What users can save with energy-efficient cooking stoves and ovens

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1. Introduction to residential cooking technology

Cooking is the most universal residential energy service. It is responsible for around 5% of all greenhouse-gas emissions worldwide, which is about 2 billion tonnes of CO2 equivalent emissions per year. Around three quarters of this is due to inefficient biomass or coal-based cooking in developing countries. Around 50% of energy for this solid-fuel cooking could be saved with very low costs and high net benefits. Switching to energy-efficient and low-carbon modern cooking appliances may allow even higher savings but at higher costs.

Due to their importance for energy efficiency improvements relative to other cooking technologies, we focus on two types of cooking appliances:

- Improved biomass cooking stoves to replace three-stone fires or inefficient stoves using biomass (e.g. wood or crop residues)
- Improved electric and gas cookers (hobs and ovens)

Residential cooking stoves and ovens are used by households for cooking and baking food. A broad range of different technologies and designs are used for cooking in the world today. Whilst the most basic way of cooking or heating food - above an open fire fuelled by biomass - is still predominant in many developing countries, in industrialised countries sophisticated stoves or cookers prevail, which use electricity or gas to deliver the required heat for the cooking process. Figure 1 overleaf presents the calculated shares of different fuels in the total worldwide fuel consumption for cooking, reflecting not only numbers of households using the different fuels but also the different energy efficiency of cooking with these fuels.

The assumable most environmentally friendly way of cooking is based on the use of renewable energies as primary energy source for cooking, as is the case with sustainably produced biogas from organic waste matter (including manure and sewage) or solar cooking stoves for instance. However, these solutions are not feasible or attractive to households everywhere, and particularly solar cooking stoves have not distributed well in the past. Natural gas and petroleum gas (LPG) will in most situations be the next best alternative in terms of primary energy and greenhouse gas emissions, preferable over electricity unless the latter is predominantly produced from renewable energies in a country or region.

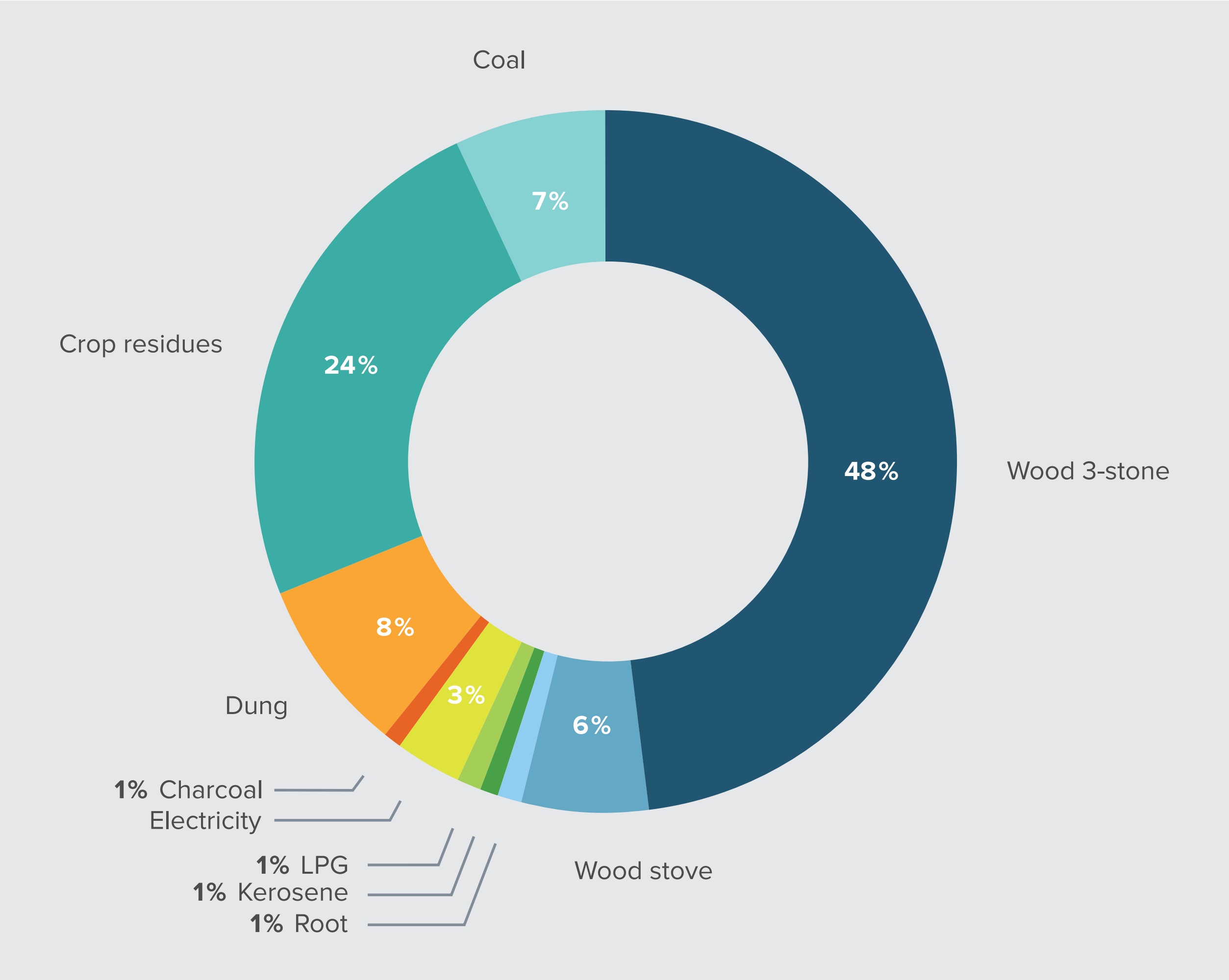


Figure 1: The relative shares in fuel consumption for cooking of different fuels worldwide

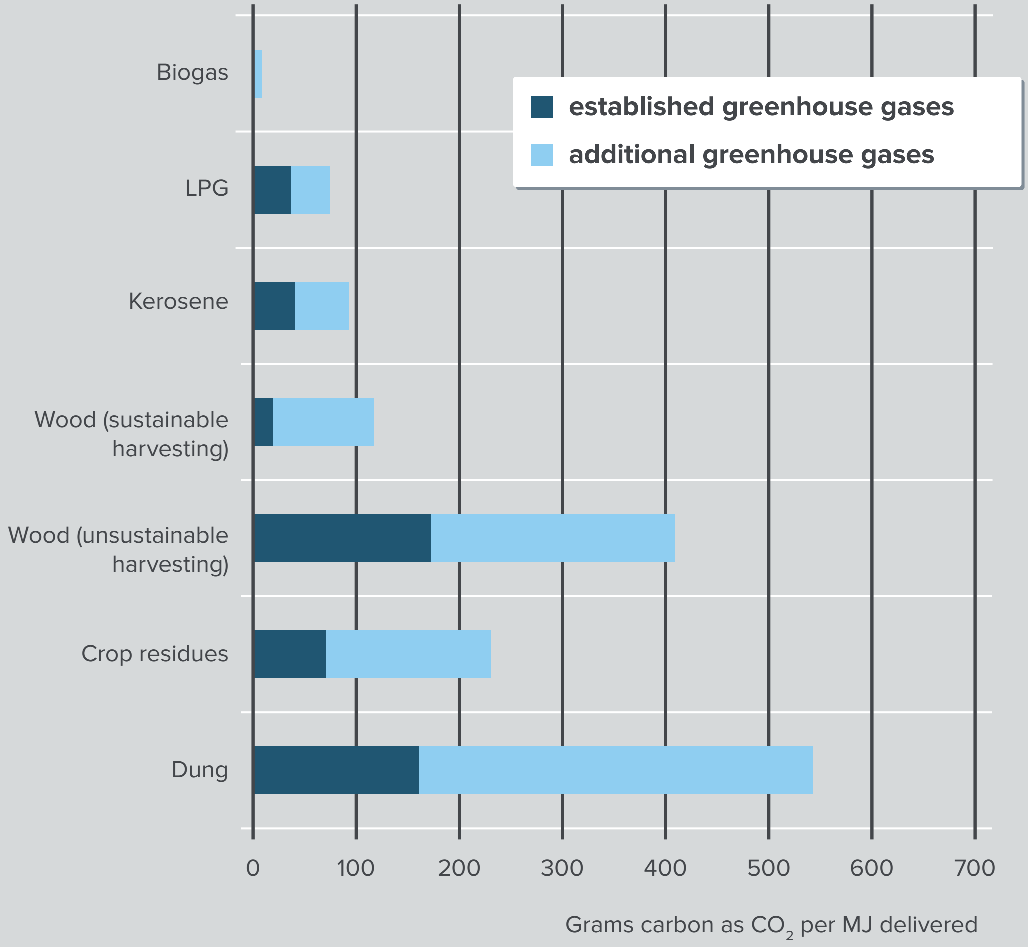
Source: Grupp 2004

Designs and technologies for cooking stoves differ largely worldwide and range from simple three-stone cooking stoves fuelled by biomass to highly sophisticated stoves using induction technology powered by electricity. The predominant type of cooking stove is still the wood fuelled three-stone stove. Other fuel types often used in developing countries are crop residues, coal and dung. More convenient cooking fuelled by LPG, kerosene or electricity often remains a privilege for households from urban areas and developed countries. In addition, these households often have the opportunity to cook or bake with more specific cooking devices such as microwaves, grills or rice cookers, which exist next to or as an integrative part of their sophisticated cooking ranges. In addition to different stove designs and fuels, households use different equipment such as pans, pots and so on to prepare their food depending on prevailing customs and cultures. Due to the large variation of different stove designs and equipment, this document focuses solely on the most common types of stoves, fuels and equipment. Among others - microwaves, rice cookers, grills or different types of cookware influencing the overall efficiency of cooking as well have to be excluded.

Analysis on the use of different cooking fuels suggests that about 88 per cent of the energy content of all fuel consumed for cooking are biomasses such as wood, dung, crop residues or charcoal. This is due to the large number of biomass users, the low energy content of biomasses and inefficient stove designs. The daily fuel-wood consumption alone accounts for about 7 million m^3 in absolute terms (Grupp 2004). The use of biomass fuels and coal for cooking and heating accounts for between 10% and 15% of global primary energy use (WHO 2006). In many developing countries, biomass accounts for more than 90 per cent of the energy consumption of households (IEA & OECD 2006).

In developed countries in contrast, households rely primarily on gas and electricity for cooking. For instance it is estimated that 55 per cent of British households use gas for cooking while 45 per cent rely on electricity amounting to a total energy consumption of an estimated 8 TWh/year in 2009 (Defra 2009). The use of electric hobs and ovens in the EU-27 amounts to 60 TWh/year, which is 7.5 per cent of the total electricity consumption of all households (European Commission 2011). In the western region of Australia, cooking accounts for around 12% of the total energy used of an average household (Government of Western Australia 2011). In the EU, energy saving potentials for the stock of domestic electric ovens accumulates to 42 per cent when combining several improvement options. Energy consumption of the EU stock of domestic gas ovens could be reduced by 25 per cent, while domestic electric (radiant hobs) only have a maximal reduction potential of 14 per cent and domestic gas hobs 16 per cent saving potentials on much higher costs (Mudgal 2011).

Cooking contributes to around 5 per cent at least of worldwide greenhouse gas emissions (GHG), whereas most of these emissions can be traced back to developing countries and emerging economies. This is caused by the high number of users, predominance of low efficient appliances and non-sustainable wood management (Grupp 2004). Figure 2 overleaf presents the CO_2 emissions of different fuels common for cooking in developing countries and emerging economies in relation to their respective energy content. The level of GHGs associated with cooking on modern appliances mainly depends on the share of gas cooking appliances relatively to electric cooking appliances as well as the mix of electricity generation.



Note:
20-year greenhouse gas emissions in grams carbon as CO_2 emitted per megajoule (MJ)
• based on established greenhouse gases, carbon dioxide (CO_2), methane (CO_4) and nitrogen dioxide (N_2O);
• based on established and additional greenhouse gases, carbon monoxide (CO) and non-methane hydrocarbons (NMHC).
Emissions from different fuel/stove combinations in India were systematically assessed using a standardized cooking test.

Figure 2: Household energy and global warming: CO2 emissions of different fuels common for cooking in developing countries and emerging economies in relation to their respective energy content

Source: WHO 2006

According to calculations by the WHO, policy interventions aiming to make households switch to improved stove designs or more sophisticated cooking fuels are very cost-efficient. The comparison of costs and benefits arising from such interventions shows that in monetary terms about US$ 100 billion could be saved within ten years by halving the number of people cooking with solid fuels in an inefficient way through the provision of access to improved stove designs and more sophisticated fuels (WHO 2006).

The variability of the technology in terms of efficiency and savings potential is very high, depending on the type of appliance and the fuel that is used. Thus, the efficiency is mostly dependent on the type of cooking stove – there is a very big difference between open fire cooking in many poor countries and modern stove technology. While an induction hob is about 90% efficient relative to the electricity input (but maybe only 35 % relative to primary energy in an electricity system with predominantly fossil-fuelled power plants), a three-stone fire might have an efficiency of about 10-15%. In terms of primary energy, gas stoves are generally the most efficient cooking stoves. Concerning greenhouse gas emissions, gas stoves are also advantageous, at least when electricity generation is assumed to be mostly based on fossil fuels (Grupp 2004).

Taking different stove and fuel types together, the following figure presents what may be called the "energy efficiency landscape" for cooking. It presents opportunities for incremental improvements in terms of energy efficiency, which will not only save energy, time, and money but also reduce greenhouse gas emissions. Some options, such as solar cookers and biogas cook stove, may achieve additional reductions in greenhouse gas emissions through combining improved designs and fuel switches.

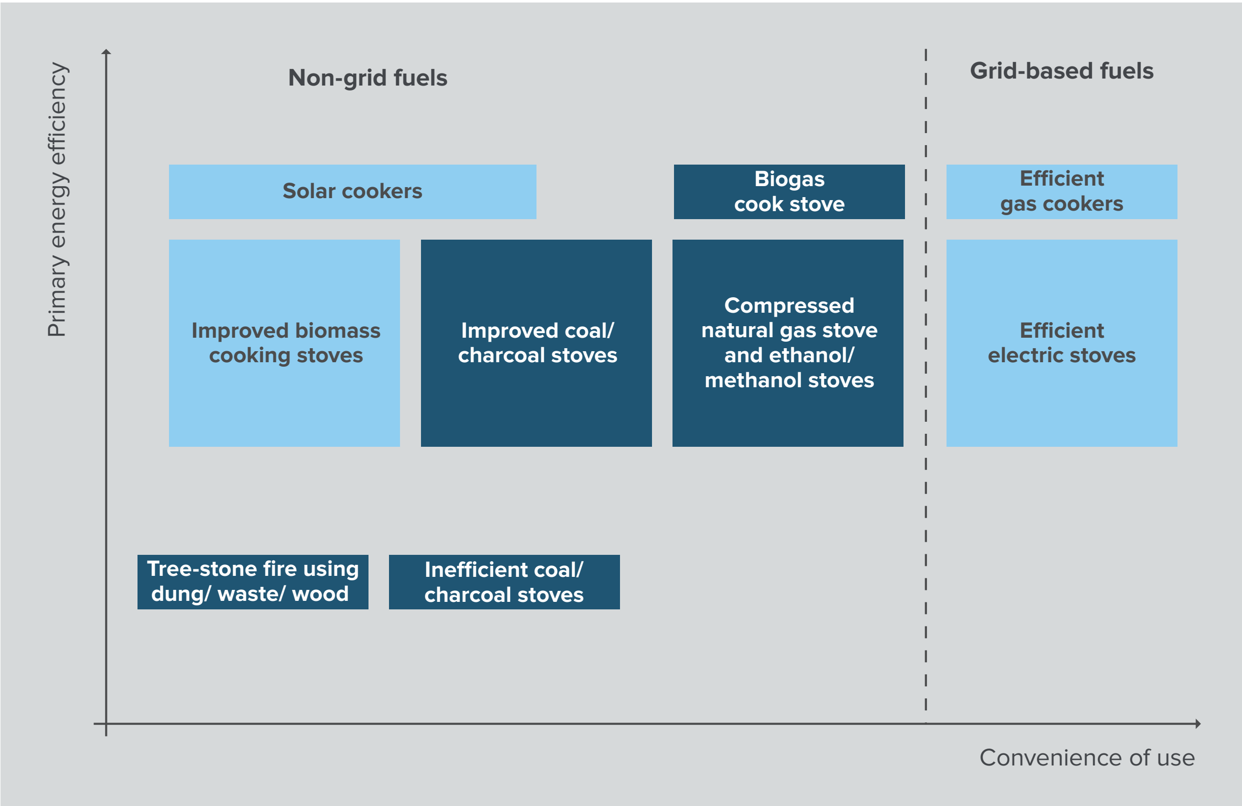


Figure 3: Simplified cooking energy efficiency landscape: Opportunities for cooking stoves improvements (light blue boxes are covered, dark blue has not been covered in the scope of the bigEE project)

Source: Wuppertal Institute 2013

It needs to be taken in consideration that the figure largely simplifies. The feasibility of measures taken to improve the energy efficiency of cooking highly depend on local conditions such as local infrastructures and access to fuels, fuel prices, financial resources of households, availability of government support or local customs and cultural preferences.

Generally, global cooking technology can be divided into (1) sophisticated electric and gas cookers, stoves and ovens mainly used in industrialised countries and by a rising number of middle to high income households worldwide, and (2) more basic and simple cooking technologies used by the low to middle income households mainly from rural areas in developing countries. Among the latter, biomass is still the most widespread fuel used. We will therefore mainly focus on two types of cooking technologies and their respective improvement potentials in terms of energy efficiency (marked light green in figure 3):

- Improved biomass cooking stoves to replace three-stone fires or inefficient stoves using biomass (e.g. wood or crop residues), with a mention of solar cookers as a potential alternative
- Improved electric and gas cookers (hobs and ovens)

2. Energy saving potential for two major types of domestic cooking appliances

As mentioned in chapter 1 above, we focus on two major types of domestic cooking appliances here. In chapter 2.1, we first turn to the very large potential improvements and energy savings for users of biomass cooking appliances. An excursion briefly touches solar cookers as an alternative. Afterwards, chapter 2.2 presents the same issues for the other end of the cooking energy efficiency ladder—sophisticated electric and gas hobs and ovens as they are used in industrialised countries but also increasingly by middle class households in developing countries.

2.1 Improved biomass cooking stoves

For about 2.5 billion people in the world, improved biomass cooking stoves are the cheapest way to save firewood, crop residues or dung, while reducing both harmful impacts on human beings and their environment. Energy savings of up to 80% and significant reductions of GHG emissions, indoor pollution and deforestation can be achieved.

Globally more than 2.5 billion people still rely on biomass such as wood, waste or dung for cooking. Without any policies addressing this challenge this number will increase to more than 2.6 billion by 2015 and to 2.7 by 2030 due to a growing population, mainly in developing countries. In 2004, the household energy use in developing countries accounted for about 10 per cent of the world's primary energy demand, whereas about 7 per cent was directly related to the use of biomass (IEA & OECD 2006).

Table 1: People still relying on biomass for cooking and other household energy needs

	Total population		Rural		Urban	
	%	million	%	million	%	million
Sub-Saharan Africa	76	575	93	413	58	162
North Africa	3	4	6	4	0.2	0.2
India	69	740	87	663	25	77
China	37	480	55	428	10	52
Indonesia	72	156	95	110	45	46
Rest of Asia	65	489	93	455	35	92
Brazil	13	23	53	16	5	8
Rest of Latin America	23	60	62	59	9	25
Total	**52**	**2 528**	**83**	**2 147**	**23**	**461**

Source: IEA & OECD 2006

In developing countries, cooking stoves account for more than half of the total residential energy use and in many poor countries more than 80% of the household energy consumption is for the purpose of cooking (Smith et al. 2000). Policy interventions that target this group of biomass users through the dissemination of improved cooking stoves are the cheapest way to save fuel input through improved stove designs, thereby achieving higher levels of energy efficiency as well as reduced levels of emissions harmful to human beings and the environment.

Biomass cooking stoves are mainly found in developing countries and represent basic ways of cooking food. Cooking on traditional biomass stoves is mostly related to very low levels of energy efficiency. The most basic type of cooking with biomass is the so called “three-stone fire”, which is made by arranging three stones in such way that it is possible to place a pot for cooking above it. Although this type of biomass cooking is most inefficient and bears serious risks to human health and the environment, it has been around for thousands of years and is still the most prevalent way of cooking in the world (Cleveland 2004). Alongside the three-stone fire, other traditional cooking designs are commonly used in many parts of the world. As most biomass cooking stoves are not produced using industrial production processes but rather homemade, many different types and designs of biomass cooking stoves can be found worldwide. Variations across countries mainly result from historically evolved cultural preferences, availability of resources, cooking habits and climatic circumstances. Unfortunately most of these stove designs are disadvantageous in terms of their energy efficiency. On these grounds, many efforts have been made in order to improve the energy efficiency and reduce risks for human beings and to the environment related to the cooking of traditional households. These efforts have resulted in a large number of so called “improved cooking stoves” which again vary in terms of design, performance and costs.

2.1.1 Overview, Description of the appliance

Biomass cooking stoves are devices, in which biomass (wood, agricultural residuals etc.) is used to furnish heat for cooking. Although the three-stone fire is very common it is often modified in many ways. This includes sinking the combustion zone below ground level or constructing a barrier around it to shield the fire. However, most types of these traditional cooking stoves are not only inefficient but also pollute the indoor air affecting the health of the householders. According to the WHO, up to 1.5 million people die each year as a result of indoor air pollution. The Lancet study even states 3.5 million people per year (Lim et al. 2012, WHO 2006).

The first attempts to improve traditional solid biomass stoves were made in India in the 1950s. These stoves were designed with a chimney to remove smoke from the kitchens. In the 1970's the oil crisis brought energy issues back to the top of the agenda and improved cooking stove programmes were considered as a solution to the fuel wood crisis and deforestation and desertification around the world (FAO 1983a). During this period the research was focused on the technical aspects like thermodynamic and heat transfer. Various international donors promoted and improved cooking stoves all over the world, particularly in Asia, Africa and Latin America (FAO 1983a). However, the effects of these programmes have often been short-lived. This was basically a result of neglecting the requirements of users. But since then a shift of the core target from environmental protection to human welfare improvement has taken place (Rouse 1999). In the course of this shift, the needs of the users gained more attention.

Many different models of improved solid biomass stoves with hundreds of variations exist. The designs vary from small, portable stoves to large stoves designed for permanent fixture in a household. Some of the features of these improved stoves can include (Practical Action 2009):

- a chimney to remove smoke from the kitchen
- an enclosed fire to retain the heat
- careful design of pot holder to maximize the heat transfer from fire to pot
- baffles to create turbulence and hence improve heat transfer
- dampers to control and optimise the air flow
- a ceramic insert to minimise the rate of heat loss
- a grate to allow for a variety of fuel to be used and ash to be removed
- metal casing to give strength and durability
- multi pot systems to maximise heat use and allow several pots to be heated simultaneously

2.1.2 BATs of biomass / improved cooking stoves

Most alternative cooking stove designs continue to use solid biomass as a fuel due to the absence of any other readily available source of energy (ASME 2007). These stoves continue to rely on forest resources or other biomass but reduce the amount of fuel needed for the same procedures.

Important for the success of improved stoves is the understanding of the user’s needs and requirements for the stove. Therefore it is necessary to involve the users in the design process to learn about their cooking habits and lifestyle (FAO 1983a). Cooking of meat and vegetables for example require different designs than staple foods (Practical Action 2009). Furthermore, fuel sources and locally available building materials differ to a great extent. Also, the type and size of the fuel determine the design of the combustion chamber of the cooking stove and air supply required. Almost no single stove design is suitable for burning all types of solid biomass. This means that the kind of cooking fuel available in a region is a crucial parameter when it comes to designing and selecting appropriate solid biomass stoves for a target population (Wuppertal Institute 2011).

The improved rocket stove

One example for an improved cooking stove is the *improved rocket stove* which among others is disseminated in many African countries by GIZ through their Programme for Basic Energy and Conservation (ProBEC). While a conventional three-stone fire uses 6,553 kJ to boil 1 litre of water and then simmer it for 30 minutes, a rocket stove uses only 2,470 kJ/l to fulfil the same tasks and cuts cooking time from about 20 minutes down to 15 minutes (MacCarty et al. 2008).

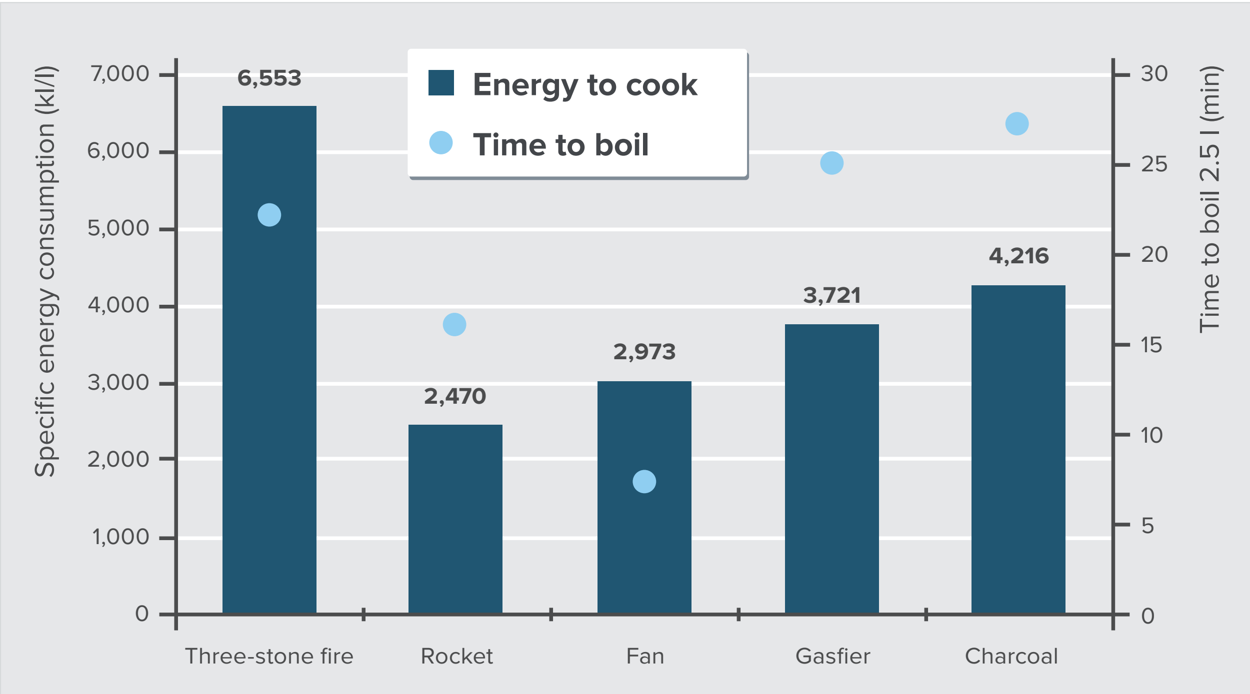


Figure 4: Specific energy consumption (energy consumed to bring boil 1 l water and then simmer for 30 minutes) and time to boil 2.5 l for the various stoves. Average of three tests. This chart does not include the energy to power the fan, running at 1 W for 37 minutes, or 2.25 kJ of additional energy input. Similarly, the charcoal energy consumption does not consider the energy lost while making the charcoal fuel. Results may differ if tested with other types of rocket, fan, gasifier, or charcoal stoves.

Source: MacCarty et al. 2008

The improved biomass cooking stove *Save 80*

Another example is the improved biomass cooking stove *Save 80,* which has for instance been introduced to refugee camps in Chad and Kenya. As its name indicates, it allows its user to save 80 per cent of wood fuel normally used for cooking on a basic three-stone stove. In addition, it also drastically cuts greenhouse gas emissions. For example, distribution of 120,000 stoves is estimated to result in reducing 350,000 tonnes of CO_2 per year in Indonesia.

Overview of these and further examples

Some of the commonly used models in different regions are presented in the following tables:

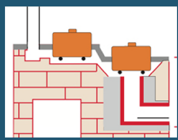
Table 2: Different types of improved cook stoves

Name	Area	Material	Features	Main objective	Price
Lorena	Latin America, Central America	mud and sand,	▪ fixed ▪ multiple openings for pots ▪ massive body ▪ chimney ▪ everything can be built from local material	Reducing indoor air pollution	US$ 15
Save 80	South East Asia	Stainless steel	▪ No fumes ▪ Strongly reduced wood consumption ▪ Waste wood sufficient	Improving efficiency	80 EUR
Rocket	Africa	bricks, clay, ceramics, sometimes metal	▪ portable ▪ use of lightweight insulating material combustion chamber to minimize heat loss ▪ cylindrical or L-shaped combustion chamber ▪ noisy operation ▪ mostly built out of local materials	Improving efficiency	US$ 20-300 (depending on size and material)
Ecostove	Central America	metal and ceramics	▪ fixed ▪ fire is entirely enclosed within the firebox which is placed within a box of insulated material ▪ Above the fire there is a plancha (a large griddle metal) pots are placed on a metal griddle heated by the hot combustion gas ▪ free from soot as pots do not contact the flue gas	Reducing indoor air pollution	US$ 60

Ceramic Jiko Stove	East Africa	metal outside and ceramics inside	▪ portable, lightweight ▪ lasts approximately 30 months with intensive use ▪ outside casing can be produced locally from crafts man, while the ceramic inner lining is produced by specialized enterprises ▪ if fuel is purchased, the payback period is 2.3 month	Improving efficiency	US$2 -5
FL Fuel-Saving Composite Stove	China	cast iron, concrete	▪ fixed ▪ chimney ▪ single-pot stove, in line with the local cooking habits ▪ Suitable for use with either an iron cauldron or an aluminium cylindrical pot.	Improving efficiency	starting from US$ 12
Improved Chulhas (popular models are Laxmi, Parvati, Grihalaxmi & Bhagyalaxmi)	India	mud, cement, clay, sometimes metal	▪ fixed or portable ▪ chimney ▪ potential life span of 5 years ▪ can usually accommodate one or two pots ▪ the improved chulha can fabricated in a workshop or directly in the household	Improving efficiency and reducing indoor air pollution	starting from US$9

Source: GTZ 2007; ERTC 2003; HEDON 2010; HEDON 2003; FAO 1983b

Table 3: Different types of improved cook stoves with pictures

Fixed		Portable	
Improved „Chulah“ • Many variations; possibly with chimney • Fuel: ‘green’ biomass • Region: mainly in Asia		**Thai Bucket** • Many variations; inner core ceramic; metal mantel • Fuel: mainly charcoal • Region: Asia	
„Inkawasi” • Two pots; chimney • Fuel: ‘green’ biomass • Region: Peru		**Ceramic “Jiko”** • Many variations; inner core ceramic; metal mantel • Fuel: mainly charcoal • Region: East Africa	
Rocket Lorena • Two pots; chimney • Fuel: ‘green’ biomass • Uganda, Kenya		**“Sampada”** • Gasification; low power; charcoal production • Fuel: ‘green’ biomass • Region: India	
“Jinqilin” • Industrial production; semi-gasifier; chimney • Fuel: ‘green’ biomass • Region: China		**“Envirofit”** • Industrial production • Fuel: ‘green’ biomass • Region: India	

Source: Wuppertal Institute 2011

2.1.3 Impacts on energy efficiency, environment and health

Dissemination of improved biomass cooking stoves entails environmental, social and economic benefits due to improved energy efficiency, reduced greenhouse gas emissions and deforestation, and lower health impacts from indoor combustion smoke.

Energy efficiency

It has been estimated that approximately 2.7 billion people worldwide will rely on solid biomass for cooking in 2030 (IEA & OECD 2006). Today, especially in rural areas of developing countries, many people still use inefficient modes of cooking caused by the use of basic stove designs. The introduction of improved cooking stoves to these households could tap large energy efficiency potentials related to cooking at relatively low costs. Fuel inputs could be reduced by up to 80 per cent depending on the type of improved biomass stove introduced and on the technology used before by the household in question. Taking into consideration the huge number of people relying on biomass cooking, policy interventions aiming at the introduction of improved biomass stoves represents a highly relevant and sounded measure to ensure higher levels of energy efficiency.

An example may highlight that both energy consumption for cooking in developing countries and the potential energy savings from improved biomass cooking stoves are very high. Survey data from a study in Uganda suggests that the average quantity of food cooked per household is 3.19 kg per meal. The amount of wood used to cook this amount on a three-stone fire amounts to 1.77 kg, while an average household prepares 11 meals each week (Adkins et al. 2010). If we accept these rough assumptions, each household in rural Uganda consumes about 20.25 GJ per year using a three-stone fire for cooking. An improved cooking stove such as the Save 80 could reduce fuel wood input by up to 80 per cent, which is equal to cutting the wood fuel input from 1.77 to 0.35 kg per meal. Hence, the use of an improved biomass stove could cut cooking related primary energy consumption of a single household by up to 16.25 GJ/year to a level of 4.00 GJ per year. The use of an improved rocket stove design instead of the Save 80 may significantly reduce costs of the measure to improve energy efficiency and still allow savings of about 12.15 GJ/year per household (around 60 % of the original fuel consumption).

These enormous energy savings are a strong argument for the implementation of policy programmes, which foster the dissemination of improved biomass stoves in rural areas in developing countries. → *In the bigEE policy guide, you can find an example of a financial incentive programme for energy-efficient cooking stoves from China.*

Emissions

The emissions from stoves are dependent on various parameters involved in the combustion process, such as the type of fuel, the type and design of the stove and the operating conditions (Bhattacharya et al. 2002). Therefore, it is quite difficult to cite a definitive value. An estimate has been derived by Grupp (2004). He calculated that cooking is responsible for around 5% of all greenhouse-gas emissions worldwide, which is about 2 billion tonnes of CO_2 equivalent emissions per year. Figure 6 shows that biomass cooking, particularly the three-stone fire, contributes more than three quarters of this. Improved biomass cooking stoves could therefore reduce greenhouse-gas emissions significantly at a net economic benefit or low cost.

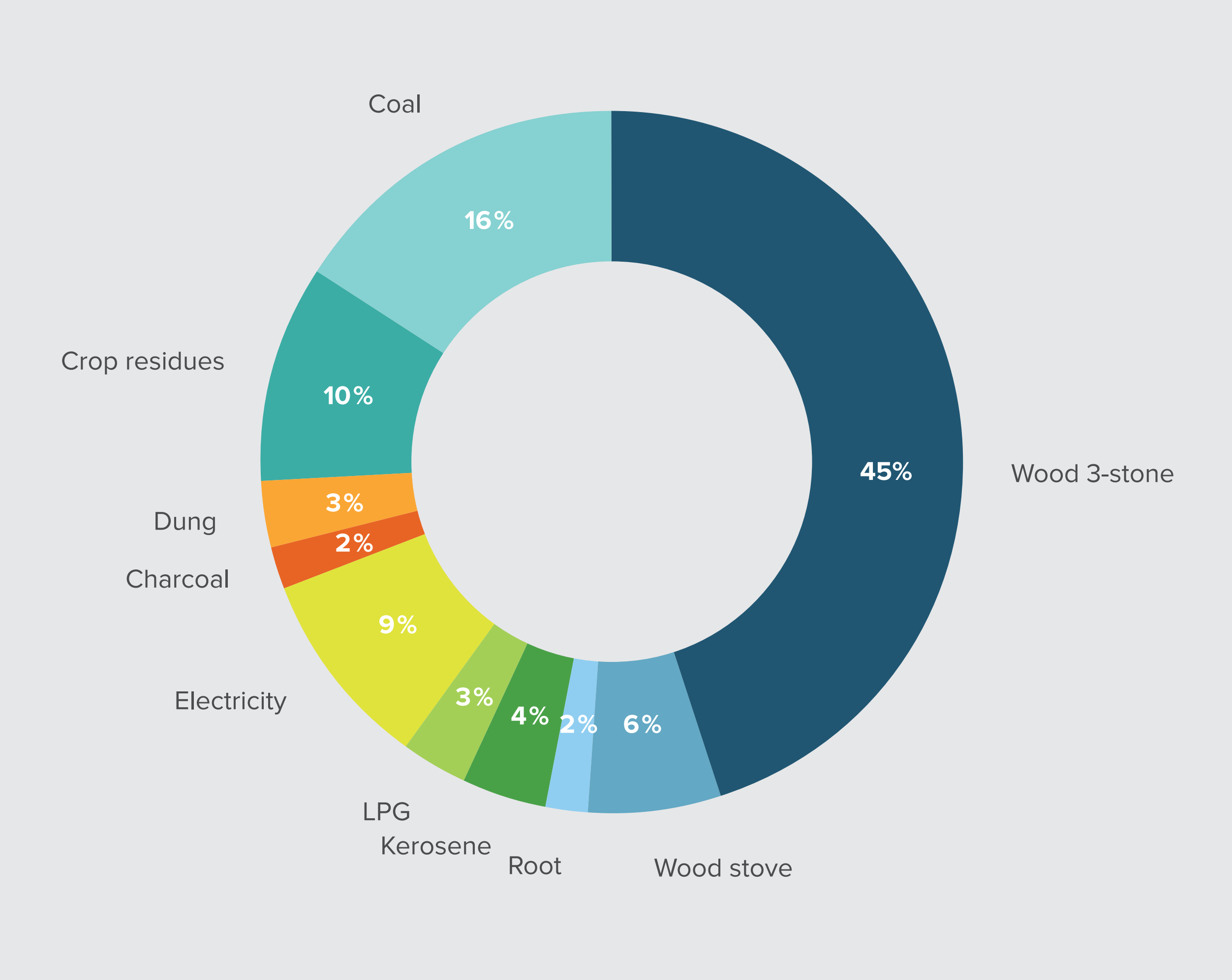


Figure 5: Relative global emission shares of the different cooking fuels, in CO_2e.

Source: Grupp 2004

In addition to the greenhouse gas (GHG) carbon dioxide (CO_2), cooking stoves that use biomass emit methane (CH_4), Nitrous oxide (N_2O), carbon monoxide (CO), non-methane hydrocarbons (NMHCs) and the especially health damaging black or elemental carbon (EC) particulate matter. MacCarty et al. show that improved designs can significantly reduce emission of different global warming agents and thereby avoid risks for the environment. Emissions of different GHGs are shown in the table below for the improved rocket type cooking stove and fuel switch to charcoal as compared to the three-stone fire (MacCarty et al. 2008). Simple stoves using solid fuels do not only convert the fuel into carbon dioxide but rather, due to poor combustion conditions, these stoves divert a significant portion of the fuel carbon into products of incomplete combustion (PIC). As the table shows, the more energy-efficient rocket stoves also reduce PIC emissions.

Table 4: Specific emissions, or mass of emissions produced to boil 1 l and then simmer for 30 minutes

Specific Emissions (g/l)	**Three-stone fire**	**Rocket**	**Charcoal**
CO_2	536	206	300
Methane	0.6	0.1	3.0
N_2O	0.0	0.0	0.0
NMHC	1.4	0.3	2.5
CO	37	4	72

Source: MacCarty et al. 2008

With a simplified assumption made that black carbon emissions per kg of fuel are the same for both traditional and improved stoves and therefore vary according to the type and amount of fuel used (FAO 2010), the following emissions factors for black carbon can be calculated:

- wood-fired stoves – 1g per kg;
- crop-residue-fired stoves – 0.75g per kg;
- dung-fired stoves – 0.25g per kg.

Table 5: Black carbon emission factors for three stoves

Stove type	**Emission factor (g/kg)**	**Emission (g) per meal Uganda case)**
Three-stone	0.88	1.56
Rocket stove	1.16	0.81
Charcoal stove	0.20	n.a.

Source: FAO 2010; MacCarty et al. 2008; Adkins et al. 2010; own calculation

Although the emission factors in the table suggest that the emissions of black carbon for the improved cooking stove model, called the rocket stove, are higher than for the three-stone stoves, the amount of kgs of fuel used for the same activity is far less and so is the absolute emission for cooking in comparison to the three-stone fire. For the amounts of fuel wood needed to cook a meal in Uganda (Adkins et al. 2010), the rocket stove would almost halve emissions of black carbon.

Deforestation

The forecasted dependence of 2.7 billion people worldwide on solid biomass as fuel source leads to unsustainable wood use and ongoing deforestation. Globally, deforestation contributes to the build-up of harmful GHG in the atmosphere, and thus to global warming. Locally, deforestation can generate soil erosion, pollution of streams with sediments, loss of biodiversity and desertification (UNEP 2005). The wide dissemination of improved cook stoves could help to slow down deforestation.

Health

Inefficient and poorly ventilated stoves, burning biomass fuels such as wood, crop waste and dung cause significant indoor air pollution, which is the cause for the deaths of an estimated 1.6 million people annually (WHO 2002). The smoke emitted during combustion contains thousands of health-damaging substances. Measurements showed that in most households in the developing world, the standards of air pollution levels in developed countries are exceeded by a factor of 2 to 60 (Gordon et al. 2004; Bruce et al. 2002). Improved stoves can avoid or at least reduce the amount of smoke generated during combustion through more efficient combustion processes or chimneys leading the smoke outside, for example.

2.1.4 A potential substitute to biomass: Solar Cooking

Solar cookers are devices that are used to prepare food by harnessing solar radiation as their energy source. Cooking with freely available solar energy is a healthy and environmentally friendly alternative or addition to using wood fuel, gas or electrical energy. The technology is most appropriate in sunny and dry regions with sufficient levels of solar radiation (but it has his followers in less sunny countries as well); however, in order to ensure the successful implementation of this technology, local needs, cooking habits and social conditions must also be taken into account.

Optimistic assessments assume that the adoption of solar cookers could save more than 35% of this fuel wood. Estimations on potential net GHG emission savings vary between 690kt and 140,000kt of CO_2 per year (Grupp 2002).

Figure 6: Carbon credits in benefit of Andean Solar Villages

Source: WISIONS 2012

More information can be found at the pages provided by the WISIONS project on Solar Cooking: www.wisions.net, as well as in GIZ publications, e.g., “Here comes the sun”, download at www.giz.de/hera, and https://energypedia.info/wiki/Cooking_with_Sun

2.2 Energy-efficient sophisticated gas and electric cooking stoves and ovens

Energy savings of 10 to 30 % can be cost-effective for both gas and electric stoves, and up to 50 % for ovens. In most countries, costs and primary energy can also be saved by switching from electricity to natural gas or biogas.

For example, EU analysis outlines an energy saving potential of up to 25 per cent for the stock of cooking appliances in the EU. Largest and cost-effective potentials for energy savings of 42 per cent can be found with electric ovens, followed by gas ovens with 25 per cent. Potential energy savings for improved domestic electric and gas hobs would accumulate to 14 per cent but can only be realised on much higher costs (Mudgal 2011).

Sophisticated cooking stoves use either electricity or gas to enable its users to cook and bake. They can be divided in a hob function and an oven function, which are either sold together as cookers or separately as hob and oven. A hob (also called range in the USA) is a flat surface containing hotplates or burners—where pots are put on top, while an oven is an enclosed compartment, which is heated by the burning of gas or through electricity-heated iron bars. Sophisticated cooking stoves can mostly be found in households of industrialized countries or in urban areas of developing countries, as a precondition is the access to either an electricity grid or to gas. In contrast to biomass cooking stoves, all sophisticated cooking stoves are produced in industrialized production processes and often sold to end users by specialised retailer shops.

Whilst the potential for improved biomass stoves or their substitution by cleaner and more energy-efficient cooking technologies in developing countries is high and rather cheaply available, energy saving potentials in industrial countries (using gas, electric stoves) within the same technology is still high, but related to higher costs.

However, avoiding incorrect use of the cooking stoves may provide further energy savings. This can include choosing the optimal size of the pot in relation to the size of the cooking stove top (hobs) or by avoiding heat loss through the use of a cooking lid on the pot.

In addition, using specialised cooking devices—such as rice cookers or electric water kettles—may also be more energy-efficient than using the hobs and a pot.

Generally, studies show that cooking with gas is most efficient in terms of primary energy use as there are no generating losses (EC 2011a; Öko-Institut 2008). Table 6 shows an energy calculation for boiling 1000 litres of water. In terms of primary energy efficiency, gas is best because there are no generating losses but gas has the highest direct heat loss at 255 kWh compared to only 57 kWh for induction and 114 kWh for electric (EC 2011a, VHK 2010).

Table 6: Primary Energy Consumption for Boiling Water

Cooking Method	Total primary energy consumed KWh	Energy efficiency
Induction	699	15%
Electric	792	13%
Gas	461	23%

Source: EC 2011a, VHK 2010

More detail on comparing the primary energy efficiency of electric and gas hob technologies will be presented in chapter 2.2.5, after we have discussed the different technologies in the following.

2.2.1 Electric cooking stoves: hobs

Overview, Description of the appliance

Electric cooking stoves use electricity to provide the necessary heat for cooking, heating and baking.

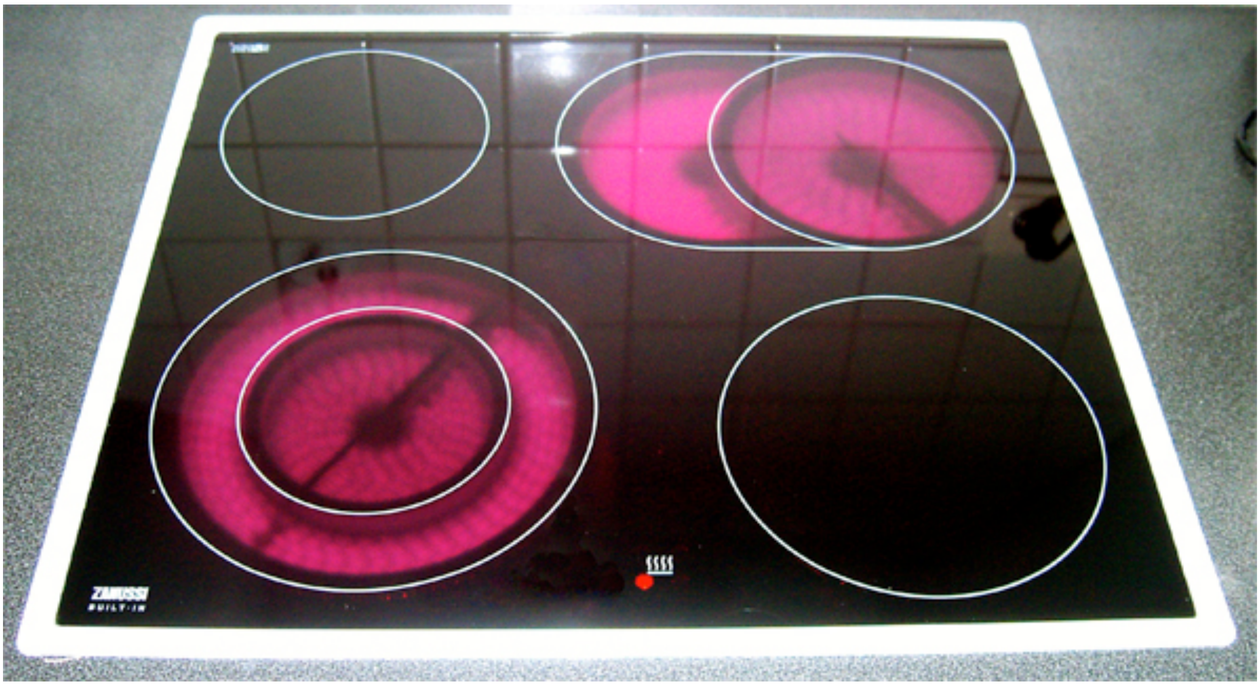


Figure 7: Electric Hob (Ceran)

Source: Wikimedia

Conventional electric hobs use attached iron plates as their heating unit, while more sophisticated models use infrared, halogen or induction heating units, which are positioned below glass ceramics. In contrast to models using iron plates, infrared or halogen heaters, induction-based cooking plates do not emit heat, but an alternating magnetic field which induces a current in the ferromagnetic bottom of a pot specially designed for this way of cooking. Depending on their size, hobs can incorporate different numbers of heating units.

Best available technologies and saving potential

Although figures from different test and studies differ, a study from 1995 exemplifies that electric induction is by far more efficient with an energy efficiency in transferring heat to the food, not considering heat losses from the latter, of 80.2%, followed by electric solid plate (59.4%) and electric radiant (57.2%) (EC 2011a; Schaetzke 1995). However, early designs of induction hobs often had high stand-by electricity consumption, so care should be taken to reduce this consumption too.

Analysis in the EU, for example, indicates that improvements such as heat output control, pot sensors or cooking sensors can lead to added energy savings of about 14 to 16 per cent at costs of €160 (EC 2011a), cf. also Table 7.

Table 7: Comparison of electric hob base case with the related BAT and LLCC technology combinations

		Change in total energy use	Change in life-cycle cost
Domestic electric (radidant) hob	LLCC	0%	0%
	BAT	-14%	+8%

Source: Mudgal 2011

BAT: best available technology; LLCC: least life-cycle cost

Additional information

In the EU for example, electric hobs are responsible for about 5 per cent of the overall residential electricity use; hobs used 37 TWh in 2004. Energy consumption depends largely on varying consumer behaviour, the quantities of food prepared, and the qualities of stoves and equipment used. Electricity consumption by ceramic hobs ranges between 47.7 and 675.6 kWh/year, induction hobs between 140.2 and 512.5 kWh/year and hot plates from 31.8 to 307.2 kWh/year (EC 2011a). The latter seem to be used less, so their consumption is less despite lower energy efficiency compared to ceramic and induction hobs.

2.2.2 Electric cooking stoves: ovens

Overview, Description of the appliance

Electric ovens for baking and cooking vary largely across their size, functions they provide and are sold either as a stand alone or build-in device. Different models range between 5 and 120 litres in size. Some ovens provide specific functions, such as self-cleaning mode, grill or forced convection, which allows circulation of heated air inside the oven through a built-in fan. Depending on size and used technology, the energy consumption of electric ovens can range between 0.59 kWh and 1.99 kWh when measured by the EU's standard wet brick test (EC 2011b).

Best available technologies and saving potential

In the EU, highly energy-efficient electric ovens are awarded with an A class label by the current EU energy labelling scheme. The labelling scheme relates to three different sizes of oven – small, medium and large. Small electric ovens with a volume between 12 and 35 litres are required to consume not

more than 0.6 kWh per baking cycle, medium sized ovens with volumes between 35 and 65 litres are allowed to consume not more than 0.8 kWh per baking cycle and ovens with a size more than 65 litres may not consume more than 1 kWh per baking cycle in order to be awarded with an A label.
EU analysis indicates that compared to a base case that is much less efficient than class A, cost-effective energy saving potential of around 40 %, as presented in Table 8, still exists. Data from the UK shows that consumption per use of electric ovens had already been reduced by 25 per cent from 1.5 kWh initially in 1980 to 1.1 kWh in 2008, assumingly due to the growth in market share of A-class ovens (EC 2011b).

Table 8: Comparison of electric oven base case with the related BAT and LLCC technology combinations

		Change in total energy use	**Change in life-cycle cost**
Domestic electric ovens	LLCC	-39 %	-16%
	BAT	-42%	-2.5%

Source: Mudgal 2011

BAT: best available technology; LLCC: least life-cycle cost

2.2.3 Gas cooking stoves: hobs

Overview, Description of the appliance

Gas cooking stoves burn natural gas, propane, butane or other flammable gas to provide the necessary heat for cooking and baking. Gas is either delivered directly to the household through gas pipes or in gas bottles if households do not have access to gas grids.The top part of the appliance contains a hob equipped with a certain number of gas burners, which burn gas directly to produce the heat necessary for cooking. Most common models place burners on top of a stainless steel or ceramic surface, while other models place burners beneath a glass ceramic surface.

Figure 8: Gas Hob

Source: Wikimedia

Best available technologies and saving potential

Gas hobs are generally more efficient than hobs powered by electricity when primary energy is considered (Öko-Institut 2008). Gas burners attached on top of a stainless steel or ceramic surface are more efficient than gas burners beneath glass ceramic. Figures from tests show that differences between burners on stainless steel or glass ceramic in terms of energy efficiency performance are extremely small, while burners positioned beneath glass ceramic lead to lower energy efficiency. While burners placed above the surface needed 330 and 340 Wh, burners beneath glass ceramic consume 480 Wh to fulfill the same task in the following test - (Warentest, 2004).

For the example of the EU, savings of around 16 % seem feasible but at a significant cost (see Table 9).

Table 9: Comparison of gas hob base case with the related BAT and LLCC technology combinations

		Change in total energy use	Change in life-cycle cost
Domestic gas hob	LLCC	0%	0%
	BAT	-16%	+39%

Source: Mudgal 2011

BAT: best available technology; LLCC: least life-cycle cost

2.2.4 Gas cooking stoves: ovens

Overview, Description of the appliance

Gas ovens burn gas to heat the oven's interior and are sold as stand-alone or build-in devices. As electric ovens, gas ovens differ across size and provided functions. The size of domestic ovens range between 5 and 120 liters. Depending on size and used technology, energy consumption of gas ovens range from 4.29 MJ up to 8.85 MJ when measured by the wet brick test (EC 2011b). Gas ovens are perceived to not heat as even as electric ovens do and a trend in favour of electric ovens can be detected, despite advantages of gas in terms of fuel cost and primary energy needs (MTP 2006). This preference is supported by figures from the EU indicating that more than 77 per cent of EU-15 households use electric ovens, although country specific differences can be identified. While 50 per cent of households in France use gas ovens, they are almost negligible in Scandinavian countries (EC 2011b).

Best available technologies and saving potential

In terms of primary energy efficiency gas ovens with natural convection are the most efficient appliances for baking (Öko-Institut 2008). Although reliable data on the energy consumption of gas ovens is difficult to find, tests of the energy input into domestic gas ovens show that energy consumption largely varies. According to data from CECED the most energy saving model with natural convection consumes 4.29 MJ (energy consumed in a wet brick contest), while oven types with fan convection consume with 6.01 MJ slightly more than that (EC 2011b). In the EU for example, gas ovens have up to 25 % of energy savings potential but it does not seem cost-effective today (Table 10).

Table 10: Comparison of gas oven base case with the related BAT and LLCC technology combinations

		Change in total energy use	Change in life-cycle cost
Domestic gas oven	LLCC	-12%	-1%
	BAT	-25%	+23%

Source: Mudgal 2011

BAT: best available technology; LLCC: least life-cycle cost

2.2.5 Primary energy efficiency of hob technologies in comparison

With regard to primary energy efficiency, gas is much more efficient because the energy it contains can be directly converted into heat for cooking, while electricity first needs to be produced in power plants that sometimes only convert a third of the primary energy into electricity. All types of hobs using gas burners have clear advantages compared to electric hobs when primary energy efficiency is considered.

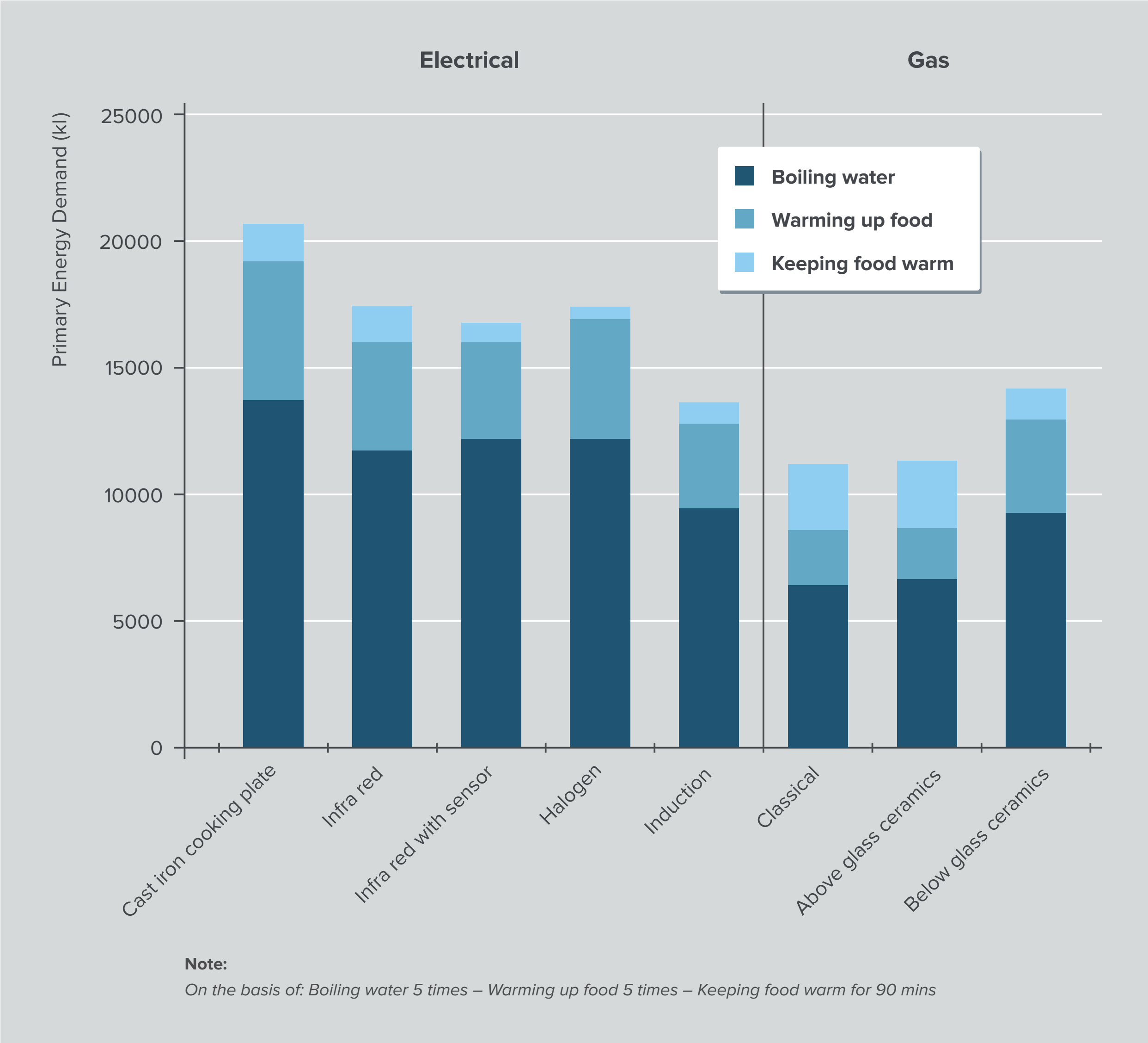


Figure 9: Comparison of different hobs with related primary energy consumption

Source: Öko-Institut 2008

While the primary energy consumption of gas burners on top of stainless steel or glass ceramic is almost only half that of iron plates, heating by infrared or halogen still consumes about one third more energy. In terms of primary energy use, induction is the most energy-efficient electric technology for cooking and almost reaches the same efficiency levels as gas burners beneath glass ceramics, which are the least efficient with the gas-based appliances (Öko-Institut 2008).

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