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Life-Cycle-Assessment for Stoves and Ovens

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Abstract

This report analyzes and compares cooking alternatives by means of a Life-Cycle-Assessment (LCA) for the situation in Switzerland. For this purpose, data are collected to assess the use of electricity, natural gas, liquefied petroleum gas, wood ,and kerosene. Information about the cooking possibilities is partly adopted from a prior investigation of cooking alternatives in India (Jungbluth 1995). Data for the necessary upstream processes are taken from the inventory of Frischknecht et al. (1996). The database ECOINVENT is used for the inventory computation. The assessment pursues two goals:

- Elaborating an inventory for cooking that can be used in coming LCA studies
- Comparison of various cooking options.

Useful heat delivered by the cooking alternatives is chosen as the functional unit for the comparison. Besides, LCA data are given for a certain energy input to the distinguished stoves and ovens. As a consequence it is possible to calculate the environmental impacts of cooking related to the amount of energy used. A first evaluation using the method of Eco-indicator 95+, supplemented by an additional investigation of some environmental impact categories (radioactive releases, space use, waste heat and ecotoxicity), shows a small environmental advantage for cooking with natural gas in Switzerland in comparison to an electric stove (Swiss electricity mix). But, due to data and methodological uncertainties the environmental performance of the two possibilities is assessed here to be the same. Wood is an interesting ecological alternative, especially if the stove is combined with room heating. If natural gas is not available, the use of liquefied gas is not preferable to electricity regarding the environmental impacts. A comparison of gas use in Switzerland with electric cooking in Germany shows, that the latter option has considerably higher impacts because the electricity production is mainly based on fossil fuels. Cooking with kerosene or wood on a simple open fire exhibits relatively high environmental impacts. It has also be shown, that the environmental impacts depend considerably on the efficiency of the stove used and on the energy consumed due to the users' behavior. The inventory data shown in annex 6.5 may be used in further LCAs, e.g., when comparing the preparation of meals.

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Preface

The project „*Energy, Greenhouse Gases and Way of Living*„ (Project No. 5001-044667/1) is part of the research work for the integrated project „*Social Transformation Processes for a Sustainable Switzerland*„ (IP Society I). This project is financed by the Swiss National Science Foundation as a part of the *Priority Programme Environment (SPPU)* . This programme aims to bring together scientific knowledge from different disciplines to find new ways and strategies for a sustainable development. The research projects of the 2nd phase started in 1996 and will run until the end of 1999. The IP Society aims to investigate the nourishing sector as an integrated coupled social-natural system. Research parties, coming from different disciplines, will investigate the structure of the necessity field, the coupling between the socio-economic and the ecological system and the alternatives for a sustainable development within this field. An overview of the nine projects involved in the IP is presented in Tab. 1.

Tab. 1 Overview of the Projects of the Integrated Project Society I

TP	Title	Scientific Background	Principal Investigators and Institutions
1	Ecological economies between self-organization and external steering	Economics	Dr. Jürg Minsch/IWÖ-HSG, University St. Gallen
2	rganizational and inter-organizational learning towards sustainability	Political Science and Economics	Prof. Dr. Matthias Finger/ IDHEAP, Lausanne
3	Education and public relations for a sustainable Switzerland in the area of nourishing	Education/Journalism	Dr. Regula Kyburz-Graber, ETH und Uni Zürich
4	Mediation for a sustainable use of cultivated land	Communication and Advisory Sciences	Michel Roux/Landwirtsch. Beratungszentrale Lindau
5	Strategies and instruments for the promotion of ecological innovations in a regional context.	Geography	Prof. Dr. Paul Messerli/GIUB, Universität Bern
6	From ecological niches to ecological mass markets	Business management	Prof. Dr. Thomas Dyllick/ IWÖ-HSG, Univ. St. Gallen
7	Inhibiting and supporting factors of the conversion of ecological social representations into food and consumption behavior	Psychology	Prof. Dr. Mario von Cranach/ Institut für Psychologie, Universität Bern
8	Energy, greenhouse gases and way of living	Environmental Sciences, Natural and Social Science Interface	Prof. Dr. Roland Scholz/ UNS, ETH Zürich
9	Environmental Prioritizing. From Indicators for environmental impacts towards environmental indices	Environmental Sciences, Natural and Social Science Interface	Prof. Dr. Ruedi Müller-Wenk/ IWÖ-HSG, UNS, ETH Zürich

Our research work aims to investigate and analyze the environmental impacts linked with household consumption patterns in the necessity field of nourishing. It will consider the different types of life-styles represented in Swiss households. In parallel, at the chair of Environmental Sciences, Natural and Social Science Interface (UNS) different projects are dealing with methodological development of the tool Life-Cycle-Assessment[1].

This working paper presents an Life-Cycle-Assessment for Stoves and Ovens used in Swiss Households. The results can be used in assessments investigating the environmental impacts of nourishing. Thanks are due to Mr. Nipkow (Arbeitsgemeinschaft Energie-Alternativen, Zürich), Mr. Hasler (TIBA-Heizsysteme, Bubendorf, CH), Mr. Joos (Ruhrgas AG, Dorsten), Mr. Baumgartner and Mr. Crescini from SVGW (Schweizerischer Verein des Gas- und Wasserfachs) for assistance in my investigations. The critical evaluation and advice in preparing the manuscript provided by Rolf Frischknecht, Stefanie Hellweg, Patrick Hofstetter and Olaf Tietje is gratefully acknowledged.

[1] An overview about recent and running projects can be found on http://www.uns.umnw.ethz.ch.

Ausführliche Deutsche Zusammenfassung

In diesem Bericht wird ein ökologischer Vergleich verschiedener Kochmöglichkeiten durchgeführt. Für die in der Schweiz am gebräuchlichsten Varianten, Kochen mit Gas (Erdgas und Flüssiggas), Elektrizität[2] (Herd und Mikrowelle) und Holz, werden die für eine Ökobilanz notwendigen Daten zusammengestellt. Zusätzlich wird eine Grobabschätzung für die Varianten Kochen mit Petroleum und Kochen auf einem offenen Holzfeuer vorgenommen. Teilweise werden die ökologischen Folgen der Kochmöglichkeiten mit Daten aus einer vorhergehenden Untersuchung in Indien abgeschätzt (Jungbluth 1995).

Daten aus der Untersuchung von Frischknecht et al. (1996) zur Bereitstellung verschiedener Brennstoffe bzw. von Elektrizität werden mit den Daten einer Sachbilanz für die verschiedenen Kochmöglichkeiten verknüpft. Zum Emissionsverhalten verschiedener Verbrennungskocher gibt es bisher nur wenige veröffentlichte Werte, die teilweise stark schwanken. Untersucht wurden vor allem die Emissionen von NO_x und CO. Andere Schadstoffe wurden nur in Einzelfällen gemessen. Zur Zeit laufen zwei weitere Untersuchungen in Indien und China zu diesem Thema.

Die Ökobilanz wird mit zwei Zielen erstellt. Zum einen soll eine Datengrundlage für den Einbezug des Kochens in Ökobilanzen von Nahrungsmitteln geschaffen werden. Ausserdem sollen die zur Verfügung stehenden Kochmöglichkeiten, soweit möglich, unter ökologischen Gesichtspunkten verglichen werden. Als funktionelle Einheit für den Vergleich wird die durch den Kocher zur Verfügung gestellte nutzbare Wärme, ausgedrückt in TJ (Tera Joule), gewählt. Dieser Wert gibt an, welcher Anteil der zum Kochen verwendeten Energie in einem standardisierten Kochvorgang zur Erwärmung von Wasser in einem auf den Herd gestellten Kochtopf effektiv genutzt werden kann.

Die Effizienz des Herdes, also das Verhältnis zwischen der Nutzwärme und dem theoretischen Energiegehalt des Energieträgers hängt in der Realität nicht nur von den Kochereigenschaften ab. Während der praktischen Anwendung hat auch das Nutzungsverhalten einen deutlichen Einfluss auf Effizienz und Emissionsverhalten. Einflussparameter sind z.B. die Wahl der richtigen Topfgrösse, die richtige Positionierung des Kochtopfs und geschicktes Einstellen der Leistungsregelung.

In Fig. 1 werden die Abschnitte des Lebenszyklus anhand des Beispieles Kochen im Haushalt mit Flüssiggas aus Stahlflaschen gezeigt, für die in der vorliegenden Untersuchung eine Sachbilanz erstellt wird. Untersucht wird der eigentliche Kochvorgang mit der nötigen Infrastruktur (Herd) und die im ECOINVENT bisher fehlenden Schritte des Handels mit Kochbrennstoffen. Alle vorgelagerten Prozessschritte wurden bereits von Frischknecht et al. (1996) bilanziert. Die hiermit verbundenen Umweltfolgen fliessen in die Berechnung mit ein.

Die Resultate der Sachbilanz werden mit der Methode des Eco-indicator 95+[3] für verschiedene Kategorien von Umweltschäden[4] zusammengefasst. Da diese Methode einige Umweltbelastungen nicht abbildet, die im untersuchten Zusammenhang allerdings relevant sein können, werden zusätzlich Flächeninanspruchnahme, Emission radioaktiver Stoffe, Abwärme (als Mass für den Verbrauch nicht erneuerbarer energetischer Ressourcen) und Ökotoxizität verglichen.

[2] Diese Variante wurde zusätzlich für die Situation in Deutschland untersucht, um den Einfluss unterschiedlicher Systeme der Elektrizitätzerzeugung für den Vergleich zu untersuchen.

[3] Eine Erklärung dieser Methode wird im Annex 6.2 und 6.1 gegeben.

[4] Folgende Wirkungskategorien werden für den Eco-indicator 95 zusammengefasst: Schwermetalle, Wintersmog, Versaeuerung, Krebserregende Substanzen, Treibhauseffekt (100 Jahre), Überdüngung, Ozonabbau, Photosmog unter Einbezug von NO_x. Die ursprüngliche Methode wurde für diesen Bericht in einigen Punkten ergänzt und wird aufgrund dieser Veränderungen als Eco-inidcator 95+ bezeichnet (vgl. Annex 6.2).

Der Vergleich zeigt zunächst den Unterschied der beiden Kochmöglichkeiten mit Elektrizität. Die Stromerzeugung in der Schweiz basiert vor allem auf Kernenergie und Wasserkraft. Dementsprechend werden Umweltfolgen vor allem in den Kategorien Radioaktivität und Flächeninanspruchnahme verursacht. In Deutschland spielen dagegen fossile Energieträger für die Stromerzeugung eine weitaus wichtigere Rolle, die z.B. zu relativ hohen Auswirkungen für den Treibhauseffekt führen. Die Option „Elektrisch Kochen in Deutschland“ ist in dieser Untersuchung diejenige mit den deutlich höchsten Umweltbelastungspotential für die untersuchten Umweltfolgen.

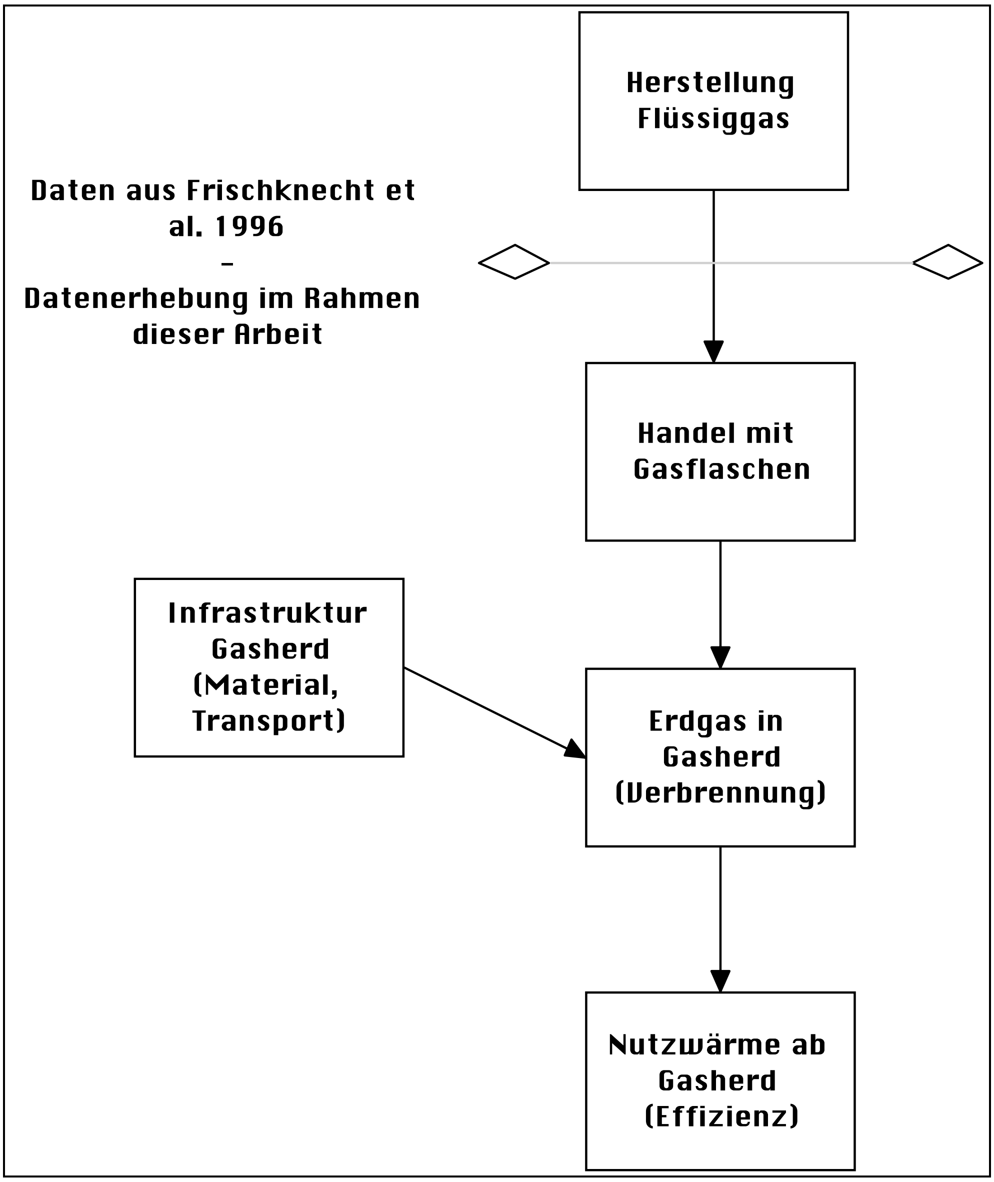

Fig. 1 Für die Betrachtung eines Flüssiggaskochers in dieser Arbeit untersuchte Abschnitte des Lebenszyklus

Ein Vergleich des Kochens mit Gas und Elektrizität in der Schweiz zeigt leichte Vorteile für den Gebrauch von Erdgas in einigen der betrachteten Umweltkategorien. Die Methode Eco-indicator 95+ alleine zeigt eine ungefähr gleich hohe Belastung für beide Optionen. Aber aufgrund der methodischen Unsicherheiten (Bewertung von Landnutzung, Radioaktiven Emissionen und Innenraumbelastung) sowie der grossen Varianz für die Effizienz von genutzten Herden zeigt sich hier keine der beiden Alternativen als die eindeutig bessere. Auf die Festlegung einer Reihenfolge wird deshalb verzichtet.

Kochen mit Holz stellt sich dann als ökologisch durchaus interessante Alternative dar, wenn der Holzherd in Kombination mit einer Heizung verwendet wird und somit die Energie optimal aus-genutzt werden kann. Die Verwendung von Flüssiggas ist ökologisch gesehen schlechter als die Verwendung von Elektrizität. Für Gebiete, in denen kein Erdgas zur Verfügung steht, ist der Elektroherd die ökologisch bessere Alternative.

Bei einer Bewertung der Umwelteinflüsse durch das Kochen mit Gas und Holz muss berücksichtigt werden, dass hierbei Emissionen in unmittelbarer Nähe von Menschen stattfinden. Diese sollten eigentlich bei der Betrachtung der toxikologischen Effekte höher bewertet werden als diejenigen Emissionen aus Industrieanlagen, da die Ersteren sicherlich eine hohe Immissionsbelastung zur Folge haben. Auch durch das Kochen mit Elektrizität können sich evtl. unmittelbare Gesundheitsgefahren durch die Belastung mit Magnetfeldern (Induktionsherde oder Mikrowelle) ergeben, die allerdings in diesem Bericht nicht detailliert untersucht werden.

Die Ergebnisse der Sachbilanz aus dieser Untersuchung können als Grundlage für weitere Untersuchungen dienen. Mit den eingegebenen Daten ist es möglich, eine Berechnung durchzuführen, wenn die benötigte Wärmemenge[5] zum Kochen oder die Menge der beim Kochen verbrauchten Energie[6] bekannt ist.

[5] Die Module „Nutzwaerme ab ...“ liefern hierzu die nötigen Daten. Die Eingabe erfolgt in der Einheit TJ.
[6] Diese Berechnung kann mit den Modulen „*Energieträger* in *Energieträger*-Herd“ erfolgen. Vgl. hierzu Tab. 20. Die evtl. benötigten Umrechnungsfaktoren sind in Tab. 7 aufgeführt.

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Abbreviations

CH	Schweiz / Switzerland
D	Deutschland / Germany
DIN	Deutsche Industrie Norm
ECOINVENT	Data base for the computation of the inventory
EI	Eco-indicator 95+
eta	Efficiency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life-Cycle-Assessment
LCI	Life-Cycle-Inventory-Analysis
LPG	Liquefied Petroleum Gas
NMVOC	Non-Methane-Volatile-Organic-Compounds
PAH	Poly Aromatic Hydrocarbons
PE	Polyethylene
PET	Polyethyleneterephtalat
PM	Particulate matter
SVGW	Schweizerischer Verein des Gas- und Wasserfachs
UNS	Umweltnatur- und Umweltsozialwissenschaften
TJ	Tera (10^{12}) Joule

Dictionary

Some of the Tables and Figures in this report are labeled with German expressions because the computer program used, gives the output with these labels. Tab. 2 gives the translation for the frequently used terms.

Tab. 2 Dictionary German - English

German	English
3 Steinefeuer	3-stone fire
Abwaerme	waste heat
Bedarf erneuerbarer energetischer Resourcen	use of renewable energetic / energy resources
Elektroherd	electric stove
Erdgas	natural gas
Flaecheninanspruchnahme	space use
Fluessiggasherd	LPG stove
Gasherd	gas stove
Geruch	malodorous air
Holzherd	wood stove
Humantoxizität (Wasser, Luft, Boden)	human toxicity (water, air, soil)
Kerosin	kerosene
Krebserregende Substanzen	cancerogenic substances
Mikrowelle	micro wave
Nutzwaerme	useful heat
Ökotoxizität (Wasser, Boden)	ecotoxicity (aquatic, terrestrial)
Ozonabbau	ozone depletion
Petroleumkocher	kerosene stove
Photosmog	photochemical oxidant forming, summer smog
Radioaktivität	radioactivity
Resourcenabbau	resource depletion
Schwermetalle	heavy metals
Strom	electricity
Stueckholz	wood
Treibhauseffekt	greenhouse effect
Überdüngung	nutrification
Versäuerung	acidification
Wintersmog	winter smog

1 Goal and Scope Definition

1.1 Introduction

This survey is part of the work in the research project „Energy, Greenhouse Gases and Way of Living“. The project aims to investigate and analyze the environmental impacts linked with household consumption patterns. The main focus is laid on nourishment and activities linked with this necessity field. For calculating the environmental impacts linked to the consumption of different types of foodstuff, information about the preparation of the meals has to be considered. Cooking is part of this preparation. Until now, not much is known about the environmental impacts and cooking was not investigated in an life-cycle-assessment (LCA) for the situation in an industrialized country to our knowledge. This study was started to fill this gap.

Nowadays, cooking with electricity becomes increasingly important in Switzerland. The availability and use of gas and wood stoves are decreasing. Due to an increasing number of private household (+ 6.8% between 1990 and1995) the total energy used for cooking is still increasing even if the specific consumption decreases with more efficient appliances and lower intensity of use (EVED 1996). Tab. 3 shows the share of different types of energy used for cooking in 1990. Electric appliances had a share of 78.6% in the energy use of all stoves used.

Tab. 3 Energy use for cooking in Switzerland in 1990 (Prognos 1994)

	Energy use in 1990 (PJ)	Percentage share in 1990	Percentage share only stoves
Electric stove	5.14	57.1	78.6
Dish washing appliances	1.20	13.3	-
ther electric appliances	1.26	14.1	-
Gas stoves	0.93	10.3	14.2
Wood stoves	0.47	5.3	7.2
Total	**9.00**	**100**	**100**

1.2 Goals

The study was started with two goals:

1. Elaboration of a database for the inclusion of LCI data for cooking in other coming LCA studies of food and nourishing. These studies are planned to be made for various types of food products and will consider the preparation stage.
2. Ecological comparison of various types of cooking appliances using different types of energy in Switzerland.

1.3 Functional Unit

The functional unit to fulfill the first objective is defined as **energy throughput to the stove**, measured in TJ (Tera Joule) for the different energy carriers. Thus, it is possible to calculate the environmental impacts of cooking if the amount of energy necessary for a preparation is known.

The question for a functional unit for the second goal is not a simple one. The users' sight is „How much energy do I need to prepare a certain meal or to heat up a certain amount of water?". But until now there is no standardized measurement for a comparison of the energy use due to the use of various cook stoves. The functional unit should be **useful heat** expressed in TJ as a value that gives the amount of heat energy efficient for the cooking process. This value should consider the efficiency differences between various types of cookstoves. Further details can be found in chapters 2.2.2. and 2.2.3. The only difference between the outcome for the two functional units is the inclusion of the efficiency. Thus the results for energy throughput to the stove divided through the efficiency gives the result for useful heat.

1.4 Investigated Alternatives

The aim of the study is to show the environmental impacts of cooking alternatives as they exist in Switzerland today. Most of the inventory data are from 1996. The following commonly used alternatives for the preparation of meals are investigated in this study:

- Gas stove and oven using natural gas or liquefied gas
- Electric range and oven
- Microwave oven
- Wood stove

To see the impact of an electricity production structured in a different way, cooking with electricity is also investigated for the situation in Germany. Further on data for cooking with kerosene and wood mainly based on prior investigations are elaborated for:

- Kerosene stove
- 3-stone-fire (Cooking on an open wood fire)

2 Inventory Analysis

Most of the data for the upstream processes, necessary for the supply of energy or fuels for cooking where available for the situation in Switzerland from the „Ökoinventare von Energiesystemen“ (Frischknecht et al. 1996). Some information is based on a diploma thesis, investigating various cooking alternatives in India (Jungbluth 1995). New information for the situation in Switzerland, where available, is included in the inventory.

The computation of the data is done with ECOINVENT. It was developed within the work for the „Ökoinventare von Energiesystemen“ (Frischknecht et al. 1996). ECOINVENT is a relational database. The computation is executed on a UNIX-computer using the tool MATLAB. The linkage between the various processes investigated in the LCA is executed as shown in Tab. 4. The table can be read as follows. For the production of 1 kg product from process 1 about 0.2 TJ from process 2 are necessary. This is linked with a direct release of 0.5 kg of the impact 1 (e.g. an air emission). The output table is computed by an inversion of the input matrix. It is structured similarly and contains the cumulated figures for all processes involved.

Tab. 4 Structure of the input data for ECOINVENT

		Process 1	Process 2
	Unit	kg	TJ
Process 1	kg	0	0.1
Process 2	TJ	0.2	0.01
Impact 1	kg	0.5	2

Fig. 2 shows the advance for the investigation for the example „Cooking with Liquefied Petroleum Gas“. All upstream processes, e.g. extraction of crude oil and production in the refinery are already included in the ECOINVENT-database. The background data of this life-cycle-inventory-analysis are considered during the calculation. The investigation of foreground data starts with the distribution of the types of energy used for cooking. Next stage in the life cycle is the combustion in the stove termed here as „Fluessiggas in Fluessiggasherd“. An input for this process is the infrastructure necessary, namely the stove that has to be produced and brought to the user. The last module investigated is „Nutzwaerme ab Gasherd“. This stage is necessary to consider the efficiency of the stove used.

The following chapters show the inventory data in units which are useful for understanding[7]. All data of the LCI elaborated in this chapter are included in Tab. 21 in annex 6.4.2. This table gives the data in units used for the calculation. An overview about new modules implemented in ECOINVENT is given in Annex 6.4.1. The results of the life-cycle-inventory-analysis for all environmental impacts investigated are given in Annex 6.5, Tab. 24.

[7] The transport distance is given for example in km and not in tkm/TJ because the latter figure does not give much practical insight.

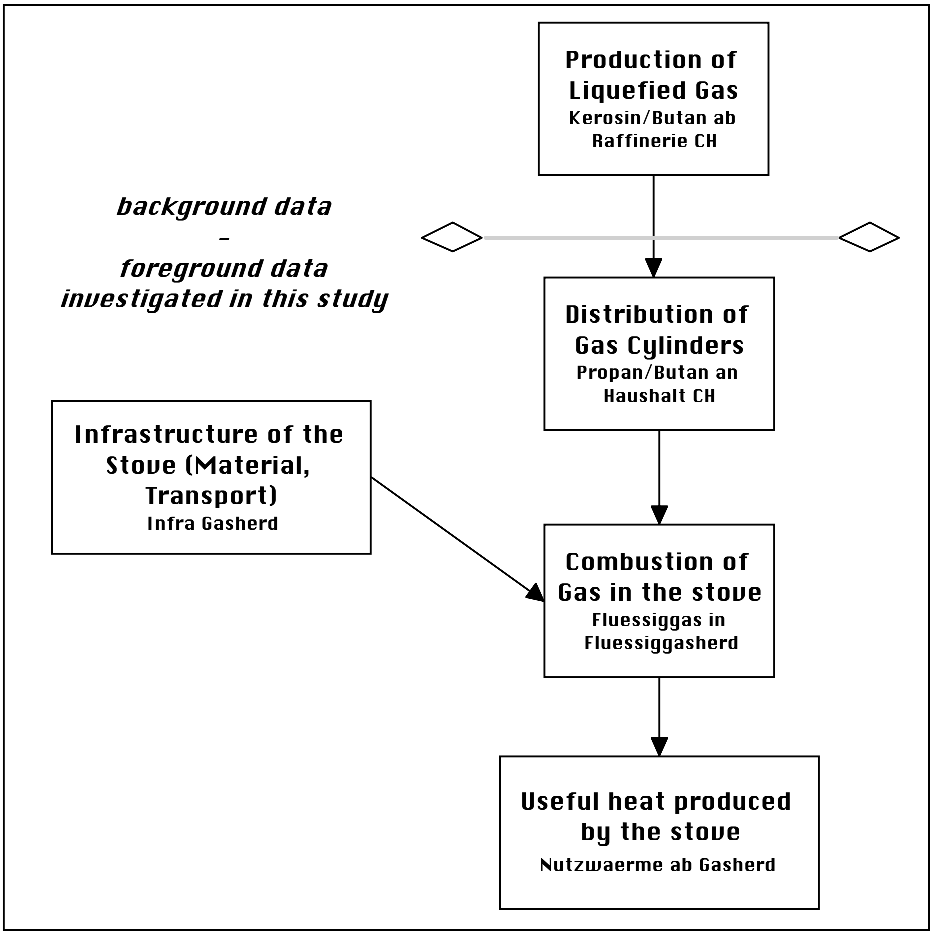

Fig. 2 Life-cycle investigated for cooking with liquefied gas in the inventory and module names used in ECOINVENT

2.1 Distribution of Cooking Fuels

2.1.1 Overview

The distribution of liquefied gas is investigated from the refinery to the delivery to the consumer. This includes the filling of gas cylinders, the distribution and the transport. Emissions due to leakage are also considered.

The distribution of kerosene is investigated from the point of regional storage to the consumer. For this study a distribution in 1 liter plastic bottles is assumed. The data are based on a rough assumption and not on a specific inventory. A previous investigation has shown the relatively low impacts of the distribution. Parts of this study are quoted in the following section (Jungbluth 1995).

It was not necessary to investigate the distribution of electricity, natural gas and wood because adequate data are already included in the database ECOINVENT.

2.1.2 Life Cycle Inventory for the Distribution

Normally gas cookstoves can use natural gas delivered by pipeline in Switzerland. Town gas is not anymore in use in Switzerland. In areas not connected to the gas grid, the use of butane or propane stored in cylinders (LPG - Liquefied Petroleum Gas) is another alternative for cooking with gas.

The distribution of LPG consists of the following stages. They are combined in one module for the further calculations:

1. Transport from the refinery to the bottling plant
2. Bottling of LPG
3. Transport to the dealer
4. Storage at the dealer and sale
5. Return of empty bottles to the bottling plant

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

1. Storage tanks for bulk LPG and filling facilities
2. LPG cylinder storage and filling facilities
3. Process units
4. Utilities and effluent disposal

The operations for the LPG bottling are as follows:

1. Receipt of LPG cylinders and of LPG delivered in bulk
2. Storage of the bulk LPG in tanks
3. Cleaning and inspection of the cylinders
4. Filling of LPG cylinders
5. Handling & storage of LPG cylinders
6. Auxiliary operations

Energy is needed to run gas compressors and auxiliary equipment. During all stages of the LPG life-cycle, gas is emitted when connections or disconnections are made between pipes, stores, cylinders, etc. From production or import to the delivery into the household the actual total loss amounts to 0.3% (in India). The total emission of butane and propane due to this loss is taken into account in the bottling stage. The use of steel for cylinders is included in the material data of the bottling plant (Jungbluth 1995).

Tab. 5 shows the life-cylce-inventory for the distribution of kerosene and LPG. Most figures are used from the study of Jungbluth (1995). Emissions of NMVOC are not considered in the case of kerosene because this fuel is not refilled during the distribution and thus losses seem to be of lower importance. The weight of the PE (Polyethylene) bottle is roughly estimated to be 50 g for 1 liter bottle. The transport from the point of storage to the dealer is estimated to be 100 km. LPG cylinders are estimated to have a steel weight of 16.5 kg with an LPG filling of 14.2 kg. The life span is estimated to be 10 years with 10 fillings a year. It is assumed that the steel is recycled after use and thus no environmental impacts are considered for the treatment of the waste material. The land use considers the use by the necessary installations.

Tab. 5 Life-Cycle-Inventory-Analysis for the distribution of LPG and kerosene in Switzerland

ECOINVENT Module	English	Unit	Propan/ Butan an Haushalt CH	Kerosin an Haushalt CH
			TJ	TJ
Flaeche II-III	land use	m2a	5	1
Strom Niederspannung - Bezug in CH	electricity	TJ	0.00201	-
Abwaerme in Luft p	waste heat	TJ	0.00201	
Kerosin ab Regionallager CH	kerosene from storage point	t	-	23.3
Propan/ Butan ab Raffinerie CH	LPG from storage point	t	22.2	-
Transport LKW 28 t	truck transport	tkm	6'810	2450
PET 0% Rec.		kg	-	1190
Stahl unlegiert	steel	kg	257	
				4
Zement	cement	kg	22	11
PE in KVA	waste treatment	kg		1190
NMVOC p		kg	66.5	-

2.2 Cooking

2.2.1 Overview

Many different stoves using different technologies are available. For this survey these different types are not distinguished. An overview about the various types of stoves using gas or electricity is given by Schmidt et al. (1996a, 1996b).

The emissions of NO_X, CO, CO_2, NMVOC (Non-methane-volatile-organic-compounds), N_2O and CH_4 were investigated for the cooking alternatives using different fuels. Emissions found for the sum indicator NMVOC were split up into different substances based on an estimation following the data for the same fuels given by Frischknecht et al. (1996). Emissions of other substances as, e.g., heavy metals were adopted from combustion processes investigated in the same study, using the same fuel.

2.2.2 Efficiency of Cookstoves

The efficiency of cookstoves depends on various influence factors. It should describe the relation between energy input (in form of fuels or electricity) and the energy output (in form of useful heat for cooking). Influence factors are for example heat transfer, temperature, pressure, humidity, type of technology and cooking practice. Savings of cooking energy are possible by implementing a few simple energy-saving-tips (Nipkow 1996).

Some countries have developed a standard measurement for the efficiency, normally with a water boiling test. The German standard (DIN EN 30) prescribes an efficiency of more than 58% for gas stoves. The newer EN 30-1-1 sets this standard to 52%. The efficiency of electric stoves is standardized (DIN 44547) at not less than 43% or 53% depending on whether the cooking starts with a cold or a warm plate[8].

The type of vessels used and other parameters have a large influence on the test results. The efficiency of new stoves in this test is normally ranges from 60% to 70% (Jungbluth 1995). Tab. 6 shows the efficiency for various cooking alternatives as given by two investigators. The efficiencies found show relative high differences. The optimum cooking appliance in a

[8] The efficiency in this norm describes the relation between theoretical energy output of the stove (measured by heating up a certain amount of water from 20ºC to 100ºC) and the energy throughput in the time necessary.

certain situation depends also on the type of preparation method and the expected result. From these figures it is not possible to assess an average for the stoves used in Switzerland.

Wood stoves have normally a quite lower efficiency. Data from Swiss woodstoves were available only for a combination of cooking and room heating. Here the theoretical efficiency[9] is between 70% to 90%. About 60% of the heat can be used for cooking which would lead to figures of about 42% to 54%. A calculation with the amount of wood used for heating up 2 kg of water comes to an efficiency of 23% for the cooking[10].

The efficiency of stoves and ovens can be compared by measuring the energy used to prepare a standardized meal. These tests show that a preparation in an oven needs generally more energy than this on a stove (up to 3 - 4 times more). Specialized appliances, e.g. egg cooker or water boilers need less energy. Gas ovens are not as efficient as electric ones. Microwave ovens are more efficient only for small portions (Nipkow 1996 and personal communication with the author). But from these tests it is not possible to estimate a general efficiency for one appliance.

Tab. 6 Efficiency of various cooking applications in Switzerland

Type of energy	Type of cooking application	Average[*]	Efficiency in one test[ç]
Electricity	Immersion heater		90% - 95%
	Cast Iron Plate	60%	35% - 50%
	Glass ceramic plate	75%	45%
	Induction stove	90%	60% - 72%
	Grill	20%	
	ven	45%	
	Microwave oven		30% - 50%
Gas	pen flame	58% (58% - 64%)	
	Cooking plate	60%	
	Glass ceramic plate	75%	
	Grill	15%	
	ven	40%	5%

Sources: [*]Bundesamt für Konjunkturfragen, RAVEL, Küche und Strom, 1993
[ç]Personal communication J. Nipkow, 1997, Water boiling test, cooking of 1 liter water from 15 °C to 100 °C.

The efficiency might also be compared by an investigation of energy used in average for fulfilling the households needs. An investigation of RUHRGAS shows that households having an electric stove use only 82% of energy compared to these using gas appliances[11].

The data for the efficiency are estimated to be 58% and 70% for gas and electric stoves respectively considering especially the information on the energy used in practice. The microwave is calculated here with an efficiency of 45%[12]. The efficiency of kerosene stoves is es-

[9] The efficiency is calculated as the energy content of the fuel minus energy losses with the heated flue gasses due to the enthalpy, due to incomplete combustion of the fuel and due to losses of unburned particles with the ash.

[10] Personal communication with P. Hessler and brochures of the TIBA AG, Heizsysteme, Bubendorf (CH). About 1.5 kg of wood are used to boil 2 kg water.

[11] Energy use in kWh of electricity or gas used by households of different sizes in Germany. Personal Communication with L. Joos, Ruhrgas, Dorsten and own calculation with the distribution of household sizes in Switzerland (BfS 1994). A problem of this figure is, that differing circumstances under that households of different sizes live (e.g. income, social situation) might lead to misguiding results. Also the distribution of cooking with gas or electricity might not be the same for all classes of the society.

[12] The figure for the microwave seems to be quite low, considering that a cooking in a microwave does not cause much waste heat. The reason for the comparable low figure in the only measurement available is not clear. Further investigations should look on the efficiency of microwave ovens in more detail.

timated to be 54% (Jungbluth 1995). The efficiency of the wood stove is estimated to be 70% considering that the energy used for heating would be only a lost if it is not wishful, e.g., while using the stove in the summer. Here the figure for an open 3-stone fire is estimated to be 15%.

Fig. 3 shows the range of figures investigated by various authors as shown before for the efficiency of different types of cookstoves. A further comparison in chapter 3.1 will look on a wide range of efficiencies possible for the various stoves in a sensitivity analysis.

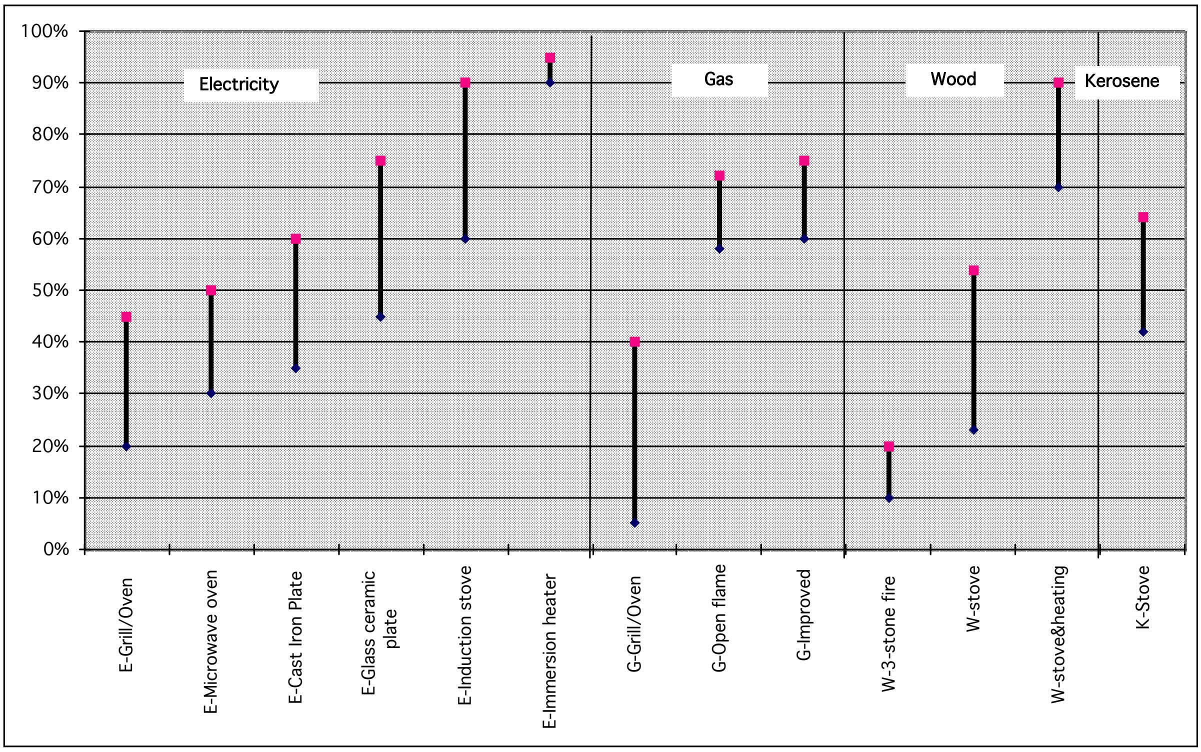

Fig. 3 Range of figures for the efficiency of various cookstove types (Sources quoted in the text)

2.2.3 Specific Energy Use of Stoves

Calculation for the environmental impacts can also be made with a known amount of energy used and the calculated values of the modules „*Energy* in *Stove*“. Tab. 7 shows the energy use per minute for various types of cooking appliances. A multiplication of the figure for the energy use in a certain time, e.g., 30 minutes of cooking on an electric stove, with the corresponding results of the LCI for this appliance makes it possible to calculate the environmental impacts.

Data for gas ovens were not available. Figures for the power of plates give normally the maximum value. If the plate is not used on the highest level or if it is switched off automatically during longer periods of cooking using an electric stove, the energy use is lower (shown here as the *Minimum* figure). This is also shown by the figure „Electric oven (warm-up + constant use) that is measured in a standardized way[13]. The figures for the wood stoves give the energy use for a combination of heating and cooking. The percentage of energy used for cooking is about 60% if the full area available for this purpose is used. Thus, for a winter

[13] The test describes the energy use of an oven to reach a temperature of 200°C and to hold this temperature for one hour (Herd-Info 1996).

situation the figures vary between 0.34 and 0.9 MJ/min while in summer a higher figure has to be used.

Tab. 7 Power and energy use per minute of various cooking appliances

		Minimum	Maximum	Minimum	Maximum
		W	W	MJ/min	MJ/min
Microwave	Highspeed Warm Up	650	800	0.039	0.048
	Cooking	250	700	0.015	0.042
	Defrosting	150	190	0.009	0.011
	Warm keeping	80	140	0.005	0.008
Electric	Stove (1 Plate)	1000	2800	0.060	0.168
	Oven	2200	3900	0.132	0.234
	Oven (warmup+constant)	400	1200	0.024	0.072
Gas	Stove (1 Plate)	1000	2600	0.060	0.156
	Oven	1500	2500	0.090	0.150
Wood	Stove & Heating Combination	5600	15000	0.336	0.900
	Only use as Stove	-	-	0.617	1.542
Kerosene	Stove	1000	4000	0.060	0.240

2.2.4 Cooking with Gas

The use of natural gas or LPG is possible with different types of cookstoves. The stoves are made mainly of steel and a small part of glass and other materials. The weight of stove + oven combinations as normally used in the Swiss kitchen, ranges from 45 kg to 55 kg. The capacity of the whole combination is normally about 10 kW. The life time of all stoves is estimated to be 15 years. Modern gas stoves do use some electricity for lightning the fire automatically and for lighting the oven (Herd-Info 1996). Specific information on energy use for the production of gas stoves in Switzerland could not be found. This figure is estimated to be the same as for an electric stove.

In Jungbluth (1995) three various emission scenarios were considered in the LCI because the emission data covered a large range. The figure for a gas stove in India in Tab. 8 represents the mean scenario in this survey. The reason for the large differences is not clear. For this survey emission data measured by the Schweizer Verein für Gas- und Wasser and given by Joos (1994) and Schmidt et al. (1996a, 1996b)[14] were used for a new estimation. The mean, minimum and maximum values of these surveys are shown in the fourth to sixth column of Tab. 8.

CO emission rates investigated by various authors show a large variation. Cookstoves in Switzerland show CO generally emission values far below the standard of 2000 ppm and the approximate value of 1000 ppm (about 56 kg/TJ) often used during tests[15]. The CO emissions can rise by the factor two if the stove does not run under full power.

[14] The estimation made by (Schmidt et al. 1996a) is based on two other investigations:
Moschandreas, D., Relwani, S., Johnson, D., Billick, I. *Emission rates from unvented gas appliances*. Environ Int. 1986; **12**:247-253
Dansk Gasteknisk Center, *Sammenligning af El- og gaskomfurer*. Teknisk note nr. 3/1991. Hørsholm, oktober, 1991

[15] The measurements available for this study showed that the estimation for CO in the previous study (Jungbluth 1995) was much too high.

Tab. 8 Emission data for gas stoves and estimated figures for the LCI

Unit (kg/TJ In)	*India Mean Estimation Gas Stove*	*Mean values Europe*	*Minimum value Europe*	*Maximum value Europe*	*Number of figures Europe*	***Estimation Natural Gas***	***Estimation LPG***
N X	42,0	26,5	2,0	41,0	5	**26,0**	**26,0**
PM	0,1		-	-	-	**0,1**	**0,1**
C	504,0	65,2	3,6	243,0	7	**25,0**	**25,0**
Methan	0,8	-	-	-	-	**0,5**	**0,0**
NMV C	56,0	2,8	-	2,8	1	**4,0**	**4,0**
N2	0,6	-	-	-	-	**0,5**	**0,5**
S 2	4,4	0,9	1,4	1,4	2	**0,5**	**1,0**
C 2	63.600	55.556	55.556	56.000	1	**55500**	**63600**
Formaldehyd s	-	0,2	0,2	0,2	1	**0,2**	**0,2**
N	-	19,1	16,0	22,8	4		
N 2	-	11,6	11,0	12,3	2		

Sources: Second column investigated by Jungbluth (1995) for cookstoves in India
Third to sixth column give the average figures of different surveys in Europe quoted in the text
Last two columns are an own estimation that is explained in the text.

The last two columns of Tab. 8 show the estimation made for the calculations in this survey. The estimation for CO is not made with the average figure of the various investigations because the measurements made in Switzerland showed to be quite lower. A calculation of the mean, excluding the values not from Switzerland, gives a figure of about 23 kg/TJ that is rounded to 25 kg/TJ. The figure for NO_x is estimated to be the average of the various surveys. Methane and N_2O emissions are estimated with the figures found for the Indian situation. The estimation for LPG considers the lower methane content and the higher sulfur content of this fuel. The estimation for NMVOC considers the one figure found for Europe. It is estimated a little higher to consider the much higher values found in the prior research. Emissions of CO_2 and other pollutants are estimated with the figures given for the module „Erdgas in Heizung atm. Brenner <100 kW" by Frischknecht et al. (1996) (see Tab. 21).

Radioactive substances can be enriched in the gases propane and butane during the refining processes. Frischknecht et al. (1996) examined the content of radioactive substances in LPG produced from crude oil. The content of ^{222}Rn was given to be 0.1 kBq/Nm^3 of gas. Radon has a half-life period of 4 days. Thus it can be shown that radioactive release due to the combustion of the gas can be neglected in comparison to other releases during the life cycle (~3000 kBq/$TJ_{useful\ heat}$ against 8.2 E+6 kBq/TJ from other processes involved in the life-cycle.

2.2.5 Cooking with Electricity

Cooking with Electricity does not cause any direct emissions. Thus for the LCI only information regarding the necessary infrastructure (manufacturing of the stove, materials used and transport distances) has to be collected. Electric ranges are mainly produced in Switzerland. The weight of a stove & oven combination is normally about 50 kg - 55 kg and it consists mainly of steel and glass (Herd-Info 1996).

A screening LCA for the production of a microwave oven showed that the most contributing processes (to the environmental impacts) are the raw material production processes for most of the oven's components. But detailed results of the study were not available for this survey (Seungdo et al. 1996). Schmidt et al. (1996a) outlined the minor direct effects of production for other stoves. They calculated the primary energy use for producing a stove to be 600 MJ.

Elektrolux needs in average about 130 MJ and 108 MJ of electricity and oil respectively for the production of one household appliance[16]. This figure[17] is used here for calculating the environmental impacts of the production. An estimation for glass and steel used is made for the inventory.

Tab. 13 shows the estimated figures for electric ranges and microwave ovens. Cooking on an electric range is investigated also for Germany using the same inventory for the stove, but considering the difference in electricity production[18].

2.2.6 Cooking with Wood

In some areas of Switzerland, wood is used as a cooking fuel. The possible environmental impacts are estimated in this survey for cooking on a wood stove in a household and for cooking on an open fire for example during camping or while using a barbecue.

The woodstoves are normally used as a combination for cooking and heating. Thus it fulfills two functions in one. Households, having access to other energy sources, e.g. gas or electricity, use the wood stove mainly in winter time while heating is also necessary. In the summer other appliances are used. Some people use the stoves also during the whole year. The chapter on wood stoves is mainly based on the information given by one supplier[19].

Emission data for the situation in Switzerland were available only for NO_x, particles, CO and CH_4 (Nussbaumer 1988 (measurement for two stoves) and information by TIBA). A new improved stove & central heating combination developed by TIBA promises a reduction of the emissions by the factor 2, 10 and 20 for NO_x, CO and CH_4 respectively. The figures for various stoves (minimum and maximum) and the mean values for the normal stoves are shown in Tab. 9.

Tab. 9 Range of emission values for wood-stoves in Switzerland (mg/Nm³)

	TIBA Stove & Heating (Min)	*TIBA Stove & Heating (Max)*	*Stove & Heating (Min)*	*Stove & Heating (Max)*	*Stove & Heating (Min)*	*Stove & Heating (Max)*	*TIBA improved Central Heatingstove*	***Mean of standard stoves excl. improved stove***
N x	150	300	181	194	153	172	105	**192**
Fly Ash	20	40	270	292	81	160	30	**144**
C	5,00E+03	1,00E+04	7,91E+03	9,37E+03	8,90E+03	1,33E+04	7,50E+02	**9,09E+03**
CH4	250	1500	0	0	0	0	55	**875**
HC	0	0	143	709	60	306	0	**305**
Source	TIBA	TIBA	Nussbaumer	Nussbaumer	Nussbaumer	Nussbaumer	TIBA	calculation

Sources: Personal communication P. Hessler, TIBA AG (columns 2,3 and 8),
measurement for two different stoves by Nussbaumer (1988) (columns 4 to 7),
calculation of the mean excluding the improved TIBA stove in column 9

Tab. 18 in the annex 6.3 shows further results of emission data for woodstoves. These measurements have been made for stoves normally used in developing countries. The minimum, maximum, mean values and the number of measurements of these surveys are given in Tab. 10. The table shows also the average of the Swiss measurements and the estimation for the LCI for NO_x, particles, CO and CH_4. The scenario is calculated for a 3-stone fire (open fire) and for an average cookstove used in Switzerland. The figure for N_2O is estimated with the value found in foreign countries. All other figures (except these for the infrastructure) are es-

[16] Elektrolux, Switzerland: „Ökologische und ökonomische Fortschritte in der Haushaltsapparatebranche“. n.d., data from one factory.
[17] Considering the upstream energy use these figures are about the same as found for Denmark by Schmidt et al. (1996a).
[18] High usage of water and nuclear power in Switzerland, higher dependence on fossil fuels in Germany.
[19] Personal communication with P. Hessler and brochures of the TIBA AG, Heizsysteme, Bubendorf (CH).

timated with the figures given by Frischknecht et al. (1996) for „Stueckholz in Feuerung 30kW“.

Tab. 10 Range of emission values for wood-stoves in developing countries and estimation of the LCI for wood stoves

	Mean Swiss Standard (kg/TJin)	Simple stoves Mean (kg/TJin)	Simple stoves Min (kg/TJin)	Simple stoves Max (kg/TJin)	Number of figures Simple stoves	Estimation Wood-stove & heating (kg/TJin)	Estimation 3-stone-fire (kg/TJ)
S 2		31	20	42	3	**21**	**21**
N x	105	104	65	164	5	**100**	**100**
Fly Ash	79	342	1	1.227	7	**80**	**300**
C	5,00E+03	7,93E+03	1,21E+03	1,28E+04	12	**5,00E+03**	**8,00E+03**
CH4	160	668	65	1.137	6	**150**	**500**
NMV C	-	3.238	65	12.788	10	**119**	**3.000**
HC	112	-	-	-	-	**-**	**-**
N2	-	14	7	26	5	**2**	**10**
C 2	0,00E+00	1,49E+05	1,07E+05	1,73E+05	8,00E+00	**9,59E+04**	**9,59E+04**

Sources: Column 2 calculated from Tab. 9, column 3 to 6 from Tab. 18, last two columns are own estimations

2.2.7 Cooking with Kerosene

The use of kerosene cookstoves is calculated here as an additional scenario even if these types of cookstoves have only a minor position on the market for example for the use during camping. The environmental interventions are calculated based on the information given by Jungbluth (1995). Some information of this study is quoted below.

For the use with Kerosene, different types of cookstoves are marketed. They can be broadly classified as being of the ”**pressurized**” or the ”**wick**” type. Fig. 4 shows a typical **pressurized cookstove** of the offset burner type. The kerosene is delivered to the burner by an overpressure 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.

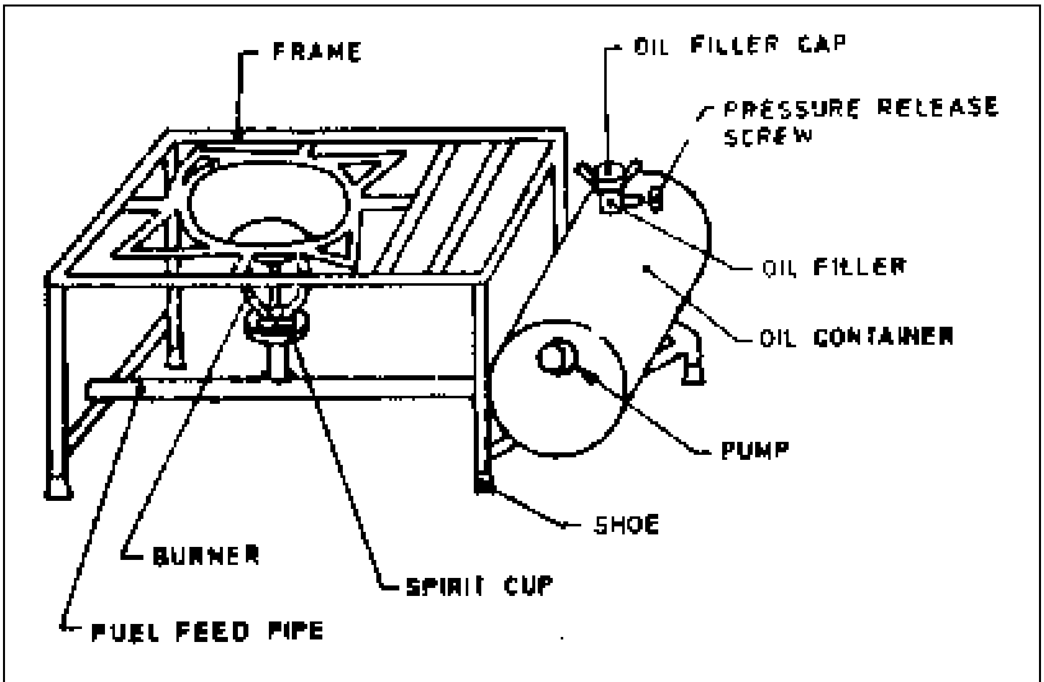

Fig. 4 Typical oil pressure stove of the offset burner type in India

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. Due to the preheating, emissions of some air pollutants in the starting phase are probably higher. 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 pressurized cookstoves work quite loudly.

A difficult question in the estimation of the emissions of pressurized kerosene stoves is whether the emissions in the heating phase should be included or not. The emissions during this phase are very high. Lauterbach et al. (1995) found that the emissions in the first 3 minutes for some pollutants are much higher than during cooking. The next table 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) 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 larger than the increases in emission factors, so that total emissions per task were lower. This fact was also found by Lauterbach et al. (1995) for some pollutants. The change of the flue gas concentration, if the kerosene stove is used with a higher power, is given in the next table.

Tab. 11 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 et al. 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

Emission data for kerosene cookstoves were investigated by various authors. These measurements show large variation. Thus it is rather difficult to establish average values for a survey. The LCI scenario should give the emission figures over a period of one hour cooking with a prior heating time of 3 minutes.

For this survey, data of the mean scenario given by Jungbluth (1995) are used for the further calculations. Emission figures for NO_x, Particles, N_2O, SO_2, and CO_2 are about these found by Frischknecht et al. (1996) for other oil combustion devices. The figures found in India for CH_4 and NMVOC are considerable higher[20]. The estimation was based only on one measurement in a survey. Emissions of different single NMVOC are estimated to be three times higher than the figures given by Frischknecht et al. (1996) in Tab. IV.11.46 for a LowNOx-Kessel. This considers the high emissions during the starting time. The rest of 133 kg/TJ is considered as unspecified NMVOC. The life expectancy is estimated at 15 years.

2.2.8 Life Cycle Inventory for Cooking and Baking

The life cycle inventory for some emissions of the various cooking alternatives is given in Tab. 12. The full inventory for further pollutants is shown in Tab. 21. A distinction is not made between stoves and ovens in this survey because no specific data of emissions were

[20] Methane: about 3 kg/TJ versus 10.5 kg/TJ, NMVOC: 3.5 kg/TJ versus 143 kg/TJ.

available for the gas ovens. The impacts of oven used can be calculated considering the efficiency of this option as investigated in chapter 2.2.2.

Tab. 12 Some inventory data for cookstove emissions and efficiency

Unit (kg/TJin)	Gasstove	LPG-Gasstove	Kerosene Stove	Wood stove & heating	3-stone fire
eta	58%	58%	54%	70%	15%
N X	26	26	71,7	100	100
PM	0,1	0,1	9	80	300
C	25	25	573	5.000	8.000
Methane	0,5	-	11,5	150	500
NMV C	4,0	4,0	143	119	3.000
N2	0,5	0,5	1	2	10
S 2	0,5	1,0	93	21	21
Formaldehyd	0,2	0,2	-	-	-
C 2	5,55E+04	6,36E+04	7,34E+04	9,59E+04	9,59E+04
Electricity (Use)	0,010	-	-	-	-

eta - efficiency

Tab. 13 gives the data for the infrastructure of the stoves. Data for packaging materials are broadly estimated. The material use for a gas or electric stove is estimated with the data given by Schmidt et al. (1996a). These figures consider that a part of the material does not go into the product but is used during production (e.g. production wastes). For all materials except steel (full recycling) a final treatment in an incineration plant is assessed. Waste heat due to the use of oil and electricity is also considered. For wood stoves and microwaves some materials are estimated, where no specific information was available.

Tab. 13 Inventory data for the infrastructure of various cookstoves

	Unit	Infra Gas	Infra Electric	Infra Microwave	Infra Wood	Infra Kerosene
Power of the stove	kW	2,5	2,5	1,0	7,0	2,0
Transport (Lorry)	km	50	50	50	50	50
Transport (Ship)	km	-	-	10.000	-	-
Transport (Train)	km	200	200	200	200	200
Steel	kg	43	43	15	150	2
Glas	kg	6,00	6,00	1,00	1,00	-
Ceramics	kg	-	-	-	30,00	-
Aluminium	kg	0,09	0,09	0,03	0,10	-
Painting	kg	7,20	7,20	1,00	7,20	-
Copper	kg	0,18	0,18	0,05	0,20	-
Mineral wool	kg	1,10	1,10	0,20	3,00	-
PVC	kg	0,12	0,12	0,10	0,20	-
Zinc	kg	0,20	0,20	0,05	0,20	-
Cardboard	kg	4,0	4,0	2,0	4,0	1
Polystyrol EPS	kg	1,0	1,0	0,5	1,0	-
Electricity (Manufacturing)	TJ	1,08E-04	1,08E-04	3,60E-05	1,08E-04	2,16E-05
il (Manufactoring)	TJ	1,26E-04	1,26E-04	4,20E-05	1,26E-04	2,52E-05
Total life energy use	TJges	0,108	0,108	0,022	0,227	0,0864
Load	h/a	800	800	400	600	800
Life Time	a	15	15	15	15	15

The energy use for the production of a microwave oven is estimated to be just one fourth of this for a full-size stove-oven combination because of the lower weight and size of this appliance. The „Power of the stove“ figure is estimated for the average use, considering that normally only a few plates or the oven and not the full facility is in use. It is estimated that the stoves are in use for approximately two hours a day with exception of the microwave that is normally not used as long. The load of the wood stove is also estimated to be lower because this stove might not be in use during summer. The transport distances are roughly estimated following the approach chosen by Frischknecht et al. (1996) on page III.30. Microwave ovens are often imported from South-Eastern-Asian countries. Thus a transport for the import with a ship is estimated here.

The full information of all inputs converted to the necessary units to ECOINVENT, including the figures for estimation of process emissions taken oven from other modules, is given in the annex 6.4.2, Tab. 21.

3 Impact Assessment

In this chapter the results of the life-cycle assessment for the various cooking alternatives investigated are presented and analyzed. The classification used is explained. Firstly all alternatives are compared. The influence of the efficiency on the environmental impact scores and the values for the Eco-indicator 95+ are investigated in detail. This is followed by a more detailed analysis of the results for the calculation of Eco-indicators 95+ and the contribution of different stages in the life-cycle for the total results. The results of the calculation for Eco-indicators 95+ are shown in Tab. 22 of annex 6.2. The impact score profile is given for 23 environmental impact categories in annex 6.2, Tab. 23. The results of the life-cycle-inventory-analysis for all environmental impacts investigated are given in Annex 6.5, Tab. 24.

3.1 Categories for the Impact Assessment

There are different concepts to conduct the impact assessment in an LCA. They can be distinguished in fully and partly aggregated models. A good overview for the state of the art is given for example by Braunschweig et al. (1996). (Heijungs et al. 1992a) developed a concept for the classification of different environmental impacts to impact categories. Developing the concept for the Eco-indicator 95, Goedkoop (1995) improved and extended this approach. A description of this method is given in annex 6.1. Tab. 14 shows the effects distinguished in the two reports.

Twenty-three categories of environmental impact categories are distinguished in the calculation with ECOINVENT. These impact categories describe different environmental hazards or problems often considered while discussing about environmental themes, e.g., global warming, use of resources, etc. But some of these categories describe effects overlapping because they where adopted from different methods or they describe the same effect in a different time horizon. The third column of Tab. 14 gives the effects implemented in the database ECOINVENT. The last column of the table gives a short description of the different environmental impacts.

For this report the calculation of Eco-indicators 95 for nine environmental impacts as described in annex 6.1 has been implemented in the database ECOINVENT. The advance for the implementation is described in the Annex 6.2. The inclusion is linked with a few changes of the original method. This approach is used for evaluation in this report and named as Eco-indicator 95+. Except pesticides[21], environmental effects as distinguished by Goedkoop (1995), are included in this approach.

But the method Eco-indicator 95+ does not give a good picture of all environmental impacts of electricity production based on hydro- and nuclear power in Switzerland and therefore yields to misleading results.

Thus the actual investigation will look on some additional impact categories calculated in ECOINVENT and not included in the concept of Eco-indicator 95+. The impact categories radioactivity, space use, waste heat (as an indicator for the use of energy resources) and eoctoxicity are used for the valuation. The Eco-indicator 95+ does not give a picture of the first three effects. Waste heat might not be as important for the environment, but this impact category is used here as an indicator for non-renewable energy resources. Some heavy metals do

[21] Up to now, pesticides were not included in the database ECOINVENT because they do not play a role for the processes investigated so far.

cause also ecotoxicity effects and are included in the calculation of the Eco-indicator 95+. They are thus being „double counted" which should be considered when discussing at the results.

Tab. 14 Effect scores for the classification in LCA as distinguished by various authors

Environmental effects (Heijungs et al. 1992a)	**Environmental effects** (Goedkoop 1995)	**Umweltkategorien** (EC INVENT and Frischknecht et al. 1996)	**Description of the environmental effect**
		Bedarf energetischer Ressourcen • nicht erneuerbare • erneuerbare	Use of various energy resources expressed in MJ primary demand. The demand of non-burnable resources, e.g. hydro or nuclear power, is calculated with an equivalence factor using the upper heating value for fuels or the value for energy used in the nuclear reactor.
		Flächeninanspruchnahme	Use of land for the various processes involved, described as land occupation in square meters years. Four categories of land use are distinguished in EC INVENT.
acidification	acidification	*Versaeuerung*	Release of substances responsible for acidification (Waldsterben, sour lakes). Measurement of the propensity to release H^+ compared with this of S $_2$, expressed as equivalents to S $_x$.
aquatic / waste heat		**Abwaerme**	Release of waste heat to the environment. Releases of heat are normally linked with combustion processes or the use of energy. The indicator gives thus an idea for the use of non-renewable energy.
cancerogenic substances	carcinogenic substances	*Krebserregende Substanzen*	Release of substances that might cause cancer (human) expressed as equivalents to PAH.
damage			Damage describes a deterioration in the quality of the environment, not directly attributable to depletion or pollution. The effect has yet not been operationalized.
ecotoxicity (aquatic, terrestrial)		**Ökotoxizität (Wasser, Boden)**	Description of ecotoxicity effects in different compartments of the environment. The assessment is mainly based on investigated N EL (no observed effect level) concentrations.
greenhouse effect	greenhouse effect	*Treibhauseffekt* (20, *100*, 500 Jahre)	Contribution of various gases to the greenhouse effect expressed as an impact equal to one kg of C $_2$.
	heavy metals	*Schwermetalle*	Release of heavy metals to the environment expressed as equivalents of 1 kg lead. Heavy metals are responsible for various human toxicity and ecotoxicity effects.
human toxicity (water, air, soil)		Humantoxizität (Wasser, Luft, Boden)	Description of toxic effects to human beings from substances released to different environmental compartments. The indicator gives the weight (of a human being) theoretically poisoned to a tolerable maximum in kg.
malodorous air		Geruch	Release of malodorous air expressed in cubic meters necessary to rarefy the release to a tolerable maximum.
noise			Noise linked to the different processes involved. The effect has yet not been operationalised.
nutrification	eutrophication	*Überdüngung*	Release of substances responsible for eutrophication in lakes, rivers and seas expressed in equivalents to P $_4$.
ozone depletion	ozone layer depletion	*Ozonabbau*	Release of substances responsible for the degradation of the earth's` ozone layer expressed in equivalents to R11.
	pesticides		Kilograms of total pesticides released to the environment. The possible harm is not specified for different substances.
photochemical oxidant forming	summer smog	Photosmog *Photosmog inkl.* NO_x	Substances responsible for the formation of summer smog (ozone) expressed in equivalents to ethylene. The inclusion of N $_x$ is only necessary if this gas is a limiting factor. This is the case in Switzerland but not in some other European countries.
radioactivity		**Radioaktivität**	Release of radioactive substances in kBq. The indicator does not consider differences in the effects caused by different types of releases.
resource depletion • abiotic • biotic		Resourcenabbau	Use of non-energy resources.
victims			The effect has yet not been operationalised.
	winter smog	*Wintersmog*	Release of air pollutants causing winter smog expressed as equivalents of 1 kg S $_2$.

Environmental effects considered for the method Eco-indicator 95+ are written in *italics.*
Environmental effects used additionally in this survey for the valuation are written in **bold**.

3.2 Comparison of all Cooking Alternatives

Fig. 5 shows the relative environmental impacts of various cooking alternatives in comparison to the alternative with maximum impacts. This figure is calculated with the efficiencies estimated for the cookstoves[24]. Cooking with the kerosene stove shows the highest[22] scores for ecotoxicity. The 3-stone fire shows to have the highest impacts while using the concept of Eco-indicator 95+. Cooking with electricity has the highest impact in case of radioactivity and space use (in Switzerland) or waste heat (in Western-Germany).

The use of LPG for cooking shows to have higher impacts for all investigated impacts than the use of natural gas. The production of LPG is calculated in ECOINVENT based on the assumption, that the fuel is produced from crude oil in refineries (Frischknecht et al. 1996). It is also possible to produce LPG directly from natural gas with less environmental impacts, but the share of this production option for the LPG consumed in Switzerland[23] is relative small.

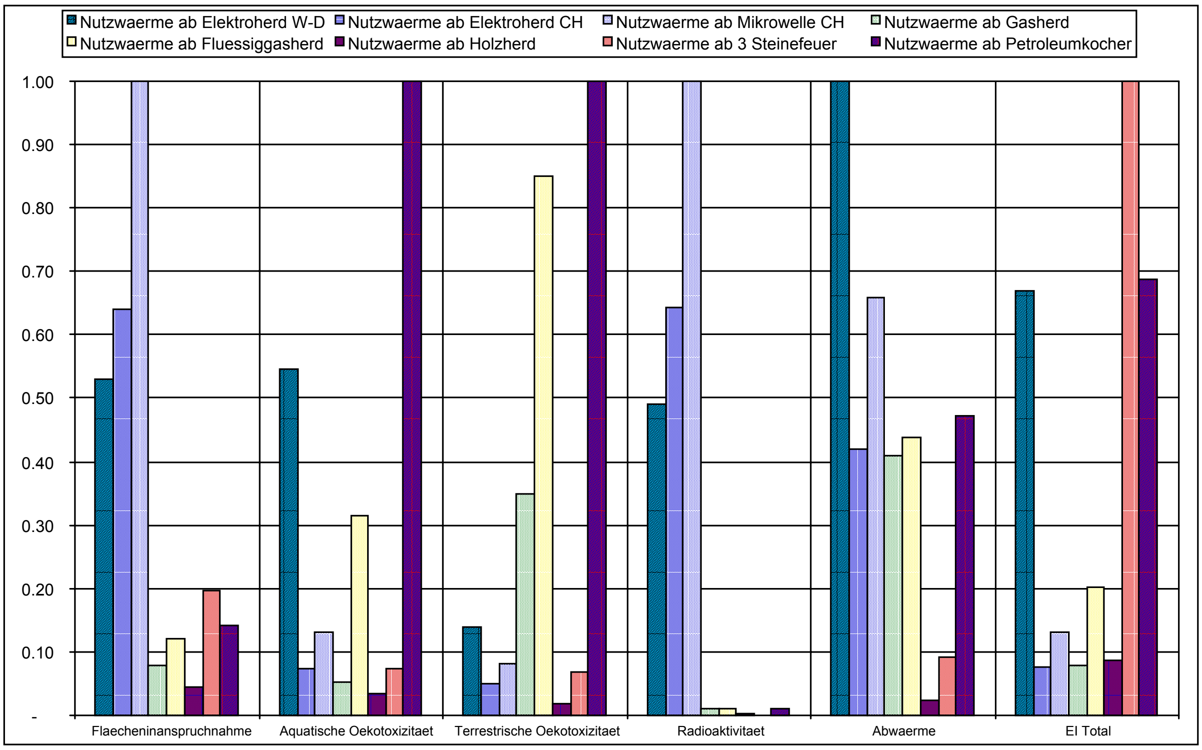

Fig. 5 Relative comparison of all investigated cooking alternatives in comparison to the alternative with the highest impacts (Value = 1 in the figure)

3.3 Influence of the Efficiency for the Results

A more detailed investigation will now look on the influence of the efficiency for the stove used. The range of efficiencies likely for the different types of stoves is given in Fig. 3 in

[22] Cooking with kerosene was not investigated in detail for this study. The emission figures of the stove are based on measurements for stoves in developing countries. It is possible, that the environmental impacts due to the cookstove emissions might have been overestimated in this report.

[23] In 1996, 83% of liquefied gas consumed was produced in Swiss refineries. The bulk of gas imported came from Germany (90%) and other European countries. These countries have a small proportion of national natural gas extraction and do produce LPG also mainly in refineries. Thus it can be assumed that the simplification of solely production in refineries does not influence the results much (Personal communication with Dr. Berg, Erdöl-Vereinigung, Zurich, 4.6.97).

chapter 2.2.2[24]. The comparison for Eco-indicator 95+ points is shown in Fig. 6. It is split in two parts with different scales to make the comparison more easy. Cooking with electricity in Germany shows to have the highest impacts. Close by is cooking on a 3-stone fire and on a kerosene stove, because these options normally have a quite lower efficiency. These options are followed by cooking with LPG and wood. The figures for gas and electricity[25] (CH) are close together, considering that the latter normally has the higher efficiency.

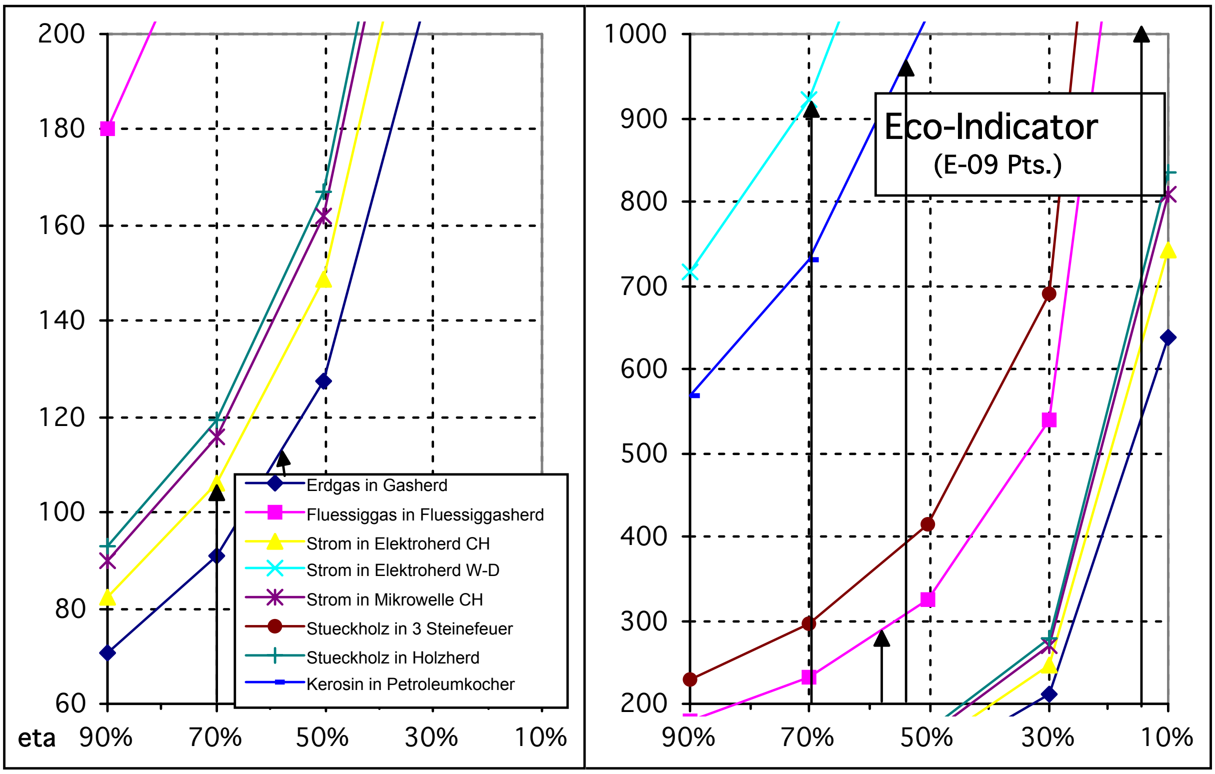

Fig. 6 Comparison of Eco-indicator 95+ points for a range of stove efficiencies. The arrows mark the average efficiencies of the cooking alternatives

Fig. 7 shows the comparison for the impact categories. Space use is the highest for the electric stoves in every case followed by kerosene. Natural gas stands a little bit better than LPG. The outcome of a comparison wood - gas depends on the efficiency assumed while wood stoves do have a quite lower one.

Kerosene has the highest impacts in ecotoxicity categories. For terrestrial ecotoxicity the gas stoves show the second highest impacts in nearby every case followed by electricity use in Germany. The other alternatives are close together. In case of aquatic ecotoxicity an electric stove in Germany has the highest impacts followed by an LPG one in Switzerland. Cooking with natural gas has lower impacts than all other options.

The amount of waste heat released is highest for the electric stove in Germany. This shows the bad overall energy efficiency of this options for the case of fossil fuel based electricity production. Cooking with gas and electricity in Switzerland are close together, electricity being a little bit better. Release of radioactivity shows to be higher for the electric stoves in every case. The other options have relative low impacts and thus this impact is not compared in detail.

[24] The mean figures estimated for the efficiency of the different alternatives in this report were:

3-stone fire	wood stove	electric stove	gas stove	kerosene stove
15 %	70 %	70 %	58 %	54 %

[25] Differences between the microwave oven and a normal stove are minor for this comparison in most cases.

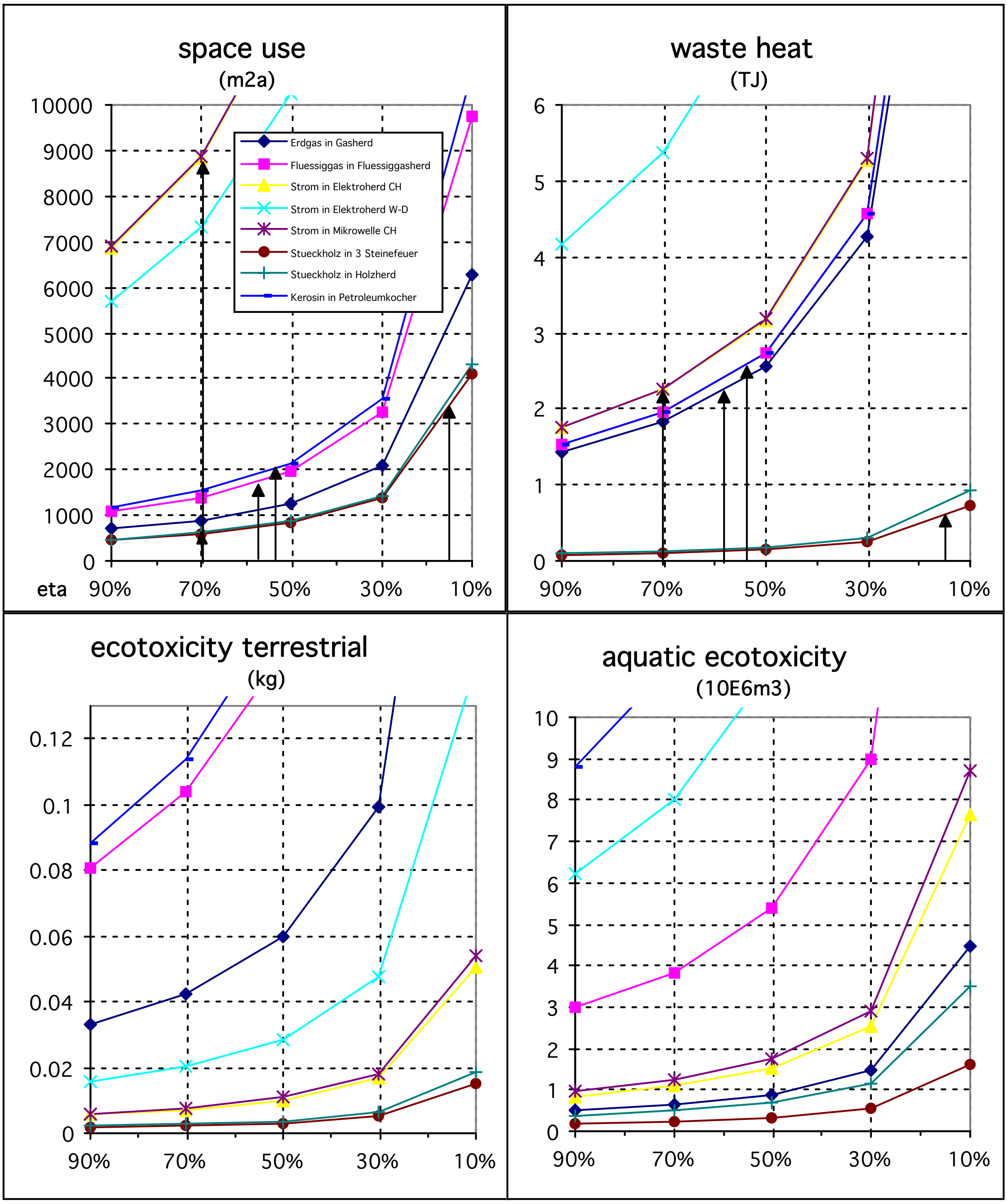

Fig. 7 Comparison for different impact categories for a range of stove efficiencies

3.4 Detailed Analysis using Eco-indicator 95+

This section will give a detailed analysis of the share contributed by different impact categories to the total of Eco-indicator 95+ points calculated. Fig. 8 shows this analysis. The absolute figure of found for cooking with electricity and gas in Switzerland was about the same. But, the two alternatives show to have a different structure of the environmental impacts caused.

The release of heavy metals and the contribution to acidification are the most important categories for the electricity using options. The impacts of the gas stove are determined by the contribution to global warming, acidification, heavy metals and summer smog. A changing valuation method might also change the outcome of the comparison between these two alternatives.

For the options using wood the contribution to photochemical smog plays an important role. NO_x emissions are responsible for this result. The contribution to global warming is relatively small because CO_2 emissions are not accounted for the biogenic[26] fuel. Cancerogenic substances have a high importance for the kerosene stove. This is mainly due to the emissions of PAH (Poly Aromatic Hydrocarbons). Their emission factor is based on an assumed distribution for the investigated emissions of NMVOC`s. The result for this pollutant is not reliable and before using this result, further investigations should clarify this point. PAH`s are not included in the emission figures for a wood stove, which might lead to a bias in the comparison.

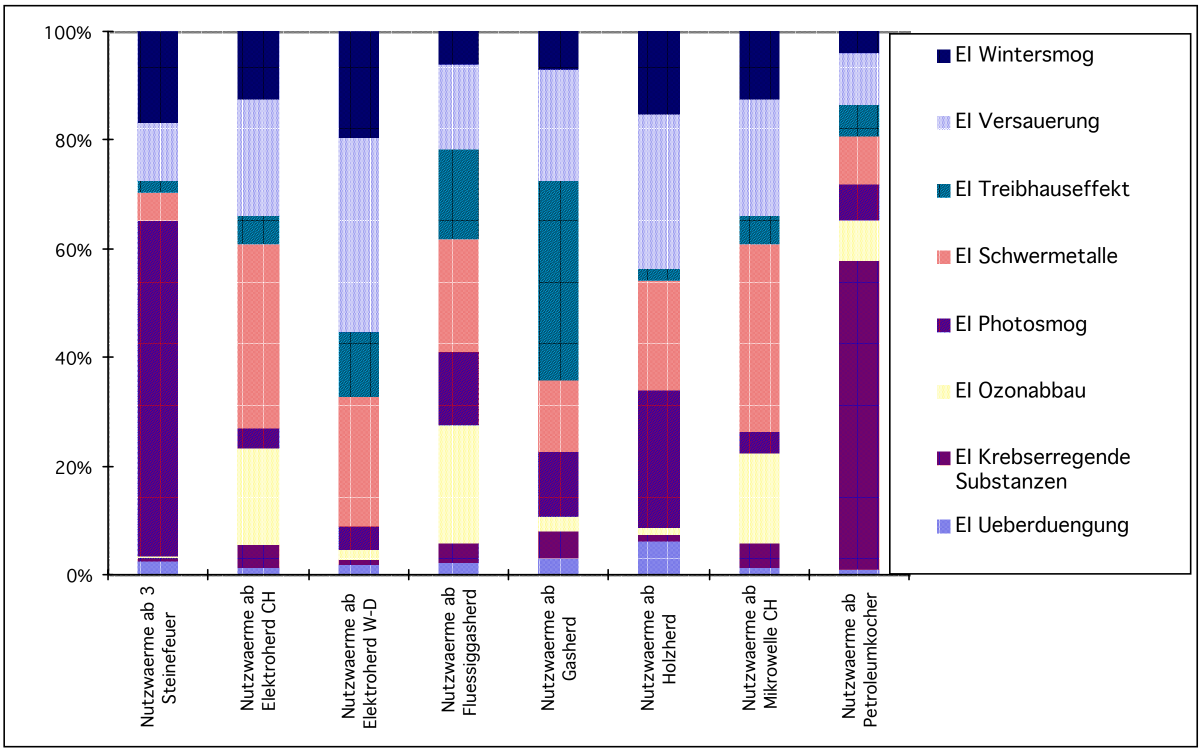

Fig. 8 Share of different impact categories for the calculated Eco-indicator 95+ points

3.5 Contribution of Various Stages in the Life-Cycle

For evaluating the environmental impacts of cooking with gas, wood and kerosene it has to be taken into account that combustion flue gases are emitted directly beside people when cooking. Thus these emissions should normally be weighted higher than these taking place during industrial upstream processes.

In the eighties and nineties there were some discussion about the possible health effects of using gas appliances in households. Jarvis et al. (1996) found in an epidemiological study that

[26] The amount of CO_2 bound during the plantation of wood equals the CO_2 released during combustion.

women[27] who reported they mainly used gas for cooking had an increased risk of several asthma-like symptoms. Nitrogen oxide is made responsible for the observed health effects due to using unvented gas appliances in homes. Other studies observing the linkage between health effects and type of cooking appliances had different outcomes. Some found hints for these effects in specific groups of persons, others did not. A detailed discussion of the local health impacts of various cooking alternatives was made by Schmidt et al. (1996a, 1996b).

Considering this discussion the manufactures of stoves tried to develop appliances with lower NO_x emissions. Consulting organizations give also the advice to look for a proper ventilation of the kitchen while using gas stoves.

Fig. 9 compares the origin of impacts for various stages of the life-cycle. Four stages are shown for LPG - Upstream processing, distribution, infrastructure of the stove and cooking. The cooking itself has a high impact for the release of heat. For many of the other impact categories the production of the fuel in the upstream life-cycle plays an important role. The production of the stove and the distribution do play only a minor role for the total impacts caused.

The stages for the life-cycle of natural gas are distinguished in direct emissions („Gasherd direkte Emissionen), emissions due to the production of the fuels in upstream processes („Erdgas Upstream“) and due to the production of the stove itself. The direct emissions are mainly important in the categories waste heat, radioactivity and Eco-indicator 95+. Impacts in the category aquatic ecotoxicity play some role for the production of the stove. The production of the fuel is important for impacts in the categories land use and ecotoxicity.

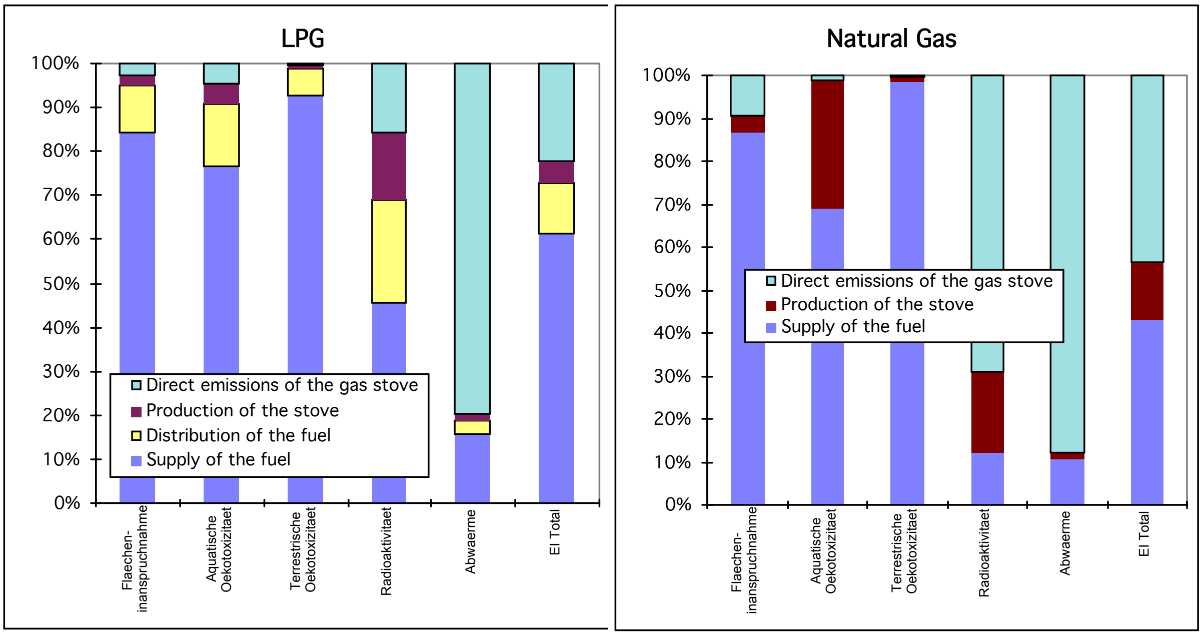

Fig. 9 Contribution of various life-cycle stages for the environmental impacts of cooking with natural gas and LPG

In the case of wood the main part of gaseous emissions takes place during cooking. While using a modern wood stove, most of these emissions do go through the chimney and only a small part reaches the person cooking directly. Cooking on an open fire exposes the persons

[27] These markers of respiratory morbidity were not found for men. The authors explained this founding with the thesis, that women may be more susceptible than men to the products of gas combustion or they may have greater exposure because they cook more frequently than men.

around to high concentration of different toxic flue gases. The same holds true for cooking on a kerosene stove. It was not possible to distinguish the different meaning of emissions taking place from industrial sides and these during cooking in this LCA. This would be a task for further methodological improvements.

The power generation shows to have the highest share in nearly all impacts caused in the case of cooking with electricity. Only waste heat is produced in a considerable amount during the cooking itself. The infrastructure has a relative low share in the environmental impacts.

4 Interpretation

The life-cycle-impact-assessment gives interesting insights in environmental impacts caused by various cooking options. A first result is the large gap between the results for electric cooking in Western-Germany and Switzerland due to the differences in the electricity production. Power generation in Switzerland is mainly based on nuclear fuels and hydro-power whereas in Germany fossil fuels have the highest share. The comparison between gas (CH) and electricity (D) shows a clear preference for the first.

There is not such a clear outcome if the alternatives are compared for the situation in Switzerland. A comparison based only on the method of Eco-indicator 95+ does not provide satisfying results because the impacts of electricity production in Switzerland in some categories, e.g. radioactive releases and land use are not valued. From a valuation using the additional impact categories radioactivity, space use, waste heat (as an indicator for the use of energy resources) and eoctoxicity, cooking with natural gas is better considering radioactive releases and space use. With regard to terrestrial ecotoxicity and waste heat the impacts caused by a gas stove are higher than those of using electricity. In other categories the impacts of gas use are about the same.

Considering the uncertainty of data (e.g. efficiencies of different stoves) and methods (impact assessment for indoor pollution) the differences of the two possibilities do not lead to a clear ranking. The overall environmental impacts of cooking with gas or electricity in Switzerland are assessed here to be about the same.

The impacts of cooking with wood depend mainly on the question whether or not the waste heat of the stove is used for room heating. Thus the stove achieves a high overall efficiency. Cooking with wood is an ecological alternative to the other options if the heat of the fire can be used for room heating. Cooking on a 3-stone fire shows to have relative high environmental impacts. Especially the toxic effects[28] to human being should be considered while valuing this option.

Cooking with LPG might be a theoretical alternative to the other types of energy. But from an environmental point of view there is no clear constraint for it. The use of kerosene for cooking is also not environmentally friendly in comparison to the other alternatives.

It should be taken into account, that the environmental impacts depend considerably on the efficiency of the stove used and on the energy consumed due to the users' behavior. Thus for all types of stoves further developments towards a higher efficiency and proper roles for the consumers' behavior are desirable to minimize the environmental impacts of cooking.

To compare the cooking alternatives more reliable, further methodological improvements are necessary for the inclusion of land use and radioactive releases in the method Eco-indicator 95. Further on a separated valuation of indoor air quality effects is necessary to assess the health effects of pollutants released during cooking in more detail.

The data investigated in this report are satisfying in regard to the inclusion of the environmental impacts of cooking in further LCA studies. But to compare different cooking alternatives in detail more information is necessary regarding the efficiency of stoves and a good method to compare it. An other data gap are the measurements of emissions available for the

[28] The figure for the environmental effect human toxicity (8940 kg) is about three times higher than this for the second worst option electric stove in Germany.

stoves burning fuels. More measurements giving more details about different types of air pollutants are desirable.

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6 Annex

6.1 The Eco-indicator 95: a tool for designers

text copied from http://www.pre.nl/eco-ind.html (3.6.97)

Designers need some kind of a yardstick to measure the environmental impact of a material, or process. Without such a tool a designer is left guessing if he or she wants to take the environment into account. The Eco-indicator 95 is developed to provide such tool. An Eco-indicator is a value that expresses the total environmental load of a material or process in a single figure.

6.1.1 Introduction

Environmental care behind the drawing board has been a familiar concept for some years in the attempt to achieve more environmentally sound products. But what is the environment, and how to bring it behind a drawing board or CAD computer? Until now there is no unambiguous measure for environmental impacts of products, which makes it difficult to develop environmentally sound products. For Philips, Ned Car, Océ and Schuurink, this prompted the request to the NOH to start the Eco-indicator project. These (and other)companies are starting to use the Eco-indicators as a tool for their designers.

6.1.2 Ecodesign with Eco-indicators

Every product has to some extents impacts on the environment. Raw materials have to be extracted, the product has to be manufactured, distributed and packaged. Ultimately it must be disposed of. Furthermore, environmental impacts often occur during the use of products because the product consumes energy or material itself. If we wish to assess a product's environmental impact, all its life cycle phases must therefore best ride. An environmental analysis of all the life cycle phases is termed a Life Cycle Assessment, or LCA for short. A life cycle assessment can be used in two ways:

- To determine the total environmental impact of products or design alternatives with the aim of comparing them. For a designer an LCA can provide a solution if he has to choose between design alternatives or between different components or materials.
- To determine the most important causes of one product's environmental impact. A designer can then concentrate on these to achieve improvements here first.

A designer wishing to use life cycle assessments in the design process has been faced by two major problems to date:

- The result of a life cycle assessment is difficult to interpret. Within a life cycle assessment it is possible to determine the contribution of a product life cycle to the greenhouse effect, acidification and other environmental problems while the total environmental impact remains unknown. The reason is the lack of mutual weighting of the environmental effects.
- In general the careful collection of all the environmental data in a product's life cycle is complex, expensive and time consuming. As a result extensive LCA's cannot usually be carried out during a design process.

The Eco-indicator project has resolved these problems as follows:

1. The LCA method has been expanded to include a weighting method. This has enabled one single score to be calculated for the total environmental impact based on the calculated effects. We call this figure the Eco-indicator.
2. Data have been collected for most common materials and processes. The Eco-indicator has been calculated from these data. The materials and processes have been defined such that they fit together like building blocks. Thus there is an indicator for the production of a kilo of polyethylene, one for the extrusion of a kilo of polyethylene and one for the incineration of thermoplastics.

The Eco-indicator of a material or process is thus a number that indicates the environmental impact of a material or process, based on data from a life cycle assessment. The higher the indicator, the greater the environmental impact. The Eco-indicator brings environmental assessments within the designer's reach.

6.1.3 Application of the Eco-indicator as a tool

The application of the Eco-indicator is quite simple. A designer must list the amounts of materials, energy and processes that occur during the life cycle of a product. Then look up the Eco-indicator values for these materials and processes, and multiply the amounts with the corresponding Eco-indicator value. When this is done one can analyze which processes contribute most to the overall effects. The next step is to look for alternative design solutions and analyze whether these alternatives are indeed preferable from an environmental point of view. In Fig. 10 below the results of an analysis of a coffee maker are presented. The size of the boxes indicate the Eco-indicator value of the process or material. It is clear that the electricity use and the paper filter use are dominating. This means a designer has to consider ways to reduce the use of paper and electricity first.

One option could be the use of a thermos jug, since this would eliminate the use of electricity to keep the coffee warm. He can now calculate the environmental burden of the production of the jug and analyze how this balances with the reduced use of electricity.

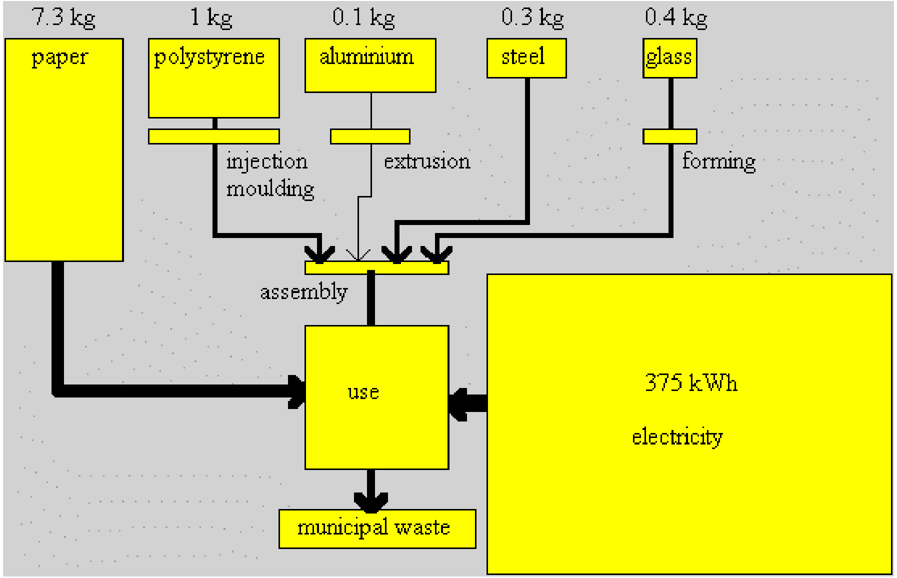

Fig. 10 The coffee machine process tree, where the size of the process blocks is proportional to the relative importance of the process.

6.1.4 The computation of Eco-indicators

A crucial aspect of the Eco-indicator is the transparency of the computation. This is needed to understand the meaning of the indicator and to be able to compute new indicators when needed. The Eco-indicator is described in a report that is publicly available and can also be calculated with SimaPro. The Eco-indicator project has kept as close as possible to the methodology of the life cycle assessment (LCA) method as described by SETAC and CML. This is an important starting point because an analysis using the Eco-indicator method is intended to provide the same result as an LCA as far as possible. This starting point means that the method's initial phases are the same as the LCA steps:

- Inventory phase. Within the project 100 LCAs have been drawn up (or existing ones have been revised). This means that all the relevant processes have been analysed and all emissions have been collected to form an impact table, a total overview of emissions.
- Classification. A number of environmental effects have been calculated on the basis of the impact table.

Classification enables the environmental effects of two products to be compared. For this the presentation as shown in Fig. 11 is often used. This figure illustrates a comparison between a paper and a plastic bag.

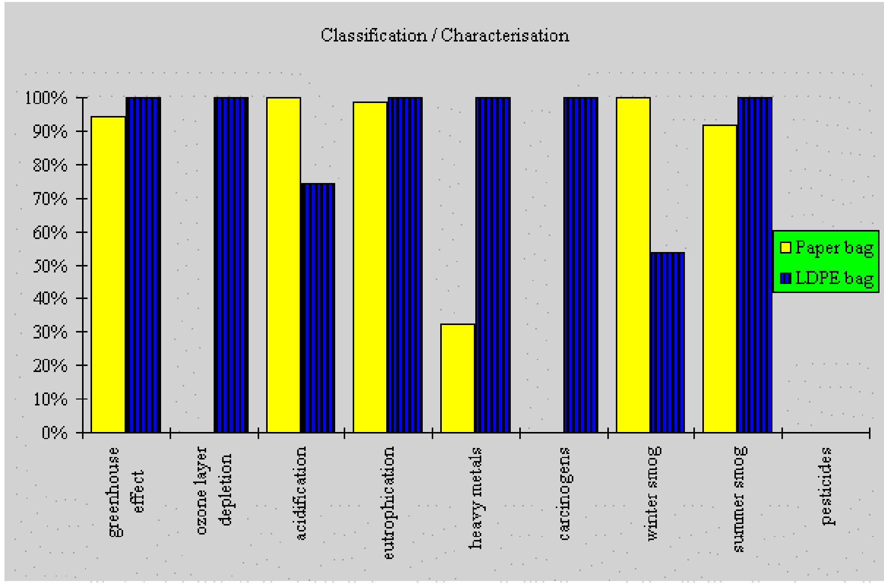

Fig. 11 Example of a comparison between a plastic and a paper bag. The highest score for each effect is set at 100%.

Up to this point the Eco-indicator follows the classic LCA method. However, in this example the result proves to be difficult to interpret. The paper bag causes more winter smog and acidification, but has a better score on the other environmental effects. Thus the LCA does not reveal which is the better bag. What is missing is the mutual weighting of the effects. Although the LCA method describes how this should be done, the weighting step is almost never carried out because of a lack of data. The Eco-indicator project has plugged this gap.

6.1.4.1 Normalisation and evaluation

Based on Fig. 11 it is hardly possible to decide which bag is more environmentally-friendly. In the first place this is because the higher of the two values is scaled to 100%. In reality this is a meaningless scale. A score of 100% can represent a very small or a very large emission. The first step in any further interpretation consists of comparing the scores with another value. In LCA terminology this is called the normalisation step. Inner project we developed an inhabitant equivalent for the Normalisation step, i.e. the environmental effects that an average European person causes in one year. The values of the first step are normalized to the average European, as shown in Fig. 12 The effects are now compared on the scale of inhabitant equivalents. From this it becomes apparent that the scores for ozone layer depletion, eutrophication, pesticides and carcinogens are very low in absolute terms. The two smog scores and the scores for acidification, heavy metals and the greenhouse effect are relatively high.

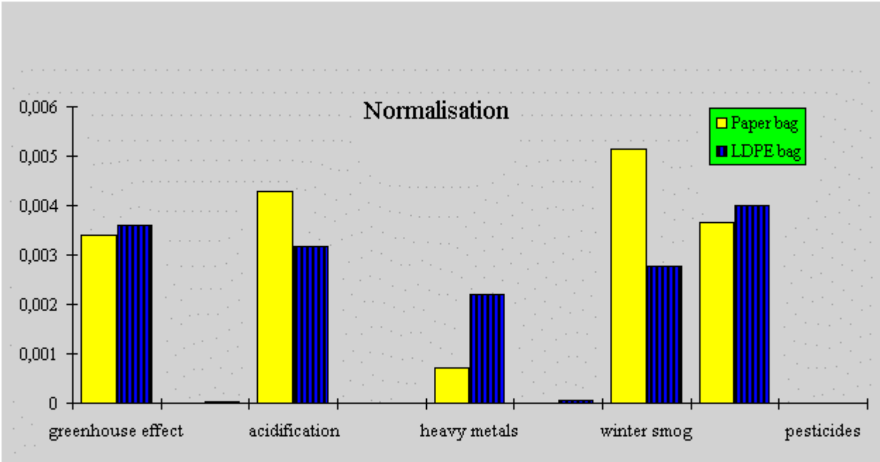

Fig. 12 The effect scores from Fig. 11 are normalized here to the effects that an European person causes in one year. 1000 bags thus cause a0.003rd part of the greenhouse effect that this person causes in one year.

Normalisation reveals which effects are large and which are small in relative terms. However, it does not yet say anything about the relative importance of the effects. A small effect can very well be the most important. A weighting step is therefore necessary to achieve an overall result. This step has been carried out in Fig. 13 The weighting factors used in this last step are discussed in the following paragraph.

All effects are now scaled to a certain measure of seriousness. In this example the seriousness is indicated in Eco-indicator points.

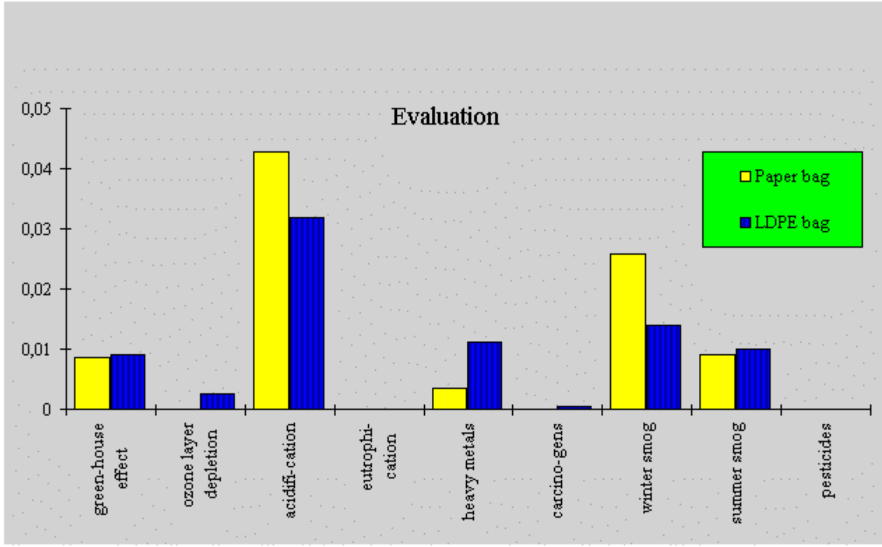

Fig. 13 The evaluation step: weighted and normalized effect scores.

If all the columns are plotted along the same scale, the column lengths (Eco-indicator points) can in principle be totalled. This has been done in Fig. 14 It now becomes clear that the paper bag is somewhat less environmentally friendly, although the difference is minor.

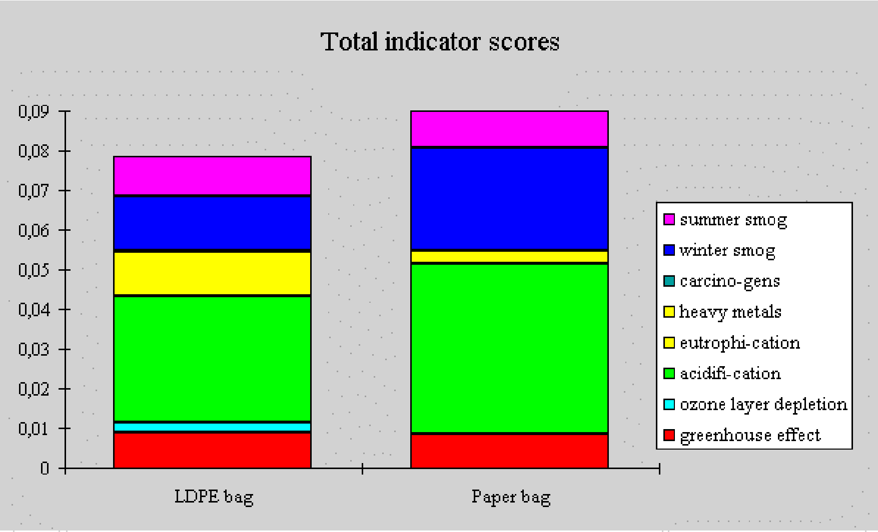

Fig. 14 After weighting the column lengths can be totalled. The paper bag proves to have a slightly greater environmental impact than the plastic bag. However, the difference is so small that, given the uncertainties, no hard-and-fast conclusion is possible in this case.

6.1.4.2 Backgrounds to weighting

Based on these graphs the weighting of effects seems to be very straightforward. The problem, of course, lies in determining the weighting factors. Much consideration has been given to this subject in the Eco-indicator project. After detailed analysis of the options the so-called Distance-to-Target principle was chosen for determining the weight factors. This principle has already been in use for some years in the Swiss Ecopoints weighting system. The underlying premise is that there is a correlation between the seriousness of an effect and the distance between the current level and the target level. Thus if acidification has to be reduced by a factor of 10 in order to achieve a sustainable society and smog by a factor of 5, then acidification is regarded as being twice as serious; the reduction factor is the weighting factor. This principle has been refined and improved in the project, but there is insufficient space to detail the improvements here. Please order the final report if you want to know more.

The term „target level“ still embodies a major problem. What is a good target level, and how can such a level be defined? The above-mentioned Swiss Ecopoints method uses political target levels from government policy papers. These levels are often defined on the basis of a compromise between feasibility (cost) and desirability.

In the Eco-indicator project it was decided to define target levels that are independent of politics and are based on scientific information. The problem then arises again that scientists have different views on what constitutes a good target level, because different environmental problems cause different types of damage. Smog, for example, results in health complaints, while acidification causes major damage to forests. To ensure that the target level for acidification is equivalent to that for smog a correlation must be established with the damage caused by the effect. The premise is that the target level for each effect yields uniformly serious damage. The following damage levels are assumed to be equivalent:

- The number of fatalities as a consequence of environmental effects. The level chosen as acceptable is 1 fatality per million inhabitants per year.
- The number of people who become ill as a consequence of environmental effects. This refers in particular to winter and summer smog. The acceptable level set is that smog periods should hardly ever occur again.
- Ecosystem degradation. A target level has been chosen at which „only“ 5% ecosystem degradation will still occur over several decades.

Setting equivalents for these damage levels is a subjective choice that cannot be scientifically based. It is therefore also possible to make different assumptions which could cause the weighting factors to change. The current choice came about after consultation with various experts and a comparison with other systems, including the Swedish EPS system. Fig. 15 is a schematic representation of the Eco-indicator principle:

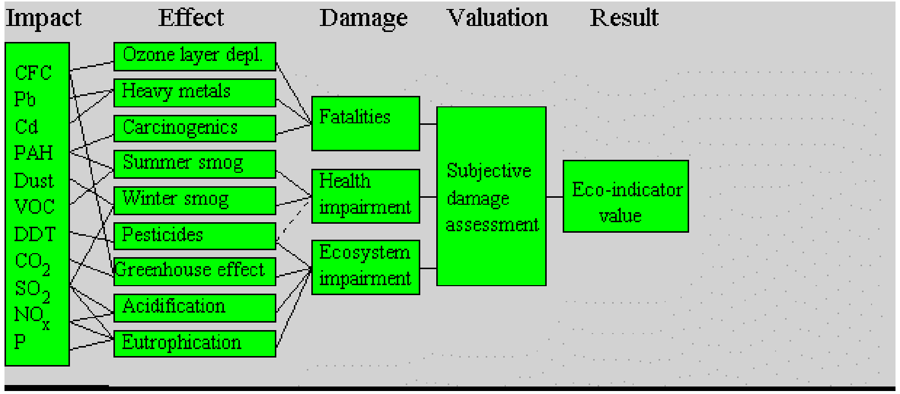

Fig. 15 Eco-indicator weighting principle

To establish a correlation between these damage levels and the effects a detailed study was carried out of the actual state of the environment in Europe. Determined were the current status of each effect, as well as by what degree a particular effect has to be reduced to reach the damage level defined for it. Much work has been carried out particularly by the Dutch National Institute for Public Health and Environmental Hygiene(RIVM) in this field. Detailed maps of Europe are now available in which the environmental problems are shown in a high degree of detail. These data were used to determine the current level of an environmental problem and by what factor the problem must be reduced to reach an acceptable level. A table lists the weighting factors and the criteria applied.

This table reveals that high priority must be given to limiting substances causing ozone layer damage and the use of pesticides. The latter is becoming a very serious problem in the Netherlands in particular. Furthermore, a great deal of consideration must be given to the diffusion of acidifying and carcinogenic substances. It is apparent from the table that a number of effects that are generally regarded as environmental problems have not been included. The reason for omission of a number of effects is given below:

Toxic substances that are only a problem in the workplace Many substances are only harmful if they occur above a certain concentration. Such harmful concentrations can occur relatively easily in the workplace, while the concentration outside often remains very low and well below the damage threshold. This happens because the substances are generally diluted to a large extent and because many substances disappear from the atmosphere because of natural decomposition processes. Only substances that actually are found in harmfull concentrations are included in the Eco-indicator, while the rest are disregarded. This means that a product with a low Eco-indicator score can still cause poor working conditions because substances are released that are harmful locally.

Exhaustion (depletion) of raw materials If a product made of very rare raw materials is used this rarity is not expressed in the indicator; after all, the fact that a substance is rare doesnot cause any damage to health. The emissions arising from extraction of the raw materials are included and are usually extensive because ever lower-grade ores have to be used. Incidentally, the term „exhaustion“ is very difficult to define. Alternatives are available for most raw materials, and recycling could enable raw materials to remain in circulation for much longer. In fact minerals never disappear from the Earth; at worst they are diffused in an unfortunate manner.

Waste The fact that waste occupies space is not particularly important in environmental terms because the amount of ecosystem lost to the mountains of waste is relatively small compared with the damage to ecosystems caused, for example, by acidification. However, the substances released by waste (heavy metals, or CO2 on incineration) are very important. These latter effects are included in the indicator, but the quantity of waste in itself is not part of the assessment process.

As a result of these differences the Eco-indicator can be seen as an indicator of emissions, and raw materials depletion and the use of space by waste must be evaluated separately at present.

6.1.5 Conclusion

The Eco-indicator is primarily a tool for the designer. It allows the designer to make its own LCA´s with the help of 100 pre-defined LCA´s for commonly used materials and processes. The designer can use the Eco-indicator in two ways:

- To get the questions right (what are the primary causes of the environmental burden of a product)
- To get the answers right (which design alternative has the lowest environmental burden)

The methodology is an extension of the SETAC LCA methodology, it uses a Normalisation and an evaluation stage. The evaluation is based on the best available knowledge of the environmental damage of effects on an European scale.

6.1.6 Bibliography

1. Ahbe S. et al. Methodik für Oekobilanzen (Method for Environmental Life Cycle Assessments), Buwal, publication 133, October 1990, Bern,Switzerland. This report (in German) describes the development of the Swiss Ecopoints weighting method.
2. Goedkoop M.J.; Demmers M.; Collignon M.X.; The Eco-indicator 95, Manual for designers; NOH report 9524; PRé consultants; Amersfoort(NL); juli 1995; ISBN 90-72130-78-2. This report describes the application of the Eco-indicators by designers. It does not require anyknowledge on LCA's.
3. Goedkoop M.J.; The Eco-indicator 95, Final report (in English); NOH report 9523; PRé Consultants; Amersfoort (NL); juli 1995; ISBN90-72130-80-4. This report describes the methodology used. It does require some knowledge on LCA's.
4. Goedkoop M.J.; Cnubben P; De Eco-indicator 95, bijlage rapport (annexe report); NOH report 9514 A; PRé Consultants; Amersfoort (NL);juli 1995, ISBN 90-72130-76-6 (only available in Dutch). 5
5. Heijungs R. (final editor) et al; Environmental life cycle assessment of products, Guide and Backgrounds, NOH report 9266 and 9267; Leiden;1992; commissioned by the National Reuse of Waste Research Programme (NOH), in collaboration with CML, TNO and B&G. This is thewidely used guide for LCA practicioners.
6. RIVM, The environment in Europe: A global perspective, Sept. 1992, ISBN 90-6960-031-5. This report describes most of the environmentaldamage caused by environmental effects.
7. SETAC, Society of Environmental Toxicology and Chemistry, Guidelines for Life-Cycle Assessment, a 'Code of Practice', Brussels, Belgium,1993. This is a general description of the basic principles of LCA

8. SimaPro 3.1, Database software program, includes the Eco-indicator methodology, PRé Consultants, Amersfoort, The Netherlands.

6.2 Calculating Eco-indicator 95+ with ECOINVENT

Goedkoop (1995) has proposed a method to aggregate various environmental impacts to one value - the Eco-indicator 95. A description of this concept is given in the annex 6.1. This concept was included in the computation routine of ECOINVENT for this report. The advance follows mainly the proposal made by Goedkoop with a few changes and is from now on cited as **Eco-indicator 95+**. An Excel-Work Sheet prepared for the report of Braunschweig et al. (1996) has been used for a new calculation.

The weighting factors for the impact categories greenhouse effect, ozone depletion, acidification, nutrification, heavy metals cancerogenic substances, winter smog and photochemical oxidant forming are taken from the reports of Goedkoop (1995) and (Heijungs et al. 1992a, Heijungs et al. 1992b). Until now, data for pesticides are not included in the database, because there are no such releases. Thus no Eco-indicator 95+ is calculated for this impact category.

The weighting factors for summarizing the greenhouse effect of various substances are updated with new results published by the Intergovernmental Panel on Climate Change[29] (IPCC 1996, p. 121). The formation of summer smog is calculated including NO_x. This approach is adapted to the special geographical situation in Switzerland were hydrocarbons are not the limiting substances for the formation of summer smog and NO_x plays a role for the smog formation (Frischknecht 1995).

The changes made it necessary to compute new normalization factors for these two effects. The normalization factors for heavy metals and carcinogens were also changed due to new information available (Schmucki 1996). Tab. 15 shows the normalization factors[30] and Tab. 16 shows the characterization factors used for the computation. Tab. 17 gives the figures for the total Eco-indicator 95+ points of each substance used in the inventory of ECOINVENT[31].

Tab. 15 Normalization factors used for calculating the Eco-indicator 95+

	Treibhaus-effekt 100a 1994	**Ozon-abbau**	**Versäuerung**	**Überdüngung**	**Schwer-metalle**	**Krebserre-gende Substanzen**	**Wintersmog**	**Photosmog inkl. NOx**
Normalization	**kg CO2-equiv.**	**R11-equiv.**	**kg SOx-equiv.**	**kg PO4-equiv.**	**Pb Equiv. kg**	**PAH Equiv. kg**	**SO2 Equiv. kg**	**kg Ethylen-equiv.**
Base ("f"):	7.76E+12	4.60E+08	5.60E+10	1.90E+10	1.00E+08	4.80E+07	4.70E+10	2.16E+10

Tab. 16 Characterization factors for the calculation of Eco-indicator 95+

		Treibhauseffekt 100a 1994	Ozonabba u	Versäuerun g	Überdüngun g	Schwer-metalle	Krebserregende Substanzen	Wintersmog	Photosmog inkl. NOx
	nit	kg CO2-equiv.	R11-equiv.	kg SOx-equiv.	kg PO4-equiv.	Pb Equiv. kg	PAH Equiv. kg	SO2 Equiv. kg	kg Ethylen-equiv.
1,1,1-Trichlorethan p	kg	100	0.12	0	0	0	0	0	0.021
Acetaldehyd s	kg	0	0	0	0	0	0	0	0.527
Aceton s	kg	0	0	0	0	0	0	0	0.178
Aldehyde p	kg	0	0	0	0	0	0	0	0.443
Alkane p	kg	0	0	0	0	0	0	0	0.398
Alkane s	kg	0	0	0	0	0	0	0	0.398
Alkene p	kg	0	0	0	0	0	0	0	0.906
Alkene s	kg	0	0	0	0	0	0	0	0.906
Ammoniak als N f	kg	0	0	0	0.4243	0	0	0	0
Ammoniak als N s	kg	0	0	0	0.4243	0	0	0	0

[29] The report is published on http://www.unep.ch/ipcc/ipcc-0.html and can also be ordered in this way.

[30] The figures calculated by Goedkoop (1995) for normalization factors were: greenhouse effect (Treibhauseffekt) = 6.50E+12 kg, heavy metals (Schwermetalle) = 2.70E+07 kg, cancerogenic substances (Krebserregende Substanzen) = 5.40E+06 kg, summer smog (Photosmog) = 8.90E+09 kg.

[31] Future users of this program should keep in mind to change also the corresponding values of Eco-indicator 95+ if the classification factors are updated due to new knowledge. This work can easily be done using the EXCEL-sheet ECOIND95+.XLS that contains all necessary computation routines. This file is stored at the ECOINVENT server in the directory ~/users/Alle/.

		Treibhauseffekt 100a 1994	Ozonabbau	Versäuerung	Überdüngung	Schwer-metalle	Krebserregende Substanzen	Wintersmog	Photosmog inkl. NOx
	nit	kg CO2-equiv.	R11-equiv.	kg SOx-equiv.	kg PO4-equiv.	Pb Equiv. kg	PAH Equiv. kg	SO2 Equiv. kg	kg Ethylen-equiv.
Aromaten p	kg	0	0	0	0	0	0.000011	0	0.761
Aromaten s	kg	0	0	0	0	0	0.000011	0	0.761
As Arsen m	kg	0	0	0	0	0	0.044	0	0
As Arsen p	kg	0	0	0	0	0	0.044	0	0
As Arsen s	kg	0	0	0	0	0	0.044	0	0
BaP Benzo(a)pyren m	kg	0	0	0	0	0	1	0	0
BaP Benzo(a)pyren p	kg	0	0	0	0	0	1	0	0
BaP Benzo(a)pyren s	kg	0	0	0	0	0	1	0	0
Benzaldehyd s	kg	0	0	0	0	0	0	0	-0.334
Benzol m	kg	0	0	0	0	0	0.000011	0	0.189
Benzol p	kg	0	0	0	0	0	0.000011	0	0.189
Benzol s	kg	0	0	0	0	0	0.000011	0	0.189
Butan p	kg	0	0	0	0	0	0	0	0.41
Butan s	kg	0	0	0	0	0	0	0	0.41
Buten p	kg	0	0	0	0	0	0	0	0.959
Cd Cadmium m	kg	0	0	0	0	50	0	0	0
Cd Cadmium p	kg	0	0	0	0	50	0	0	0
Cd Cadmium s	kg	0	0	0	0	50	0	0	0
CH3Br p	kg	0	0.6	0	0	0	0	0	0
CH4 Methan m	kg	21	0	0	0	0	0	0	0.007
CH4 Methan p	kg	21	0	0	0	0	0	0	0.007
CH4 Methan s	kg	21	0	0	0	0	0	0	0.007
CO2 Kohlendioxid m	kg	1	0	0	0	0	0	0	0
CO2 Kohlendioxid p	kg	1	0	0	0	0	0	0	0
CO2 Kohlendioxid s	kg	1	0	0	0	0	0	0	0
COD f	kg	0	0	0	0.022	0	0	0	0
COD s	kg	0	0	0	0.022	0	0	0	0
Dichlormethan p	kg	9	0	0	0	0	0	0	0.01
Ethan p	kg	0	0	0	0	0	0	0	0.082
Ethan s	kg	0	0	0	0	0	0	0	0.082
Ethanol p	kg	0	0	0	0	0	0	0	0.268
Ethanol s	kg	0	0	0	0	0	0	0	0.268
Ethen p	kg	0	0	0	0	0	0	0	1
Ethen s	kg	0	0	0	0	0	0	0	1
Ethylbenzol p	kg	0	0	0	0	0	0.000011	0	0.593
Ethylbenzol s	kg	0	0	0	0	0	0.000011	0	0.593
Formaldehyd p	kg	0	0	0	0	0	0	0	0.421
Formaldehyd s	kg	0	0	0	0	0	0	0	0.421
H 1211 Halon p	kg	4900	4	0	0	0	0	0	0
H 1301 Halon p	kg	5600	16	0	0	0	0	0	0
HCl Salzsaeure p	kg	0	0	0.88	0	0	0	0	0
HCl Salzsaeure s	kg	0	0	0.88	0	0	0	0	0
Heptan p	kg	0	0	0	0	0	0	0	0.529
Hexan p	kg	0	0	0	0	0	0	0	0.421
HF Fluorwasserstoff p	kg	0	0	1.6	0	0	0	0	0
HF Fluorwasserstoff s	kg	0	0	1.6	0	0	0	0	0
Hg Quecksilber m	kg	0	0	0	0	1	0	0	0
Hg Quecksilber p	kg	0	0	0	0	1	0	0	0
Hg Quecksilber s	kg	0	0	0	0	1	0	0	0
Ion Antimon Sb f	kg	0	0	0	0	2	0	0	0
Ion Arsen f	kg	0	0	0	0	1	0	0	0
Ion Arsen s	kg	0	0	0	0	1	0	0	0
Ion Barium f	kg	0	0	0	0	0.14	0	0	0
Ion Barium s	kg	0	0	0	0	0.14	0	0	0
Ion Blei f	kg	0	0	0	0	1	0	0	0
Ion Blei s	kg	0	0	0	0	1	0	0	0
Ion Bor f	kg	0	0	0	0	0.03	0	0	0
Ion Bor s	kg	0	0	0	0	0.03	0	0	0
Ion Cadmium f	kg	0	0	0	0	3	0	0	0
Ion Cadmium s	kg	0	0	0	0	3	0	0	0
Ion Chrom-III f	kg	0	0	0	0	0.2	0	0	0
Ion Chrom-III s	kg	0	0	0	0	0.2	0	0	0
Ion Chrom-VI f	kg	0	0	0	0	0.2	0	0	0
Ion Chrom-VI s	kg	0	0	0	0	0.2	0	0	0
Ion Mangan f	kg	0	0	0	0	0.02	0	0	0
Ion Mangan s	kg	0	0	0	0	0.02	0	0	0
Ion Molybdaen f	kg	0	0	0	0	0.14	0	0	0
Ion Molybdaen s	kg	0	0	0	0	0.14	0	0	0
Ion Nickel f	kg	0	0	0	0	0.5	0	0	0
Ion Nickel s	kg	0	0	0	0	0.5	0	0	0
Ion Quecksilber f	kg	0	0	0	0	10	0	0	0
Ion Quecksilber s	kg	0	0	0	0	10	0	0	0
LT Radio. Rn222	kBq	0	0	0	0	0	0	0	0
Methanol s	kg	0	0	0	0	0	0	0	0.123
Mn Mangan p	kg	0	0	0	0	1	0	0	0
Mn Mangan s	kg	0	0	0	0	1	0	0	0
N2O Lachgas m	kg	310	0	0	0	0	0	0	0
N2O Lachgas p	kg	310	0	0	0	0	0	0	0
N2O Lachgas s	kg	310	0	0	0	0	0	0	0
NH3 Ammoniak p	kg	0	0	1.88	0.3494	0	0	0	0
NH3 Ammoniak s	kg	0	0	1.88	0.3494	0	0	0	0
Ni Nickel m	kg	0	0	0	0	0	0.44	0	0
Ni Nickel p	kg	0	0	0	0	0	0.44	0	0
Ni Nickel s	kg	0	0	0	0	0	0.44	0	0
Nitrate p	kg	0	0	0	0.42	0	0	0	0

		Treibhauseffekt 100a 1994	Ozonabbau	Versäuerung	Überdüngung	Schwer-metalle	Krebserregende Substanzen	Wintersmog	Photosmog inkl. NOx
	nit	kg CO2-equiv.	R11-equiv.	kg SOx-equiv.	kg PO4-equiv.	Pb Equiv. kg	PAH Equiv. kg	SO2 Equiv. kg	kg Ethylen-equiv.
NMVOC m	kg	0	0	0	0	0	0	0	0.416
NMVOC p	kg	0	0	0	0	0	0	0	0.416
NMVOC s	kg	0	0	0	0	0	0	0	0.416
NOx Stickoxide als NO2 m	kg	0	0	0.7	0.13	0	0	0	0.754
NOx Stickoxide als NO2 p	kg	0	0	0.7	0.13	0	0	0	0.754
NOx Stickoxide als NO2 s	kg	0	0	0.7	0.13	0	0	0	0.754
PAH Polyzyklische aromatische HC p	kg	0	0	0	0	0	1	0	0
PAH Polyzyklische aromatische HC s	kg	0	0	0	0	0	1	0	0
Partikel m	kg	0	0	0	0	0	0	1	0
Partikel p	kg	0	0	0	0	0	0	1	0
Partikel s	kg	0	0	0	0	0	0	1	0
Pb Blei m	kg	0	0	0	0	1	0	0	0
Pb Blei p	kg	0	0	0	0	1	0	0	0
Pb Blei s	kg	0	0	0	0	1	0	0	0
Pentan p	kg	0	0	0	0	0	0	0	0.408
Pentane s	kg	0	0	0	0	0	0	0	0.408
Phosphate f	kg	0	0	0	1	0	0	0	0
Phosphate s	kg	0	0	0	1	0	0	0	0
Propan p	kg	0	0	0	0	0	0	0	0.42
Propan s	kg	0	0	0	0	0	0	0	0.42
Propen p	kg	0	0	0	0	0	0	0	1.03
Propen s	kg	0	0	0	0	0	0	0	1.03
Propionaldehyd s	kg	0	0	0	0	0	0	0	0.603
R11 FCKW p	kg	4000	1	0	0	0	0	0	0
R113 FCKW p	kg	5000	1.07	0	0	0	0	0	0
R114 FCKW p	kg	9300	0.8	0	0	0	0	0	0
R115 FCKW p	kg	9300	0.5	0	0	0	0	0	0
R12 FCKW p	kg	8500	1	0	0	0	0	0	0
R13 FCKW p	kg	11700	1.07	0	0	0	0	0	0
R134a FKW p	kg	1300	0	0	0	0	0	0	0
R141b H-FKW p	kg	630	0.11	0	0	0	0	0	0
R142b H-FKW p	kg	2000	0.065	0	0	0	0	0	0
R22 FCKW p	kg	1700	0.055	0	0	0	0	0	0
SF6 p	kg	23900	0	0	0	0	0	0	0
SOx als SO2 m	kg	0	0	1	0	0	0	1	0
SOx als SO2 p	kg	0	0	1	0	0	0	1	0
SOx als SO2 s	kg	0	0	1	0	0	0	1	0
Styrol p	kg	0	0	0	0	0	0	0	0.761
Tetrachlormethan p	kg	1400	1.08	0	0	0	0	0	0.021
Toluol p	kg	0	0	0	0	0	0	0	0.563
Toluol s	kg	0	0	0	0	0	0	0	0.563
Trichlormethan (Chloroform) p	kg	4	0	0	0	0	0	0	0
Xylole p	kg	0	0	0	0	0	0	0	0.849
Xylole s	kg	0	0	0	0	0	0	0	0.849

Tab. 17 Eco-indicator 95+ for various substances (E-09 points)

Stoff:	Eco-Indicator in E-09 Pt.	Stoff:	Eco-Indicator in E-09 Pt.	Stoff:	Eco-Indicator in E-09 Pt.
1,1,1-Trichlorethan p	2.6E+01	Ethylbenzol p	7.1E-02	Ni Nickel m	9.2E+01
Acetaldehyd s	6.1E-02	Ethylbenzol s	7.1E-02	Ni Nickel p	9.2E+01
Aceton s	2.1E-02	Formaldehyd p	4.9E-02	Ni Nickel s	9.2E+01
Aldehyde p	5.1E-02	Formaldehyd s	4.9E-02	Nitrate p	1.1E-01
Alkane p	4.6E-02	H 1211 Halon p	8.7E+02	NMVOC m	4.8E-02
Alkane s	4.6E-02	H 1301 Halon p	3.5E+03	NMVOC p	4.8E-02
Alkene p	1.0E-01	HCl Salzsaeure p	1.6E-01	NMVOC s	4.8E-02
Alkene s	1.0E-01	HCl Salzsaeure s	1.6E-01	NOx Stickoxide als NO2 m	2.5E-01
Ammoniak als N f	1.1E-01	Heptan p	6.1E-02	NOx Stickoxide als NO2 p	2.5E-01
Ammoniak als N s	1.1E-01	Hexan p	4.9E-02	NOx Stickoxide als NO2 s	2.5E-01
Aromaten p	9.0E-02	HF Fluorwasserstoff p	2.9E-01	PAH Polyzyklische aromatische HC p	2.1E+02
Aromaten s	9.0E-02	HF Fluorwasserstoff s	2.9E-01	PAH Polyzyklische aromatische HC s	2.1E+02
As Arsen m	9.2E+00	Hg Quecksilber m	5.0E+01	Partikel m	1.1E-01
As Arsen p	9.2E+00	Hg Quecksilber p	5.0E+01	Partikel p	1.1E-01
As Arsen s	9.2E+00	Hg Quecksilber s	5.0E+01	Partikel s	1.1E-01
BaP Benzo(a)pyren m	2.1E+02	Ion Antimon Sb f	1.0E+02	Pb Blei m	5.0E+01
BaP Benzo(a)pyren p	2.1E+02	Ion Arsen f	5.0E+01	Pb Blei p	5.0E+01
BaP Benzo(a)pyren s	2.1E+02	Ion Arsen s	5.0E+01	Pb Blei s	5.0E+01
Benzaldehyd s	-3.9E-02	Ion Barium f	7.0E+00	Pentan p	4.7E-02
Benzol m	2.4E-02	Ion Barium s	7.0E+00	Pentane s	4.7E-02
Benzol p	2.4E-02	Ion Blei f	5.0E+01	Phosphate f	2.6E-01
Benzol s	2.4E-02	Ion Blei s	5.0E+01	Phosphate s	2.6E-01
Butan p	4.7E-02	Ion Bor f	1.5E+00	Propan p	4.9E-02
Butan s	4.7E-02	Ion Bor s	1.5E+00	Propan s	4.9E-02
Buten p	1.1E-01	Ion Cadmium f	1.5E+02	Propen p	1.2E-01
Cd Cadmium m	2.5E+03	Ion Cadmium s	1.5E+02	Propen s	1.2E-01
Cd Cadmium p	2.5E+03	Ion Chrom-III f	1.0E+01	Propionaldehyd s	7.0E-02
Cd Cadmium s	2.5E+03	Ion Chrom-III s	1.0E+01	R11 FCKW p	2.2E+02
CH3Br p	1.3E+02	Ion Chrom-VI f	1.0E+01	R113 FCKW p	2.3E+02
CH4 Methan m	7.6E-03	Ion Chrom-VI s	1.0E+01	R114 FCKW p	1.8E+02
CH4 Methan p	7.6E-03	Ion Mangan f	1.0E+00	R115 FCKW p	1.1E+02
CH4 Methan s	7.6E-03	Ion Mangan s	1.0E+00	R12 FCKW p	2.2E+02
CO2 Kohlendioxid m	3.2E-04	Ion Molybdaen f	7.0E+00	R13 FCKW p	2.4E+02
CO2 Kohlendioxid p	3.2E-04	Ion Molybdaen s	7.0E+00	R134a FKW p	4.2E-01
CO2 Kohlendioxid s	3.2E-04	Ion Nickel f	2.5E+01	R141b H-FKW p	2.4E+01
COD f	5.8E-03	Ion Nickel s	2.5E+01	R142b H-FKW p	1.5E+01
COD s	5.8E-03	Ion Quecksilber f	5.0E+02	R22 FCKW p	1.3E+01
Dichlormethan p	4.1E-03	Ion Quecksilber s	5.0E+02	SF6 p	7.7E+00
Ethan p	9.5E-03	Methanol s	1.4E-02	SOx als SO2 m	2.8E-01
Ethan s	9.5E-03	Mn Mangan p	5.0E+01	SOx als SO2 p	2.8E-01
Ethanol p	3.1E-02	Mn Mangan s	5.0E+01	SOx als SO2 s	2.8E-01
Ethanol s	3.1E-02	N2O Lachgas m	1.0E-01	Tetrachlormethan p	2.4E+02
Ethen p	1.2E-01	N2O Lachgas p	1.0E-01	Toluol p	6.5E-02
Ethen s	1.2E-01	N2O Lachgas s	1.0E-01	Toluol s	6.5E-02
		NH3 Ammoniak p	4.3E-01	Trichlormethan (Chloroform) p	1.3E-03
		NH3 Ammoniak s	4.3E-01	Xylole p	9.8E-02
				Xylole s	9.8E-02

6.3 Emission figures used in the LCI

Tab. 18 Emission data for wood-stoves from different surveys (mg/Nm³)

	EM 1995	EPA 1992	EPA 1992	Fischedick 1993	TEMIS 2.1	Kleeman 1992	Joshi et al. 1989 (impr,konv)	Joshi et al. 1989 (impr)	FAO 1993	Richter 1995 (min.)	Richter 1995 (max.)	TERI 1987 3 stone	TERI 1987 Floor
SO2 :	77	-	-	-	-	37							
NOx :	119	-	-	299	150	186							
Fly Ash :	2 868	-	-	484	100	2230	368	543	1.5				
CO :	1 000	19376	19182	19893	2200		3294	12013	15113	11626	23251	20151	12594
CH4 :	119	1744	1550	2067	590								
NMVOC :	119	2519	2325	1620	880	372				5813	23251	16082	
N2O :	48	12	12	-	30								
CO2 :	344 300	313890	302264	312598	-					193759	280951	254212	232511

EM 1995 — *Environmental Manual for Power Development - Data Sources and Data Compilation*. Version 1.00, Computer program prepared by Öko-Institut for GTZ, Darmstadt, FTP[32]: cserv.usf.uni-kassel.de, Login: anonymous, Directory: /pub/em, Files: *.zip, ctober 1995

EPA 1992 — US Environmental Protection Agency, *Greenhouse Gases from small-scale Combustion in Developing Countries - A pilot study in* Manila. K.R. Smith et al., January 1992

FA 1993 — *Regional wood energy development programmme in Asia: India improved cookstoves*. A compendium, Field doc. No. 41, FA Bangkok 07/1993

Fischedick 1993 — Fischedick, Brigitte 1993: *Umweltverträglichkeitsstudie über den Einsatz verbesserter Herde in den Sahelländern Mali und Niger*. für die Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), by Environmental Concept, Berlin

Joshi et al. 1989 — Joshi, V, Venkataraman, C, Ahuja, D R: *Emission from Burning Biofuels in Metal Cookstoves*. Environmental Management, Vol. 13 (6), 1989, Springer International

Kleeman 1992 — Kleeman, BPPT/KFA (Badan Pengkajian Dan Penerapan Teknologi/Forschungszentrum Jülich), *Environmental Impacts of Energy Strategies for Indonesia - Emission coefficients and Spatial Distribution of Emission Sources*. IC Consult Report for the Indonesian-German Research Project

TEMIS 2.1 — *Total Emission Model of Integrated Systems*. Version 2.1, Program and database prepared by the Öko-Institute and the University of Kassel, FTP: *cserv.usf.uni-kassel.de*, Login: *anonymous*, Directory: */pub/envsys*, Files: *.*, March 1995

TERI 1987 — TATA Energy Research Institute, *Evaluation of Performance of Cookstoves in Regard to Thermal Efficiency and Emissions from Combustion.* Final project Report submitted to the Ministry of Environment, Forests & Wildlife, Government of India, New Delhi

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[32] FTP - File transfer program, This database is available as a free software on the INTERNET by using the described ftp-server (Command: *ftp ftp.cserv.usf.uni-kassel.de*)

6.4 Input of data to ECOINVENT

6.4.1 Additional Modules for ECOINVENT

Two new categories are implemented in ECOINVENT for this report. „Allgemeine Dienstleisungen Handel“ (CatId = 34) concludes all modules of distribution stages in the life-cycle. Modules for end uses in households are implemented in „Endverbrauch Haushalt“ (CatId = 35).

All new modules created and investigated for this survey are listed in Tab. 20. The first two modules are these necessary for describing the distribution. The following „Infra“ modules describe the infrastructure that means here the stove itself. All „energy in stove“ modules describe the transformation of an energy carrier to heat. Modules starting with „Nutzwaerme ab ..“ are used to include the efficiency of this transformation in the calculations. Tab. 19 gives an overview of new modules implemented in ECOINVENT for the calculation of Eco-indicators 95+.

Tab. 19 New modules in ECOINVENT for the calculation of Eco-indicator 95+

CatId	MName	Unit	Clarific	Technology	TechnTime	TechnLevel	Geography	MarketShare	Reference
-5	EI Ueberduengung	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Krebserregende Substanzen	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Ozonabbau	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Pestizide	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Photosmog	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Schwermetalle	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Treibhauseffekt	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Versauerung	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Wintersmog	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Pestizide	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen
-5	EI Total	E-09 Pts.	Eco-indicator 95 + Ergänzungen				Europe		ESU-Arbeitspapier Kochen

Tab. 20 Input of new modules to ECOINVENT for the life-cycle-inventory-analysis

CatId	MName	Unit	Clarific	Technology	TechnTime	TechnLevel	Geography
34	Kerosin an Haushalt CH	TJ		Distribution fuels	1996	average	CH
34	Propan/ Butan an Haushalt CH	TJ		Distribution fuels	1996	average	CH
35	Erdgas in Gasherd	TJ		Cookstove combustion	1995	average	CH
35	Fluessiggas in Fluessiggasherd	TJ		Cookstove combustion	1995	average	CH
35	Kerosin in Petroleumkocher	TJ		Cookstove combustion	1995	average	CH
35	Strom in Mikrowelle CH	TJ		Cookstove combustion	1996	average	CH
35	Strom in Elektroherd CH	TJ		Cookstove combustion	1996	average	CH
35	Strom in Elektroherd W-D	TJ		Cookstove combustion	1996	average	D
35	Stueckholz in Holzherd	TJ		Cookstove combustion	1995	average	CH
35	Stueckholz in 3 Steinefeuer	TJ		Cookstove combustion	1996	average	CH
35	Infra Elektroherd	TJ		Material cookstove	1995	average	CH
35	Infra Gasherd	TJ		Material cookstove	1995	average	CH
35	Infra Holzherd	TJ		Material cookstove	1995	average	CH
35	Infra Petroleumkocher	TJ		Material cookstove	1995	average	CH
35	Infra Mikrowelle	TJ		Material cookstove	1996	average	CH
35	Nutzwaerme ab 3 Steinefeuer	TJ		Cookstove efficiency	1995	average	CH
35	Nutzwaerme ab Elektroherd CH	TJ		Cookstove efficiency	1996	average	CH
35	Nutzwaerme ab Elektroherd W-D	TJ		Cookstove efficiency	1996	average	D
35	Nutzwaerme ab Fluessiggasherd	TJ		Cookstove efficiency	1996	average	CH
35	Nutzwaerme ab Gasherd	TJ		Cookstove efficiency	1996	average	CH
35	Nutzwaerme ab Holzherd	TJ		Cookstove efficiency	1995	average	CH
35	Nutzwaerme ab Petroleumkocher	TJ		Cookstove efficiency	1995	average	CH
35	Nutzwaerme ab Mikrowelle CH	TJ		Cookstove efficiency	1996	average	CH

6.4.2 Inventory and Inputs to ECOINVENT

Tab. 21 Input of LCI data to ECOINVENT

MName		Propan/ Butan an Haushalt CH	Kerosin an Haushalt CH	Infra Gasherd	Infra Elektroherd	Infra Mikrowelle	Infra Holzherd	Infra Petroleumkocher	Erdgas in Gasherd	Fluessiggas in Fluessiggasherd	Kerosin in Petroleumkocher	Strom in Elektroherd CH	Strom in Mikrowelle CH	Strom in Elektroherd W-D	Stueckholz in Holzherd	Stueckholz in 3 Steinefeuer
	Unit	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Abwaerme in Luft p	TJ	2.01E-03	0.00E+00	1.00E-03	1.00E-03	1.67E-03	4.76E-04	2.50E-04	9.52E-03						1.38E-02	1.38E-02
Abwaerme in Luft s	TJ	0.00E+00	0.00E+00	1.17E-03	1.17E-03	1.94E-03	5.56E-04	2.92E-04	1.11E+00	1.09E+00	1.07E+00	1.00E+00	1.00E+00	1.00E+00	1.13E+00	1.13E+00
Acetaldehyd s	kg								1.00E-03	1.00E-03	2.46E-01				1.34E+00	1.71E+01
Aceton s	kg										6.00E-01					
Acrolein s	kg										4.60E-02					
Alkane s	kg										3.00E+00				2.01E+01	2.57E+02
Alkene s	kg										2.40E-01				6.48E+01	8.27E+02
Aluminium 0% Rec.	kg			8.33E-01	8.33E-01	1.39E+00	4.41E-01	0.00E+00								
Aluminium95: in KVA	kg			8.33E-01	8.33E-01	1.39E+00	4.41E-01	0.00E+00								
Aromaten s	kg										2.40E-01					
BaP Benzo(a)pyren s	kg								1.00E-05	1.00E-05					1.30E-04	1.66E-03
Benzaldehyd s	kg										7.20E-02					
Benzol s	kg								4.02E-01	4.02E-01	2.40E-01				2.01E+01	2.57E+02
Butan p	TJ	3.33E+01														
Butan s	kg	0.00E+00							1.11E+00	1.11E+00	1.80E+00					
Cd Cadmium s	kg														5.18E-05	5.18E-05
CH4 Methan s	kg								5.00E-01	0.00E+00	1.15E+01				1.50E+02	5.00E+02
CO Kohlenmonoxid s	kg								2.50E+01	2.50E+01	5.73E+02				5.00E+03	8.00E+03
CO2 Kohlendioxid s	kg								5.55E+04	6.36E+04	7.34E+04				9.59E+04	9.59E+04
Cr Chrom s	kg														1.62E-01	1.62E-01
Cu Kupfer s	kg										1.00E-03				3.24E-02	3.24E-02
Deckfarbe	kg			6.67E+01	6.67E+01	4.63E+01	3.17E+01	0.00E+00								
Deckfarbe in Inertstoffdeponie	kg			6.67E+01	6.67E+01	4.63E+01	3.17E+01	0.00E+00								
Diesel in Baumaschine	TJ			1.17E-03	1.17E-03	1.94E-03	5.56E-04	2.92E-04							4.65E-03	4.65E-03
Erdgas in Gasherd	TJ															
Erdgas in Industriefeuerung >100kW Euro	TJ														7.96E-06	7.96E-06
Erdgas ND-Abnehmer CH	TJ								1.00E+00							
Essigsaeure s	kg								1.51E-01	1.51E-01						
Ethan s	kg										2.40E-01					
Ethen s	kg										6.00E-01					
Ethin s	kg										1.20E-01					
Ethylbenzol s	kg														6.70E-01	8.55E+00
Flaeche II-IV	m2a	5.23E+00	6.24E-01													
Fluessiggas in Fluessiggasherd	TJ															
Formaldehyd s	kg								2.00E-01	2.00E-01	7.20E-02				2.68E+00	3.42E+01
Glas (Flach-) beschichtet	kg			5.56E+01	5.56E+01	4.63E+01	4.41E+00	0.00E+00								
Glas95: in KVA	kg			5.56E+01	5.56E+01	4.63E+01	4.41E+00	0.00E+00								
HCl Salzsaeure s	kg										9.40E-02				1.10E+00	1.10E+00
HF Fluorwasserstoff s	kg										9.00E-03				3.24E-02	3.24E-02
Hg Quecksilber s	kg								5.50E-05	5.50E-05	5.00E-04					
Holzasche gemischt in KVA	kg														1.26E+02	1.26E+02
Infra Elektroherd	TJ											1.00E+00		1.00E+00		
Infra Gasherd	TJ								1.00E+00	1.00E+00						
Infra Holzherd	TJ														1.00E+00	
Infra Mikrowelle	TJ												1.00E+00			
Infra Petroleumkocher	TJ										1.00E+00					
Karton (Verpackungs-)	kg			3.70E+01	3.70E+01	9.26E+01	1.76E+01	1.16E+01								
Karton in KVA	kg			3.70E+01	3.70E+01	9.26E+01	1.76E+01	1.16E+01								
Keramik	kg						1.32E+02									
Kerosin ab Regionallager CH	t		2.33E+01													
Kerosin an Haushalt CH	TJ										1.00E+00					
Kerosin in Petroleumkocher	TJ															
Kupfer	kg			1.67E+00	1.67E+00	2.31E+00	8.82E-01	0.00E+00								
Kupfer in Inertstoffdeponie	kg			1.67E+00	1.67E+00	2.31E+00	8.82E-01	0.00E+00								
Leckage Erdgas Schweiz Hochdruck	m3								5.50E+01							
Mineralwolle	kg			1.02E+01	1.02E+01	9.26E+00	1.32E+01	0.00E+00								
Mineralwolle in Inertstoffdeponie	kg			1.02E+01	1.02E+01	9.26E+00	1.32E+01	0.00E+00								
Mn Mangan s	kg														1.68E-01	1.68E-01
N2O Lachgas s	kg								5.00E-01	5.00E-01	8.60E-01				2.00E+00	1.00E+01
NH3 Ammoniak s	kg														9.07E+00	9.07E+00
NMVOC s	kg										1.32E+02				2.60E+00	2.60E+00
NOx Stickoxide als NO2 s	kg								2.60E+01	2.60E+01	7.17E+01				1.00E+02	1.00E+02
PAH Polyzyklische aromatische HC s	kg								1.00E-02	1.00E-02	1.38E+00					
Partikel s	kg								1.00E-01	1.00E-01	8.60E+00				8.00E+01	3.00E+02
Pb Blei s	kg														1.94E-02	1.94E-02
PE in KVA	kg		1.19E+03													
Pentane s	kg								1.61E+00	1.61E+00	1.20E+00					
PET 0% Rec.	kg		1.19E+03													
Polystyrol EPS	kg			9.26E+00	9.26E+00	2.31E+01	4.41E+00	0.00E+00								
Propan p	TJ	3.33E+01														
Propan s	kg	0.00E+00							5.02E-01	5.02E-01	3.60E-01					
Propan/ Butan ab Raffinerie CH	t	2.22E+01														
Propan/ Butan an Haushalt CH	TJ									1.00E+00						
Propen s	kg										8.00E-02					
Propionaldehyd s	kg										7.20E-02					
Propionsaeure s	kg								2.01E-02	2.01E-02						
PS95: in KVA	kg			9.26E+00	9.26E+00	2.31E+01	4.41E+00	0.00E+00								
PVC in KVA	kg			1.11E+00	1.11E+00	4.63E+00	8.82E-01	0.00E+00								
PVC schlagfest	kg			1.11E+00	1.11E+00	4.63E+00	8.82E-01	0.00E+00								
SOx als SO2 s	kg								5.00E-01	1.00E+00	9.30E+01				2.07E+01	2.07E+01
Stahl in KVA	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00								
Stahl niedriglegiert	kg	2.57E+02	4.31E+00	3.95E+02	3.95E+02	6.94E+02	6.61E+02	1.74E+01								
Strom in Elektroherd CH	TJ															
Strom in Elektroherd W-D	TJ															
Strom in Mikrowelle CH	TJ															
Strom Niederspannung - Bezug in CH	TJ	2.01E-03		1.00E-03	1.00E-03	1.67E-03	4.76E-04	2.50E-04	9.52E-03			1.00E+00	1.00E+00			
Strom Niederspannung - Bezug in W-D	TJ													1.00E+00		
Stueckholz frei Lager	t														5.41E+01	5.41E+01
Stueckholz in 3 Steinefeuer	TJ															
Stueckholz in Holzherd	TJ															
TCDD-Aequivalente	ng								3.00E+01	3.00E+01	5.70E+01				1.75E+04	1.75E+04
Toluol s	kg								2.01E-01	2.01E-01	1.20E-01				6.70E+00	8.55E+01
Transport Hochseefrachter Container tkm	tkm			0.00E+00	0.00E+00	9.23E+03	0.00E+00	0.00E+00								
Transport LKW 28 t	tkm	6.81E+03	2.45E+03	2.90E+01	2.90E+01	4.61E+01	4.34E+01	1.45E+00							1.19E-01	1.19E-01
Transport Schiene	tkm			1.16E+02	1.16E+02	1.85E+02	1.74E+02	5.79E+00							6.37E-01	6.37E-01
Xylole s	kg														2.68E+00	3.42E+01
Zement	kg	2.18E+01	1.05E+01													
Zink fuer Verzinkung	kg			1.85E+00	1.85E+00	2.31E+00	8.82E-01	0.00E+00								
Zn Zink s	kg										7.00E-04				1.94E-01	1.94E-01

6.5 Environmental Profile for the Modules Investigated

Tab. 22 Results of the LCA for Eco-indicators

		EI Ueberduengung	EI Krebserregende	EI Ozonabbau	EI Pestizide	EI Photosmog	EI Schwermetall	EI Treibhauseffekt	EI Versauerung	EI Wintersmog	EI Total
		E-09 Pts.	E-09 Pts.	E-09 Pts.	E-09	E-09 Pts.	E-09 Pts.	E-09 Pts.	E-09 Pts.	E-09 Pts.	E-09 Pts.
Kerosin an Haushalt CH	TJ	2.79	3.74	38.2	0	20.5	45.4	6.94	22.8	8.92	149
Propan/ Butan an Haushalt CH	TJ	2.51	3.51	34.7	0	19	29.1	5.7	21	8.66	124
Erdgas in Gasherd	TJ	2.01	3.07	1.84	0	7.56	8.32	23.5	13.1	4.4	63.8
Fluessiggas in Fluessiggasherd	TJ	3.54	6.11	35	0	21.9	33.8	26.6	25.7	9.74	162
Infra Elektroherd	TJ	0.137	0.524	0.279	0	0.379	4.74	0.421	1.22	0.973	8.66
Infra Gasherd	TJ	0.137	0.524	0.279	0	0.379	4.74	0.421	1.22	0.973	8.66
Infra Holzherd	TJ	0.143	0.771	0.246	0	0.37	6.3	0.551	1.38	1.36	11.1
Infra Mikrowelle	TJ	0.296	0.89	0.746	0	0.831	7.41	0.735	2.59	1.86	15.4
Infra Petroleumkocher	TJ	0.0164	0.0222	0.0192	0	0.0454	0.174	0.0242	0.0957	0.0527	0.45
Kerosin in Petroleumkocher	TJ	5.26	291	38.2	0	33.6	45.6	30.8	48.5	19.7	512
Nutzwaerme ab 3 Steinefeuer	TJ	33.2	7.12	5.06	0	856	70.5	29	151	231	1380
Nutzwaerme ab Elektroherd CH	TJ	1.31	4.51	18.8	0	3.85	36.2	5.6	22.6	13.4	106
Nutzwaerme ab Elektroherd W-D	TJ	17	9.42	16.7	0	39.9	219	110	330	180	922
Nutzwaerme ab Fluessiggasherd	TJ	6.08	10.5	60.1	0	37.6	58.2	45.8	44.1	16.8	279
Nutzwaerme ab Gasherd	TJ	3.46	5.27	3.16	0	13	14.3	40.5	22.5	7.56	110
Nutzwaerme ab Holzherd	TJ	7.31	1.37	1.44	0	30.2	24.1	2.47	34.2	18.1	119
Nutzwaerme ab Mikrowelle CH	TJ	2.39	7.81	30.2	0	6.98	62.1	9.4	38.1	22.8	180
Nutzwaerme ab Petroleumkocher	TJ	9.74	538	70.8	0	62.1	84.4	56.9	89.7	36.5	948
Strom in Elektroherd CH	TJ	0.917	3.15	13.1	0	2.69	25.3	3.92	15.8	9.36	74.3
Strom in Elektroherd W-D	TJ	11.9	6.59	11.7	0	27.9	153	76.6	231	126	645
Strom in Mikrowelle CH	TJ	1.08	3.52	13.6	0	3.14	28	4.23	17.2	10.3	81
Stueckholz in 3 Steinefeuer	TJ	4.97	1.07	0.758	0	128	10.6	4.35	22.6	34.7	207
Stueckholz in Holzherd	TJ	5.12	0.96	1	0	21.2	16.9	1.73	23.9	12.7	83.5

Tab. 23 Impact score profile after the characterization step

		Flaechenin-anspruch-nahme	Bedarf erneuer-barer energe-tischer Res-sourcen	Bedarf nicht-erneuer-barer energe-tischer Res-sourcen	Res-sourcen-abbau	Treibhaus-effekt 20a 1994	Treibhaus-effekt 100a 1994	Treibhaus-effekt 500a 1994	Ozonabbau	Photosmog	Photosmog inkl. NOx	Versaeuerung
		m2a	MJ	MJ	-	kg CO2-equiv.	kg CO2-equiv.	kg CO2-equiv.	R11-equiv.	kg Ethylen-equiv.	kg Ethylen-equiv.	kg SOx-equiv.
Kerosin an Haushalt CH	TJ	1.06E+03	3.74E+03	1.41E+06	2.93E-10	2.56E+04	2.16E+04	1.98E+04	0.176	121	177	127
Propan/ Butan an Haushalt CH	TJ	949	4.94E+03	1.28E+06	2.68E-10	2.14E+04	1.77E+04	1.61E+04	0.159	114	165	117
Erdgas in Gasherd	TJ	626	1.22E+04	1.31E+06	4.00E-10	8.71E+04	7.31E+04	6.72E+04	0.00845	22	65.4	73.3
Fluessiggas in Fluessiggasherd	TJ	974	7.98E+03	1.31E+06	3.41E-10	8.66E+04	8.28E+04	8.10E+04	0.161	117	189	143
Infra Elektroherd	TJ	25	3.04E+03	2.42E+04	7.29E-11	1.47E+03	1.31E+03	1.23E+03	0.00128	0.779	3.28	6.8
Infra Gasherd	TJ	25	3.04E+03	2.42E+04	7.29E-11	1.47E+03	1.31E+03	1.23E+03	0.00128	0.779	3.28	6.8
Infra Holzherd	TJ	24.6	1.97E+03	3.07E+04	3.86E-11	1.96E+03	1.71E+03	1.60E+03	0.00113	0.738	3.2	7.7
Infra Mikrowelle	TJ	42.3	6.20E+03	4.20E+04	6.89E-11	2.57E+03	2.28E+03	2.15E+03	0.00343	1.55	7.19	14.5
Infra Petroleumkocher	TJ	2.75	704	1.69E+03	1.04E-12	83.3	75.1	71.3	8.83E-05	0.0688	0.393	0.535
Kerosin in Petroleumkocher	TJ	1.07E+03	4.45E+03	1.42E+06	2.94E-10	1.00E+05	9.55E+04	9.35E+04	0.176	180	291	271
Nutzwaerme ab 3 Steinefeuer	TJ	2.72E+03	8.79E+06	1.96E+05	4.83E-11	2.05E+05	9.00E+04	3.19E+04	0.0232	6.79E+03	7.40E+03	843
Nutzwaerme ab Elektroherd CH	TJ	8.85E+03	1.30E+06	2.53E+06	4.40E-09	1.83E+04	1.74E+04	1.57E+04	0.0864	9.84	33.3	126
Nutzwaerme ab Elektroherd W-D	TJ	7.33E+03	1.51E+05	5.72E+06	3.87E-09	3.64E+05	3.40E+05	3.29E+05	0.0767	28.9	345	1.85E+03
Nutzwaerme ab Fluessiggasherd	TJ	1.67E+03	1.37E+04	2.25E+06	5.86E-10	1.49E+05	1.42E+05	1.39E+05	0.276	201	325	247
Nutzwaerme ab Gasherd	TJ	1.08E+03	2.09E+04	2.26E+06	6.88E-10	1.50E+05	1.26E+05	1.16E+05	0.0145	37.8	112	126
Nutzwaerme ab Holzherd	TJ	618	1.89E+06	8.58E+04	6.56E-11	1.56E+04	7.67E+03	3.94E+03	0.0066	128	261	192
Nutzwaerme ab Mikrowelle CH	TJ	1.38E+04	2.02E+06	3.97E+06	6.82E-09	3.09E+04	2.92E+04	2.65E+04	0.139	17	60.4	213
Nutzwaerme ab Petroleumkocher	TJ	1.97E+03	8.23E+03	2.62E+06	5.45E-10	1.85E+05	1.77E+05	1.73E+05	0.325	332	537	502
Strom in Elektroherd CH	TJ	6.19E+03	9.08E+05	1.77E+06	3.08E-09	1.28E+04	1.22E+04	1.10E+04	0.0604	6.88	23.3	88.3
Strom in Elektroherd W-D	TJ	5.12E+03	1.05E+05	4.00E+06	2.71E-09	2.55E+05	2.38E+05	2.30E+05	0.0536	20.2	242	1.29E+03
Strom in Mikrowelle CH	TJ	6.20E+03	9.11E+05	1.79E+06	3.07E-09	1.39E+04	1.31E+04	1.19E+04	0.0626	7.66	27.2	96
Stueckholz in 3 Steinefeuer	TJ	408	1.32E+06	2.94E+04	7.24E-12	3.08E+04	1.35E+04	4.79E+03	0.00349	1.02E+03	1.11E+03	126
Stueckholz in Holzherd	TJ	433	1.32E+06	6.00E+04	4.59E-11	1.09E+04	5.37E+03	2.76E+03	0.00462	89.4	183	134

		Ueber-duengung	Aqua-tische Oeko-toxizitaet	Terres-trische Oeko-toxizitaet	Human-toxizitaet Luft	Human-toxizita et Wasser	Human-toxizitaet Boden	Radio-aktivitaet	Abwaerme	Geruch	Schwer-metalle	Krebs-erregende Substanzen	Wintersmog
		kg PO4-equiv.	10E6 m3	kg	kg	kg	kg	kBq	TJ	m3 air	Pb Equiv. kg	PAH Equiv. kg	SO2 Equiv. kg
Kerosin an Haushalt CH	TJ	10.6	7.92	0.0795	273	0.81	0.000631	4.34E+06	0.302	3.76E+10	0.908	0.018	84.2
Propan/ Butan an Haushalt CH	TJ	9.54	2.56	0.0723	238	0.681	0.000547	3.89E+06	0.262	7.12E+10	0.582	0.0168	81.7
Erdgas in Gasherd	TJ	7.66	0.447	0.0298	174	0.118	0.000161	4.63E+06	1.28	1.66E+12	0.166	0.0147	41.5
Fluessiggas in Fluessiggasherd	TJ	13.4	2.69	0.0727	342	0.729	0.000552	4.77E+06	1.37	1.51E+11	0.677	0.0294	91.9
Infra Elektroherd	TJ	0.52	0.132	0.000378	80.7	0.0479	5.61E-06	8.80E+05	0.0175	6.91E+10	0.0947	0.00252	9.18
Infra Gasherd	TJ	0.52	0.132	0.000378	80.7	0.0479	5.61E-06	8.80E+05	0.0175	6.91E+10	0.0947	0.00252	9.18
Infra Holzherd	TJ	0.542	0.189	0.000367	55.7	0.0728	4.00E-06	8.17E+05	0.0193	1.12E+11	0.126	0.0037	12.8
Infra Mikrowelle	TJ	1.12	0.241	0.000741	84.7	0.084	1.01E-05	1.40E+06	0.0294	1.21E+11	0.148	0.00427	17.6
Infra Petroleumkocher	TJ	0.0622	0.00785	3.37E-05	1.2	0.0024	5.43E-07	1.06E+05	0.00137	3.49E+09	0.00348	0.000107	0.498
Kerosin in Petroleumkocher	TJ	20	7.93	0.0796	453	0.812	0.000632	4.44E+06	1.37	9.72E+11	0.912	1.4	186
Nutzwaerme ab 3 Steinefeuer	TJ	126	1.08	0.0101	8.95E+03	0.135	9.84E-05	8.15E+05	0.489	4.23E+14	1.41	0.0342	2.18E+03
Nutzwaerme ab Elektroherd CH	TJ	4.98	1.09	0.00719	625	0.454	9.45E-05	4.80E+08	2.26	2.52E+11	0.724	0.0216	126
Nutzwaerme ab Elektroherd W-D	TJ	64.8	8.02	0.0204	3.03E+03	6.04	0.000181	3.67E+08	5.37	1.11E+12	4.38	0.0452	1.70E+03
Nutzwaerme ab Fluessiggasherd	TJ	23.1	4.63	0.125	589	1.25	0.00095	8.21E+06	2.36	2.59E+11	1.16	0.0505	158
Nutzwaerme ab Gasherd	TJ	13.2	0.768	0.0513	299	0.203	0.000277	7.96E+06	2.2	2.86E+12	0.286	0.0253	71.3
Nutzwaerme ab Holzherd	TJ	27.8	0.502	0.00269	505	0.133	2.68E-05	1.34E+06	0.132	7.31E+12	0.482	0.00659	171
Nutzwaerme ab Mikrowelle CH	TJ	9.08	1.94	0.012	979	0.785	0.000157	7.47E+08	3.54	5.08E+11	1.24	0.0375	215
Nutzwaerme ab Petroleumkocher	TJ	37	14.7	0.147	837	1.5	0.00117	8.22E+06	2.54	1.80E+12	1.69	2.59	345
Strom in Elektroherd CH	TJ	3.48	0.763	0.00503	437	0.318	6.61E-05	3.36E+08	1.58	1.76E+11	0.506	0.0151	88.3
Strom in Elektroherd W-D	TJ	45.3	5.61	0.0142	2.12E+03	4.22	0.000127	2.57E+08	3.76	7.79E+11	3.06	0.0316	1.19E+03
Strom in Mikrowelle CH	TJ	4.09	0.872	0.00539	441	0.354	7.06E-05	3.36E+08	1.59	2.29E+11	0.56	0.0169	96.7
Stueckholz in 3 Steinefeuer	TJ	18.9	0.162	0.00152	1.34E+03	0.0202	1.48E-05	1.22E+05	0.0732	6.34E+13	0.212	0.00513	327
Stueckholz in Holzherd	TJ	19.4	0.351	0.00188	353	0.093	1.88E-05	9.39E+05	0.0925	5.12E+12	0.338	0.00461	120

Tab. 24 Results of the life-cycle-inventory-analysis computation with ECOINVENT for all investigated environmental impacts (See following pages)