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Life cycle inventory for cooking

Some results for the use of liquefied petroleum gas and kerosene as cooking fuels in India

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The use of energy for cooking is one of the most important sectors for the energy consumption in India. Results of a life cycle inventory are presented for the use of kerosene and liquefied petroleum gas as cooking fuels. The situation in India was investigated through life cycle inventories for the following stages of the life cycle: Extraction of crude oil and natural gas, processing in refineries and fractionating plants, distribution, product transports (including energy imports) and cooking. Environmental impacts are summarized with final calculated ecological profiles for cooking with the two fuels in different cooking scenarios. These results are analysed regarding the origin of the environmental impacts in the life cycle. A direct comparison shows in the majority of the investigated indicators an ecological advantage in the use of liquefied petroleum gas over kerosene. In addition, a reflection on the economic conditions and the social consequences of both life cycles is made. © 1997 Elsevier Science Ltd.

Keywords: Cooking; Life cycle assessment; India

Introduction

The use of different fuels for cooking is one of the most important sectors for energy use in India: Cooking consumes about 35% to 45% of the total energy if all energy carriers are considered. In developed countries cooking consumes less than 10% of total national fuel consumption. Nevertheless, only 10% of the commercial energy that is electricity and fossil fuels is consumed in India's household sector. The main commercial energy carriers for residential use are Superior Kerosene Oil (SKO) and Liquefied Petroleum Gas (LPG). Together these two products have a 5.2% share of the energy consumed in households. The bulk of energy consumption in households consists of biomass (non-commercial) fuels such as firewood (59%), dung (20%) and agricultural residues (14%) normally collected by the users themselves (TERI, 1994a).

The use of commercial energy at 235 kgoe (kilograms of oil equivalent) yr^{-1} $capita^{-1}$ is low in comparison to developed countries with values of approximately 5000 kgoe yr^{-1} $capita^{-1}$. In the years from 1981/82 to 1991/92 the available commercial energy increased from 101 Mtoe (Million tons of oil equivalent) to 194 Mtoe. Main users of commercial energy are the industrial and the transport sectors. LPG consumption grew at an annual rate of over 16% and the one of kerosene by 6% between 1984/85 and 1991/92 (TERI, 1994a).

Existing research work concentrates on particular aspects of cooking, for example deforestation, efficiency of cookstoves, or health risks (TERI, 1994a; TERI, 1994b; Smith *et al.*, 1992; Dave, 1987). Nevertheless the discussion about advantages and disadvantages of different existing cooking possibilities can only be decided if the environmental effects of cooking fuels are regarded over the whole life-cycle of those fuels. The methodological technique adopted for the investigation is a life cycle assessment (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.

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- 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).

Essential parts of an LCA are goal definition, life cycle inventory (LCI), environmental impact assessment and evaluation of the results (Berg *et al.*, 1994; DIN, 1994).

For the survey the computer program TEMIS 2.0[1] (Total Emissions Model for Integrated Systems) was used as a tool to undertake the necessary calculations. Figure 1 shows all information that must be collected for each process in order to calculate the emissions and impacts of the process. To run the program, data on the fuels used and the processes involved is required. 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.

Comparison of liquefied petroleum gas and kerosene as cooking fuels

Goal definition

The goal definition is a basic requirement to clearly define the exact investigatory purpose of the LCA (DIN, 1994). The goal of this life cycle inventory (LCI) is to show the impacts of a cooking session in Dhanawas, a small village in a rural region near New Delhi. Its situation of energy use was investigated by TERI (TERI, 1994b). Therefore it is possible to compare the results with other fuels for cooking. Dhanawas is in the district of Gurgaon, 15 km from Gurgaon, in the state of Haryana. It is situated approximately 7 km from the neighbouring Faroukhnagar and about 45 km from Delhi. The investigation describes the situation in India in the year 1993/94. It was not possible to find all the information required for this year. Thus, sources from 1984 to April 1995 were used to maintain sufficient data.

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 effective for cooking and the theoretical energy delivered by the fuel. This leads to the definition of the functional unit as useful energy delivered by burning the fuel. The scenario for the survey is calculated on the basis of a requirement for effective energy of 1 GJ in Dhanawas. The value of 1 GJ resembles the annual requirement of one person.

Inventory

Life cycle of LPG and kerosene in India. 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 is also subject of the investigation (DIN, 1994). The investigated life cycles for the two fuels LPG and kerosene are shown in Figure 2.

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. The resources are transported by pipeline or with tankers to the processing facilities. The transport processes and connected aspects of the life cycle are investigated for the LCI. This involves the empty return trips and transport of packages, too.

The crude oil is processed in refineries. LPG and kerosene

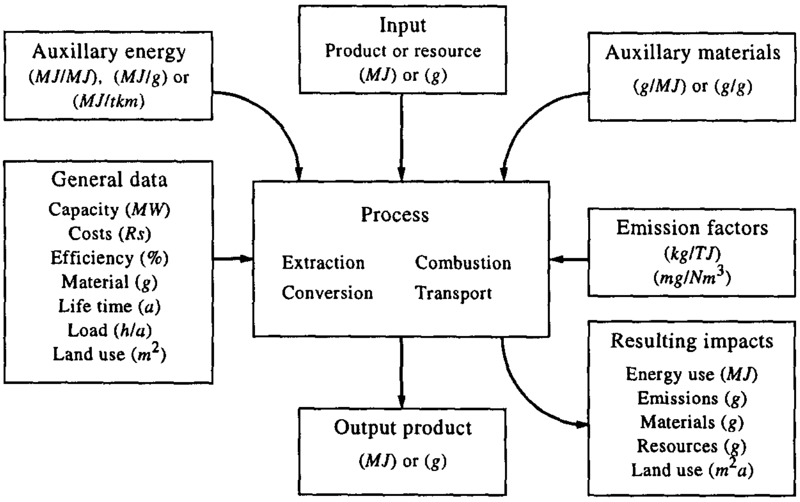

Figure 1 Structure of a process module in TEMIS 2.0. The necessary information data input and the results calculated by the program are shown. The obligatory unit is given in brackets (Nm^3= Norm cubic meter, standardized values for 1013 hPa and 273 K)

[1]The current version TEMIS 2.1 is available as public domain software via the Internet <ftp://cserv.usf.uni-kassel.de/pub/temis/

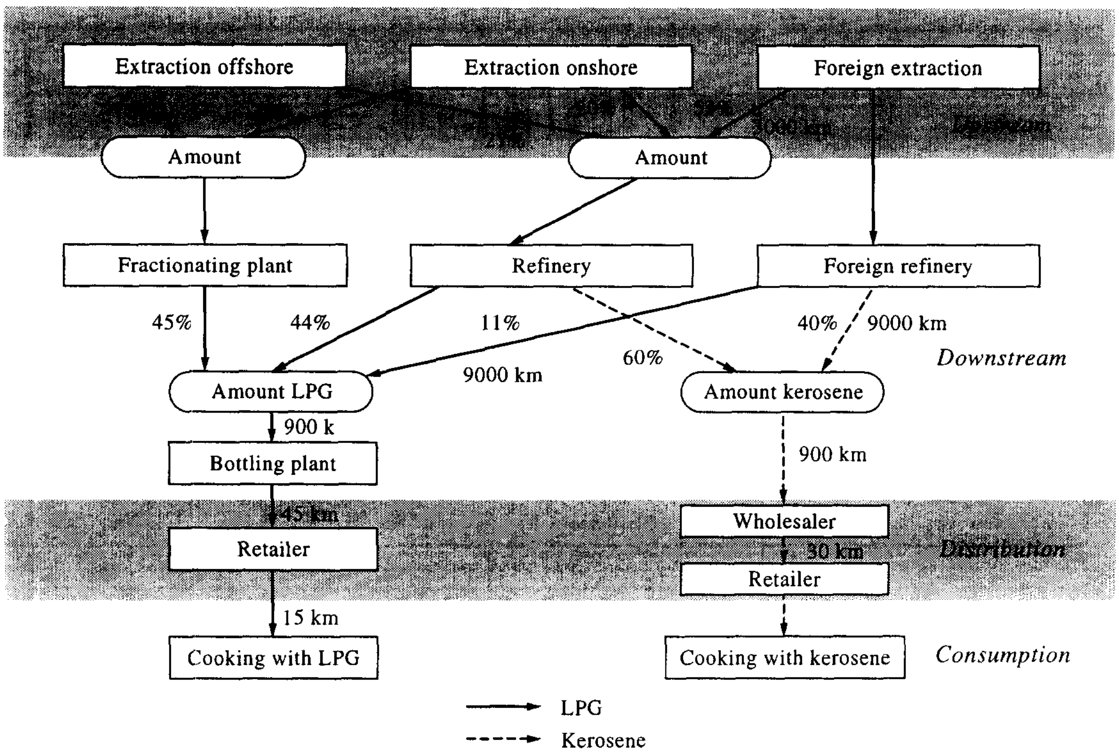

Figure 2 Stages in the life cycle for liquefied petroleum gas and kerosene in India. Percentage share of different production cycles and estimated transport distances

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.

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

Figure 2 points out the percentage share of foregoing stages in the life cycle. The cycle of kerosene is much more influenced by imports. This is because LPG is also produced from natural gas which is not imported to India. About 40% of kerosene is produced in foreign refineries whereas the value for LPG is only 11%.

Figure 2 shows also the estimated transport distances between the stages of the life cycle. 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 1400 km. LPG processed from offshore gas is transported over the same distance.

Investigated indicators and their meaning. Indicators are mainly quantifiable values for environmental pollution. The choice of indicators for this survey was influenced by existing regulations for emissions from production sites in India. To make general estimations, sufficient data is available only for pollutants that are subject of these regulations. 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. Materials are an input in the life cycle. Investigated materials are water, chemicals, steel and cement. The production of these materials was not investigated, thus the impacts are not included in the final results.

One indicator in the section of water pollution is the discharged effluent. 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. Toxic water pollutants are substances like phenol, oil and grease.

Air pollution mainly consists of flue gases emitted from combustion devices. Sulfur 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 into the atmosphere which may contain toxic chemicals and thus they are also hazardous to living organisms.

A group of gases contributing to the global warming is summarized under the category of greenhouse gases. Of those ones CO, CO_2, NO_X, methane, NMVOC (non-methane volatile organic compounds) and N_2O are taken into account. The indicator CO_2 equivalents (CO_2 eq) aggregates the climatic impacts of each greenhouse gas for a period of 100 years and compares it to CO_2.

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. 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 a 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.

Some aspects of inquiry 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 investigations in these areas should supplement the LCI.

Economic indicators are not surveyed in all LCA's. In the 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. 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.

Matrix for the life cycle inventory. Not all indicatorsdescribed 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 shown in Table 1. The different stages of the life-cycle are numbered with I to X.

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 step in the process. The fields in the second half of the matrix (except the costs and subsidies) describe qualitative impacts. 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. Each field is marked with a sign that indicates the nature of the investigation in the LCI.

Collection of data for cooking. The flow of energy and materials between the environment and the examined system is compiled for all stages of the life cycle. Preliminary calculations indicate that the efficiency and the emissions of the cookstoves determine the results of the scenarios considerably. All environmental impacts of the upper life cycle are lower if the efficiency is greater. The direct emissions from cookstoves are largely responsible for air pollutants. Own investigations of cookstove emissions and values found in the literature (Dave, 1987; Öko-Institut, 1995; Smith *et al.*, 1992; BPPT/KFA, 1992; TERI, 1987; Yamanaka *et al.*, 1978) show big differences. The LCI scenario for kerosene stoves considers in an average cooking session also the high emissions due to the preheating. To estimate the range of possible emissions from cooking with kerosene and LPG, three estimates are made. They are shown in Table 2. The worst case considers the upper range of emissions and a low efficiency given in literature. The mean process stands for a possible, 'normal' average, and the optimum process shows values for an optimized cookstove.

Results of the horizontal analysis

The values for the indicators are calculated or compiled for all stages of the life cycle to give the following horizontal analysis for an assumed scenario. Interesting aspects of these results are analysed and interpreted. Possible effects on the environment due to the calculated emissions are described in a following step. The results are evaluated in a final step, then.

Environmental profile for the supply of cooking energy. The environmental impacts due to the cooking and the supply of the fuels are calculated with the data investigated in the vertical analysis. The environmental profile for the six cooking scenarios with LPG and kerosene in Dhanawas is shown in Table 3. The table shows the calculated values for all quantifiable indicators in a scenario for the supply of 1 GJ useful energy for cooking. This includes the impacts of all stages of the life cycle as shown in Figure 2. The found data can be compared as follows: Cooking with LPG is better than with kerosene with regard to water use, chemicals, effluents, SO_2, PM, CH_4, NMVOC, CO_2, wastes, and all water pollutants except TDS even if the worst-case scenario of LPG is compared with optimum use of kerosene.

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

Table 1 Matrix of life stages and investigated indicators for the LCI of fossil cooking fuels

I	II	III	IV	V	VI	VII	VIII	IX	X	Indicator	
♦	♦	♦	—	—	—	♦	♦	♦	♦	Liquid fuels	Energy use
♦	♦	♦	♦	—	—	♦	—	—	—	Gaseous fuels	
—	—	♦	—	—	—	—	—	♦	—	Solid fuels	
—	?	♦	—	♦	—	—	—	♦	—	Electricity	
♦	♦	♦	♦	?	?	♦	?	?	♦	Human power	
♦	♦	♦	?	♦	—	?	—	—	—	Water	Materials
—	♦	♦	♦	♦	♦	♦	♦	♦	♦	Steel	
♦	—	♦	♦	♦	♦	—	—	?	?	Cement	
♦	♦	?	—	—	—	—	—	—	—	Chemicals	
♦	♦	♦	♦	♦	—	?	?	—	—	Effluents	Water pollution
♦	♦	♦	?	?	—	?	?	?	?	BOD	
♦	♦	♦	?	?	—	?	?	?	?	COD	
—	—	♦	?	?	—	—	?	—	—	Phenol	
♦	♦	?	?	?	—	—	—	—	—	TDS	
♦	♦	♦	?	?	—	—	—	—	—	TSS	
♦	♦	♦	?	—	?	—	♦	?	?	Oil and grease	
♦	♦	♦	♦	—	—	♦	♦	♦	♦	SO_2	Air pollution
♦	♦	♦	○	—	—	♦	○	○	♦	NO_X	
♦	♦	♦	○	—	—	♦	○	○	♦	CO	
♦	♦	♦	○	—	—	♦	○	○	♦	PM	
♦	♦	○	○	♦	♦	♦	○	○	♦	Greenhouse gases	
♦	—	—	—	—	—	—	—	—	—	Cuttings	Waste
♦	♦	♦	?	—	—	—	♦	—	—	Waste (others)	
?	♦	♦	♦	♦	♦	♦	♦	♦	♦	Land use	Other impacts
?	♦	♦	?	—	—	—	○	?	?	Flora and fauna	
♦	♦	?	?	—	—	♦	—	○	○	Noise	
♦	♦	?	—	—	—	—	—	—	—	Temperature	
♦	♦	?	?	?	♦	♦	?	?	♦	Health risks	Society
—	—	—	—	—	—	♦	—	—	—	Gender specific shares	
—	—	—	—	—	?	♦	—	—	—	Time budget	
—	—	—	—	—	♦	♦	—	—	—	Product use	
—	—	—	—	—	—	♦	—	—	—	Cultural plurality	
♦	♦	?	?	?	—	♦	♦	?	♦	Accidents	
?	♦	♦	?	?	?	♦	?	?	?	Costs	Economy
—	—	♦	♦	—	♦	♦	?	?	?	Subsidies	
♦	♦	♦	♦	♦	—	—	♦	—	—	International co-operation, dependence	
♦	♦	♦	♦	♦	♦	♦	—	—	♦	Market concentration	
—	♦	♦	♦	—	—	—	—	—	—	Couple products	

Upstream (resource extraction): I=exploration; II=exploitation.
Downstream (production): III=refinery; IV=gas processing plant; V=bottling plant.
Distribution: VI=wholesaler, retailer.
Consumption: VII=cooking.
Transport: VIII=sea; IX=rail; 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.

cement if the mean scenarios are compared. Thus, including the production of steel and cement in the LCI will lead to a higher rise in the values for some indicators of the LPG cycle. Comparing the remaining indicators like energy use, CO, N_2O, CO_2 eq and cuttings results in advantages for the LPG mean scenario in comparison to the mean kerosene scenario.

Share of cooking in the environmental profile. One interesting aspect is the share of direct impacts during cooking compared to the total impacts over the whole life cycle of LPG and kerosene. The share of LPG and kerosene in the total energy consumption for the mean cooking scenarios amounts to 85.4% and 85.8%, respectively. Thus, about 15% of the energy carriers used are burnt prior to cooking.

Figure 3 shows the share of cooking in the total impacts during the life cycle. About 40% of NO_X and 90% of CO are emitted during cooking. Particulate matter 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 scenarios, produces about half of its total emissions at this stage. The emission of SO_2 is affected only by the sulfur content of the fuel. Thus, there are no differences for the different scenarios of cooking with one fuel.

Table 2 Estimates for kerosene (SKO) and LPG cookstoves in the LCI

	Unit	LPG-optimum	LPG-mean	LPG-worst-case	SKO-optimum	SKO-mean	SKO-worst-case
eta (efficiency)	%	72	64	60	64	54	42
Capacity	kW	2.3	2.3	2.3	1.50	1.50	1.50
NO_X	mg/Nm^3	100	150	200	150	250	300
PM	mg/Nm^3	0.0	0.5	1	15	30	400
CO	mg/Nm^3	250	1800	2900	500	2000	8000
Methane	mg/Nm^3	0	3	5	0	40	80
NMVOC	mg/Nm^3	50	200	250	100	500	900
N_2O	mg/Nm^3	1	2	4	1	3	7

Estimations based on measurements by: Dave (1987), Öko-Institut (1995), Smith *et al.* (1992), BPPT/KFA (1992), TERI (1987), Yamanaka *et al.* (1978) and own surveys.

Table 3 Environmental profile and cost data for the supply of 1 GJ useful energy by LPG and kerosene cookstoves in Dhanawas

	Unit	LPG-optimum	LPG-mean	LPG-worst-case	SKO-optimum	SKO-mean	SKO-worst-case
Energy use							
Energy use	(MJ)	1641	1847	1970	1839	2179	2802
Materials							
Water	(l)	224	252	269	352	417	536
Steel	(g)	473	529	562	377	434	538
Cement	(g)	119	134	143	94	111	143
Chemicals	(g)	115	130	139	182	216	277
Water pollution							
Effluents	(l)	178	201	214	339	402	517
BOD	(g)	0.43	0.49	0.52	0.55	0.66	0.84
COD	(g)	1.9	2.2	2.3	2.6	3.1	4.0
TDS	(g)	9.9	11	12	11	13	16
TSS	(g)	0.90	1.01	1.08	1.15	1.37	1.76
Oil and grease	(g)	5.5	6.2	6.6	12	15	19
Phenol	(mg)	2.6	3.0	3.2	4.2	5.0	6.4
Air pollution							
CO_2	(kg)	108	122	130	132	157	202
CO_2 eq	(kg)	116	134	145	144	176	244
SO_2	(g)	92	103	110	284	336	432
NO_X	(g)	140	180	216	188	276	390
CO	(g)	126	830	1406	250	1093	5501
PM	(g)	11	12	14	19	30	291
CH_4	(g)	106	120	129	132	178	256
NMVOC	(g)	326	434	486	507	813	1318
N_20	(g)	0.62	1.14	2.17	0.66	1.85	5.11
Waste							
Cuttings	(g)	885	995	1061	915	1085	1395
Waste	(g)	65	73	78	90	106	137
Ashes	(g)	396	445	475	156	185	238
Land use	(m^2)	0.32	0.35	0.37	0.24	0.27	0.32
Costs (subsidized)	(Rs)	242	267	282	108	127	162
Costs (not subsidized)	(Rs)	—	—	—	224	264	338

To assess the overall health impacts of the life cycle 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 connected with higher risks due to the higher emissions of the cookstove.

Emissions of methane are significant in the upper part of the life cycle. Only 20–30% 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 CO_2 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 (eg water pollutants) the relevant emissions are prior to delivery to the household (and therefore the cooking stage).

Supply of the fuels to the household. The supply of 1 kg of LPG and SKO to the household, including all stages of the life cycles except cooking, was compared for the investigation. The energy input to produce these two fuels equals about 18% of their energy content. The production and supply of 1 kg fuel is linked with an emission of 740 g CO_2 equivalents. The supply of LPG to the consumer is more environmentally sound than that of kerosene for the majority of investigated indicators. Effluents and water pollutants are emitted about 10–60% more for the supply of kerosene than for a comparable amount of LPG. The environmental impacts of material production were not investigated for

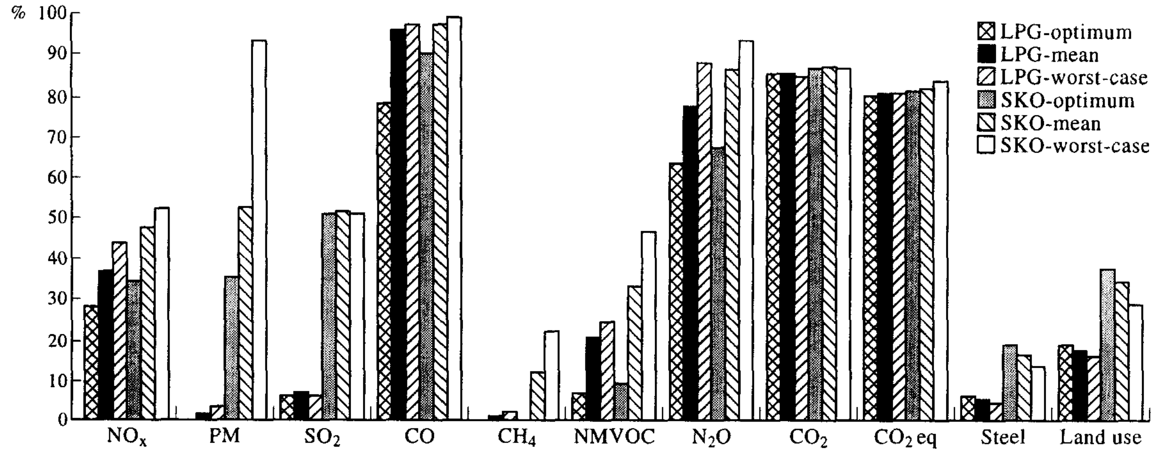

Figure 3 Share of the cookstove emissions in terms of flue gas emissions, steel and land use among the total impacts during the life cycle for the six cooking scenarios (Values of LPG are related to the environmental profile of LPG, values of SKO are related to the environmental profile of SKO)

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 the study.

Stages of the life cycle prior to cooking. To analyse the found data further on three sections of the direct life cycle for LPG and kerosene are investigated separately excluding the step of cooking. The upstream sector includes the exploitation of the resources crude oil and natural gas. The second section consists of 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. Table 4 shows the percentage share of these sectors for the total impacts in the life cycle prior to cooking.

About 50% of the energy is used in the downstream sector. In comparison the energy use for LPG in the downstream sector has a lower proportion than that one for kerosene because of the less energy consuming gas processing plants. In the LPG scenario steel 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 (over 70%). The other sectors also have a share for this indicator due to the burden of the used fuels.

Table 4 Percentage share of investigated impacts in different stages of the life cycle prior to cooking (%)

	Upstream		Downstream		Transport	
	SKO	LPG	SKO	LPG	SKO	LPG
Energy use	28.7	32.6	55.4	53.6	15.9	13.8
Water	12.2	23.7	84.4	72.7	3.4	3.6
Steel	17.5	12.8	37.6	61.8	44.9	25.5
Cement	49.2	38.6	19.9	30.5	31.0	30.9
Chemicals	72.0	76.4	25.3	20.7	2.7	2.9
Effluents	3.2	5.2	93.8	91.0	3.0	3.9
BOD	48.1	62.1	49.0	35.0	2.9	2.9
COD	31.8	48.1	65.8	49.2	2.4	2.6
TDS	87.8	89.7	9.1	8.0	3.1	2.2
TSS	58.5	69.5	38.4	27.8	3.1	2.6
Oil and grease	21.5	62.6	34.1	33.8	44.4	3.6
Phenol	0.0	0.0	100.0	88.9	0.0	11.1
CO_2	37.6	37.3	36.8	43.2	25.5	19.5
CO_2 eq	34.5	35.4	36.9	48.1	28.5	16.5
SO_2	12.4	18.7	41.3	54.3	46.4	27.0
NO_X	29.8	31.7	20.3	21.5	49.9	46.8
CO	26.8	24.9	22.0	22.1	51.2	53.0
PM	19.0	17.6	31.7	39.3	49.3	43.2
CH_4	65.6	64.5	30.4	32.0	4.0	3.5
NMVOC	4.5	4.9	45.1	90.5	50.4	4.6
N_2O	38.0	32.6	33.2	37.7	28.7	29.7
Cuttings	67.2	52.8	17.1	34.0	15.7	13.2
Waste	68.8	75.7	28.3	20.7	2.8	3.6
Land use	5.3	1.9	61.7	43.5	32.9	54.7

Water is mainly used as cooling water in refineries. Thus, effluent is also discharged mainly from the downstream sector (90%). Nevertheless, the share for water pollutants is nearly the same for the downstream and upstream sector except TDS as it was not investigated for the refineries. Oil and grease are emitted in large amounts by tankers and through the discharge of the cuttings into the sea. Waste and cuttings have a high share in the first part of the life cycle (over 50%).

The analysis regarding air pollutants shows a heterogeneous picture. Sulfur dioxide is emitted in a great extent due to imports by tankers because they use fuel oil with high sulfur content. This amounts to a share of 50% for the transport sector in the kerosene scenario. Refineries are also a significant source. The transport devices cause a great share of the NO_X, CO and particle emissions (over 50%). 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. Trucks and light commercial vehicles are the main single source of NO_X and CO. The transports have a share of about 30% for emissions of air pollutants.

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 mass of particles is due to the 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 the distance journeyed.

Fuels used in the life cycle. To produce 1 GJ of useful energy for cooking, between 1.64 GJ and 2.80 GJ of primary energy is used depending on the cooking scenario. The following results are valid for the mean cooking scenarios with LPG and kerosene, respectively. 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% over the whole life cycle. About 2.16 GJ are produced by burning the fuel in the kerosene cooking scenario, respectively 1.83 GJ for LPG. This is 99% of the total energy use which includes also unburned losses of energy carriers. The most important auxiliary energy carrier in the life cycle is natural gas (flaring) with a use of 104 MJ and 115 MJ for LPG and kerosene, respectively. 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.

Fuel oil, diesel oil, fuel gas, hardcoal and coke are other energy carriers used for producing the fuels. Fuel oil (transports and auxiliary energy) 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 total amount of other fuels burnt is 267 MJ and 306 MJ respectively for the LPG and kerosene production.

Costs for cooking. The costs for cooking with LPG and kerosene depend mainly on the efficiency of the used cookstove. They are shown in Table 3. Kerosene can be bought at a so called fair price shop at a subsidized price or on the free market. At the time of investigation LPG was sold mainly at subsidized price. Price data from free marketing was not available. Cooking with subsidized kerosene bought on ration cards 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 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.

Qualitative indicators. Different qualitative indicators were compared for the use of the two cooking fuels LPG and kerosene. 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. Table 5 shows a subjective evaluation of the main positive and negative effects for both fuels. It points out the indicators connected with an advantage for one of the two types of cooking. The results of the table shall not be misinterpreted as a clear preference for LPG because these differences are only small.

Total impacts of cooking in India. The total impacts of cooking with fossil fuels are calculated with the data for the availability of kerosene and LPG in 1992/93. For this scenario it is assumed that this amount is consumed wholly for cooking even if a part is used for other purposes like lighting. The environmental impacts are not restricted to India. Some of the impacts (due to imports) occur in foreign countries.

The values can be compared to classify the environmental burden caused by cooking with LPG and kerosene. The emissions of CO_2 due to cooking with LPG and kerosene amount to 3.8% of the total emissions. The comparison for other gases shows 1%, 0.4% and 0.7% for CO, methane and N_2O, respectively. The share of LPG and kerosene of the total energy consumption in India amounts to 3% (TERI, 1994a).

Conclusions

The life cycle inventory for cooking with fossil fuels probably investigates for the first time parts of the Indian energy sector in this manner. The environmental burdens are summarized 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

Table 5 Main differences between the two fuels in the direct comparison of qualitative indicators

Advantage for cooking with kerosene

Subsidies

Both types of fuel are subsidized. But for many Indian people the access to the subsidized 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 cannot 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 subsidized 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.

Market concentration

The Indian market was until recently state controlled. This led 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 enterprizes. The opening might be more difficult in the case of LPG because of the higher initial efforts necessary to start an independent distribution system.

Advantage for cooking with LPG

Health risks

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. Cooking with kerosene is connected with higher risks for the cook and her family 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.

Noise

Noise is emitted during all stages of the life cycle. The main effects on the public appear to occur with the transportation by trucks as they have the biggest influence on populated areas. There are higher emissions of noise when cooking with kerosene.

Time budget

Cooking is the critical stage for a look on the time budget. Using LPG takes less time to cook due to the better performance and the fuel supply to the household's door.

Product use

Cooking with LPG is connected with an easier product use 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.

Couple products

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 competition to the more important diesel oil, thus the amount produced is influenced by the demand for this fuel in India. A rising demand could lead to a shortage of diesel oil. LPG does not have such an important couple product.

the economic conditions and the social consequences during the life cycle. The comparison of LPG and kerosene as cooking fuels leads to some interesting results:

The investigation of the fuel supply to the households, this includes all stages of the life cycle except cooking, shows an environmental advantage of LPG for most of the investigated indicators. 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 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 environmental advantage of LPG is more obvious if cooking as the last stage of the life cycle is included in the environmental profile. Cooking with gas has a significantly higher efficiency and causes fewer emissions of air pollutants.

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 (eg NO_X, SO_2, CH_4, NMVOC and particulate matter) are emitted in high share before the consumption of the fuels. The results show that it is necessary to consider the emissions of all stages during the life cycle for an evaluation of the environmental impacts of kerosene and LPG.

The comparison of qualitative indicators shows some advantages for LPG. These are, for example, the easier product use and the lower health risks. Therefore, LPG is strongly preferred by those consumers that have access to this fuel. Kerosene is less subsidized today. The price of cooking depends on the efficiency of the used cookstoves. Cooking with subsidized kerosene is the cheapest possibility. Using LPG or non-subsidized kerosene is linked with similar costs.

Cooking with LPG and kerosene emitted as much as 3.8% of the total carbon dioxide emissions in India if the investagation considers the whole life cycle. 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. This is due to the low overall efficiency in the electricity life cycle.

A liberalization of the Indian energy market will lead to a better availability of kerosene and LPG on a higher cost level. Changes followed up by the policy are the extended usage of natural gas and the reduction of wasteful flaring.

The found data is useful as a base for other studies in the energy sector of India[2]. The data for transports and refineries is reliable. More investigation would be useful for the petroleum extraction, the transport distances and the material production. Another goal for future studies is the investigation of material production processes in India. This data should be included in future LCI. An LCI study on cooking with biomass fuels is under work at the Technical University Berlin.

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[2]The detailed LCI and the data will soon be available in a dataset for the computer program Environmental Manual <http://www.usf.uni-kassel.de/service/em/emhome.htm.

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