,132	5.29%
Total		-	-	115,842	100.00%

The difference between input and output in Indian refineries in 1993/94 reached from 0.61% to 1.29% of the output. The average of these **losses** for 1993/94 in India was 0.95%. Today it is possible to reduce the loss to 0.5-0.6% (OCC 1995; IOC 1994/12). The share of flaring in these losses is not clear. For this study the share of flaring in the total losses is estimated to be 30%. This considers also the information about the hydrocarbon emissions of refineries as described in chapter 5.3.2.3. This estimation is also in the range of values found for European refineries (FRISCHKNECHT ET AL. 1995). Table 5.8 shows the amount of flared gas. This is considered as an additional energy use.

5.3.2 Emission of Air Pollutants

5.3.2.1 Standards for Emissions and Ambient Air Quality

Recently the statutory requirements for pollution control have become stricter, especially after the enactment of the Environmental Protection Act in 1986. Air-emissions standards for sulphur dioxide and particulate matter (PM) have been evolved by the Central Pollution Control Board (CPCB). Besides the standards for concentrations the height of the stacks is prescribed. The standards for sulphur dioxide emissions are provided in Table 5.9. To secure nation wide compliance with these prescribed standards task forces have been constituted by the CPCB for the major industries (TERI 1993/01).

Table 5.9: Air pollution emission standards for SO_2 from oil refineries in India (CBWP 1985/07)

Process	***SO_2 Emission Limits***	
Distillation	0.25	kg per tonne of feed
Catalytic cracker	2.5	kg per tonne of feed
Sulphur recovery unit	120	kg per tonne of sulphur in the feed

To control the prescribed standards, sulphur dioxide is measured on-line in a few refineries. Other emissions of air pollutants (CO, NO_X, PM) are controlled only one off testing. Along with the control of sulphur dioxide emissions, parameters for the ambient air quality are monitored in and around the refineries. Thus it is also possible to obtain some information about the pollution due to spread emissions. Ambient air quality criteria are prescribed for different categories of usage. They are shown in Table 5.10 (IOC 1995; TERI 1993/01).

Table 5.10: Ambient air quality criteria (µg/m³) (TERI 1993/01; TREND 1995)

Category	***SO_2***	***NO_2***	***CO***	***SPM***
General: Annual Average	80	100	-	200
General: 24 h Average	130	200	-	400
General: 1 h Average	655	470	-	-
Sensitive: Annual Average	30	30	1,000	100
Sensitive: 24 h Average	30	30	-	200
Industrial/mixed	120	120	5,000	500
Residential/rural	80	80	2,000	200

In the discussion of environmental impacts, the newly set up refinery in Mathura is of special importance. This refinery is located about 40 km upwind of Agra, the site of India’s most important tourist attraction, the Taj Mahal. Before it was built, it was discussed whether the refinery, along with other local sources of acid pollutants, causes damages to this famous monument. Accordingly the prescribed standards and the pollution controls in this refinery are the strictest in the country. This refinery is run by the Indian Oil Corporation (IOC) that attempts to influence the public opinion with an open public information policy (GOYAL ET AL. 1990).

5.3.2.2 Sources of Air Pollutants

Direct emissions from a refinery consist of exhaust gases from the burning of fuels in furnaces, boilers and motors. Surplus fuel and refinery gases are flared. Uncontrolled emissions of the refinery are those of hydrocarbons due to leaks. They can only be monitored indirectly by ambient air quality measurements (IIP 1994/12; IOC 1995; OCC 1995).

There are two types of sources for SO_X in the refinery. The first is the combustion of fuels that contain sulphur. Except for one refinery in Digboi that uses fuel oil with a sulphur content of 4 wt%, all refineries use fuel oil with a sulphur content between 0.2 wt% and 0.6 wt%. Some refineries also reduce the sulphur content of the fuel gases to minimise the emissions of sulphur dioxides (NEERI 1995).

The other sources are FCC, flaring and the Sulphur Recovery Unit (SRU). The share for both types is half of the total emissions. This amounts in the Mathura refinery to 50 kg/h from flaring, 150 kg/h from FCC and 60 to 70 kg/h from SRU. The emission of SO_2 from these sources based on the given data is estimated to be about 6.7 kg/TJ *{III-D-1}* (IOC 1994/12a; IOC 1995).

Hydrocarbons are emitted without control in various parts of the refinery due to leaks in the system. The losses are due to evaporation, losses in tank operation, losses due to refilling actions, losses with the wastewater and flaring of lean gas. Storage facilities are the most significant sources of hydrocarbon emissions. Vapours are either emitted when storage tanks ‘breathe’ or when vapours are displaced during filling and when liquids evaporate. Floating roof tanks are provided for the storage of high vapour pressure hydrocarbons to minimise evaporation loss from liquid surface (the effected emission reduction may reach 95%) (TERI 1993/01).

Emissions of *particulates* occur mainly with catalyst fines from catalyst regenerators *{III-D-4}*. In typical installations, two or three stage cyclones are located in regenerator vessels of FCC units for catalyst recovery. As a control measure, Electrostatic Precipitators (ESP) are used in some refineries to collect fine particles from regenerator exit gases. Particles are also emitted from the coking process (TERI 1993/01).

Sources of *CO* include catalyst regenerators, coking operations, boilers and process heaters *{III-D-3}*. Catalyst regenerators in FCC units emit significant amounts of CO which can be burnt in CO boilers. Carbon monoxide emissions of furnaces are no problem because of the high amount of excess air (TERI 1993/01; IOC 1994/12).

5.3.2.3 Inventory for the Emissions

Due to the very few prescribed standards, measurements of air pollutants are rare. Data when available is only from single measurements and it is unclear how far they give a representative picture. Not all Indian refineries meet the air quality guidelines for the air pollutants SO_2 and particulate matter (IOC 1995; PETROTECH 1995).

Table 5.11 shows averages of emission values for some refineries in 1994 *{III-D-1..4}*. They are based on single time stack measurements. Only for Haldia and Guwahati was there enough data available to calculate a weighted mean. The table also shows the average emission values for a German refinery and the prescribed standards for gas and oil furnaces in Germany. The low values for NO_X and CO in the Indian refineries seem to be particularly unreliable. It is possible that the Indian values were not standardised to a certain oxygen content in the flue gases and were not standardised on a temperature. This might be a reason for the great differences.

Table 5.11: Average emission values from different stacks in 1994 for Indian refineries and the prescribed standard. Emissions of a German refinery and the standards for gas and oil furnaces in German refineries (mg/m³)

	SO_2	NO_X	PM	CO
Haldia	3,470	131	271	2.8
Guwahati	103	7.4	61	*n.a.*
Barauni	440	49	219	*n.a.*
Visag	759	526	381	*n.a.*
Digboi	11	1.3	*n.a.*	*n.a.*
Gujarat	68	2.6	*n.a.*	*n.a.*
German refinery	75	260	4	16
Indian Standard for refineries	**1,200**	**-**	**150**	**-**
German standard for gas furnace	**35**	**350**	**5**	**50**
German standard for oil furnace	**1,700**	**450**	**50**	**175**

n.a. - not available

***Sources:** Holborn 1995; IOC 1995; NEERI 1990/08, 1995*

A comparison with the values given by ÖKO (1994/12) for boilers used in refineries also indicates recorded values are too low in the given emission data. They are shown in Table 5.12. The emission of air pollutants for the LCI is again calculated with *generic* combustion devices for the three fuels[3]. These combustion devices are assumed to have an *eta* (efficiency of combustion) of 1. The estimation considers the shown stack measurements, the Indian standards and the values given by ÖKO (1994/12). The data for the estimated combustion devices are also shown in Table 5.12 *{III-D-1..5}*. The emissions due to flaring are estimated with the same generic combustion device as for the petroleum exploitation.

Table 5.12: Emission values for calculations in TEMIS (ÖKO 1994/12) and estimates for the combustion devices in Indian refineries (mg/Nm³)

	NO_X	PM	CO	CH_4	NMVOC	N_2O
Oil boiler	1,000	50	150	1	25	5
Reduction	60%	0%	0%	0%	0%	0%
Emission	400	50	150	1	25	5
Oil boiler (CIS)	500	150	250	0.50	50	0.50
Reduction	0%	0%	0%	0%	0%	0%
Emission	500	150	250	0.50	50	0.50
Fuel oil estimation	**500**	**150**	**200**	**1**	**25**	**2**
Gas boiler	200	0.50	100	10	25	1
Reduction	25%	0%	0%	0%	35%	35%
Emission	150	0.50	100	10	16.25	0.65
Gas boiler (CIS)	400	5	250	25	50	1
Reduction	0%	0%	0%	0%	0%	0%
Emission	400	5	250	25	50	1
Fuel gas estimation	**300**	**4**	**150**	**15**	**30**	**1**
Coke boiler	400	10,000	250	0.50	25	25
Reduction	0%	60%	70%	99.5%	0%	0%
Emission	400	4,000	75	0	25	25
Coke estimation	**400**	**500**	**200**	**0.1**	**20**	**25**

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[3] The reason for this advance is described in chapter 4.2.2.7.

The amount of emitted hydrocarbons is estimated by PETROTECH (1995) with 4 to 5 t/h for a 6 Mtpa refinery (=158 kg/TJ). The data for emissions of hydrocarbons due to losses are shown in Table 5.13. The hydrocarbon emissions are calculated as the loss of the refinery (see 5.3.1) less the estimated flaring, the emissions of hydrocarbons with the wastewater and the discharged wastes *{III-D-5}*. The emission of methane is estimated to be 1/11 of the total hydrocarbon emissions. The rest is assumed as NMVOC. This ratio was proposed in ÖKO (1994/12). The estimation for India differs from the values given by ÖKO (1994/12) for TEMIS.

Table 5.13: Emissions of hydrocarbons from refineries due to loss (CFHT 1995; ÖKO 1994/12; Own calculation)

	Estimation for the LCI (kg/TJ)	*TEMIS (kg/TJ)*	*Total emission in India (thousand tonnes)*
CH_4	15	1	31.3
NMVOC	148	10	313.0

5.3.3 Water Use and Discharge of Effluents

The use of water in a refinery depends on the type of cooling system. In India refineries have *once through* or *re-circulation* systems. The two refineries in Madras and Visag (Vishakhapatnam) use sea water; other refineries use treated effluents or river water for cooling. The latter is more expensive because a fee must be paid for the water. Other requirements for water comprise of steam generation, service water (cleaning, etc.), sanitary and fire water. Some refineries recycle a part of the treated water for irrigation of gardens, agricultural land and green belts, for cooling and as firewater. The CBWP surveyed the water use *{III-B-1}* in 1982 and found a median of 23 thousand tonnes per tonne of processed crude for once through cooling water systems and 1,700 tonnes per tonne of processed crude for re-circulation cooling systems (ACHARYA/DAS 1995, CBWP 1982; NEERI 1995).

Table 5.14: Wastewater sources in a refinery (NEERI 1990/09)

Wastewater source	*Daily amount (m^3/d)*
Oily waste stream	1,920
Cooling tower	1,920
Sanitary	720
Sanitary town	240
Mercaptan oxidation stream	2
Total	**4,702**

The different wastewater sources in a refinery are shown in Table 5.14 *{III-C-1}*. The refinery effluents typically contain oil, phenols, sulphides, cyanide, ammonium, dissolved and suspended solids that originate from process operations, storage-tank water-drainage, cooling tower blow down and other sources[4]. Other liquid chemical wastes are mainly acidic and alkaline effluents from petroleum product treatment units (MANNING/SNIDER 1983; TERI 1992/07).

The six refineries of the IOC have fully fledged effluent treatment plants (ETP) comprising of physical, chemical and biological treatment. Today all Indian refineries meet the MINAS standard for effluents (PETROTECH 1995; IOC 1994/12a).

The calculated water balance for the Indian refineries is shown in Table 5.15. The **water use** includes water for cooling, processes and sanitary use. The given value is the average of 12 re-

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[4] A detailed list of wastwater sources from refinery unit processes is given by MANNING/SNIDER (1983).

fineries *{III-B-1}*. The theoretical amount of *discharged water* is shown in the second row. This takes into consideration data about the water use and the capacity of the ETP. This value is used for the indicator **effluents** *{III-C-1}*. The last row shows the estimated quantity of effluents discharged after treatment containing the later investigated water pollutants. Neither cooling water nor reused water are considered in this calculation. The value of **effluent with pollutants** is used to calculate the amount of discharged water pollutants.

Table 5.15: Water balance for the Indian refineries (kg)

	Total	Number of data
Water use	4.38E+11	12
Effluent and cooling water	4.10E+11	12
Effluent with pollutants	2.19E+10	10

Sources: *Own calculation with Acharya/Das 1995; BPCL 1995; CBWP 1982; CPCB 1994/01; HPCL 1995/02; IOC 1995; NEERI 1990/09, 1991/04, 1995; PETROTECH 1995*

The MINAS for refineries prescribes maximum permissible concentrations of pollutants in the effluents. The standard is based on a wastewater generation of 700 litres per tonne of processed crude oil (CBWP 1982). Table 5.16 shows the minimum, maximum and mean of the values for the investigated refineries. The emission of water pollutants with the effluents was calculated as a weighted mean. In the first step the total emissions of the pollutants were calculated with consideration to the amount of *effluent with pollutants*. These values were added and the average concentration in the total discharged wastewater was calculated. This average concentration is used in the second step to calculate the product specific emissions for the LCI *{III-C-2..7}*.One refinery in Bombay did not meet the normal CPCB standard. The prescribed limits for this refinery are higher. This is the reason that the value for BOD is higher than the standard. The emission of water pollutants is calculated with the mean values for the concentration and the value for discharged *effluents with pollutants*.

The table shows also the range of comparable values for refineries in Europe and the GUS found by Frischknecht et al. (1995). The given value for the discharge of effluents is higher because it considers the additional discharges of cooling water. The found concentrations of water pollutants are smaller than the Indian values. The total emissions are of a comparable figure if it is considered that the concentrations must be multiplied with the amount of effluents.

Table 5.16: Average concentration of water pollutants in the effluents of Indian refineries

	Number of data	Minimum	Maximum	Mean (used for the LCI)	Indian standard	Inter-national
Effluent (kg/TJ)	*9*	6,753	30,560	**10,389**	18,002	104,000
BOD (mg/l)	*11*	3.6	50	**17**	15	1-1.1
COD (mg/l)	*6*	27	231	**98**	250	30-33
TSS (mg/l)	*9*	8	30	**17**	20	1-10
Phenol (mg/l)	*10*	nil	1.10	**0.46**	1.0	0.04-0.2
Oil & Grease (mg/l)	*11*	0.7	20.4	**9.6**	10	0.25-0.6

Sources: *Own calculation with Acharya/Das 1995; BPCL 1995; CBWP 1982; CPCB 1994/01; CFHT 1995; HPCL 1995; IOC 1995; NEERI 1990/09, 1991/04, 1995; PETROTECH 1995; TEDDY 1994; Range of data for international refineries by Frischknecht et al. 1995 (Data for effluents include cooling water)*

5.3.4 Solid Wastes

The different types of waste fractions from a refinery are given in Table 5.17. Solid wastes generated during refinery operations consists mainly of oily sludge from storage tank bottoms or oil separators and the chemical or biological sludge from ETP facilities. Tarry material is generated during acid refining of some products. Oily sludge is treated in melting pits for the recovery of oil. Left over sediments and dry sludge are disposed off by land filling within the site of the refinery. Chemical and biological sludge are disposed off by land filling after neutralisation or natural degradation in drying beds. Land treatment and sludge farming techniques for more efficient disposal of residual sludge are being experimented with certain refineries (PETROTECH 1995; IOC 1994/12a; IOC 1995).

Table 5.17: Fractions of different sludge and wastes in a refinery (NEERI 1991/04)

Type of waste	*Tonnes per year*
Oily tank sludge	300
Separator for ETP sludge	250
Chemical sludge	400
Hazardous waste	200
Biological sludge	2,500
Total	4,000

The average waste produced by a refinery can be estimated to be around 1,000 to 4,000 tonnes per year. The oil from this sludge is recovered and between 75 to 700 tonnes treated sludge is disposed of per year[5]. The total amount of disposed waste is calculated to be 10,800 tonnes per year for all the refineries in total *{III-E-2}*. This calculation takes into consideration available data for 9 refineries (ACHARYA/DAS 1995; CBWP 1982;CPCB 1994/01; NEERI 1990/09, 1991/04, 1995; IOC 1994/12A; IOC 1995).

5.3.5 Other Environmental Impacts

To improve the environmental situation near the refinery, green belts or *ecological parks* are set up in the surroundings *{III-F-2}*. They are developed to serve the purpose of pollution sink and to improve the look of the surrounding area. The ecological park being developed surrounding the treated effluent polishing point of the Mathura refinery covers 18,000 m² (IOC 1994/12a). It is questionable how far these small parks can avoid the wider dispersion of pollutants emitted from the refinery. The Indian refineries on average operate for 24 hours a day, 345 days of the year. The land use in the average refinery complex is approximately 470 ha. The area for the total project including green belts, marketing, pipeline installations and living areas is about 890 ha *{III-F-1}* (IOC 1995).

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[5] The refinery in Digboi disposed the produced wastes from the 1940s until 1982 inside their area. The amount of this dumping pit today is 30,000 tonnes (PETROTECH 1995).

5.3.6 Allocation of the Impacts

With regard to the life cycle inventory, the production of the following fuels (as described in chapter 3.2) in refineries is investigated:

- Liquefied petroleum gas (LPG)
- Kerosene (SKO)
- High speed diesel (HSD) and light diesel oil (LDO)
- Fuel Oil (HPS and LSHS)
- Fuel gas
- Coke

It was not possible to investigate the different production stages separately for all Indian refineries. The entire process was taken as a black box and all indicators were investigated for this system. In a second step the investigated environmental loads for the indicators are allocated by general **allocation criteria**. The possible allocation criteria are described in chapter 4.2.3.1.

Economic value of the products is not useful as an allocation criteria in India because prices do not reflect the true market value because the subsidy system. The allocation criteria *lower heating value* would be the easiest way, but various authors have shown that this does not reflect the existing differences regarding the production of the refinery products (FRISCHKNECHT 1994; FRISCHKNECHT ET AL. 1995; ÖKO 1994/12; RØNNING 1994).

ÖKO (1994/12) deducted **allocation coefficients** to calculate the energy use for different refinery outputs. The average value for an **indicator** (e.g. energy use in the refinery) under a specific *allocation criteria* (e.g. LHV) is multiplied with the allocation coefficient to calculate the product specific use or emission for this indicator.

FRISCHKNECHT (1994) has shown that allocation coefficients are related to the types of refineries, the composition of products and the investigated indicator. The specific energy use for a product depends also on the production unit. The direct production of LPG from crude oil, for example, is less energy consuming than the secondary production in the FCC (IIP 1994/12).

Allocation coefficients are investigated by different authors and given in Table 5.18. The coefficients investigated by ÖKO (1994/12) describe the situation in German, Swiss and US-American refineries. The comparison of LHV and mass in the second column indicates that the difference between these two allocation criteria is small.

The last column of the table gives the estimates for the allocation of energy use and emissions of air pollutants in the life cycle inventory. The estimation considers the shown investigated coefficients and the refinery production in India. The *allocation coefficient* for the light distillates and heavy ends is estimated to be 1.5 and 1 respectively. The coefficient for middle distillates (HSD, SKO) is chosen in a way that the overall balance for the emissions of Indian refineries is met. Kerosene is treated in the same way as diesel oil because it is a similar product. In a first step the environmental load of the refinery is allocated to all products similarly by the lower heating value. In a second step these burdens are multiplied by the allocation coefficients to consider the differences in the production. The emissions of water pollutants are allocated in a more specific way because they vary for every product and every indicator.

Table 5.18: Allocation coefficients investigated for different allocation criteria, indicators and refinery products and the estimation for the LCI

Indicator	*Energy use*	*LHV*	*Catalyst use*	*Thermal energy*	*Electricity use*	*Emissions to water*	*Air pollutants*	*Energy use*	***Energy use, air pollutants***
Allocation criteria	LHV	Mass	Mass	Mass	Mass	Mass	Mass	Mass	**LHV**
Gas oil	*n.a.*	1.01	0.4	0.5	0.5	1.0 - 1.2	*n.a.*	*n.a.*	**0.813**
Fuel oil	1.0	0.95	1.1	1.0	1.0	0.3 - 1.7	*n.a.*	*n.a.*	**1.0**
Petrol	2.0	1.02	2.1	2.0	1.5	0.9 - 1.2	*n.a.*	*n.a.*	**1.5**
Diesel oil	0.5	1.01	*n.a.*	0.5	0.5	0.9 - 1.2	0.4 - 0.58	0.42	**0.813**
Kerosene	*n.a.*	1.02	*n.a.*	0.5	0.5	0.6 - 1.1	*n.a.*	*n.a.*	**0.813**
Propane/ Butane (LPG)	1.5	1.08	*n.a.*	1.5	1.5	0.9 - 1.2	*n.a.*	*n.a.*	**1.5**
Fuel gas	1.0	1.14	*n.a.*	1.0	1.0	0.9 - 1.2	*n.a.*	*n.a.*	**1.0**
Coke	*n.a.*	0.95	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	*n.a.*	**1.0**
Source:	ÖKO 1994/12	FRISCHKNECHT 1994 FRISCHKNECHT ET AL. 1995					RØNNING 1994		**Estimation for the LCI**

The allocation for the water pollutants is more complicated. FRISCHKNECHT ET AL. (1995) investigated detailed allocation coefficients for a list of water pollutants. These coefficients are calculated for an allocation by mass. The values are multiplied for this study with the factor for mass to LHV allocation as shown in Table 5.18. Table 5.19 shows the used values for a list of water pollutants. Other water pollutants, the water use, the discharge of effluents, wastes, the use of land and materials are all calculated with a coefficient of 1. This follows the proposals made by FRISCHKNECHT ET AL. (1995).

Table 5.19: Allocation coefficients for the emissions of water pollutants (FRISCHKNECHT ET AL. 1995)

Indicator	***BOD***	***COD***	***Phenol***	***Oil & Grease***
Allocation criteria	LHV	LHV	LHV	LHV
Fuel Oil (HPS)	0.5	0.3	1.8	0.3
Petrol	1.1	1.2	0.9	1.2
Diesel oil	1.2	1.1	0.9	1.2
Kerosene	1.0	1.0	0.6	1.1
Propane/ Butane (LPG)	1.0	1.1	0.8	1.1
Fuel Gas	1.0	1.1	0.8	1.1
Coke	1.0	1.0	1.0	1.0

5.3.7 Final Inventory for Refineries

Table 5.20 shows the **final data** of the LCI for refineries in India. The differences caused by using different allocation coefficients (as described in chapter 5.3.6) are calculated. All investigated qualitative indicators are comprehended in this table. This data will be used for the further calculation of environmental impacts. The table gives also the data for *international* refineries to calculate the impacts of imports. The data for the international refinery are multiplied for the use in TEMIS with the allocation coefficients, as given in Table 5.18 and Table 5.19, to consider the foreign production of LPG and kerosene. The last column of the table gives a comparison with the values for the production of LPG in European refineries as investigated by FRISCHKNECHT ET AL. (1995). All the information in the previous sections concerning quantitative indicators is related to the products quantified in MJ (TJ). *Eta* describes the percentage output of throughput. Fuels used in the refinery are calculated first as products. The mass of steel and cement is calculated with data given by ÖKO (1994/12).

The data for the international refinery are estimated, using the data of FRISCHKNECHT ET AL. (1995), ÖKO (1994/12) and BUWAL (1995). Again big differences between the Indian and the international refineries are avoided to hinder a bias in the analysis for LPG and kerosene. GEMIS 2.0 gives an eta of 95% for the OPEC refineries in comparison to 99.5% of German refineries. The energy use of the OPEC refineries is given a value of only 2%. Thus the overall energy efficiency is nearly the same. BUWAL found 9.35% for the energy use in refineries. The reason for the high energy use in comparison to the Indian refineries might be higher complexity of the plants. FRISCHKNECHT ET AL. found a value of 4.8% for the production of LPG. The energy use for the international refinery delivered by fuel gas and fuel oil combustion is estimated to be about 5%.

BUWAL gives the hydrocarbon emissions at 163 kg/TJ. This is within the range of values found for India (165 kg/TJ) and much more than investigated by ÖKO (11 kg/TJ) and FRISCHKNECHT ET AL. (10 kg/TJ). The additional emissions of sulphur found for Europe are in the range of the Indian values (7 kg/TJ).

The amount of used water investigated by FRISCHKNECHT ET AL. (90 kg/TJ) is smaller than the value found for India (207 kg/TJ). A possible reason is the different use of cooling water in the refineries. The value for the effluents in Europe (90 t/TJ) lies between the Indian values for total water discharge and the discharge of polluted effluents (194 t/TJ and 10 t/TJ). The value for oil investigated by BUWAL is much higher (3.9 kg/TJ) than the Indian value (0.07 kg/TJ). The values of the BUWAL study are taken from different sources and it was not possible to evaluate this data. Values for water pollutants were also investigated by FRISCHKNECHT ET AL. for refineries which deliver their products to Europe. The values for BOD and TSS are on the same level. The values for COD, oil & grease and phenol are higher than the values found for India. The production of waste is calculated by BUWAL and FRISCHKNECHT ET AL. with higher values than in this study (37 kg/TJ and 18 kg/TJ). But the Indian value of 5.1 kg/TJ seems to be reliable because adequate information was available.

The values found for the energy use and the emissions of water pollutants in the Indian refineries appear relatively reliable. Uncertainties exist about the true emission data for combustion devices and the discharged amount of effluents. Further research work is necessary for the investigation of unspecified emissions of hydrocarbons from the refineries. More information needs to be collected in future studies about the imports of petroleum products to India and the accurate data for the international refineries concerned.

Table 5.20: Refinery data in India for the TEMIS calculations, data for an international refinery and a comparison with values for an European refinery producing LPG

	Unit	Indian refineries			International	Europe
Allocation coefficient		**(0.813)**	**(1)**	**(1.5)**	**(1)**	**LPG**
Capacity	MW	5,907	5,907	5,907	1,000	1,000
eta (products/crude)		99.06%	99.06%	99.06%	99.00%	-
Electricity use	MJ/MJ	1.71E-04	2.10E-04	3.15E-04	-	4.64E-03
Fuel gas use	MJ/MJ	0.01198	0.0147	0.02210	0.015	6.83E-03
Fuel oil use	MJ/MJ	0.0260	0.0320	0.0481	0.035	0.0365
Coke use	MJ/MJ	0.00402	0.0049	0.00742	-	-
Flaring	MJ/MJ	0.0023	0.0029	0.0043	-	-
Total auxiliary energy	MJ/MJ	0.0445	0.0548	0.0822	0.05	0.0483
CH_4	kg/TJ	12	15	22	15	1
NMVOC	kg/TJ	120	148	222	150	8
SO_2	kg/TJ	5.5	6.7	10.1	6	12
Water use	g/MJ	207	207	207	150	90
Effluent discharge	kg/TJ	1.94E+05	1.94E+05	1.94E+05	1.90E+05	9.0E+04
BOD	kg/TJ	0.172[#]	0.172	0.172[†]	0.14	0.1
COD	kg/TJ	1.02[#]	1.02	1.12[†]	1.2	3.3
TSS	kg/TJ	0.231	0.231	0.231	0.2	0.1
Phenol	kg/TJ	0.00197[#]	0.00326	0.00261[†]	0.005	0.016
Oil & grease	kg/TJ	0.081[#]	0.0733	0.081[†]	0.3	0.3
Waste	kg/TJ	4.17	5.12	7.69	15.0	18
Load	h/a	8,280	8,280	8,280	8,280	8,280
Life time	a	20	20	20	20	20
Land use	m^2	8.22E+06	8.22E+06	8.22E+06	2.0E+06	7.3E+07
Steel	g	2.07E+11	2.07E+11	2.07E+11	5.0E+10	5.5E+10
Cement	g	5.91E+10	5.91E+10	5.91E+10	1.0E+10	1.2E+10

Sources: *Own calculation for India with Acharya/Das 1995; BPCL 1995; CBWP 1982;CPCB 1994/01; CFHT 1995; HPCL 1995; IOC 1994/12a, 1995; NEERI 1990/09, 1991/04, 1995; PETROTECH 1995; TEDDY 1994, estimation for an international refinery with ÖKO 1994/12, BUWAL 1995, Frischknecht et al. 1995 and the Indian values and comparison with the data investigated by Frischknecht et al. 1995 for the production of LPG in Europe*

#,† - *Calculation with allocation coefficients as given in Table 5.19 for kerosene (#) and LPG (†)*

5.4 Production of LPG in Indian Fractionating Plants for Natural Gas

LPG also arises in the extraction of natural gas (approximately 3% of the quantity of natural gas) in fractionating plants (UBA 1992). The gas processing stages in these plants can be classified into two main groups. The process scheme for the fractionating plant in Hazira is shown in Figure 5.2. The first is the conditioning of gas. Different contaminants are removed from the gas. In the second stage the valuable products are extracted from the gas. The possible products are liquefied ethane/propane mixture (C2/C3), propane, LPG, natural gasoline, liquefied natural gas (NGL) and sulphur. The gaseous residual after all stages of extraction, the fuel gas or lean natural gas (LNG), can also be used as a fuel (Tiwari 1995).

Due to the contaminants H_2S, CO_2, water and liquid hydrocarbons, the natural gas cannot be used immediately. In the first conditioning stage, the *sweetening*, the gaseous contaminants H_2S and CO_2 are removed by passing the gas through an absorber. The solutions used for the absorber are mostly regenerative. At the plant in Hazira, 48 tonnes of sulphur are produced per year. The second is the removal of water vapour from the natural gas. The dehydration of gas is mainly carried out by means of liquid and solid desiccants such as triethylene glycol (TEG), activated alumna, molecular sieves, etc. These desiccants are of a regenerative type. In the last step, liquid hydrocarbons are removed by passing the gas through a gas-liquid separator (TIWARI 1995).

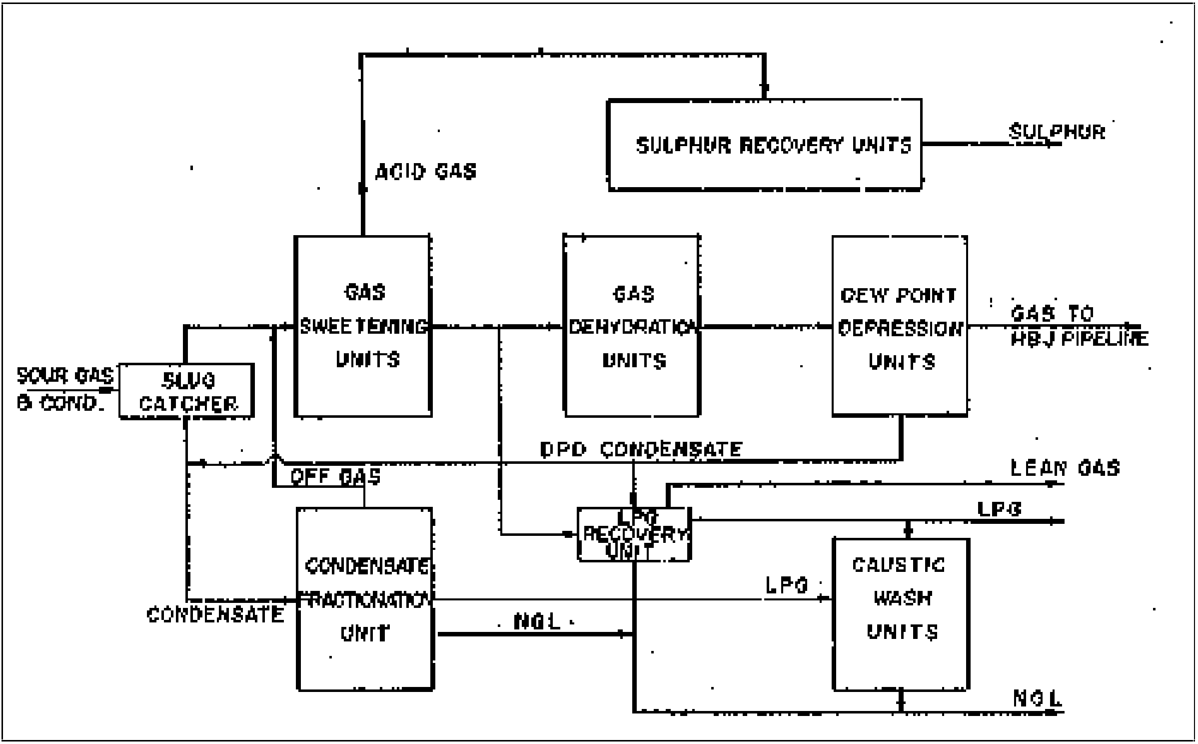

Figure 5.2: Overall process flow chart for Hazira gas terminal (BATRA 1995)

The extraction of valuable products is effected by the cryogenic process or the lean oil extraction process. In India the cryogenic process is widely used because it is economically attractive and environmentally friendly. In this process the sweet natural gas is chilled using either a refrigeration system, turbo expander process or a combination of both. With the help of external refrigeration, the gas is cooled down to minus 40°C. The condensed hydrocarbons are separated in separators and fractionated in fractionating columns to obtain the desired valuable products. LPG and NGL are recovered in the first unit. C2/C3 is recovered in the following unit (TIWARI 1995). The share of the different products can be regulated according to demand. Cooling water is normally held in closed systems. Specific effluents are produced only in small amounts from dehydrogenation *{IV-C-1}*. For these effluents, the same standards are prescribed as for refineries (PETROTECH 1995; SHAMSUNDAR 1995).

5.4.1 Energy Demand

Data about the energy use of gas processing plants *{IV-A-2}* was available for the plants of the ONGC in Hazira and Uran and for the OIL facilities in Duliajan (Table 5.21). Complete data was not available, and for the plant in Uran semi-contradictory information was given. This made it necessary to estimate the possible values.

The demand for energy results mainly from the cooling processes. The demand is met by a co-generator that produces electricity and steam. This generator uses fuel gas *{IV-A-2}*. To avoid problems in case of shut downs, provisions is made for flaring of surplus natural gas. For safety reasons, it is necessary that a small flaring fire is fed at all times. In case of difficulties in the downstream sector, the surplus natural gas can be burnt by means of it (PETROTECH 1995; SHAMSUNDAR 1995).

Table 5.21: Gas processing plants for the fractionating of natural gas in India (OIL 1995; NEERI 1995; PETROTECH 1995)

	Unit	Uran, ONGC	Hazira, ONGC	Duliajan, OIL
eta		99.89%	88.84%	99.90%
Natural gas throughput	m³/a	4.40E+09	6.97E+09	6.66E+08
Natural gas throughput	MJ/a	1.81E+11	2.86E+11	2.73E+10
LPG production	MJ/a	2.49E+10	1.95E+10	2.28E+09
LPG percentage		14.58%	7.19%	8.82%
C2/C3 production	MJ/a	2.06E+10	n.a.	n.a.
NGL production	MJ/a	1.27E+10	4.90E+10	-
LNG production	MJ/a	1.16E+11	1.86E+11	2.41E+10
Condensate production	MJ/a	6.44E+09	n.a.	9.75E+08
Products total	**MJ/a**	**1.80E+11**	**2.54E+11**	**2.73E+10**
Flaring	m³/a	4.42E+06	n.a.	n.a.
Flaring	MJ/MJ	1.01E-03	n.a.	n.a.
Auxiliary energy LNG	m³/a	1.02E+08	1.16E+08	1.22E+07
Auxiliary energy LNG	MJ	3.71E+09	4.21E+09	5.02E+08
Amount of auxiliary energy	**MJ/MJ**	**2.06E-02**	**1.66E-02**	**1.84E-02**
Capacity	MW	6,139	8,649	940
Working days	d	340	340	337
Load	h/a	8,160	8,160	8,076

5.4.2 Emission of Air Pollutants

The measurements of total emissions from stacks in the processing unit in Hazira are shown in Table 5.22 *{IV-D-1..4}*. The estimated values of the gas combustion for co-generation are shown in Table 5.22. The ratio of emissions of different pollutants as given and information about gas combustion and their estimates as described in chapter 4.2.2.7 were used for the estimates.

Table 5.22: Emission of air pollutants at the gas processing unit in Hazira from 8 to 10 stacks in 1992/93 and estimates for LNG combustion in the LCI (PETROTECH 1995)

	Minimum (kg/h)	Maximum (kg/h)	Gas combustion (mg/Nm³)
SO_2	3	61	**-**
NO_X	3	700	**250**
PM	5	300	**100**
CO	0,5	250	**90**
HC	3	130	**CH_4: 15**
			NMVOC: 30

5.4.3 Final Inventory for Fractionating Plants

The life cycle inventory is shown in Table 5.23. The estimation takes into account the data described above. Information about the energy intensity to produce different types of gases was not available. The environmental impacts are allocated by the lower heating value of the products, because this is the easiest method of calculations according to TEMIS. The emission of air pollutants due to *flaring* is calculated with the same generic device as described in the chapter 4 *{IV-D-1..5}*. The use of water and the discharge of effluents is ignored because volumes appear to be very small in comparison to the refineries and other sources during the life cycle *{IV-C-1..7}*.

Table 5.23: Estimates for an Indian gas processing plant in the life cycle inventory

	Unit	Estimation
eta		99.90%
Capacity	MW	7,000
Flaring	MJ/MJ	0.0010
Auxiliary energy LNG	MJ/MJ	0.0185
Load	h/a	8,132
Life time	a	20
Land use	m²	1,200,000
Steel	t	160,000
Cement	t	80,000

5.5 Life Cycle Inventory for Indian LPG Bottling Plants

An installation for LPG bottling normally consists of the following basic facilities:

- Storage tanks for bulk LPG and filling facilities
- LPG cylinder storage and filling facilities
- Process units
- Utilities and effluent disposal

The operations for the LPG bottling are as follows:

- Receipt of LPG cylinders and of LPG delivered in bulk
- Storage of the bulk LPG in tanks
- Cleaning and inspection of the cylinders
- Filling of LPG cylinders
- Handling & storage of LPG cylinders
- Auxiliary operations

LPG in bulk is transported and delivered in rail tank wagons with 5, 10, 12, 13, 15 or 37 ton capacity and in road tank trucks with a 6 to 18 ton capacity. Tank trucks and wagons should be unloaded by differential pressure method using an LPG compressor. Following this LPG vapour can be recovered so that the vapour pressure in the tank truck is reduced to 14,700 hPa minimum (GOI 1994/04).

The delivered LPG is pumped at the plant into stores. LPG in liquid and vapour form is stored under pressure in tanks known as pressure vessels. The storage vessels should be drained to catch the water content of the LPG. The cylinders should be received in capped condition (GOI 1994/04).

Before the filling, the cylinders are inspected, the surface is cleaned, the remaining air is evaporated and the tare weight is controlled. The cylinders are tested for leaks. To ensure that there are no leaks, the compact valve tester should be calibrated to detect leakage beyond 0.5 g/h. An average of 0.2% of the cylinders is found to be defect. If cylinders have a defective valve they should be emptied of LPG up to a pressure of 14,700 hPa. The evacuated LPG is pumped back into a tank. Thereafter the cylinder is de-pressurised by *cold flare*. This means that the remaining LPG is emitted into the atmosphere by means of a vent outside the shed. With 10 trips per year a life span of 15 to 20 years can be assumed for the cylinders and valves (GOI 1994/04; LPG-ORDER 1995; OCC 1995).

In big plants, the cylinders are filled and weighed on a production line. In small plants this work is done manually with a filling gun. All cylinders should be filled on a gross weight basis on the filling machine. The filled cylinders are stored under cover. Normally there is a big safety area around the installations to minimise the risk for the environment. To serve the demand of users for the cylinders an average of 1.5 cylinders per user are needed. Due to an overproducing capacity for cylinders, it is possible to give spare cylinders to the users so that there is no shortage if one cylinder is empty (OCC 1995; TERI 1989/3).

The cylinders for the subsidised LPG are standardised. The common cylinders have a capacity of 33.3 litres +/- 5 litres for 14.2 kg of LPG. Their tare weight is 16.5 kg *{V-B-2}*. Additional to this, cylinders with a capacity of 4, 5, 11.2, 19, 47.5 or 50 kg are permitted. There was a proposal to use 5 kg cylinders for hill areas or for users who cannot spend so much money at one time. Private entrepreneurs who sell LPG on the free market must shape their cylinders, so that no interchange is possible with the government products. Small cylinders that can be bought on the market do not take a big share of the LPG market (ARORA 1994; LPG-ORDER 1988).

The aggregate estimated data for all the Indian bottling plants and the specific data for one plant of OIL are shown in Table 5.24. **Energy** is needed to run gas compressors and auxiliary equipment. The energy needed for bottling plants lies in the range of 18 to 34 kWh electricity per tonne LPG *{V-A-4}*. In case of power cuts, the plants have auxiliary diesel generators. The estimation considers three pieces of information concerning the energy use and the data for the plant of OIL.

The **water** comes from a tube well and its use for cleaning can be estimated to be around 1,000 litres per tonne of LPG *{V-B-1}*. The quantity of discharged effluents is low. Thus the emission of water pollutants from these effluents is not considered *{V-D-1..7}*. The **land use** for a small plant is about 50,000 m² with a green belt of 30 m *{V-F-1}*. For large plants, comparable values are 500,000 m² and 80 m (BHARAT PETROLEUM 1995; OCC 1995; PETROTECH 1995). The land use values found seem to be very high. The total land use for 83 bottling plants is estimated to be 6 million square metres. This is equal to a square area with a perimeter length of 270 metres per plant.

During all stages of the LPG life cycle gas is emitted when connections or disconnections are made between pipes, stores, cylinders, etc.. The losses should be less than 0.1% at the bottling plants and less than 0.5% for the transportation activities. From production or importation to the delivery into the household the actual total loss amounts to 0.3% or 66.5 kg/TJ *{V-D-5}*. The total emissions of NMVOC are taken into account in the bottling stage (OCC 1995). The use of **steel** for cylinders is included in the material data of the bottling plant *{V-B-2}*. The economic life of cylinders and the plant installations is given by BHANDARI/THUKRAL (1994) with 20 years.

Table 5.24: Aggregated average data for all Indian bottling plants and specific data for one plant in Duliajan

	Unit	Duliajan, OIL	Estimation for the LCI
eta		99.90%	**99.70%**
LPG throughput	kg/a	5.04E+07	2.87E+09
LPG throughput	MJ/a	2.28E+09	1.30E+11
LPG cylinder output	kg/a	2.00E+07	-
LPG output	MJ/a	9.03E+08	1.30E+11
LPG output in bulk	kg/a	3.04E+07	-
LPG output in bulk	MJ/a	1.38E+09	-
LPG output total	MJ	2.28E+09	1.30E+11
LPG used	kg/a	1.42E+01	-
LPG used	MJ/a	6.42E+02	-
Electricity use	kWh	6.80E+05	7.26E+07
Auxiliary electric energy	MJ/MJ	2.71E-03	**2.01E-03**
NMVOC	kg/a	4.82E+04	8.62E+06
NMVOC	kg/TJ	21.2	**66.5**
Water use	g/MJ	-	**7.72E-09**
Effluent	kg/TJ	-	**7.72E-06**
Capacity	MW	299	**10,434**
Working days	d	212	345
Load	h/a	2,117	**3,450**
Life time	a	20	**20**
Land use	m²	-	**6,000,000**
Steel (incl. cylinder)	t	-	**340,000**
Cement	t	-	**10,000**

***Sources**: Own calculation with BHARAT PETROLEUM 1995; OCC 1995; PETROTECH 1995*

Different industrial practices, plus inadequate measures taken in response to accidents[6] have emphasised the need for the industry to review the existing state of regulation concerning design, operation and maintenance of oil and gas installations *{V-G-6}*. Operation rules regulate for example sprinkler arrangement, leak detecting and safety distance (ARORA 1994; GOI 1994/04).

5.6 Rapid Life Cycle Inventory for the Electricity Generation in North India

This chapter investigates the power generation in North India[7]. A more detailed investigation will be made by LAUTERBACH (n.d.). This assessment however was not yet available for use in this report. Thus it was necessary to estimate the power generation with draft data. The inventory is based only on limited data given by TEDDY (1994). The environmental impacts are calculated with information given by ÖKO (1994/12) and BUWAL (1991) based on the European situation.

Table 5.25 shows the estimated data for open-cast and underground mining in India. Data for the share for the two types of mining and the electricity use are based on information in TEDDY (1994). The waste generation was investigated by BUWAL. All other data are given in ÖKO (1994/12).

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[6] There was for example one accident in bottling plant near Delhi when LPG had caught fire. But there was no loss of life nor damage of bulk tanks (ARORA 1994)

[7] North India: Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab, Rajasthan and Uttar Pradesh

Table 5.25: Data for hardcoal extraction in India

	Unit	Open-cast mining	Underground mining
Share		69.5%	30.5%
Capacity	MW	1,500	1,500
Auxiliary energy electricity	MJ/MJ	0.00138	0.00415
Cuttings	kg/TJ	1.46E+04	5.27E+04
Methane	kg/TJ	112	500
Load	h/a	7,900	7,900
Life time	a	25	25
Land use	m²	1.00E+06	1.00E+06
Steel	t	100,000	100,000
Cement	t	20,000	20,000

***Sources:** BUWAL 1991; ÖKO 1994/12 and TEDDY 1994*

Table 5.26 shows the LCI for the power generation in North India. The 1.8% produced by nuclear power plants is neglected in this draft LCI. Electricity is only a small share of the total energy use. So any error due to the exclusion seems likely to be negligible. Data about the efficiency of coal power plants can be found in TEDDY (1994).

The emissions of the combustion devices are estimated to be within the range of values given by ÖKO (1994/12) under consideration of the Indian standard for particulate matter from coal power plants. The standard prescribes for new plants (since 1979) a limit of 150 mg/Nm³. Old plants in non-protected areas can have emissions of 600 mg/Nm³. The transmission and distribution losses in the Indian electricity grid are very high at 22.8%. The losses are assumed to be this quantity for the LCI. It is possible that the true losses for large scale consumers will be lower because not so many transformation stages are necessary and the amount of pilferage and un-metered supply is lower.

Table 5.26: Data for power generation in North India

	Unit	Coal	Gas	Hydro
Share		59.9%	7.8%	30.5%
Capacity	MW	500	300	50
eta		28.2%	34.0%	100%
NO_X	mg/Nm³	1,000	350	0
PM	mg/Nm³	200	5	0
CO	mg/Nm³	200	200	0
Methane	mg/Nm³	10	10	0
NMVOC	mg/Nm³	50	50	0
N_2O	mg/Nm³	1	1	0
Load	h/a	7,900	7,900	6,000
Life time	a	20	20	50
Land use	m²	10,000	10,000	10,000
Steel	t	60,000	40,000	20,000
Cement	t	30,000	2,000	100,000

***Sources:** BUWAL 1991; ÖKO 1994/12 and TEDDY 1994*

6 Life Cycle Inventory for the Distribution of LPG and Kerosene

This chapter contains the life cycle inventory for the distribution of LPG and kerosene in India. The existing network is explained and the data used in TEMIS are investigated.

6.1 Marketing of LPG in India

In India LPG is a short supply product and for this reason the growth in consumption is dependent on the availability. India consumed 3.1 million tonnes of LPG in 1993/94. The domestic sector used 90%, the commercial sector 7% and industry 3%. Due to the scarcity of the fuel non-residential use is restricted on technical essentially. For the next year consumption of 3.4 million tonnes LPG is estimated (MODAK 1995; OCC 1995).

LPG is obtainable on the parallel market and through the public distribution system (PDS). The public distribution of the cylinders is managed by an agent of the oil company. At present, LPG is distributed by retailers of the marketing divisions of the IOC (Indian Oil Corporation), BPCL (Bharat Petroleum Corporation Ltd), HPLC (Hindustan Petroleum Corporation Ltd) under the brand names INDANE, BHARAT GAS and HP GAS respectively (TERI 1989/03; WSC 1994:84).

LPG and other petroleum products have been de-canalised and *parallel marketing* was introduced in 1993. Sales by private entrepreneurs at market determined prices should augment the domestic supply of the products. So far 80 parties have declared their intention to operate in this market. Today only a small amount is sold on the free market, but the amount should increase in the future (TERI 1989/03; WSC 1994:84).

Today LPG is supplied only to towns above 20,000 population and on an exceptional basis to smaller towns. Presently 27% of the urban population and barely 1% of the rural people have access to LPG. There are 21 million families, with an average of 5.3 persons, that use LPG. But LPG is not the only cooking fuel for all of them (ARORA 1994; HINDUSTAN TIMES 1994; MODAK 1995; OCC 1995).

In India the production can not meet the demand for this fuel. There are still 11 million consumers on a waiting list. The waiting list time for a new booking of LPG in 1994 can be as much as 3, 4 or more years. During the year 1994/95 two million new LPG connections and an equal number of double barrel connections were released. On the 1 April 1994 there were 4,292 LPG distributors in the country. The current marketing plan envisages the set up of 623 new LPG distributorships (ARORA 1994; HINDUSTAN TIMES 1994; WSC 1994:84).

In December 1994, the Ministry of Petroleum and Natural Gas decided that towns with populations of less than 20,000 and adjoining villages will also be considered for new LPG distribution. The start of a distribution network for rural areas should take place within two years. In the future it is planned to meet the demands of Bombay with a grid of gas pipes. This grid is planed to connect both commercial users and over 600,000 households. This project is a joint venture with British Gas (HINDUSTAN TIMES 1994; ARORA 1994; TERI 1989/03).

6.2 Inventory for the Distribution of LPG

Full cylinders are brought by trucks from the bottling plant to the *godown* (warehouse) of the retailer. The same truck takes the empty bottles back for filling. In the godown the cylinders are stored. The LPG cylinders are delivered[1] by the retailer to the house of the customer in exchange for an empty cylinder. The retailers of the PDS give a rebate of 1 Rs for self service.

In the end of 1994 the price for a full cylinder was 93.07 Rs *{VI-H-1}*. The retail price for the cylinder itself was 500 Rs. Due to the scarcity of LPG one is not allowed to use the fuel for other purposes, only for cooking and those purposes stated by an order of the central government. The average number of LPG cylinder refills required per household per annum ranges from 7 in smaller cities to 12 in the big cities (BHANDARI/THUKRAL 1994; TERI 1989/03).

Table 6.1 shows data for an agent and godown in New Delhi. The office of the agent and the godown for storing the LPG cylinders are located at different places. The stock and the price for LPG have to be displayed by the distributor. At the time of the visit 43 of 603 cylinders were reported defect. The shown data are used for the calculation in TEMIS. For this purpose the last 3 rows are estimated *{VI-B-2, B-3, F-1}*.

Table 6.1: Data for an godown in New Delhi that distributes LPG

Customers	**8,000**	
Sold cylinder per year approximately	**63,000**	
Capacity	**1.31**	**MW**
Stored cylinders	**603**	
Defect cylinders	**43**	
Delivery within a radius of	**3**	**km**
Price	**0.1449**	**Rs/MJ**
Land use	**1,000**	**m²**
Life time	**20**	**a**
Cement	**5,000**	**kg**
Load	**3,000**	**h/a**

6.3 Marketing of Kerosene in India

Kerosene is sold through the public distribution system (PDS) in **fair price shops**. In these shops the kerosene is sold at a fixed, highly subsidised price. On a ration card everyone in India gets 2 litres per months *{VI-H-2}*. The PDS is approved by the central or state government. As on 1.4.1994 there were 6,053 SKO/LDO dealers in the country. The marketing plan envisages the setting up of 202 new retail outlets (IOC 1994/12; WSN 1994:84).

Recently the Ministry for Petroleum and Natural Gas has allowed the import and marketing of kerosene by private parties. This scheme of Parallel Marketing shall ensure increased availability of the product in the country. The dealer sells the kerosene on the free market at a floating price. So far 51 parties have entered into agreement with oil companies for import or storage of kerosene *{VI-H-3, 4}* (WSN 1994:84).

Table 6.2 shows the selling prices for kerosene in different cities for PDS and parallel marketing *{IV-H-1}*. Data for Dhanawas was not available. The State price for kerosene lies between 2.25 and 4 Rs/l. The price on the parallel private market lies between 4 and 6.50 Rs/l. The price on the world market is $200 per tonne or 5.20 Rs/l (OCC 1995).

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[1] The cylinders are transported with a bike or a three-wheeler. Transportation by bike, still seen quite often, is not allowed by the Petroleum Act of 1934. According to this act, the cylinders must be transported in an upright position (LPG-ORDER 1988).

The average price for fair price shops and free marketing is estimated to be 0.0656 Rs/MJ and 0.14 Rs/MJ respectively. Due to the high subsidy on kerosene it is very attractive to use it for adulteration with other products like HSD. Some sources assume that thus 15% of the SKO are diverted away from the target consumer categories (TERI 1989/03). In contrast to the kerosene to be imported, sold or distributed under parallel marketing system, PDS supplied kerosene is dyed blue. This is to avoid it being used for purposes other than it was proposed (SKO-ORDER 1993; WSN 1994:84).

Table 6.2: Costs of kerosene in different cities for both types of retailers

City	Type of retailer	Rs/l	Rs/MJ
Vododara	Fair price shop	2.25	0.0656
Rishikesh	Fair price shop	4.00	0.1167
Wardha	Free market	4.00	0.1167
Delhi	Fair price shop	2.00	0.0583
Delhi	Free market	6.00	0.1750

6.4 Inventory for the Distribution of Kerosene

Kerosene is transported with tank trucks from the refinery to the wholesaler. Alternatively it is transported in 18.5 litre tins. The wholesalers sell the kerosene to both types of retailers and deliver it by road tank trucks. Figure 6.1 shows a picture of a kerosene retailer in New Delhi. A fair price shop in New Delhi can be described as follows. It covers an area of 25 m². Normally a truck delivers 2,500 litres of kerosene to one retailer. The kerosene is brought from a wholesaler in New Delhi. It is refilled into 8 to 11 oil barrels standing in the open sky or under cover. One barrel contains 220 litres. If a barrel is not filled totally, the amount of kerosene is measured with a meter stick. To avoid spillage a pail is put under the outlet. The kerosene flows freely from the tank truck into the barrels. One of these barrels has no top. With a little pail and a funnel the kerosene is refilled into the containers brought by the customers.

The shop sells about 400 to 500 litres a day. This sums up to 150 tonnes per year. It can be suspected that due to evaporation and spillage hydrocarbons are emitted *{VI-C-7, D-5, G-1}*. In the cost break down for SKO the calculated cost due to leakage is 20% of the total cost borne. UBA (1993) estimates total retail losses of diesel of 0.175%. For this calculation the loss during wholesaling and retailing is estimated to be 0.1% and 0.5% respectively (TERI 1989/3). Table 6.3 shows the estimation for a wholesaler and a retailer of kerosene that is used for the calculation with TEMIS. The estimation considers the shop described above.

Table 6.3: Data for wholesaling and retailing of kerosene in India

	Wholesaler		Retailer	
Capacity	1,000	MW	460	kW
Load	3,000	h/a	3,000	h/a
Life time	15	a	10	a
NMVOC	23	kg/TJ	117	kg/TJ
Land use	100,000	m²	25	m²
Cement	100	t	1,000	kg
Steel	500	t	200	kg

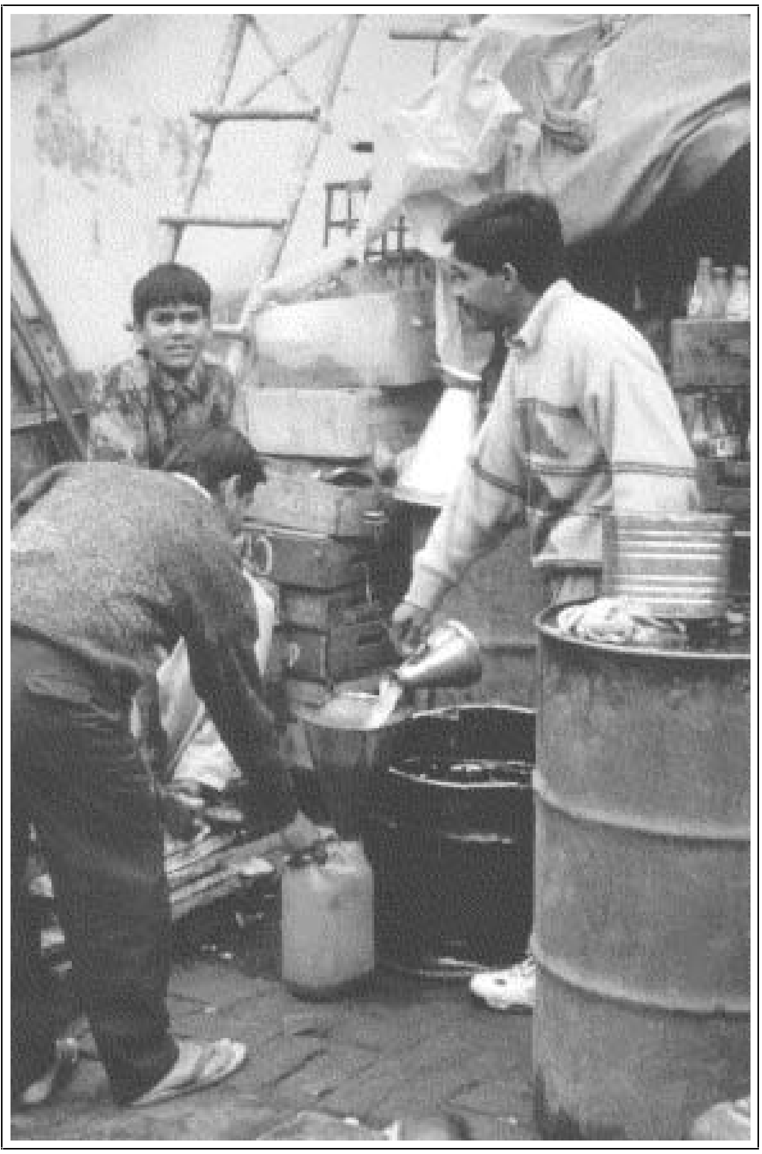

Figure 6.1: Photo of a retail shop for kerosene in New Delhi

6.5 Scenario for the Dhanawas Region

The life cycle inventory is be comparable to the study by LAUTERBACH (n.d.). Thus the scenario for the distribution is investigated for the little village of Dhanawas. In the little villages of this region LPG is not available and it is forbidden to use it there. Nevertheless people get it illegally with the help of inhabitants from the district headquarters Gurgaon. The final 15 km distance they transport it themselves. There are 5 to 10 suppliers and the next bottling plant in Ghaziabad is 45 km away (BRADNOCK 1994, SINHA 1995).

Faroukhnagar is the nearest place for the villagers of Dhanawas to buy kerosene, it is 7 kilometres away. In the block headquarters are both types of retailers. The monthly amount of kerosene on ration card is 5 litres (SINHA 1995).

7 Cooking Life Cycle Inventory

This chapter deals with the life cycle inventory of cooking, including the environmental, social and economic impacts. Kerosene and LPG cookstoves are described. The requirements of useful energy are deducted for the calculations with TEMIS. The situation for the cooking in Dhanawas is described.

7.1 Cookstoves for the Use with Kerosene

For the use with Kerosene, different types of cookstoves are marketed in India. They can be broadly classified as being of the ”**pressurised**” or the ”**wick**” type. The efficiency of old pressurised stoves ranges from 50% to 55%. Old wick stoves have an efficiency of 35% to 47% (IIP 1994/12; TERI 1989/03). Figure 7.1 shows a picture of a cookstove retailer in New Delhi. The cookstoves in the foreground are of the offset burner type, the most common types. The less frequently sold wick stoves can be seen packed on the right side.

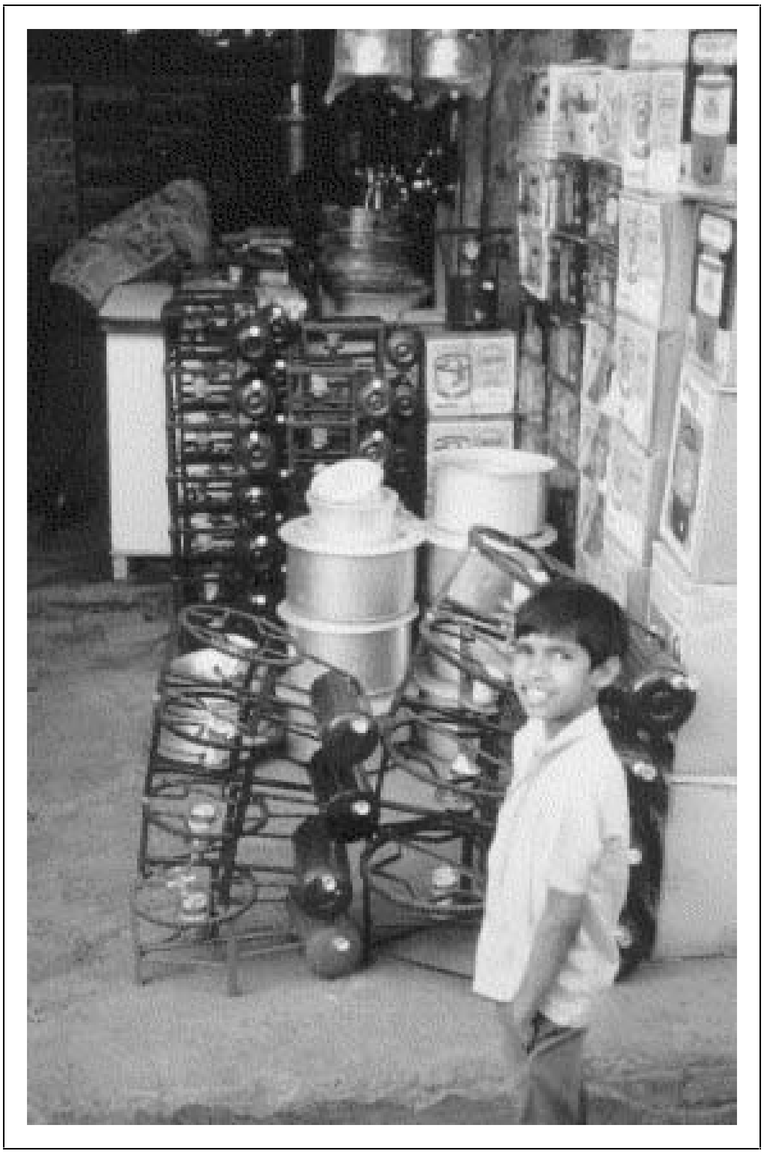

Figure 7.1: Photo of a cookstove distributor in New Delhi with pressurised cookstoves in the foreground and packed wick stoves on the right hand side

Most of the kerosene stoves on the market are pressurised. In the early pressurised stoves, the fuel tank was directly below the burner. The new offset burner stove is safer because the fuel tank is not directly attached to the burner. The specifications for Indian pressurised stoves can be found in the Indian standards 10109-1981 and 1342-1986 (ISI 1982/05, 1986/05).

Figure 7.2 shows a typical **pressurised cookstove** of the offset burner type. The kerosene is delivered to the burner by an over-pressure in the fuel tank. The pressure is built up by a manual air pump. The fuel evaporates through an injector and is mixed with ambient air. This mixture is burnt and the form of the flame is determined by the design of the burner. Some of the heat is used to warm up the incoming kerosene. It is necessary to preheat the burner in the beginning phase of cooking. A little bit of kerosene or sprit is burnt in the spirit cup under the burner. The power of the stove is regulated with a valve in the fuel pipe or by the pressure in the fuel tank. The flame is extinguished by closing the valve or by reducing the pressure on the fuel tank. Normally pressurised cookstoves work quite loudly *{VII-F-3}* (LAUTERBACH/SCHNAITER 1995).

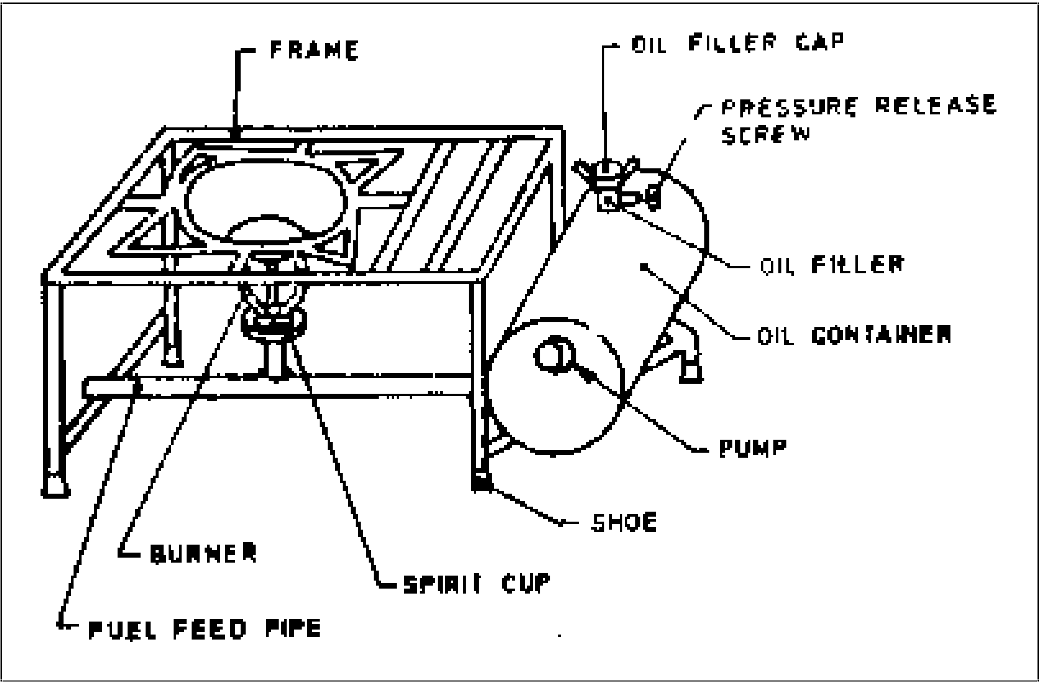

Figure 7.2: Typical oil pressure stove of the offset burner type (ISI 1982/05)

The pressurised cookstoves are obtainable in different sizes and qualities on the Indian market. The prices range from Rs 70 up to Rs 125 and Rs 415 for big, ”professional” stoves. They are available with one or two burners. The capacity of the fuel tanks ranges from 0.9 to 3.6 litres. The stoves are made mainly from steel sheets and brass rods. Nowadays the Indian standard prescribes a thermal efficiency for the stoves between 55 and 58 per cent. Most of the customers prefer the pressurised stoves because of the lower prices, the variety in shapes and the higher heat *{VII-H-1, G-4}*. The economic operating life time of kerosene stoves is assumed by TERI to be ten years (ISI 1982/05, 1986/05; TERI 1989/03).

The IIP (Indian Institute of Petroleum in Dehradun) has worked on an improved SKO pressure stove with an efficiency of 64%. At first, the kerosene is preheated by a kerosene soaked asbestos sponge. Once the stove works, the kerosene is preheated by the cooking flame. Due to the preheating emissions of some air pollutants and production of noise in the starting phase are probably higher *{VII-F-3}* (IIP 1994/12).

Specifications for the wick stove, also known as non-pressure stove, are given in the Indian standard 2980-1979. There are gravity-fed and capillary-fed types on the market. The principle of a capillary-fed **wick stove** is shown in Figure 7.3. A ring of wicks is set up over the fuel tank. They are fixed in a construction that makes it possible to adjust their height with a wick winder knob or a handle. The burning room consists of two perforated sleeves. The kerosene from the fuel tank is carried up by capillary power and evaporates at the surface of the wicks into the room between the two sleeves. The fuel is burnt with the ambient air that reaches the burning chamber through the holes in the sleeves. An outer burner casing is around the two perforated sleeves. It serves as an isolation and a shield against wind (IOC n.d.; ISI 1979/11; LAUTERBACH/SCHNAITER 1995).

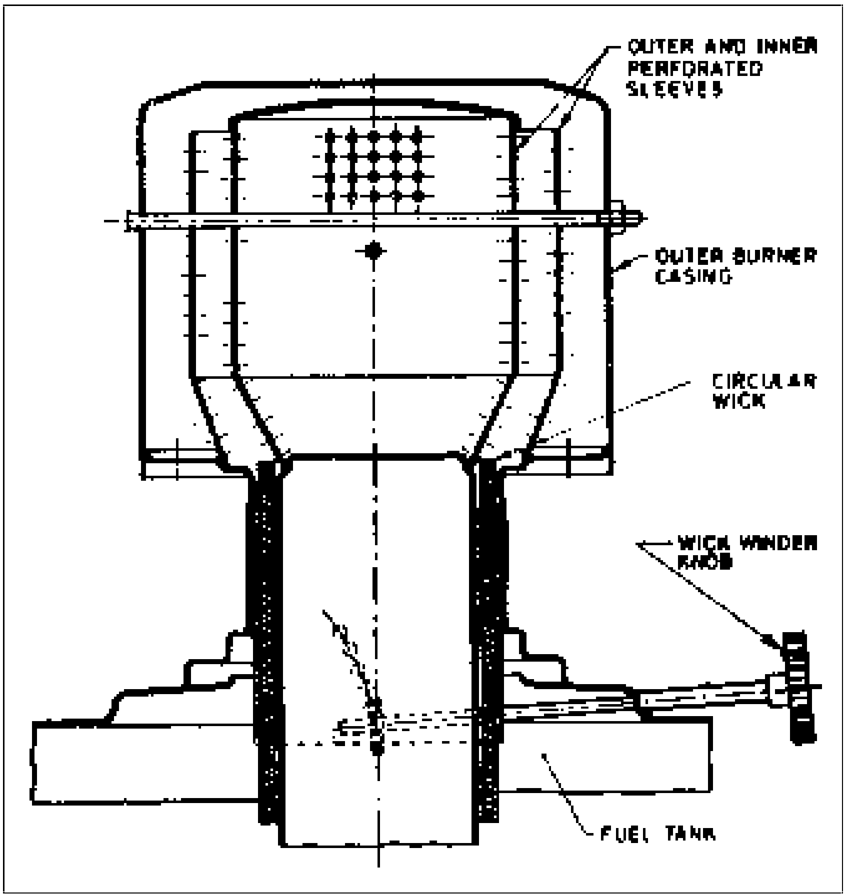

Figure 7.3: Functional principle of a capillary-fed wick stove (ISI 1979/11)

The space between the burner casing and the outer sleeve is warmed by the lighting of the wicks. The incoming ambient air is preheated while flowing through the room. The fuel-air mixture burns first at the perforation of the sleeves. With the continued preheating the blue flame burns also above the edge of the perforated sleeves. The power of the stove is regulated by the adjustable free length of the wicks. A maximum uniformly blue flame shall be obtained. The flame is put out with a metal sheet ring or by reducing the length of the wicks with the control lever (IOC n.d.; ISI 1979/11; LAUTERBACH/SCHNAITER 1995).

New improved wick stoves were designed by the IIP. One is the *Mini-Nutan*[1] with an efficiency of 58%. This price (Rs 50) is low enough to make it affordable for low income classes. The Mini-Nutan has a weight of 1.3 kg. The other type is the normal (bigger) *Nutan* for Rs 135 with an efficiency of over 60%. The two improved types have been produced since 1978. Thirteen firms have produced over 130 thousand pieces under licence of this institute *{VII-H-4}* (IIP 1994/12).

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[1] Nutan is a Hindi word meaning "new".

Figure 7.4 shows a photo of a Nutan stove and its various parts. The stove has a weight of 2.6 kg. This includes 250 g asbestos, the rest is metal. The asbestos[2] is built in between two metal sheets in the outer wall. The construction should be air tight, so that shedding of fibres is not possible. The quality of the seal is questionable given the stove is heated and this results in materials expansion. The production, the maintenance and the re-cycling of the stove and the asbestos plates, once the stove is discharged, are all linked with hazardous health risks for the workers *{VII-G-1}* (IOC 1994/12).

The improved efficiency of the Nutan stoves is due to the better preheating of the in-flowing air. The outer shell has a temperature of only 40°C to 50°C. The useful heat output is 0.95 kW. For the preheating phase a time of 1.5 to 3 minutes is required. The stoves have not been widely accepted despite their greater efficiency, because some users think that the power is not sufficient *{VII-G-4}* (IOC 1994/12; TERI 1989/03).

Figure 7.4: Photo of a superior wick stove and its individual parts (LAUTERBACH/SCHNAITER 1995)

7.2 Cookstoves for the Use with LPG

The use of LPG is possible with different types of cookstoves. The various parts of a gas installation are shown in Figure 7.5. A pressure regulator is connected to the cylinder valve. It supplies the gas at a constant pressure to the stove. This pressure regulator is connected to the stove by a rubber tube. The gas is mixed with ambient air in a specially designed mixing tube. The air-fuel mixture burns through a burner. After putting the filled vessel on the burner, the taps of the burner is opened to light the flame with a match. The flame should be blue in colour to optimise the use of the gas. The use of LPG allows a good control of the fire in comparison to other types of cooking *{VII-G-4}* (BPCL n.d.).

There are over 200 manufacturers of LPG cookstoves in India *{VII-H-4}*. They are sold on the free market in different sizes and types. There are one and two burner stoves, two burner stoves being more common. Typically the burners are of two different sizes. The consumption rate is controllable by the simmer position. The price ranges from Rs 450 to about Rs 2,000. The

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[2] The asbestos is wetted, rolled and put between two metal sheets of the frame for insulation.

stoves are made mainly of steel, and the weight ranges from 700 g to 2,000 g. The capacity for one flame is normally about 2,300 watt.

Specifications for the cookstoves used in India, are given by the Indian Standards Institution. The thermal efficiency for ”ISI” marked LPG stoves ranges from 60% to 68%. After the new standards of 1992, it has to be above 64% to fulfil the ISI specifications (ISI 1984/06; TERI 1989/03; PCRA 1993/11).

It should be possible to reduce the consumption rate in regard to the proposed burning rate. For burners with a gas rate of up to 60 litres per hour, a reduction of 33% of the rated capacity is recommended. For burners with a gas rate above 60 l/h, a reduction of 21 l/h or 25% of the rated capacity (whichever is higher) is possible. Burners with a gas rate up to 20 l/h are exempted from these provisions. With a test under using conditions it has to be proved that no soot is deposited on the burner or on the bottom of the vessel due to improper burning conditions *{VII-G-4}*. The carbon monoxide/carbon dioxide ratio of the exhaust gases under different working conditions must not exceed 2 per cent (ISI 1984/06).

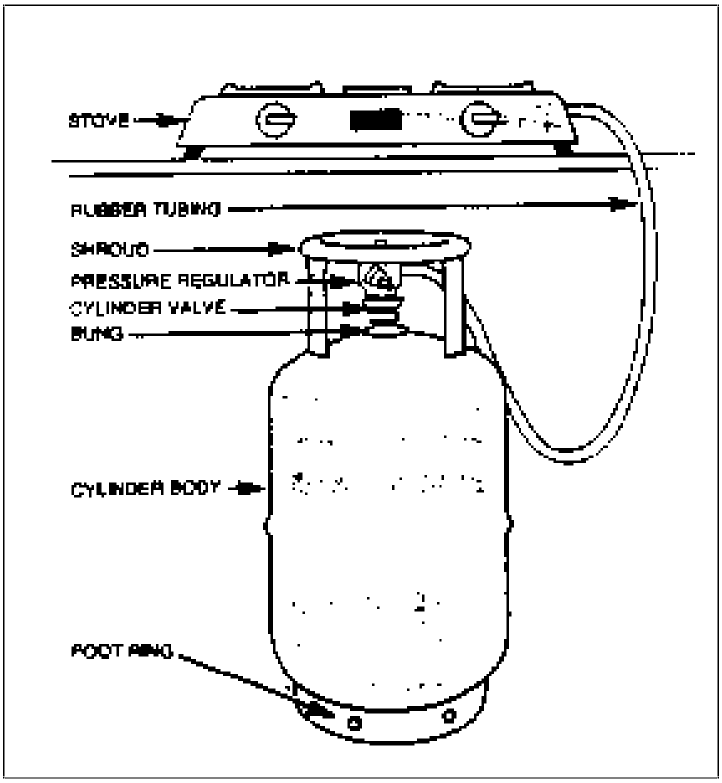

Figure 7.5: Parts of an LPG installation (BPCL n.d.)

The IIP has developed a new LPG stove with an efficiency of 72%. This stove has an improved slot with a smaller angle step optimising the way the flames are taken to the vessel. The mixing tube has a venturi-like narrowing instead of a straight tube. Soon, this technology will be made use of licence-free by stove-producers. Given this new development, the ISI specifications may be raised (IIP 1994/12).

Previous improvements for LPG stoves have not always been welcomed by the user. Some cooks think that the heat of the flame is not spread uniformly enough for a sufficient cooking of chapatis, a type of bread baked in a pan. New developments must take this criticism into account (IOC 1994/12). About 50% of cooking gas-related accidents are caused by leakage from the rubber tube. The users of LPG are advised to follow the basic safety rules *{VII-G-6}* (BPCL n.d.).

7.3 Energy Use and Emissions of Pollutants

7.3.1 Average Fuel Consumption for Cooking

The annual use of cooking energy for one household is difficult to estimate. It depends on many variables. For example (NEERAJA/VENKATA 1991):

- Number of persons
- Cooking and food habits
- Age group of the homemakers
- Regional availability
- Prices and family income
- Convenience of the fuels
- Efficiency of the used cookstove

Table 7.1 shows figures for the annual fuel consumption of Indian households *{VII-A-1, 2}*. The figures found by different authors vary in a wide range according to the above factors. The average residential consumption of LPG was 3.2 kg per head in 1993/94. If the LPG consumption is related to the registered consuming families, the average is calculated to be 141 kg per family (5 persons) and year (MODAK 1995). The average Indian person consumed 8.2 kg of kerosene in 1991/92 if the availability is divided through the inhabitants (TEDDY 1994).

The values given by TERI (1989/03) range between 6.8 and 12.6 annual refills of the LPG cylinders, depending on the city and the efficiency of the cookstove. This equals a consumption of 96 kg to 178 kg of LPG. The annual consumption of kerosene per household is assumed to range from 110 kg to 321 kg. In this scenario, the efficiency of LPG cookstoves ranges from 60% to 65%. Kerosene cookstoves are assumed to have an efficiency between 35% and 60%. Thus the useful energy requirement ranges from 2,800 MJ to 4,850 MJ per year and household.

KULKARNI ET AL. (1994) looked at the energy use in three Indian cities. The annual consumption varied depending on the family income and the city. For LPG it ranged from 8.8 to 40.3 kg and for kerosene from 8.5 to 34.6 kg per household. REDDY/REDDY (1994) investigated the energy use of urban households in Bangalore. The average consumption of LPG was estimated at 156 kg per year. The annual use of kerosene was set at 214 kg. RAIYANI ET AL. (1993) measured the energy use in Ahmedabad. The result was a fuel use of 186 kg and 183 kg for kerosene and LPG respectively.

In the survey of KULKARNI ET AL. (1994) the investigation of changes in the total household energy consumption between 1982 and 1989 is interesting. The average consumption in low- and middle-income households had fallen to one-third and to one-fifth of the 1982 level. This change can be attributed to a general change to higher efficiency fuels over the observed period. The relatively low energy use of high income households rose by approximately 62% between 1982 and 1989. This reflects the demand for an increasing number of energy services using mainly electricity (KULKARNI ET AL. 1994).

NEERAJA/VENKATA (1991) investigated the fuel consumption of rural households in the Guntur district of Andhra Pradesh. The annual use of kerosene ranged from 0.12 kg to 1.4 kg per household depending on the socio-economic status. LPG consumption ranged from 1 kg to 3.5 kg per year per family. The low values indicate that in most cases the families used different fuels. The commercial fuels were used mainly for purposes such as making coffee, breakfast tea and snacks.

Table 7.1: Annual fuel consumption of Indian households (kg per household)

	All Indian average	*Indian cities*	*Indian cities*	*Bangalore*	*Ahmedabad*	*Rural areas*
Kerosene	41	110 - 321	8.5 - 34.6	214	186	0.12 - 1.4
LPG	141	96 - 178	8.8 - 40.3	156	183	1.00 - 3.5
Source	MODAK 1995; TEDDY 1994	TERI 1989/03	KULKARNI ET AL. 1994	REDDY/REDDY 1994	RAIYANI ET AL. 1993	NEERAJA/ VENKATA 1991

The scenario for the LCI is calculated on the basis of a requirement for **useful energy** of 1,000 MJ. Table 7.2 shows the amount of fuel necessary to produce this energy with cookstoves with varieties of thermal efficiencies. The value of 1,000 MJ is a little bit more than the annual requirement of one person. This value is large enough also to calculate a result for most of the indicators using TEMIS. This estimation also reflects the fact that it is not possible to give an average energy using requirement for all households. It is possible to change this value. If the requirement for useful heat, i.e. for one city, is known, it is easy to calculate the related environmental impacts by means of the computer program TEMIS.

Table 7.2: Quantity of fuel needed to provide a useful cooking energy of 1,000 MJ using stove of different stated efficiencies (kg)

Efficiency	*Kerosene*	*LPG*
42%	55.6	52.6
56%	41.7	39.5
60%	38.9	36.8
72%	32.4	30.7

7.3.2 Efficiency of Indian Cookstoves

In general the fabrication of stoves in India is reserved for small-scale industries, which have neither the technical expertise nor the other resources necessary to produce high-efficiency stoves at the required power ranges. Further improvements for LPG and SKO stoves appear to be difficult to achieve given the increased production costs. The average efficiency of cooking fuels is given in Table 7.3. The efficiency is dependent on the type of cookstove used and on the cooking practices. Savings of up to up to 30% of LPG or kerosene are possible by implementing a few simple fuel-saving-tips[3] (BHANDARI/THUKRAL 1994; PCRA 1993/11; TEDDY 1994).

Table 7.3: Average efficiency of cookstoves using commercial fuels in India and the prescribed standards

	Average	*Standard*	*Optimum*
Kerosene (in pressure stoves)	56%[†]	55% to 58%	64%
Kerosene (in wick stoves)	42%[†]	60%	> 60%
LPG	63%	62%	72%

Sources: *TEDDY 1994; ISI 1979/11, 1984/07, 1986/05*

[†] *BHANDARI/THUKRAL (1994) assumed the average efficiency for kerosene stoves in India to be 40%*

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[3] The Petroleum Conservation Research Association (PCRA) was set up by the Government of India. It promotes petroleum conservation in various sectors of the economy. Fuel saving while cooking is possible for example by using pressure cooker, by use of optimum quantity of water or by cleaning the burner of the stove (PCRA 1993/11).

7.3.3 Measurement of Cookstove Emissions

The measurement of cookstove emissions is not easy. The stoves have no stacks to fix a sample collector in the flue gas current. The result being normally an artificial stack is constructed over the cookstove. The flue gases are collected using a bypass. Normally the results reflect an optimised use of the cookstove. In reality, mistakes are made by the user that may lead to a lower efficiency and higher emissions.

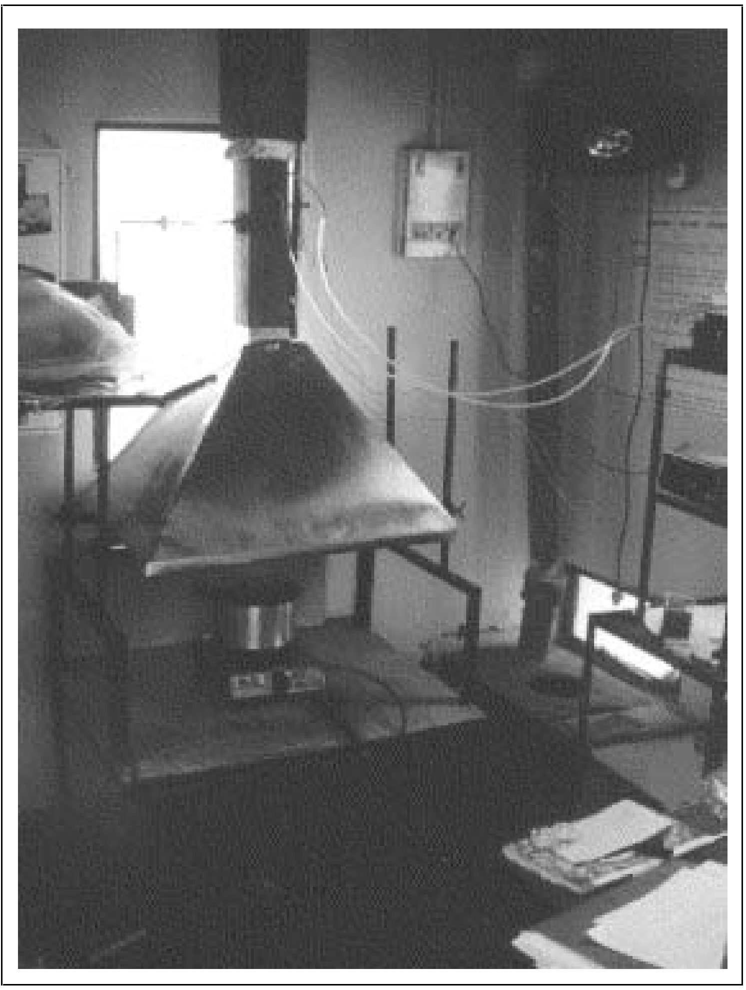

Figure 7.6: Photo of an experiment with an LPG cookstove at the TERI laboratory

Figure 7.6 shows the experimental kitchen of TERI. The photo shows an experiment to measure the emissions of an LPG cookstove. The emissions of a pre-defined cooking session are collected in a polyethylene bag. The average concentration of air pollutants in the flue gases is measured by gas chromatography.

Only the ratio of CO to CO_2 is regulated by the Indian standards for cookstoves. It must not exceed 0.02 for all types of stoves. This equals concentrations in the flue gases of 3,250 mg/Nm^3 and 2,900 mg/Nm^3 for kerosene and LPG stoves respectively, if the oxygen content of the flue gases is estimated to be 3%.

7.3.4 Inventory for Cooking with Kerosene

A difficult question in the estimation of the emissions of pressurised kerosene stoves is whether the emissions in the heating phase should be included or not. The emissions during this phase are very high. LAUTERBACH/SCHNAITER (1995) found that the emissions in the first 3 minutes for some pollutants are much higher than during cooking. Table 7.4 shows the ratios of the pollutant concentration during the starting time and while using the stove. The total emission of particles, for example in the first 3 minutes, is as high as the subsequent emissions in the following 5 hours of cooking.

In a survey, TERI (1987/02) found out that for any given fuel, the more efficient a stove, the higher the emission factors. In half of the studied cases, the increases in efficiency were greater than the increases in emission factors, so that total emissions per task were lower. This fact was also found by LAUTERBACH/SCHNAITER (1995) for some pollutants. The change of the flue gas concentration, if the kerosene stove is used with a higher power, is given in Table 7.4.

Table 7.4: Ratio for the concentration of pollutants in the flue gases between the starting time and the normal cooking session. Changes to the pollutant concentration with a higher power kerosene stove (LAUTERBACH/SCHNAITER 1995)

	Ratio	***Change***
CO	10	>=
NO_2	0.05 - 0.3	=
PM	100	=
Aldehyde and ketone	10 - 50	>=
PAH [a]	50 - 10,000	>=

[a] PAH - Polycyclic aromatic hydrocarbons

Many surveys on pollutants emitted by cookstoves investigated the ambient air situation in the kitchen. The results of these studies cannot be used for the LCI. Emission data for kerosene cookstoves, as investigated by different authors, are shown in Table 7.5. Most authors gave emission data in g/kg of fuel. These data are changed to flue gas concentrations. The oxygen content is standardised at 3 per cent. The data for some pollutants vary with the ratio of 1 to 100. The surveys may have taken different assumptions for the inclusion of emissions during starting time. In some cases the range of the measured values is also given.

SCHWENNINGER/SCHULTE (1995) investigated the influence of different parameters on the emission of carbon monoxide, e.g. power, distance stove to vessel or used burners. This parameter is a lead indicator for other pollutants. The values found differ considerably, depending on the user' practices.

It was rather difficult to establish average values for the LCI. Preliminary calculations indicate that the efficiency and the emissions of the cookstoves determine the results of the LCI considerably[4]. All environmental impacts of the upper life cycle are lower if the efficiency is greater. The direct emissions from the cookstove are largely responsible for air pollutants.

The LCI scenario should give the emission figures over a period of one hour cooking with a prior heating time of 3 minutes. To estimate the range of possible emissions from cooking with kerosene three estimates are made. They are shown in Table 7.6 *{VII-D-1..5}*. The *worst case* considers the upper range of the above given values. The *mean* process stands for a possible, „normal“ average, and the *optimum* process shows values for an optimised cookstove. The data is estimated as follows.

The value for NO_X is in the range of the found values, if the survey of DAVE is neglected. Particulate matter is estimated at a value that includes an assumption of the higher values during the starting time. The estimation for carbon monoxide considers also the Indian standards. The values for the greenhouse gases follow the studies of EPA, BPPT/KFA and the EM.

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[4] The LCA process is an iterative one where you move continuously forward and backward between preceding and following modules (BERG ET AL. 1994).

Table 7.5: Emission data for various kerosene cookstoves (mg/Nm³) and range of investigated values in brackets

	Nutan ^{d}	**Space heaters** ^{i}	**KR-Kerosette** ^{d}	**SKO stoves** ^{b}	**SKO stoves** $^{e, f}$	**Primas 101** ^{c}	**MSR-X-GK** ^{c}	**Stove** ^{a}	**Stove** ^{g,h}
eta	60%	-	57%	-	-	62% (57%-65%)	46% (38%-63%)	-	45%
Capacity	1.23 kW	-	1.01 kW	-	-	2.50 kW (1.70-2.90)	2.80 kW (0.90-3.17)	4.3 kW	2 kW
NO_X	-	20-160	-	-	209 ^{e}	289 (257-332)	331 (274-380)	[8]	-
PM	268 (98-431)	0.14-1.1	431 (163-691)	-	-	2.8 (1.5-3.8)	5.9 (5.2-7.2)	[8.5]	19 ^{h}
CO	5,122 (2,683-7,560)	32-490	8,373 (4,390-12,276)	3,089	2,000 ^{f} (500-60,000)	574 (320-810)	275 (162-393)	[50]	500 ^{g}
Methane	-	-	-	81	-	-	-	-	5 ^{h}
NMVOC	-	-	-	894 †	-	-	-	-	94 ^{h}
N_2O	-	-	-	4.1	-	-	-	-	7 ^{g}

Sources: *^{a} Dave 1987 (The measured values are likely not standardised on a oxygen content of the flue gases) ^{b} EPA 1992; ^{c} Lauterbach/Schnaiter 1995 (only cooking); ^{d} TERI 1987/02; ^{e} Yamanaka et al 1978 (for a kerosene heater); ^{f} Schwenninger/Schulte 1995 (own estimation for 3 minutes preheating and 60 minutes cooking); ^{g} EM 1995; ^{h} BPPT/KFA 1992; Traynor et al. 1983*

† - Total non-methane organic compounds (TNMOC)

Table 7.6: Estimates for three kerosene cookstoves in the LCI (mg/Nm³)

	Kerosene worst case	*Kerosene mean*	*Kerosene optimum*
eta	42%	54%	64%
Capacity	1.50 kW	1.50 kW	1.50 kW
NO_X	300	250	150
PM	400	30	15
CO	8,000	2,000	500
Methane	80	40	0
NMVOC	900	500	100
N_2O	7	3	1

Table 7.7 shows the additional data necessary for the calculations with TEMIS *{VII-B-2}*. The life expectancy is estimated at 4 years only because the practical experience made by Lauterbach/Schnaiter (1995) shows high efforts for maintenance and repairing of the cookstoves.

Table 7.7: Estimates of additional data for the kerosene cooking process

	Unit	*Minimum*	*Maximum*	*Estimation*
Load	h/a	500	1,000	**1,000**
Weight	g	1,000	2,600	**1,500**
Price	Rs	100	135	**100**
Life time	a	4	10	**4**

A further impact of the use of kerosene stoves is the polluting of water when washing the vessels. Soot is deposited on the vessel during the cooking. Washing the vessels causes emissions of COD and BOD *{VII-C-1..3}*. These impacts are difficult to calculate but they might be important under the assumption that 0.5 to 1 litre of water is used to wash the vessel after 1 to 1.5 hours of cooking. Information on this point is missing, but it can be said that cooking with kerosene is more polluting (for these indicators) than cooking with LPG. Further research work on this issue may present interesting results.

7.3.5 Inventory for Cooking with LPG

Emission data for LPG cookstoves were available from different sources. These data are shown in Table 7.8. The concentration of pollutants in the flue gases is calculated with an oxygen content of 3 per cent. Again the data cover a large range. The reason for the great differences is not clear. For the LCI, three scenarios are considered. A *worst case* scenario to estimate a cookstove with high emissions, a *mean* scenario that equals with an estimated „normal“ use of LPG cookstoves and a third scenario with an *optimised* use of LPG stoves *{VII-D-1..5, B-2}*. The values are estimated as far as possible to be in the range of the results of EPA (1992), EM (1995), BPPT/KFA (1992) and ÖKO (1994/12). The low NO_X value of YAMANAKA ET AL. does not seem to be reliable. The estimates for CO consider the Indian standards. The investment costs for the stove and a cylinder are estimated to be about 2,000 Rs *{VII-H-1}*. The life time of an LPG stove is estimated to be 7 years.

Table 7.8: Emission data for LPG cookstoves, space heaters and estimates for the LCI

	Unit	*Propane-gas*[a]	*LPG*[b]	*Space heater*[f]	*LPG*	*LPG worst case*	*LPG mean*	*LPG optimum*
eta		65%	-	-	55%[a]	**60%**	**64%**	**72%**
Capacity	kW	1.0	-	-	2.0[a]	**2.3**	**2.3**	**2.3**
NO_X	mg/Nm^3	200	-	3.5-140	7[c]	**200**	**150**	**100**
PM	mg/Nm^3	0.5	-	0.2-2.3	0.0[e]	**1**	**0.5**	**0.0**
CO	mg/Nm^3	250	1,868	2-170	700[g]	**2,900**	**1,800**	**250**
Methane	mg/Nm^3	0	3	-	-	**5**	**3**	**0**
NMVOC	mg/Nm^3	50	233	-	90[e]	**250**	**200**	**50**
N_2O	mg/Nm^3	2.5	2	-	4[d]	**4**	**2**	**1**
Load	h/a	500	1,000	-	500[d]	**1,000**	**1,000**	**1,000**
Weight	g	-	700		2,000[c]	**1,500**	**1,500**	**1,500**
Life time	a	15	7	-	5[d]	**7**	**7**	**7**
Costs	Rs					**2,000**	**2,000**	**2,000**

Sources: *[a] ÖKO (1994/12); [b] EPA (1992); [c] YAMANAKA ET AL. (1978); [d] EM (1995); [e] BPPT/KFA (1992);*
[f] APTE/TRAYNOR (1993); [g] TRAYNOR ET AL (1982) for space heaters

7.4 Investigation of Social Impacts

MAITI (1985) investigated the energy crisis and women’s role in five rural Indian villages. The study concentrated on the life of the rural poor. Most of these people use **traditional fuels** for cooking. Nevertheless, a few results of this study are also interesting for the LCI. Comparable studies on the social impacts of cooking with commercial fuels was not available.

In all the villages besides agricultural activities, women are entrusted with the major burden of household work. A survey of the quantities of food consumed by each member of the household, shows of all the household members children were best cared for, followed by men, and lastly women. Important decisions of the household are made by men, while women take numerous less important decisions (MAITI 1985).

Cooking was an exclusively female chore *{VII-G-2}*. It was daily the most time consuming activity for approximately 60 per cent of the respondents in the study. After cultivation fuel collecting was the third major activity. Cooking and food processing took between 1.6 and 5.4 hours of the daily working time that varied among 10 and 14 hours *{VII-G-3}*. The wife of the principal earner was chiefly responsible for cooking. Other female family members assisted. Two-thirds of the time spent on fuel production were contributed by women. Collecting fuel including processing took 9 per cent of the total labour time (MAITI 1985).

The women told the interviewer that an improvement in cooking techniques through the use of fuel-efficient stoves was welcome. But without chances of gainful employment, the resulting time saving would be of little importance to them. For cultural reasons, it is not impossible to replace the individual cooking system by a more efficient communal means of cooking *{VII-G-5}* (MAITI 1985).

An improvement in the convenience cooking is associated with the shifts from solid fuels to kerosene and then to gas. The convenience of gaseous fuels is linked with the ease in lighting the stove, with the ease of adjusting the heat and with the lack of smoke and general cleanliness. Cooking with LPG is less time-consuming than cooking with kerosene and some authors claim that it provides a hotter flame *{VII-G-4}* (KULKARNI ET AL. 1994; REDDY/REDDY 1994). But cooking with commercial fuels also has disadvantages in terms of preparing some traditional meals, e.g. chapatis (a type of bread). For these meals traditional stoves or ovens are more practical *{VII-G-4, 5}*.

It is unclear which social changes are associated with a change in the used cooking fuels. Some changes might rather be due to the social status of the household. In well-off households the women are mainly responsible for the cooking. But in some cases they can delegate a part of the work to employees. In which case men may also serve as cooks.

7.5 Investigation of Economic Indicators

With increasing income, households tend to shift from one energy carrier to another. This mechanism is described with the concept of the *„energy ladder“*. Figure 7.7 shows the number of households from different income groups using a particular household fuel. With rising income the preference shifts from firewood and charcoal to kerosene and latterly to LPG and electricity. The choice of the cooking fuel is also influenced not only by financial considerations. Generally people move up the ladder when they have the opportunity and resources to do so (REDDY/REDDY 1994).

Depending on the efficiency of the stoves, cooking with kerosene or LPG is linked with lower costs than cooking with other fuels. But the use of kerosene and LPG requires an initial investment for the stove. And the costs of an LPG stove or refilling a cylinder are equal to about one month’s salary for a low-income household. Hence, this option is virtually impossible for these households. The kerosene is available at subsidised prices for households with ration cards, but these are only provided to households who can show proof of legal residence *{VII-H-1, 2}*. As a result, the large population living in „temporary“ huts (or worse) are deprived of access to subsidised kerosene. The households with ration cards usually have to buy additional kerosene on the open market because the ration quota usually is inadequate. Low-income households are forced into a position of having to buy low-quality fuels in small quantities, even though these fuels are much more expensive (KULKARNI ET AL. 1994).

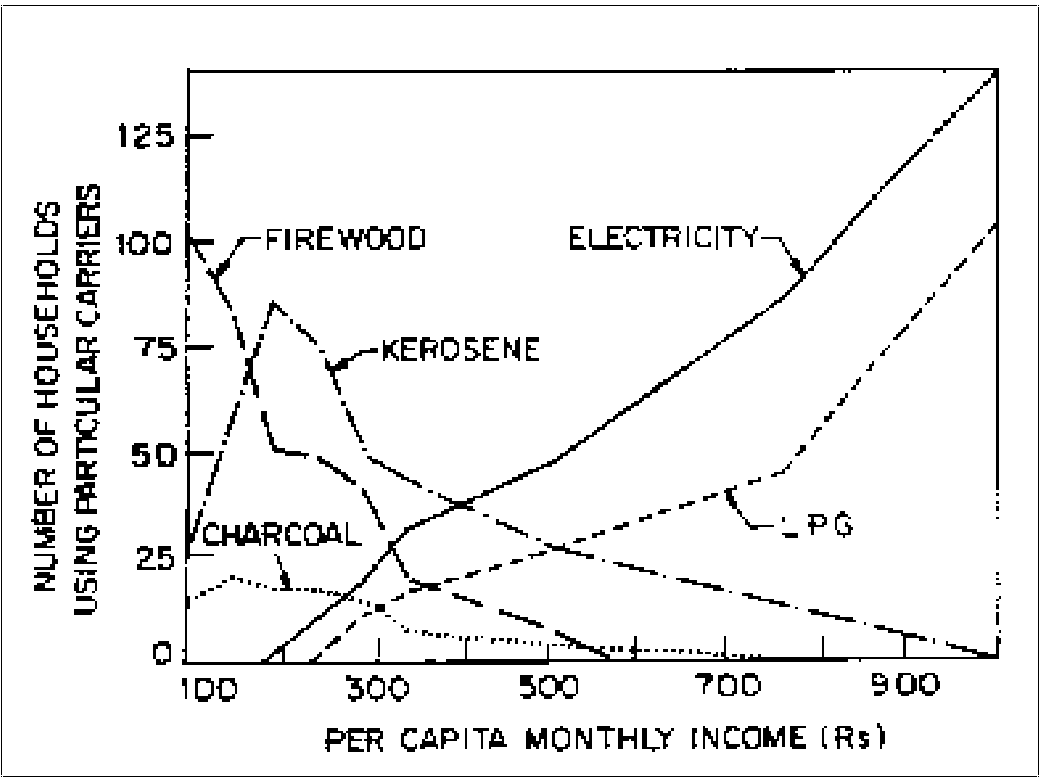

Figure 7.7: Substitution of energy carriers for cooking depending on the monthly per capita income (REDDY/REDDY 1994)

7.6 The Situation in Dhanawas

In 1987, the village Dhanawas consisted of 151 households with a population of 1,006. Cooking and water heating combined consumed more than 86% of the total energy in 1987. Biomass fuels were the resources mainly used for cooking. They met 97% of the energy demand. In 1994, 15 families used LPG as fuel. Biogas plants had emerged as an alternative to LPG, which is of limited availability. Their number had increased from 3 in 1987 to 23 in 1994 (TERI 1992, 1994).

In 1987 kerosene was used by 21% of the people, for lighting in non-electrified households and as a supplementary fuel in electrified households. A large number of the families using kerosene belonged to the economically well off categories of landless households and farmers with additional occupation. Kerosene met 1% of the total household energy consumption. The average use per family was 35.6 kg per year (TERI 1992, 1994).

8 Life Cycle Inventory for the Transport of Crude Oil, Natural Gas, LPG and Kerosene

This chapter investigates the transportation involved during different stages of the life cycle. A transport scenario for cooking in the little village Dhanawas is estimated. The forms of transport and their environmental impacts are investigated for the inventory.

The transport sector is a major energy user with a 25% share of the commercial energy consumed in India. High Speed Diesel (HSD) is the main petroleum product to meet the energy demand. The railways share of the traffic has decreased since the early 1960's while the share of traffic by road increased rather rapidly (TERI 1993/01).

8.1 Description of the Necessary Transports and Scenarios for the Inventory

The scenarios for the transportation of crude oil, kerosene and LPG are given in the next tables. The scenarios investigate the distance covered and the mode of transport between all the stages of the life cycle. These scenarios can be adapted to a special region of India by changing the transport distance. The tables show the data for a scenario that is adapted to the use of LPG and kerosene in Dhanawas.

An important aspect of utilisation of freight vehicles is the occurrence and frequency of empty trips. For logistical reasons travelling empty a part of the distance may be unavoidable. Some of the respondents in TERI (1993/05) report that for over 50 per cent of the covered distance their vehicle is without any freight. This problem of empty loads on return journey is particularly actuate with the transport of petroleum products and indeed can be assumed as being the norm. The load of the vehicles is considered in the estimations for the energy use and the environmental impacts. The distances travelled are estimated based on information given by BRADNOCK (1994), KÜMMERLY+FREY (n.d.) and POOVENDRAN (1994).

The national demand for Crude Oil, LPG and Kerosene is higher than the amount produced in India. Due to this situation, imports (mainly by tankers) are necessary. Table 8.1 gives the details of crude oil import. The vast majority of the crude oil arrives from OPEC countries in the gulf region (SENGUPTA 1994).

Table 8.1: Transport of crude oil to India

Crude Oil	*Import to India*
Single distance (km)	3,000
Tanker	100%

The imported crude is transported by pipeline to a nearby refinery. Pipelines are also used for the transport of crude oil and natural gas from the exploitation site to the processing facility. Most of these pipelines have a length of up to 100 km. Environmental issues surrounding the transportation of crude by pipeline are given in chapter 8.5. A calculation of the environmental impacts of the transportation in pipelines was not possible (as described in the same chapter). They are neglected in the life cycle inventory (IPNGS 1992; ONGC 1994/12).

Table 8.2 shows the scenario for the import of LPG and its transport to the bottling plants. LPG is bought from companies in the USA, Japan, Greece and a few Middle-Eastern countries. Handling of LPG imports is at present possible only at Bombay and Vizag. Bombay lies on the west coast of India, Vizag on the east coast. The two harbours have a limited capacity for LPG imports. For this reason, the establishment of further facilities is planed for some other harbours. Imports of LPG are received in parcels of 10,000 tonnes. These parcels will be discharged to storage facilities at nearby refineries. Given that the demand for LPG in other regions is higher than the respective production, it is obvious that LPG will have to be transported across the country (MODAK 1995; TERI 1989/03).

The total freight traffic handled at the major ports of India in 1992/93 was 166 million tonnes. Petroleum products (POL - Petroleum, oil & lubricants) have a 44% share of this traffic. For 1992/93 an estimated movement of 26 million tonnes of POL with trains was made. The average lead for the train transports is 603 km (IPNGS 1992). The distances for the bulk movement of LPG and SKO in India can be in excess of 2,000 km (e.g. Bombay to Calcutta 2,173 km).

The LPG can be delivered by rail or road from the storage facilities to the bottling plant. The investment costs for rail fed plants are normally higher, but on the plus side the transport by train is cheaper. Two thirds of the LPG are processed in road fed plants and 1/3 by rail fed bottling plants. These plants receive also a part of the LPG by road. For long distance transport from a harbour rail transport can be assumed. The ratio of rail to road transportation is estimated to be 80:20[1] (BHANDARI/THUKRAL 1994; TERI 1989/03).

Table 8.2: Transport of LPG in India

LPG	***Import to India***	***Harbour (Bombay, Vizag) or Refinery (Mathura) to Bottling Plant (Ghaziabad)***
Single distance (km)	9,000	900
Tanker	100%	-
Train	-	80%
Truck	-	20%

Table 8.3 shows the transport picture for the distribution of LPG in India. The LPG cylinders are transported normally by trucks from the bottling plant to the distributors. From there they are brought by bike or LCV (Light Commercial Vehicle) to the customer. For large bottling plants the delivery distance can go up to as much as 400 km whereas the distance for the smaller plants is normally in the range of 10 km. To calculate the transports of cylinders with a truck in TEMIS, the simple distance must be multiplied by 2 to consider also the tare weight of the cylinders. (TERI 1993/01).

Table 8.3: Transport data for LPG distribution in India

LPG	***Bottling Plant (Ghaziabad) to Retailer (Gurgaon)***	***Retailer (Gurgaon) to Customer (Dhanawas)***
Single distance (km)	45	15
Distance total (km)	90	30
Truck	100%	-
LCV	-	50%
Bike	-	50%

The data for the transport of kerosene are given in Table 8.4. The tankers bringing SKO imports may be received at any of the existing ports in the country. Imports of SKO can similarly be assumed to be transported over long distances, after arrival from the harbour. Kerosene is deliv-

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[1] The ratio rail to road movement and the transport distance have a high influence on the LCI results. This point should be investigated more detailed in an update of this study.

ered from the storage points to the wholesalers. Therefore road, rail and sometimes pipeline[2] movement is possible. The ratio of rail to road is assumed to have the same value as for LPG. Transport by road is cheaper only for short distances. In general transport via pipeline is cheaper (TERI 1989/03).

The wholesaler delivers the SKO to authorised dealers or sub-agents (retailers) by tank trucks. A truck in New Delhi typically drives 50 to 60 km per day to deliver the 10,000 litre cargo. The customers bring the kerosene from the shop to their house.

Table 8.4: Transport of kerosene in India

Kerosene	*Import to India*	*Harbour (Bombay, Vizag) or Refinery (Mathura) to Wholesaler (New Delhi)*	*Wholesaler (New Delhi) to Retailer (Faruknagar)*
Single distance (km)	9,000	900	30
Tankers	100%	-	-
Train	-	80%	-
Truck	-	20%	100%

The average distance LPG and kerosene are carried (across India) is estimated at 960 km and 930 km respectively. These values appear high, but they consider that a part of the fuels is imported and the distance from the harbour to Dhanawas is 1,400 km. LPG processed from offshore gas is transported over the same distance.

Transport of other fuels, e.g. HSD for the upstream sector, is estimated with a total transport of 300 km. The fuels are transported half and half by train and truck. Hardcoal for power plants and trains is transported 80:20 with trains and trucks. The distance is estimated to be 800 km. This considers the data given by TEDDY (1994) for average transport distances.

8.2 Freight Transport with Tankers

The majority of the imported petroleum products are brought by tankers from the Gulf Region *{VIII-H-3}*. Indian vessels carry about 61% of all transported petroleum oils and lubricants. Most of the sold fuel in international shipping bunkers is furnace oil (F.O.). Data on the energy intensity of cargo haulage for India was not available (IPNGS 1992; TEDDY 1994). Thus the calculations for the energy use and the environmental impacts of the transportation are estimated under consideration of values investigated by different authors. The estimation is made assuming an average load of 50%, because the ships are empty on their return journey. Table 8.5 shows the estimated values. The table shows the data for tankers found by BUWAL (1991), FRISCHKNECHT ET AL. (1995) and ÖKO (1994/12) *{VIII-A-1, B-2, D-1..5, F-1}*.

For the transport of crude oil additives are necessary to maintain it in a liquid state. During the transport of crude the so called BSW (bottom sediment and water) builds up. Sooner or later this must be discharged *{VIII-E-2}*. The use of tankers for oil transportation brings with it the possibility of serious accidents. The threat that this means to the marine ecosystem cannot be overstated. Potentially large colonies of fish and even whole coral reefs can be wiped out *{VIII-G-6}* (ONGC 1994/12; TERI 1993/01).

Also small accidents with the possibility of oil spillage happen frequently *{VIII-C-1..7, G-6}*. One such accident was the running to ground of the *Innovative I* in the coastal waters of Andhra Pradesh. The tanker was hired to carry 1,600 t of crude from the Rawa oil field to the refinery in Vizag. The threat of oil spills has generated criticism by environmentalists on the ”apathetic”

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[2] The movement in pipelines is not considered as described in chapter 8.5.

attitude of the oil producing companies towards safety regulations. They said that the *Oil Spill Contingency Plans* drawn up by the oil companies have evidently not been executed. In the 70’s there was another tanker accident on an island near the Indian coast (DOWN TO EARTH 1994/06; PETROTECH 1995).

OCC (1995) estimates the ocean loss of imported kerosene to be 4.5%. This value appears very high. UBA (1993) estimated the total loss to be about 0.008% of the transported crude oil amount. FRISCHKNECHT ET AL. (1995) found a value of 0.08% for the world wide crude oil transports using tankers. This value includes the spillage in smaller accidents. The loss of imports is estimated for the LCI at 0.001% per 100 km for crude oil imports and 0.0004% per 100 km for imports of petroleum products *{VIII-D-5}*. This sums up to total losses of 0.03% and 0.036% for the two assumed import scenarios. The losses are considered as emissions of oil & grease (in the case of crude or kerosene imports) in an amount of 0.1/0.04 g/tkm or as NMVOC emissions (for LPG) in an amount of 0.04 g/tkm *{VIII-C-7}*.

Table 8.5: Data for tankers and estimates (with a 50% load occupancy rate)

		Tanker		***Estimation***	***Unit***
Steel	n.a.	100	n.a.	**200**	kg
Driven distance	n.a.	80,000	n.a.	**80,000**	km/a
Lifetime	n.a.	16	n.a.	**16**	a
Fuel oil consumption	0.11	0.1	0.07	**0.2**	MJ/tkm[a]
Tonnage	40,000	1[3]	n.a.	**1**	t
NOx	0.008	0.10	0.034	**0.20**	g/tkm
PM	0.005	0.01	0.004	**0.01**	g/tkm
CO	0.001	0.016	0.0044	**0.02**	g/tkm
CH_4	n.a.	0.0003	0.0006	**0.001**	g/tkm
NMVOC	0.001	0.003	0.0009	**0.002**	g/tkm
N_2O	n.a.	0.00003	n.a.	**0.00005**	g/tkm
Waste			0.01	**0.02**	g/tkm
Source	BUWAL 1991	ÖKO 1994/12	FRISCHKNECHT ET AL. 1995		

[a] *tkm - per tonne and kilometre*

8.3 Freight Transport with Trains

The Indian railway system is the second largest in the world with a route network of 62 thousand kilometres. A work force of 1.6 million looks after the railway operations *{IX-A-5}*. In the 1950s the government initiated a programme of track electrification. However, recognising that electrification is capital intensive, diesel traction increased much faster than electric traction (KARNIK 1989).

The following data is valid for 1992/93 (unless otherwise stated). The shares for rail freight traffic and non-suburban passenger traffic were 69% and 31% respectively. The total amount of rail freight traffic was 252 billion net tkm. If the weight of the moved equipment is considered, this amounts to total 737 billion gross tkm. The share of mineral oils is 15 billion tkm. The average lead distance for moved goods was 721 km (TEDDY 1994). Table 8.6 shows the share of different moods of traction. Data of the share in net km was available only for 1989/90. The estimation for the used dispatcher of net tonne km considers the rising share of electric traction. The table shows also the distance driven by the different types of trains and an estimation of the

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[3] The transport devices are assumed to have a tonnage of 1 because otherwise the calculations made by TEMIS are incorrect.

land use for the railways *{IX-F-1}*. This estimation is based on a calculation of land, covered by tracks.

Table 8.6: Ratios for the use of energy carriers (net and gross tonne per km) in different years and estimates for the land use of rail transports

	Share of net freight	***Share of gross tonne km***	***Estimation for the share of net freight***	***Driven distance (km/a)***	***Land use (m²)***
Year	1989/90 [a]	1992/93 [b]		1992/93 [b]	1992/93
Steam traction	0.45%	3.5%	**0.4%**	**2.58E+10**	**1.15E+7**
Diesel traction	59.49%	52.3%	**54.0%**	**3.86E+11**	**1.70E+8**
Electric traction	40.06%	44.2%	**45.6%**	**3.25E+11**	**1.44E+8**

Sources: *[a] RAILWAY (1992) statistics for 1989/91* *[b] TEDDY (1994)*

The Indian Railways are a major user of liquid fuels. With the switch from steam to diesel oil and electricity traction there has been an increase in energy efficiency *{IX-A-1, A-3, A-4}*. Indian Railways have now initiated steps for the introduction of more fuel and energy efficient diesel and electric locomotives (TERI 1993/01).

Full data on the environmental impacts of rail transport are not available. Only estimations of energy consumption per tonne and kilometre are possible. Table 8.7 shows different calculations for the energy use of trains. The values are compared with the data found by FRISCHKNECHT ET AL. (1995) for the situation in Europe. Values for gross-tonne km also take the weight of wagons and locomotives into account. The use of energy for other purposes in the railway system is not represented. The shown values take the load of the system into account. The values found for Europe are a little bit higher because the ratio of gross to net tonne km is greater. For the calculation of the environmental impacts the use of total MJ per transported tonne of freight is decisive. This estimation is made in the last row *{IX-A-1, A-3..4}*.

Table 8.7: Energy use per tonne km in the Indian railway system and estimation for the LCI

	Diesel oil	***Electricity***	***Steam***
MJ/gross-tkm [a]	0.13	0.03	2.23
MJ/gross-tkm [b]	0.22	0.07	3.68
MJ/gross-tkm [c]	0.27	0.09	3.77
MJ/gross-tkm [f]	0.21	0.08	n.a.
MJ/net-tkm [a]	0.25	0.07	5.38
MJ/net-tkm [d]	0.35	0.12	8.42
MJ/net-tkm [b]	0.62	0.18	10.63
MJ/net-tkm [f]	0.47	0.18	n.a.
Estimation (MJ/net-tkm)	**0.40**	**0.12**	**7.00**

Sources: *[a] RAILWAY (1992) statistics for 1989/91* *[b] TEDDY (1994) for different years*
[c] DAS (1994) *[d] Karnik[4](1989) for 1980/81* *[f] FRISCHKNECHT ET AL. 1995 (for Europe)*

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[4] The estimation of the energy use for different types of train movement by KARNIK (1989) covers the years until 1980/81. The energy use is calculated by the division of the used fuel by the transported freight tonne kilometres. The author shares the opinion that the energy efficiency might decrease in the following years, because the average age of the locomotives will rise in the future. Besides, the production of new locomotives has not kept pace with the growing demand. The provision of diesel oil and electricity driven locomotives will also extended to less frequently used routes.

In the LCI, electricity for the trains is delivered by the same generic power plant as for the downstream sector. The environmental impacts of steam trains are calculated with a combustion device for the used fuels. The combustion device of hardcoal for steam trains is based on data given by ÖKO (1994/12). The values are shown in Table 8.8. The emissions of diesel trains are estimated with emission data investigated by FRISCHKNECHT ET AL. (1995) and ÖKO (1994/12). These data are shown in g/tkm in Table 8.8. The use of lubricants is not considered for the LCI[5]. The life time is estimated to be 15 years. The use of steel is estimated to be 3 t per ton of transport capacity.

Table 8.8: Estimation for a generic hardcoal combustion device for steam trains and emission data for a diesel oil driven train

	NO_X	PM	CO	CH_4	NMVOC	N_2O
Hardcoal combustion (mg/Nm^3)	**500**	**10,000**	**250**	**5**	**50**	**5**
Diesel train [a] (g/tkm)	0.42	0.011	0.1	0.002	0.04	0.0008
Diesel train [b] (g/tkm)	0.5	0.04	0.15	0.01	0.14	0.00005
Estimation Diesel train (g/tkm)	**0.5**	**0.03**	**0.15**	**0.005**	**0.1**	**0.0005**

Sources: *[a] FRISCHKNECHT ET AL. 1995 [b] ÖKO 1994/12*

8.4 Freight Transport with Trucks and Light Commercial Vehicles

Road freight services are almost wholly owned and operated by the private sector. With steps as the liberalisation of issuing National and Zonal permits certain impediments to the growth of this sector have been removed (TERI 1993/01).

The LCI distinguishes between light commercial vehicle (LCV) and trucks. Trucks have a total gross weight of more than 3 tonnes. LCVs are not as heavy as trucks. An average tank-lorry has an empty weight of circa 9 tonnes and can load about 7 tonnes LPG or kerosene in bulk. An Ashok Leyland truck that is used as an LPG van can transport 360 cylinders. This is equivalent to 11 tonnes freight. An LCV used for transporting LPG can carry up to 20 cylinders (614 kg). Kerosene is transported from the wholesaler to the retailer in tank trucks that have four tanks with a total capacity of 10,000 litres (TERI 1993/01).

Data about the emissions of air pollutants from Indian diesel vehicles is available as gram per kg of burnt diesel oil. The calculation is based on the studies of vehicle emissions by the Indian Institute of Petroleum (IIP 1985,1995/09). This data is compared in Table 8.9 with values found by FRISCHKNECHT ET AL. (1995) for European diesel trucks *{X-D-1..5}*.

Table 8.9: Emission data for diesel vehicles and energy use in India and Europe

	Unit	Europe	India	Estimation
NOx	g/kg	62	44	**60**
PM	g/kg	1.2	2.9	**2.9**
CO	g/kg	19	23	**23**
Methane	g/kg	0.2	n.a.	**0.2**
Hydrocarbons	g/kg	14	10	**14**
N2O	g/kg	0.08	n.a.	**0.1**
Energy use	l/100 km	16t: 26	LCV: 12	**12**
Energy use	l/100 km	40t: 38	Truck: 23	**28**

Sources: *TERI 1993/5; GOI 1991; IIP 1985, 1994/09; FRISCHKNECHT ET AL. 1995*

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[5] The amount of lubricating oil used in engines for all goods services in 1989/90 was 17.2 million litres. In the following year 16.4 million litres were used (RAILWAY 1992).

Data about the average fuel use of Indian vehicles is available but it is not clear for which gross weight they are valid. The comparison with a 16 t and a 40 t gross weight truck in Europe suggests the calculation is for a smaller truck. The estimation for the LCI is shown in the last column. It considers that some of the values found are higher for European trucks. A possible reason for the differences is in the assumption of different driving scenarios. The European values seem likely to be closer to the real circumstances.

The data for the LCI are shown in Table 8.10. The values for India are calculated with the factors for fuel emissions as shown in Table 8.9. The values are multiplied by 2 to consider the assumed average load of 50% for the truck transport. The estimation for the load in the data investigated in Europe is not clear. The land use is assumed to have a higher value. This reflects that the truck needs a larger area for driving than just the covered square meters.

The estimation for the land use considers the data found by FRISCHKNECHT ET AL. (1995) who estimated this indicator to be 0.0097 m²/tkm. The same source was used to estimate the demand for cement as a construction material to be about 3 t for the truck. The calculations by these authors demonstrated that one third of the street traffic related energy uses and emissions are caused due to the production of vehicles and the construction of streets. These impacts are not considered in the LCI for India.

Table 8.10: Emission data for Indian transport vehicles with an average load of 50% and a comparison with data for Europe

	Unit	Light Commercial Vehicle	Truck India	Small Truck Germany	Truck Germany	Truck Europe
Fuel consumption	l/100 km	12	28	45	121	38
Tonnage	t	**0.8**	**10**	10	20	16
Fuel consumption	MJ/tkm	**10**	**2**	1.57	2.13	0.85
NOx	g/tkm	**15**	**3**	1.5	0.8	0.995
PM	g/tkm	**0.75**	**0.14**	0.1	0.0575	0.080
CO	g/tkm	**6**	**1**	0.5	0.1225	0.398
CH_4	g/tkm	**0.05**	**0.01**	0.04	0.01	-
NMVOC	g/tkm	**3.5**	**0.6**	0.4	0.0875	0.199
N_2O	g/tkm	**0.025**	**0.005**	0.0001	5.0E-05	-
Material Steel	t	**0.8**	**10**	10	10	-
Material Cement	t	**0.25**	**3**			
Distance per year	km	**30,000**	**30,000**	40,000	40,000	-
Land use	m²	**180**	**1,000**	10	10	-
Life time	a	**10**	**10**	10	10	-

Sources: *Own calculation with TERI 1993/5; GOI 1991; IIP 1985, 1994/09. Data for European trucks as given by BUWAL 1991 (Europe) and ÖKO 1994/12 (Germany)*

A major problem for all users of Indian roads are the frequent **accidents**. Every year many people lose their lives on Indian streets or damage their health *{X-G-1, G-6}*. A serious accident happened on 12 March 1995 near Madras. A Public Transport Corporation bus, a tanker carrying benzene and a tractor trailer collided. In the accident 75 people died when the vehicles burst into flames. In another accident six people were killed and four suffered severe burns when an LPG tanker collided with a truck and caught fire. The accident took place near Nashik on the 25th of March (INDIAN EXPRESS 1995; THE TIMES OF INDIA 1995).

Figure 8.1 shows LPG and other tank trucks waiting outside a refinery in Bombay. Due to a breakdown of the plant, hundreds of trucks had to wait for their cargo. Some of the drivers came distances of over 1,000 kilometres. They were left waiting there for 1 or 2 weeks.

Figure 8.1: Photo of LPG-trucks waiting for cargo in front of a refinery in Bombay

8.5 Transport of Petroleum Products by Pipelines

The total length of crude pipelines is 4,000 km, of gas pipelines 3,675 km, and there is one pipeline for LPG 24 km long. Most pipelines are used for transportation between different stages of product conversion. Normally pipelines are well maintained and frequently inspected. Leaks from pipelines should be restricted to accidents (IPNGS 1992; ONGC 1994/12).

The construction of cross country pipelines has significant environmental impacts. The soil structure and the nutrient uptake pattern are disturbed. The measurements during construction can be followed up by soil erosion. Whenever a pipeline crosses a stream, the construction can lead to fishing disturbance. The vegetation along the construction route is destroyed and it will take time until the normal flora and fauna return. Pipeline failures can affect the population in the surrounding area negatively[6] (CHAKRABARTY 1995).

A calculation of the environmental impacts of the pipeline transportation in Indian was not possible. Statistical data about the products flowing between the different processing units was not available. Neither significant data about the energy use could be found. The environmental impacts in comparison to other modes of transport can be assumed to be low. The energy use is less, the danger of accidents seems to be less and the land used can be cultivated again after a few years. The energy used in offshore pipelines is included in the LCI for the extraction stage, because it is also met by the existing power stations. Also other parts of the energy use are likely to be included in data for refineries, because a few pumping stations are inside the production area.

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[6] The possible environmental impacts and measurements to minimise these impacts are described by CHAKRABARTY (1995).

8.6 Transport of Goods with Bicycle

Bikes are used to deliver the LPG cylinders to the customer. One bike carries 3 cylinders (90.2 kg). The data for the use of bikes as transport vehicles are shown in Table 8.11 *{B-1, F-1}*. The use of human power is not considered in the calculations for the LCA *(X-A-5)*. Figure 8.2 shows a photo of a bike that is used for the transport of LPG cylinders. Sometimes bikes are also used to transport kerosene in cities. A standard oil barrel fits onto a 3-wheeler bicycle. The kerosene is refilled from this barrel into the customers' container. In this case nearly 200 kg of kerosene is transported on the street. This transport mode of transport seems highly dangerous *{X-G-6}*.

Table 8.11: Data for the use of bikes as freight transport vehicles

Load factor	3,000 h/a
Tonnage	90 kg
Steel	15 kg
Driven distance	15,000 km/a
Life time	5 a
Land use	5 m²

Figure 8.2: Transport of LPG cylinders with a bicycle

9 Horizontal Analysis and Evaluation of the Results

Results from all the previous stages in the LCI are now combined with the **horizontal analysis**. This is done in two steps. First environmental data sheets for LPG and kerosene are calculated and discussed. In a second step, the overall impacts of cooking in Dhanawas are given. The results of the horizontal analysis are compared primarily in a short evaluation.

The last three steps of an LCA are carried out in one chapter, which is not the standard practice for a life cycle assessment. Normally the last steps are worked out in more detail: The emissions due to an assumed scenario are calculated in a first step. The possible effects for the environment, due to the calculated emissions, are described in a following step. The results are then evaluated in a final step.

This approach would not have been useful for this study. One aim of this study is to make a comparison with the results of an LCI for biomass fuels. The LCI for biomass fuels was not available at this time. The last steps of the LCA should bring together all these results. Accordingly the task of comparison and evaluation will be done in more detail in the study by LAUTERBACH (n.d.).

9.1 Horizontal Analysis for Quantifiable Impacts of the LPG and Kerosene Supply to Dhanawas

Table 9.1 gives the results of a scenario calculating the environmental burdens of LPG and kerosene, from its point of sale to the end consumer. This is the retailer in the case of kerosene or the delivery of LPG to the household. The results are shown for one kg and for one GJ LHV of product. The Indian values are calculated for two scenarios: A scenario considering the imports of energy carriers as described in the LCI and a scenario looking only at the production of LPG and kerosene in India. It excludes the import of resources or fuels. All indicators are calculated with the data investigated in the LCI. The computer program TEMIS 2.0 was used for this calculation. The calculation of CO_2 eq is described in chapter 2.6.

The table gives comparable values for diesel oil in Europe from the study of BUWAL (1991). Not all stages of distribution are included in these figures. This was the only available information for a refinery output that could be compared with the results of horizontal analysis. This is possible because the production of diesel oil is similar to the production of kerosene. Data that was investigated by FRISCHKNECHT ET AL. (1995) was too detailed to compare with the Indian values. The found **profiles** for LPG and kerosene are shown in Table 9.1. They are analysed, described and compared in the following sections.

9.1.1 Additional Impacts due to the Material Use

Table 9.2 shows the possible additional impact on some indicators due to the material production in grams and as percentage of the values in Table 9.1. The possible additional impacts due to the production of steel and cement were calculated with the program TEMIS 2.1 and a data set for Germany. Information about the possible impacts due to the water demand and the use of chemicals was not available from these data.

Table 9.1: Environmental profile for the supply of average (incl. Imports) and in India produced LPG and kerosene to the consumer and comparison with the profile of diesel oil in Europe

Indicator	***Unit***	***Matrix field***	***Kerosene (1 kg)***	***Indian Kerosene (1 kg)***	***LPG (1 kg)***	***Indian LPG (1 kg)***	***Diesel oil (Europe) (1 kg)***	***Kerosene (1 GJ)***	***Indian Kerosene (1 GJ)***	***LPG (1 GJ)***	***Indian LPG (1 GJ)***	***Diesel oil (Europe) (1 GJ)***
Primary energy	(MJ)	*A-1..4*	50.4	49.5	53.5	52.9	46.4	1,177	1,156	1,182	1,170	1,092
Energy	(MJ)	*A-1..4*	7.6	6.7	8.2	7.7	n.a.	177	156	182	170	n.a.
Fuels	(MJ)	*A-1..4*	7.1	6.2	7.7	7.2	3.9	166	145	171	160	92
Water	(g)	*B.1*	9,642	11,222	7,290	7,380	n.a.	224,976	261,832	161,138	163,132	n.a.
Steel	(g)	*B.2*	8.4	8.3	14.6	14.6	n.a.	197	194	322	322	n.a.
Cement	(g)	*B.3*	2.6	4.0	3.9	4.6	n.a.	60	94	86	102	n.a.
Chemicals	(g)	*B.4*	5.0	2.8	3.8	2.6	n.a.	116	66	83	57	n.a.
Effluents	(g)	*C.1*	9,300	9,065	5,814	5,168	n.a.	216,981	211,505	128,513	114,245	n.a.
BOD	(g)	*C.2*	0.015	0.017	0.014	0.015	0.006	0.35	0.40	0.31	0.32	0.14
COD	(g)	*C.3*	0.071	0.078	0.063	0.065	0.018	1.7	1.8	1.4	1.4	0.42
Phenol	(g)	*C.4*	1.10E-04	1.00E-04	9.00E-05	7.00E-05	0.00	0.0026	0.0023	0.0020	0.0015	0.00
TDS	(g)	*C.5*	0.29	0.31	0.32	0.33	13	6.8	7.2	7.1	7.3	298
TSS	(g)	*C.6*	0.032	0.032	0.029	0.029	0.006	0.74	0.75	0.65	0.64	0.14
Oil & grease	(g)	*C.7*	0.342	0.065	0.178	0.077	0.163	8.0	1.5	3.9	1.7	3.8
SO$_2$	(g)	*D.1*	3.8	1.5	2.8	1.7	3.86	88	36	62	38	91
NO$_X$	(g)	*D.2*	3.3	2.2	3.3	2.8	1.90	78	51	72	61	45
CO	(g)	*D.3*	0.72	0.64	0.87	0.83	0.25	17	15	19	18	5.9
PM	(g)	*D.4*	0.33	0.27	0.35	0.32	0.22	7.6	6.2	7.8	7.1	5.15
CH$_4$	(g)	*D.5*	3.6	3.2	3.4	3.1	n.a.	84	74	76	69	n.a.
NMVOC	(g)	*D.5*	13	12	10	9.1	6.8	296	283	221	201	160
N$_2$0	(g)	*D.5*	0.0059	0.0067	0.0074	0.0076	0.048	0.14	0.16	0.16	0.17	1.13
CO$_2$	(g)	*D.5*	482	401	516	469	n.a.	11,256	9,349	11,402	10,367	n.a.
CO$_2$ eq [†]	(g)	*D.5*	743	635	743	673	n.a.	17,326	14,817	16,414	14,886	n.a.
Cuttings	(g)	*E.1*	25	21	29	26	n.a.	586	489	637	581	n.a.
Waste	(g)	*E.2*	2.5	2.3	2.1	2.0	1.6	57	53	47	44	37
Ashes [‡]	(g)	*E.2*	4.3	4.5	12.9	13.0	n.a.	100	105	285	287	n.a.
Land use	(m²)	*F.1*	0.0042	0.0035	0.0085	0.0081	n.a.	0.10	0.08	0.19	0.18	n.a.

[†] - *Calculation described in chapter 2.6*

[‡] *Ashes are calculated by TEMIS using the ash content of the fuels*

The TEMIS data only refer to the energy use and the related emissions of air pollutants[1]. The indicator with the highest additional burden is CO. These emissions are from coke and sinter production for the steel process. The inclusion of the material production might lead to 28% and 40% higher emissions for kerosene and LPG respectively. Apart from this parameter, the additional impacts for the kerosene supply range from 0.4% to 4.3%. In the case of LPG supply, additional impacts from material production deliver a higher share for the total environmental burden, due to the higher amount of the steel and cement used. The additional impacts reach from 0.7% to 5.7%. The inclusion of environmental impacts due to the material production could change some of the LCI results. Further research work should investigate this point in more detail for the situation in India.

Table 9.2: Additional environmental burdens for the supply of one kg LPG or kerosene if the production of steel and cement is calculated with data for Germany (TEMIS 2.1)

	Kerosene (Percent of total)	***LPG (Percent of total)***	***Kerosene Additional impact***	***LPG Additional Impact***
Steel use	-	-	8.4 g	14.6 g
Cement use	-	-	2.6 g	3.9 g
Primary Energy	0.40%	0.70%	0.20 MJ	0.35 MJ
SO_2	0.8%	1.9%	0.031 g	0.054 g
NO_X	1.3%	2.3%	0.045 g	0.076 g
CO	28%	40%	0.20 g	0.35 g
PM	2.3%	3.5%	0.0075 g	0.0124 g
CH_4	1.9%	3.5%	0.069 g	0.120 g
NMVOC	0.038%	0.083%	0.0048 g	0.008 g
N_20	4.3%	5.7%	0.00025 g	0.00042 g
CO_2	3.2%	5.1%	15 g	26 g
CO_2 eq	2.2%	3.7%	16 g	28 g
Land use	0.5%	0.5%	0.00002 m²	0.00004 m²

9.1.2 Analysis of the Impacts

Figure 9.1 shows the origin of the environmental burden for the supply of LPG and kerosene in India. The summarised values for both fuels are shown in Table 9.1. Three sections of the **direct** life cycle were investigated. The **upstream** sector includes the exploitation of the resources crude oil and natural gas. The second section shows the **downstream** sector with refineries, fractionating and bottling plants. The third sector looks on the **transport and distribution** of LPG and kerosene. This includes the import of crude oil and other products with tankers, the transport of LPG and kerosene from the producer to the consumer and the impacts of their distribution. Each sector includes the production of the used energy carriers and the necessary efforts to transport the fuels to the place of consumption. The bar charts show the percentage origin for different indicators in the three stages of the life cycle. The upper bar stands for kerosene, the lower one for LPG.

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[1] The data set *standard* and the program TEMIS 2.1 were copied from an FTP server of the university of Kassel (*cserv.usf.uni-kassel.de*, Directory: */pub/envsys*). The set contains the data described in ÖKO 1994/12 in a non-official version. The date of saving this set is 22.3.1995. Calculations with the *standard* data diverge in some points from calculations with older data for TEMIS 2.1 (data set *generic*) or for the original GEMIS 2.0 (data set *standard* or *ist-west*) because these data sets contain mistakes for some processes or have been updated.

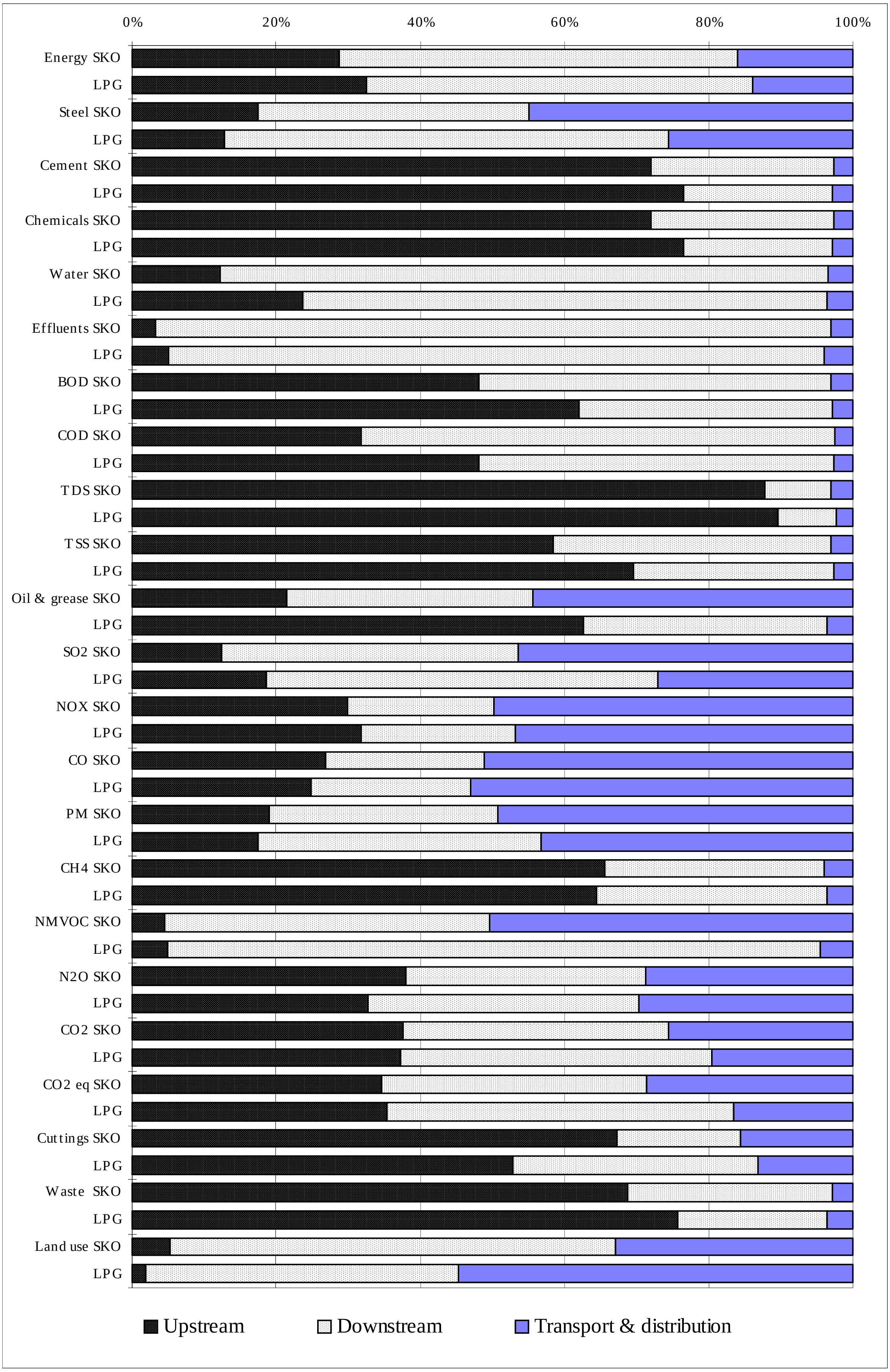

Figure 9.1: Environmental impacts in different sections of the life cycle

In comparison the energy use for LPG in the downstream sector has a lower proportion than that for kerosene because of the less energy consuming fractionating plants. The share for transport is higher in the case of kerosene due to the greater demand for imports using tankers. More steel is used in transportation of kerosene. In the LPG scenario it is mainly used for cylinders, needed to transport the LPG. The upstream sector is the main consumer of cement and chemicals, which are necessary for drilling the wells. The other sectors also have a share for this indicator due to the burden of the used fuels.

Water is mainly used as cooling water in refineries. Thus effluent is also discharged mainly from the downstream section. But in some cases the share for water pollutants is nearly the same for downstream and upstream sector. The exception to this is the emissions of TDS which was not investigated for the refineries. Oil & grease are emitted in large amounts by tankers and through the discharge of the cuttings into the sea. Waste and cuttings also have a high share in the first part of the life cycle.

The analysis regarding air pollutants shows a heterogeneous picture. Sulphur dioxide is emitted in a great extent due to imports by tankers because they use fuel oil with high sulphur content. Refineries are also a significant source. The transport devices cause a great share of the NO_X, CO and particle emissions. NMVOC are emitted in a high share with losses during the distribution stage. This is considered in the LPG scenario in the downstream stage of bottling. Methane is emitted on equally high volume during extraction with the flaring. Carbon dioxide and CO_2 equivalents are emitted by all three sectors in the same degree.

The transportation of the products takes a surprisingly high proportion of the environmental burdens of LPG and kerosene. Table 9.3 indicates this for some selected parameters. For some indicators it shows the main direct source in the scenario for the supply of one kg LPG or kerosene in India. The impacts are aggregated for all processes concerned in the life cycle including imports. Trucks for example are used not only in the transport of the cooking fuels but also in the transport of diesel oil to production devices used in the petroleum extraction.

Table 9.3: Relevance of single processes and caused emissions (g) for selected indicators in the supply scenario for 1 kg of fuel

Indicator	*Main emitting process*	*Kerosene*	*Main emitting process*	*LPG*
Water pollutants	Extraction and refineries	-	Extraction and refineries	-
Oil & grease	Tanker	0.25	Tanker	0.09
Waste	Crude extraction	-	Extraction	-
SO_2	Tanker	2	Tanker	0.8
Particles	Steam train	0.07	Steam train	0.07
NO_X	Tanker	0.95	Truck	0.84
CH_4	Flaring	1.7	Flaring	1.7
NMVOC	Distribution	5.0	Refineries	-
CO	Truck	0.21	Truck and LCV	0.37
CO_2	Flaring	130	Flaring	128
CO_2 eq	Flaring	180	Flaring	177

The table shows that transport devices are the main direct source for some pollutants. Almost half of the emitted sulphur dioxide in the life cycle of kerosene originates from transports by tankers. These tankers are also the main source for oil & grease.

Trucks and LCV are the main single source of NO_X and CO. Flaring of natural gas is important for the emissions of CO_2, methane and CO_2 equivalents. NMVOC are emitted mainly due to the losses during the life cycle and are considered in the process of refining, distribution and bottling. The high volume of particles is due to the small proportion of transportation by steam trains. Exploitation and processing in refineries are the main polluting processes in case of waste, effluent and water pollutant indicators. The environmental impacts of transportation are largely in a direct and immediate relationship to distance journeyed. Further research work needs to investigate the true impacts of transportation in more detail.

Figure 9.2 and Figure 9.3 give the distribution of fuels used for the scenarios of LPG and kerosene supply. The main fuels used as energy carriers in the life cycle are natural gas (flaring) and fuel oil (transports and auxiliary energy). Fuel oil is used in a higher degree for the kerosene scenario because of greater reliance on imports, resulting in its use as a fuel for tankers. The next important energy carrier is HSD as an energy carrier for transports. The use of natural gas marks one important possibility for environmental improvements. The reduction of flaring could lead to a considerable reduction in energy use and emission of air pollutants. Other energy carriers used in a smaller degree are fuel gas, hardcoal and coke. Fuel gas and hardcoal have a higher share in the LPG scenario because of their use as energy carriers in fractionating plants and for power plants.

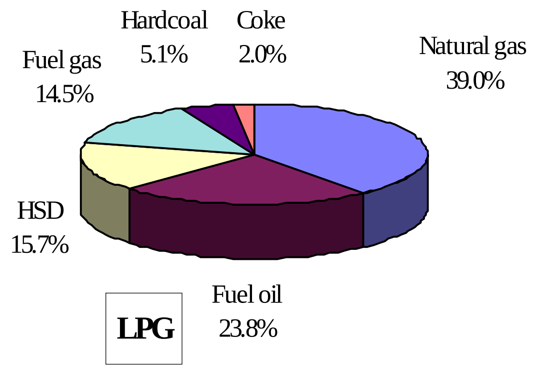

Figure 9.2: Use of different fuels for the supply of LPG

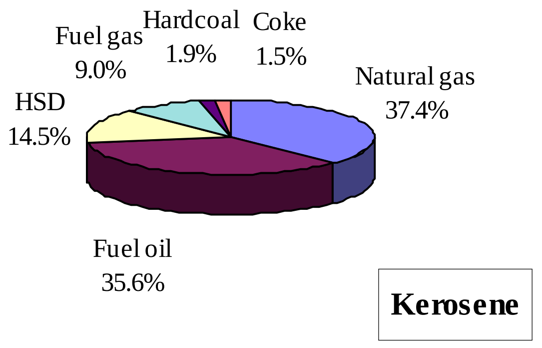

Figure 9.3: Use of different fuels for the supply of SKO

9.1.3 Profiles for the Production of LPG and Kerosene in India, the Mixed Production and Data for Europe

The energy use is shown in Table 9.1 in three sections: The total primary energy used for the product including its energy content, the energy consumption for fuels and losses and the energy content of the burnt fuels. The production of SKO, LPG and diesel oil consumes 17.7%, 18.2% and 9.2% of the fuels energy content respectively. In comparison with the values for European diesel oil, the energy use for kerosene in India is higher. The reason is the inclusion of long transports in the LCI. The inclusion of imports leads to a higher average energy use than a scenario with exclusive domestic production. The total losses in the life cycle, that is the difference between used fuels and used energy as shown in Table 9.1, amounts to 1%.

The values for the material use differed only a little between solely Indian products and the scenario including imports. But the differences seem to the result of different estimations for the use in processing facilities. About 7 to 9 litres of water are used to produce one kg of kerosene or LPG respectively. While 8 to 15 grams of steel and 3 to 4 grams of cement are consumed per kg of kerosene and LPG.

Effluents are discharged on an average of 9 litres for kerosene and 6 litres for LPG. This difference is caused by different figures for the international and the Indian production. Another reason is the lower use for LPT production in fractionating plants. The values for water pollutants for kerosene sold in India and diesel oil produced in Europe are on a comparable level, excluding the value for TDS. The reason might be the non-investigation of this indicator for the Indian refineries because of lack of data. The total value for oil & grease is much smaller if exports are excluded. This highlights the significance of tanker transports discharges to the total sum of pollutants for the life cycle.

The amount of air pollutants released is similar for kerosene and diesel oil. SO_2 and NO_X are increased considerably if imports are included. About 3.3 grams NO_X are emitted during the supply of 1 kg fuel to the consumer. The emissions of CO and NMVOC for the European scenario are only half as high as the Indian values. The total amount of greenhouse gases, calculated as CO_2 eq, is 743 g for 1 kg of either fuels.

Kerosene imports represent a greater proportion to total consumption than is the case for LPG consumption. Thus the results for this fuel are influenced in a greater degree by deviations between the Indian and the international production. Main differences between the mixed production and the only Indian production are caused by the necessary transports to import the petroleum products. Most of the values for other indicators are on the same level, if it is considered that differences might also be caused by different methodologies for the LCI in India and Europe.

9.1.4 Comparison of the Profiles

Figure 9.4 compares the environmental burdens related to the energy content of the fuel for the specific indicator. The data used is given in Table 9.1 for one GJ of the product used in India (including imports). If the bar rises to the left, this marks an advantage for SKO. The land use, for example, is about 90% higher for LPG than the comparable level for SKO.

The direct comparison shows an **advantage** to **LPG** in most of the investigated indicators. The energy used in the production of LPG is a little higher than this for kerosene due to the different allocation used for the products in the refining step and the higher energy use for the extraction of natural gas. Steel is used in greater quantities in LPG production with the need for cylinders. Water pollutants are released in higher quantity during the production of kerosene. This is because negligible emissions of effluents are associated with the production of LPG in fractionating plants. Release of oil & grease and SO_2 occurs in the main during transportation by tankers. Accordingly the volumes are higher in the kerosene scenario. The use of chemicals and the higher emissions of NMVOC in the SKO profile are linked with the greater pollution due to crude exploitation onshore. Waste is produced in a higher amount accompanying crude oil processing due to the development of BSM.

In this **provisional assessment** of the impacts, LPG seems to be more environmentally friendly than kerosene. The overall advantage could be reversed if the full effects of the production of steel and cement for the fuels are included in the LCI. With the inclusion of this the horizontal analysis for the production of LPG and kerosene gives no clear preference for one of the fuels.

A detailed LCA must compare advantages and disadvantages for different indicators in a more specific way. Several mechanisms are available for the **weighting** of the different forms of impact. One alternative is the detailed discussion of environmental impacts leading to an evaluation. The impact, for example of a specific emission of BOD, is described and the author attempts to evaluate this impact against another one, for example the emission of particulates.

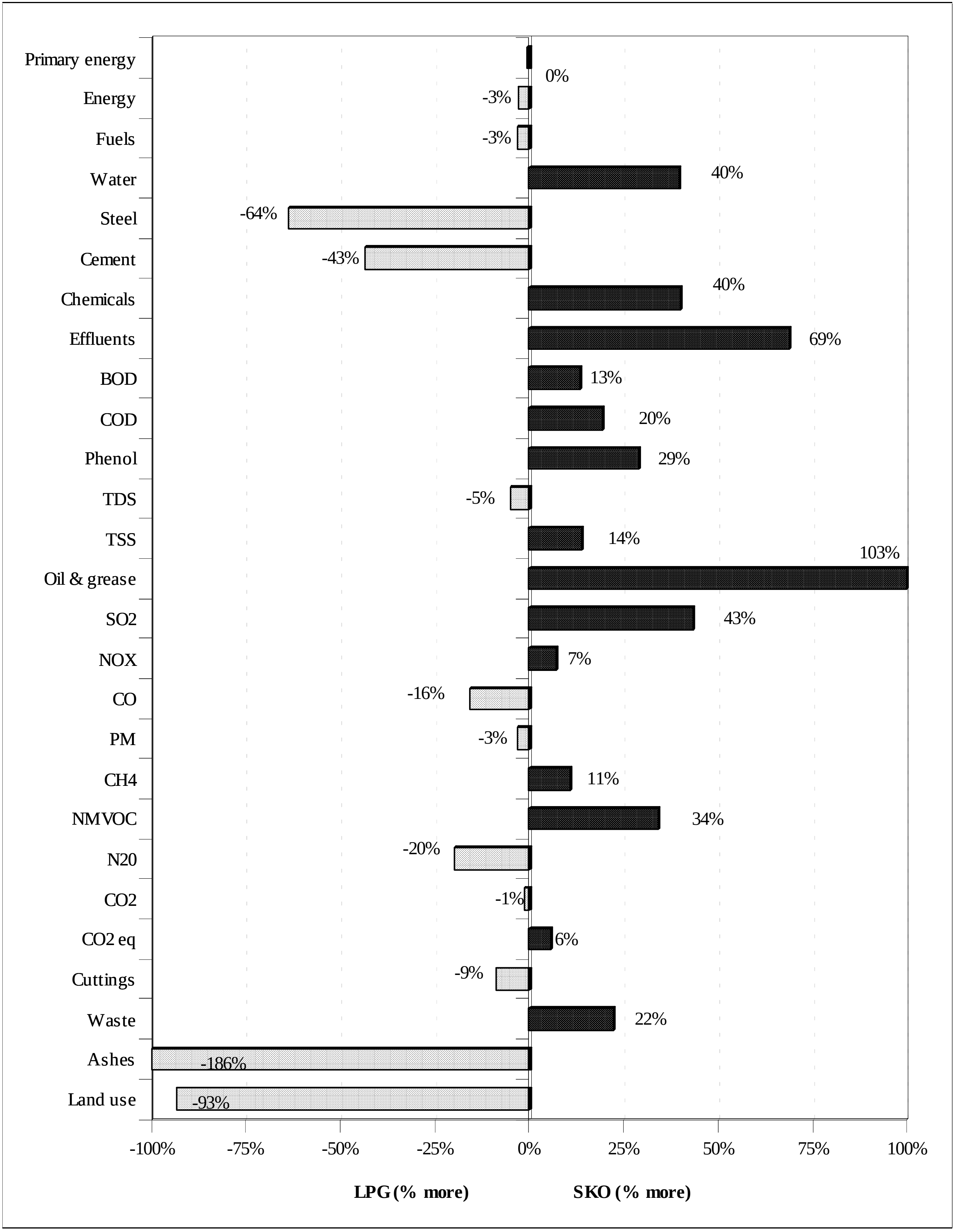

Figure 9.4: Comparison of the environmental burdens for LPG and kerosene

Another alternative is the **standardisation** of the results. The results for every indicator are multiplied by a parameter specific **weighting factor** reflecting the environmental hazards for different environmental themes (e.g. global warming or human toxicity). These factors are often considered in relation to national standards for ambient air or goals for the water quality. Another possibility for estimating these factors is a comparison of the emissions caused specifically from this production with the total emissions in a country or globally. The results of the multiplication are summed to produce one **environmental index** that can be used to compare between the different product variants (BERG ET AL. 1995).

9.2 Horizontal Analysis for Cooking in Dhanawas

Table 9.4 shows the environmental profile for the six cooking scenarios in Dhanawas. The *mean* process shows a possible normal scenario. The two processes *optimum* and *worst-case* cover the range of possible results due to the great uncertainties in the LCI for the cooking. The environmental impacts due to the cooking and the supply of the fuels are calculated with the data described in the LCI. The table shows the calculated values for all quantifiable indicators in a scenario for the supply of **1 GJ useful heat** for cooking.

The scenarios for cooking in India were compared with three scenarios for cooking in Germany. The results for these scenarios are shown in Table 9.5. These scenarios are defined using data from the *standard* data set of TEMIS 2.1. Information was available for cooking with town-gas, with propane gas in cylinders and with electricity. The values for the efficiency were changed because the original claimed to be 65% for gas stoves and 100% for electric cooking, did not appear to be reliable (TEMIS 2.1).

The German standard (DIN EN 30) prescribes an efficiency of more than 58% for gas stoves. The gas stoves are estimated to have an efficiency of 64% (like the mean stove in the Indian scenario). The efficiency of electric stoves is standardised (DIN 44547) at not less than 43% or 53% depending on whether the cooking starts with a cold or a warm plate[2]. The type of vessels used and other parameters have a big influence on the test results. The efficiency of new stoves in this test is normally ranges from 60% to 70%. The electric stove is estimated to have an efficiency of 65% (DIN 1979, 1990; KIEL 1995).

Estimates for different types of cooking are also given in the *Environmental Manual* (EM 1995). The results for cooking with natural gas, LPG, kerosene, biogas and wood as calculated by this program are shown in Table 9.5. The estimates for the biogas stove are the authors own using data from the gas stove and the data available for biogas production. The emission of CO_2 due to the burning of renewable fuels (biogas, wood) is not considered in the results. The data do not refer to a specific country. Furtheron they are termed as an *international* scenario. The data quality is preliminary. Thus the results of this calculation are not very reliable. The results of the horizontal analysis for India, the German cooking scenarios and the data given by EM (1995) are described, analysed and compared in the following sections.

9.2.1 Share of Cooking in the Total Results

Figure 9.5 gives the share of direct air pollutant emissions released during cooking as a percentage of the total emissions during the life cycle. About 40% of NO_X are emitted during the cooking. Particulates and SO_2 are emitted in only a negligible share of the total emissions for the LPG life cycle. But kerosene cooking, depending on the different cookstove estimates, produces at this stage about half of its total emissions. The emission of SO_2 is affected only by the sulphur content of the fuel. Thus there are no differences for the different scenarios of cooking with one fuel.

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[2] The efficiency describes the energy use for heating up water from 20ºC to 100ºC.

Table 9.4: Environmental profile for the cooking with LPG and kerosene in Dhanawas

		Unit	Matrix field	LPG-optimum	LPG-mean	LPG-worst-case	SKO-optimum	SKO-mean	SKO-worst-case
Energy use	Energy use	(MJ)	A-1..4	1,641	1,847	1,970	1,839	2,179	2,802
Materials	Water	(g)	B.1	224,000	252,000	269,000	352,000	417,000	536,000
	Steel	(g)	B.2	473	529	562	377	434	538
	Cement	(g)	B.3	119	134	143	94	111	143
	Chemicals	(g)	B.4	115	130	139	182	216	277
Water pollution	Effluents	(g)	C.1	178,500	200,800	214,200	339,100	401,900	516,700
	BOD	(g)	C.2	0.43	0.49	0.52	0.55	0.66	0.84
	COD	(g)	C.3	1.9	2.2	2.3	2.6	3.1	4.0
	Phenol	(g)	C.4	0.0026	0.0030	0.0032	0.0042	0.0050	0.0064
	TDS	(g)	C.5	9.9	11	12	11	13	16
	TSS	(g)	C.6	0.90	1.01	1.08	1.15	1.37	1.76
	Oil & grease	(g)	C.7	5.5	6.2	6.6	12	15	19
Air pollution	SO_2	(g)	D.1	92	103	110	284	336	432
	NO_X	(g)	D.2	140	180	216	188	276	390
	CO	(g)	D.3	126	830	1,406	250	1,093	5,501
	PM	(g)	D.4	11	12	14	19	30	291
	CH_4	(g)	D.5	106	120	129	132	178	256
	NMVOC	(g)	D.5	326	434	486	507	813	1318
	N_20	(g)	D.5	0.62	1.14	2.17	0.66	1.85	5.11
	CO_2	(g)	D.5	108,400	122,000	130,100	132,300	156,800	201,700
	CO_2 eq	(g)	D.5	116,300	134,000	145,200	143,700	176,200	243,600
Waste	Cuttings	(g)	E.1	885	995	1,061	915	1,085	1,395
	Waste	(g)	E.2	65	73	78	90	106	137
	Ashes	(g)	E.2	396	445	475	156	185	238
Other	Land use	(m²)	F.1	0.32	0.35	0.37	0.24	0.27	0.32

Table 9.5: Comparison of the profile for the mean cooking scenarios in India with data for cooking possibilities in other studies

	LPG-mean-In	***SKO-mean-In***	***Gas-cooking-GER***	***Propane-cooking-GER***	***El-cooking-GER***	***Kerosene-int***	***Gas-int***	***LPG-int***	***Biogas-int***	***Wood-int***	***Wood-improved-int***
Energy use	1,847	2,179	1,818	1,928	5,044	2,847	1,869	2,304	1,962	7,034	3,768
Steel	529	434	6,271	5,797	8,144	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Cement	134	111	280	69	1,850	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
SO_2	103	336	24	106	232	1,088	9	466	462	287	154
NO_x	180	276	132	164	375	326	103	407	291	565	303
CO	830	1,093	266	262	335	381	135	182	161	1,916	1,026
PM	12	30	4.5	9.6	37.3	87	1	59	29	2,673	1,432
CH_4	120	178	537	77	784	118	462	94	46	229	122
NMVOC	434	813	26	56	36	97	30	77	27	231	124
N_20	1.14	1.85	4.7	1.5	12	6.0	2.0	3.3	2.3	87.0	46.6
CO_2	122,000	156,800	99,513	125,300	310,000	213,000	93,854	151,900	10,751	31,659	16,960
CO_2 eq	134,000	176,200	106,700	126,500	321,800	222,400	107,500	159,700	15,607	73,665	39,464
Waste	73	106	420	478	21,847	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Land use	0.35	0.27	0.02	0.03	1.00	0.52	0.03	0.42	20.27	0.17	0.09

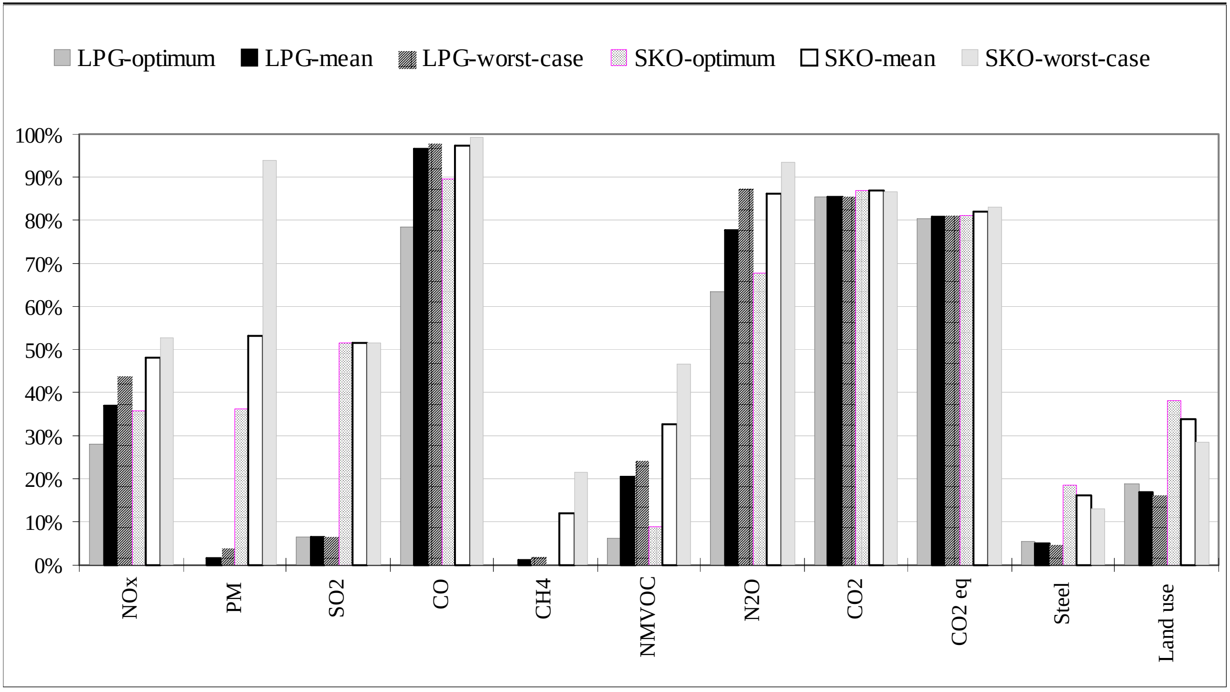

Figure 9.5: Share of cookstove emissions and other impacts among the total impacts during the life cycle

Emissions of methane are significant in the upper part of the life cycle. Only 20% to 30% of the total NMVOC's emitted by both LPG and kerosene over their product life cycle is released during cooking. For emissions of CO, CO_2, N_2O and CO_2 equivalents, cooking is the critical stage in the life cycle. But as much as 20% of greenhouse gas equivalents are caused by the production of the fuels. The use of steel and land is determined by the results until the delivery to the household. For all other indicators (e.g. water pollutants) the emissions are prior to delivery to the household (and therefore the cooking stage).

9.2.2 Environmental Profile for Cooking

To produce 1,000 MJ of useful heat for cooking between 2,802 MJ and 1,641 MJ of primary energy is used. The following results are valid for the **mean** cooking scenarios with LPG and kerosene respectively. The full results are shown in Table 9.4. The overall efficiency for cooking is in the range of 54% and 46%. About 2,158 MJ of fuels are burnt in the kerosene cooking scenario. This is 99% of the total energy use. The value for LPG is 1,830 MJ. LPG and kerosene have a share of 85.4% and 85.8% of the fuels used in this scenario. The most important auxiliary energy carrier in the life cycle is natural gas with a use of 104 MJ and 115 MJ for LPG and kerosene respectively. Fuel oil, diesel oil and fuel gas are other energy carriers used for producing the fuels. The total amount of other fuels burnt is 267 MJ and 306 MJ respectively for the LPG and kerosene production.

Cooking is connected with the discharge of 201 litres and 401 litres of effluents for the respective fuels. For example 2.2 and 3.1 grams of COD are discharged from LPG and kerosene. A total of 6.2 grams and 15 grams of oil & grease are discharged as a result of cooking with LPG and kerosene respectively. Burning of different energy carriers leads to 134 kg and 176 kg of CO_2 eq emissions in the two mean scenarios for LPG and kerosene respectively. Cooking is also linked with the discharge of 1 kg cuttings and 73 g or 106 g of other wastes. The total land use for the necessary installations is 0.35 m² and 0.27 m² for cooking with LPG and kerosene respectively.

9.2.3 Comparison of the Quantifiable Impacts for Cooking in Dhanawas

The environmental impacts of the six cooking scenarios for India are compared in Figure 9.7. The results of the cooking scenarios are standardised by division by the factor that is shown beneath the indicator. It is only possible to compare the results for one indicator. Cross indicator comparisons are not possible.

The results for the LPG and kerosene scenarios can be compared as follows. Cooking with LPG is better than this with kerosene with regard to many indicators even if the worst-case scenario is compared with optimum use of kerosene. These indicators are: Water use, chemicals, effluents, SO_2, PM, CH_4, NMVOC, CO_2, wastes, and all water pollutants except TDS.

The other results depend on the different cooking scenarios. In these cases the advantage of one possibility when comparing the mean scenarios might alternate to a disadvantage if the worst case is compared with the optimum use of the other option. Cooking with kerosene consumes less steel and cement if the mean scenarios are compared. Comparing the remaining indicators results in advantages for the LPG mean scenario in comparison to the mean kerosene scenario. But this result is reversed if an optimised use of kerosene is compared with the worst case LPG scenario.

A **preliminary comparison** of cooking with LPG and kerosene results in clear advantages to cooking with LPG if the most likely mean scenario is assumed. But this result depends significantly on the uncertain values estimated for the efficiency and emissions from the used cookstoves. A more reliable of the emissions and energy efficiency resulting from the cookstove is required. Similarly a further investigation of raw materials used in the life cycle of the two fuels might suing the overall results.

9.2.4 Comparison of the Costs

Figure 9.6 shows the individual costs connected with the cooking scenarios. The costs for stove and cylinder are depreciated over a 10 years period with an interest rate of 4%. The costs depend mainly on the efficiency of the used cookstove. Cooking with kerosene bought on ration cards through the PDS is the cheapest possibility for the consumers. It is less than half the price of the two alternatives. For the mean scenarios cooking with LPG and kerosene bought on the free market the costs are virtually identical. Using the more efficient cookstoves makes LPG cheaper. Cooking with the least efficient kerosene cookstoves makes this possibility the most expensive one.

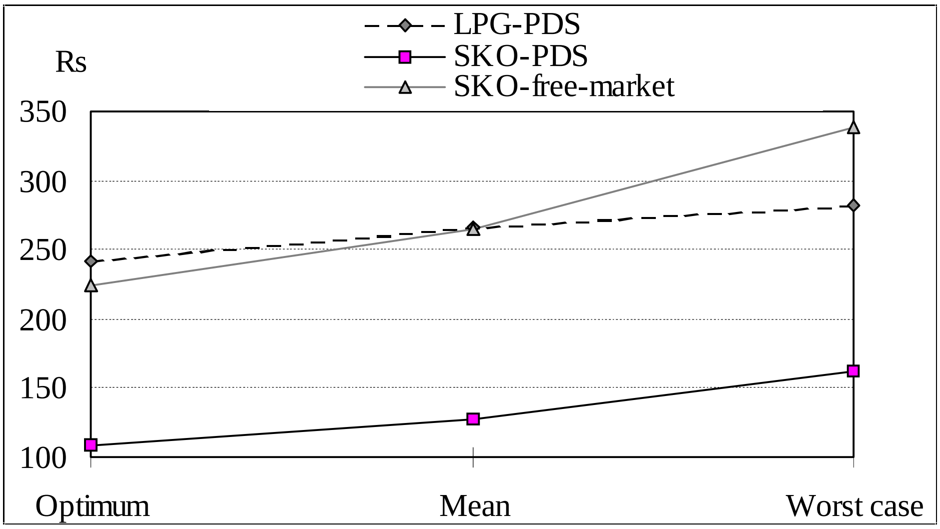

Figure 9.6: Costs for stove and fuel in the different cooking scenarios with an output of 1,000 MJ of useful heat

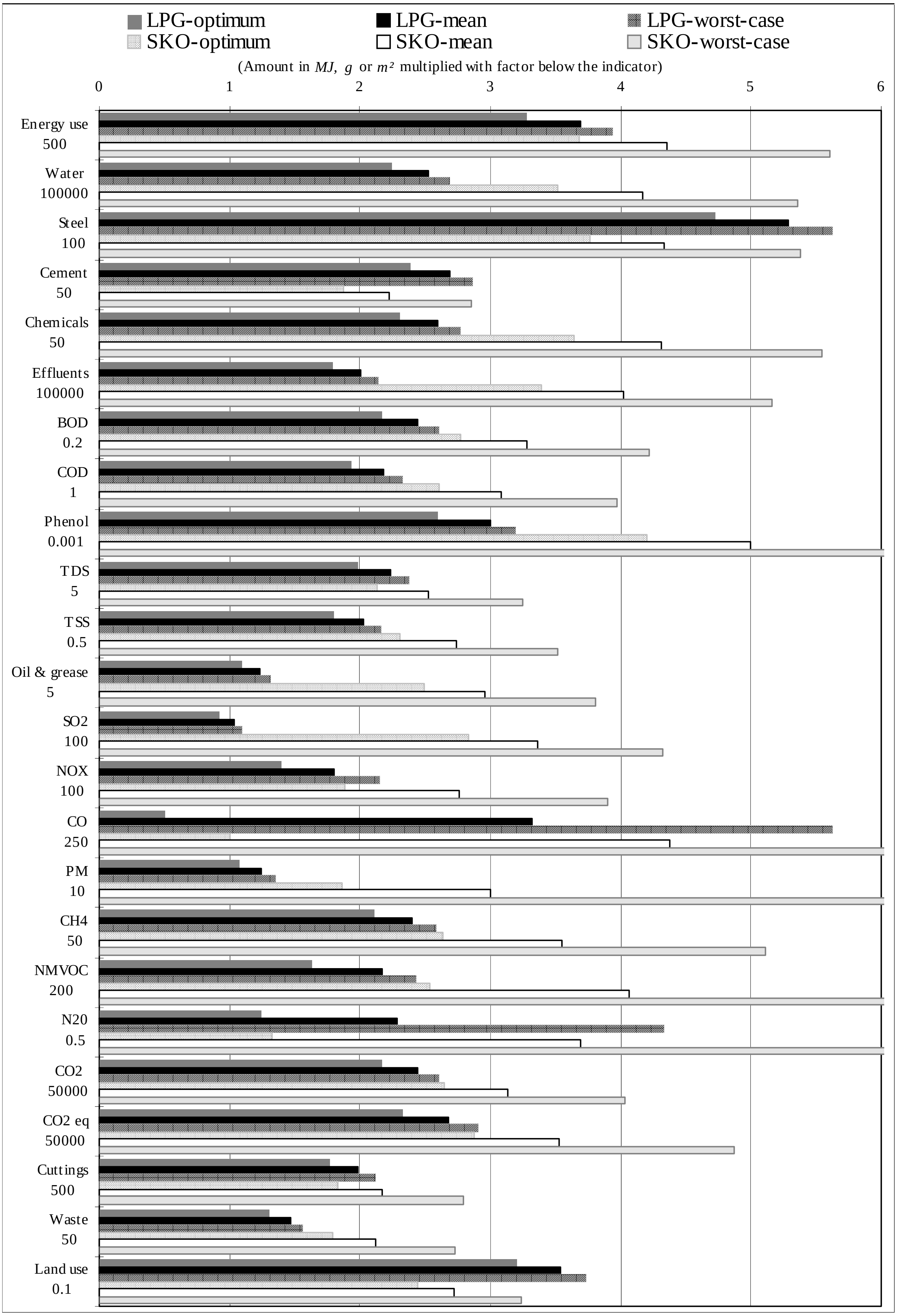

Figure 9.7: Comparison of the environmental impacts of the six cooking scenarios

9.2.5 Horizontal Analysis for Qualitative Indicators

Qualitative indicators can not be aggregated over the life cycle. It is only possible to point out the main aspects for both fuels. The social and the economic impacts are of the same form of order because the production stages are either identical or very similar. The main aspects can be described and compared as follows:

- *Flora and fauna {F-2}:* Potentially impacts can occur in all stages of the life cycle. The main impacts are caused however by the exploitation of the petroleum resources, a result of the large areas of land and sea involved. The discharge of residuals during the production also makes an impact.
- *Noise {F-3}:* It is emitted during all stages of the upper life cycle (this includes all stages except for cooking). The main effects on the public appear to occur with the transportation by trucks through they have the biggest influence on populated areas. There are higher emissions of noise when cooking with kerosene.
- *Temperature {F-4}:* Main impacts are caused by flaring and discharge of cooling water.
- *Health risks {G-1}:* All stages of the life cycle provide potential health risks for employees with the regular duties at the work place and with accidents. The public are affected with the emission of air and water pollutants. But cooking is the most important stage because considerable emissions take place near to the possible acceptor. The health risk depends on the ventilation of the kitchen. Cooking with kerosene is eventually connected with higher risks due to the higher emissions of the cookstove. Another important step is the transport because of the high rate of accidents and the direct contribution to emissions in living areas.
- *Gender specific shares {G-2}:* The main aspect for this point is the cooking. But both types of cooking share the same characteristics in this respect.
- *Time budget {G-3}:* Cooking is the critical stage. Using LPG takes less time to cook due to the better performance and the fuel supply to the household’s door.
- *Product use {G-4}:* Cooking with LPG is connected with several advantages in comparison to cooking with kerosene. The LPG distribution seems to be easier than that of the liquid fuel, because it is stored in cylinders. Kerosene requires several refills before it can be used. A disadvantage of the transport cylinders is their heavy weight, this disadvantage falls on the employees of the distributor. The use of cylinders also involves additional transport with the return of the bottles to the plant.
- *Cultural plurality {G-5}:* Both types of cooking are incompatible with some traditional ways of preparing a meal, but there do not seem to be specific differences between them.
- *Accidents {G-6}:* Accidents can happen during all stages of the life cycle. Transport seems to be the most hazardous step. Accidents during exploitation, for example blowouts, are connected with hazards for the environment and economic losses. For both types of cooking, accidents are possible. A main problem for cooking with LPG are leaks in the installation that may lead to a gas explosion. Kerosene can be spilled during cooking and thus catch fire. This may lead to injuries of the cook. To point out the more hazardous variant is impossible.

- *Costs {H-1}:* Individual costs are compared in chapter 9.2.4. Both types of cooking are connected with high costs for the Indian society due to the necessity of imports and the subsidy system.
- *Subsidies {H-2}:* Both types of fuel are subsidised. But for many Indian people the access to the subsidised fuels is limited due to several constrictions. The amount of kerosene purchasable on a ration card is not sufficient to meet the average demand of a family. Poor people can not afford the initial investment costs involved. And for the poorest the access is further restricted, if they cannot provide proof of legal residence. Access to subsidised LPG is exceptionally difficult. It is only delivered to larger cities. The investment costs are even higher, and the waiting time for an LPG connection is very long. Rich people can shorten the time by connections or corruption. The subsidy of LPG is greater than that of kerosene.
- *International co-operation and dependence {H-3}:* The indigenous petroleum production does not meet the Indian demand. Thus imports are necessary. This relies to international co-operation and dependence. The dependence will increase in the future due to the opening of the Indian market to foreign investors. Kerosene is imported in a higher amount than LPG.
- *Market concentration {H-4}:* The Indian market was until recently state controlled. This leads to a high market concentration with only a few companies. These companies do not compete on the market. This will change in the future due to opening of the market for private enterprises. This opening might be more difficult in the case of LPG because of the higher initial efforts necessary to start an independent distribution system.
- *Couple products {H-5}:* Natural gas and crude oil are couple products during the exploitation. A variation of the ratio is possible only in small boundaries. The production in refineries and fractionating plants is a mix of several couple products. Kerosene stands in concurrence to the more important HSD, thus the amount produced is influenced by the demand for this fuel. A rising demand could lead to a shortage of HSD. LPG does not have such an important couple product.

It is difficult to evaluate and outweigh the different types of qualitative indicators. Table 9.6 shows a subjective evaluation of the positive and negative effects for both fuels. It points out the indicators connected with an advantage for one of the two types of cooking. Indicators not shown in this table are assumed to have nearly the same positive and negative effects. As described before, many impacts are nearly on the same level. Thus the results of the table shall not be misinterpreted as a clear preference for LPG.

Table 9.6: Main advantages in the comparison of qualitative indicators for the two fuels

Advantage of cooking with kerosene	*Advantage of cooking with LPG*
Lower subsidies	Lower health risks
Lower market concentration	Less noise
	Better time budget
	Easier product use
	No concurrence couple products

9.2.6 Comparison of the Results with other LCI data for Cooking

The environmental impacts of cooking in India (mean scenarios for LPG and kerosene), in Germany and in an undefined (*international*) country are compared in Figure 9.8. The calculations for Germany and the international scenario were described in chapter 9.2. Table 9.5 gives the full data. The German and international results are not totally comparable with the results for India because the authors might have made different assumptions in the goal definition, e.g. for cut-off criteria. TEMIS 2.1 gives data for the energy use and the emissions of air pollutants due to the production of steel and other materials. These data are included in the scenario for Germany. The figures show the results with regard to energy use, materials, wastes and emissions of air pollutants. They are standardised with the factor given beneath each indicator to comprehend the results in one figure. All indicators except energy and land use are expressed in grams (EM 1995; TEMIS 2.1).

The energy consumption for the cooking with fossil fuels and with biogas is on the same level. The database EM gives a higher figure for the cooking with kerosene than calculated in the scenario for India. The reason is a low efficiency estimate of the cookstove. Cooking with electricity consumes much more energy because of the non-efficient steps of energy conversation. The energy consumption for cooking with wood in traditional and improved cookstoves is also relatively high because of their low efficiency.

The use of steel and cement in the scenarios calculated for Germany is much greater. But the reason is probably a different estimation of the necessary consumption. Besides, the discharged wastes seem to be higher, but the indicator waste is not directly comparable. For the German data it contains a considerable amount of residuals produced due to the treatment of flue gases in combustion devices.

The comparison regarding the air pollutants gives a heterogeneous picture. The emission of SO_2 is calculated by EM with a higher value than for India. The other international cooking possibilities are also linked with relatively high SO_2 emissions. A possible reason might be different estimates for the sulphur content of the fuels. The emissions of NO_X are given in a higher amount by EM than calculated for India. A comparison between India and Germany indicates relatively high values for cooking with electricity in Germany.

Carbon monoxide is emitted in a high amount by the Indian cookstoves in comparison to the other cookstoves. Only the emissions of wood cookstoves are of a comparable figure. The reason for the high values in India is the high estimation for the cookstove emissions. Particulates are emitted about 10 times more by cooking with wood than with the other possibilities. The emissions in India and Germany are on a comparable level. Cooking with electricity is connected with two times more emissions of PM than cooking with fossil fuels.

The emission of methane is calculated by TEMIS 2.1 and EM with a higher amount than in the Indian scenario. NMVOC are emitted in a high amount in India. Not all the emissions considered for this result are included in the data of EM and TEMIS 2.1. Missing for example is an estimation for distribution losses and for flaring. N_2O is emitted in relatively high amounts by the two wood cookstoves. Cooking with electricity is also responsible for higher emissions than cooking with fossil fuels.

The highest emissions of CO_2 are linked with the use of electricity for cooking. Cooking with biogas and wood results in relatively low emissions because the fuels are renewable. The direct emissions from burning these fuels are not considered for this indicator. A comparison of the comprehended emissions of greenhouse gases shows the highest value for electric cooking in Germany. Fossil fuels belong to the next group. Cooking with biomass is linked with the lowest emissions of CO_2 eq.

The land use figure is relatively high for cooking with biogas. But the assumption made by EM seems to be too high. The land use for forest is not considered because the wood is assumed to be a residual. The land use of the Indian possibilities is high in comparison to the values for Germany. But these scenarios include more distribution steps with a high specific land use.

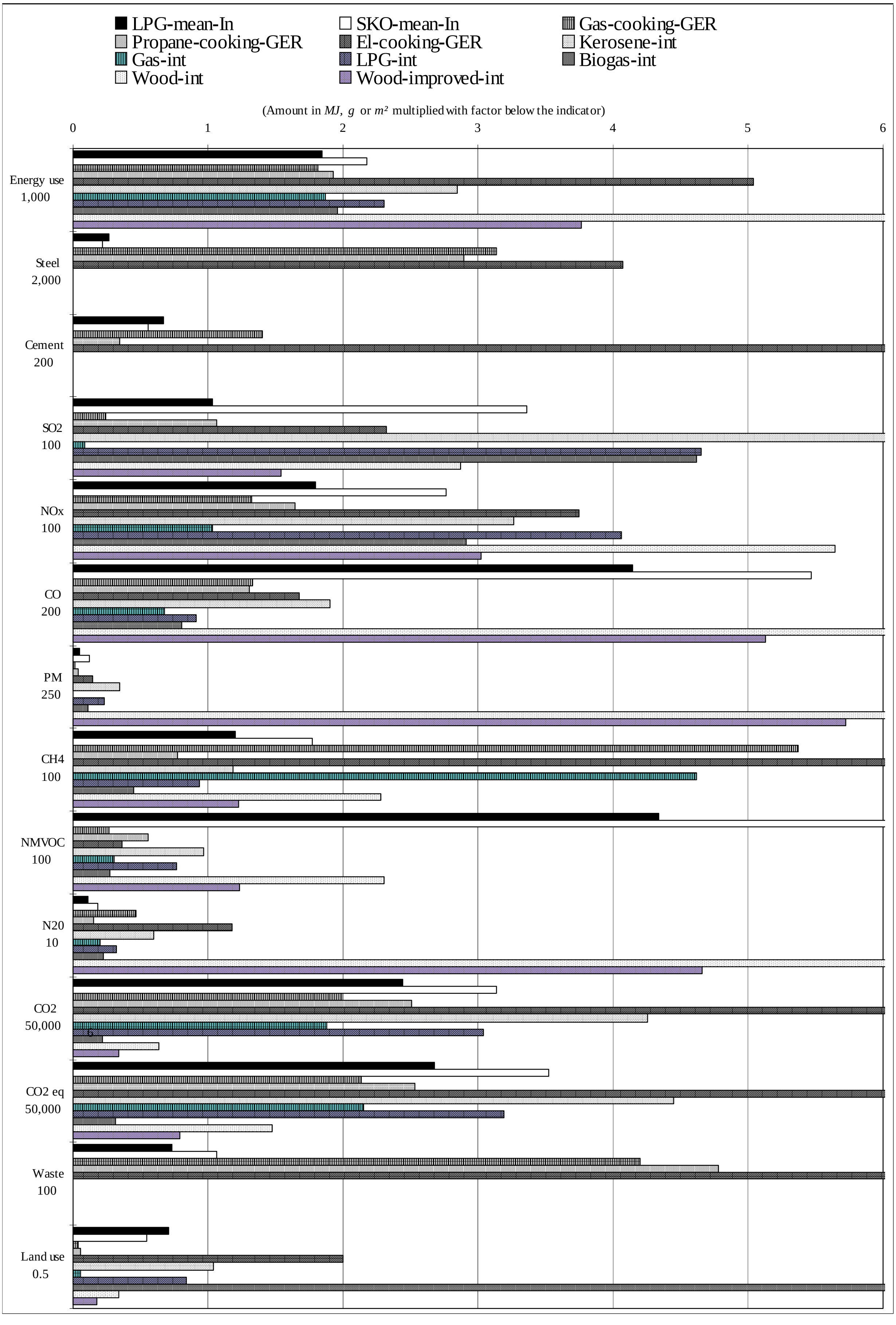

Figure 9.8: Comparison of environmental impacts for different cooking scenarios

For many indicators cooking in India is linked with higher emissions than the possibilities of cooking with gas in Germany. This has several reasons. First the degree of transports involved in the Indian scenario. And the less environmentally friendly ways energy is consumed in the upstream and downstream sectors. The LCI for India also includes some emissions that are not included in the data for Germany. These are for example the flaring and the losses during distribution. But cooking with gas or kerosene in India is more environmentally friendly than the common cooking with electricity used by the majority of households in Germany.

The comparison of different studies demonstrates the high variations existing for different LCA. The values calculated with EM do not seem to be reliable in all points. It is also stated in the program that the data quality is preliminary.

9.3 Total Environmental Burden of Cooking with LPG and Kerosene in India

The total environmental burden caused by cooking with LPG and kerosene in Indian households is shown in Table 9.7. The impacts were calculated with the mean cooking scenarios and the data for the availability of kerosene and LPG in 1992/93. It is assumed that the available fuels are consumed wholly for cooking. The environmental impacts are not restricted to India. Some of the impacts (due to imports) occur in foreign countries.

Table 9.7: Total environmental burden of cooking with LPG and kerosene in India

Indicator	Unit	Matrix field	Kerosene total use in India	LPG total use in India	Sum
Primary energy	(TJ)	A-1..4	490,376	157,141	647,518
Water	(MT)	B.1	93.8	21.4	115.2
Steel	(t)	B.2	97,538	45,011	142,549
Cement	(t)	B.3	24,993	11,424	36,416
Chemicals	(t)	B.4	48,497	11,058	59,555
Effluents	(MT)	C.1	90.4	17.1	107.5
BOD	(t)	C.2	148	42	189
COD	(t)	C.3	695	186	880
Phenol	(t)	C.4	1.1	0.3	1.4
TDS	(t)	C.5	2,839	951	3,789
TSS	(t)	C.6	308	86	394
Oil & grease	(t)	C.7	3,328	524	3,852
SO_2	(t)	D.1	75,630	8,775	84,405
NO_X	(t)	D.2	62,186	15,300	77,486
CO	(t)	D.3	245,890	70,607	316,497
PM	(t)	D.4	6,744	1,058	7,802
CH_4	(t)	D.5	39,955	10,233	50,188
NMVOC	(t)	D.5	182,937	36,900	219,837
N_20	(t)	D.5	416	97	513
CO_2	(MT)	D.5	35.3	10.4	45.7
CO_2 eq	(MT)	D.5	39.7	11.4	51.1
Cuttings	(t)	E.1	244,083	84,683	328,766
Waste	(t)	E.2	23,915	6,245	30,160
Land use	(km^2)	F.1	61	30	91

Table 9.7 shows that kerosene is responsible for the main share of impacts due to cooking with fossil fuels because the amount of used kerosene is higher. Cooking in India is connected with the use of 36 thousand tonnes cement per year. Effluents are discharged of an amount of 108

million tonnes per year and the sulphur dioxide emissions as a result of cooking with fossil fuels are calculated to be about 84 thousand tonnes.

Table 9.8 compares the emission of greenhouse gases emitted by the cooking with the total emissions in India. The compared figures were not calculated for the same balance room. The figures for cooking with fossil fuels include emissions of greenhouse gases outside India (import of fuels). The total emissions shown above are calculated for India. Thus the values for cooking do not stand for a share on the total emissions. But the values can be compared to classify the environmental burden caused by the cooking with LPG and kerosene.

The emissions of carbon dioxide due to cooking are as high as 3.8% of the total emissions. The comparison for other gases shows 0.9%, 0.32% and 0.64% for CO, methane and N_2O respectively. The share of LPG and kerosene of the total energy consumption in India amounts to 3%. Thus the found values are reliable considering that other energy carriers are also burnt in the life cycle (Chapter 1.2; TEDDY 1994).

Table 9.8: Comparison of greenhouse gas emissions due to cooking with total emissions in India (TEDDY 1994)

	Unit	*Cooking with fossil fuels*	*Total emissions in India*	*Comparison of cooking with the total emissions*
CO	t	316,497	35,200,000	**0.90%**
CH_4	t	50,188	15,700,000	**0.32%**
N_20	t	513	80,000	**0.64%**
CO_2	MT	46	1,191	**3.84%**

9.4 Uncertainties of the Results

The results are determined considerably by the LCI for the cooking which is based only on a few studies, with results varying over wide range. Thus this seems to be the feature in the LCI with the least reliable results. Secondly there is considerable uncertainty regarding the resource extraction. The third main factor liable to uncertainties in the results is the inventory for necessary transport devices and distances. Changes in any of these aspects will influence the total results in an unpredictable manner.

The LCI for the other parts of the life cycle seem to be reasonably reliable. Further investigations here can be expected to lead only to small corrections in the results. The most reliable indicators in the overall horizontal analysis are energy use and emission of CO_2. The variation in the overall results appears to be high enough to lead to a shift in the overall evaluation. The comparison of LPG and kerosene shows at present based on this LCI an advantage for LPG. But the potential impacts of both possibilities are similar enough that new results in the LCI might alter this overall evaluation.

10 Outlook

Further new results may emerge after comparison with the study on biomass fuels which is not yet complete. These results might lead to new objectives for energy policy in India. But the opportunities for change are restricted. Rising the availability of kerosene or LPG is limited due to the missing foreign exchange for imports. Increasing the exploitation of indigenous resources is also difficult. Chances followed up by the policy are the extended usage of natural gas and the reduction of wasteful flaring.

The study in hand probably for the first time investigates parts of the Indian energy sector by means of a life cycle assessment. The data found is useful for further studies on the environmental impact of products. The data for refineries and transports is reliable. Further investigation surrounding the exploitation of petroleum resources would be useful. Another goal for future studies is the investigation of material production processes in India. This data should be included in future LCI.

The investigation of environmental impacts in a life cycle inventory in a developing country faces the same problems as the first LCI in Europe or the USA. The difficulties to gain a sufficient database are the most relevant problems. Comprehensive data for each sectors is not available. Data has to be compiled from information obtained on an individual basis from each company in the sector. Employees of the companies are very uncertain what information can be handed over for public consumption. The hierarchical structure in state controlled enterprises increased the problems by causing impediments in gaining information from the people concerned. Reliable measurements were available only for a limited number of indicators. Other pollutants seldom were subject to regulations and thus measurements do not exist.

Besides, it is questionable how far a life cycle assessment is a useful instrument for the product policy in a developing country. The India people often do not have the choice between different alternatives which are more or less environmentally friendly. Political decisions are influenced primarily by the availability of the different products in the country. The room for changes is very small. Most consumers do not consider the eco-friendliness of a product. For them the product use and the availability, with consideration of their income, are decisive. A look on environmental pollution is important in the immediate surrounding. In the case of cooking this means the direct emissions of the cookstove.

Political decisions of international organisations, for example the World Bank, might be influenced by studies on the environmental-friendliness of different options. These organisations often to a considerable extent determine the policy of a developing country. One problem while using the results of an LCA for their policy might be the overvaluation of global problems, e.g. greenhouse gas emissions, in comparison to local problems.

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