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Environmental impacts of different methods of coffee preparation

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Abstract

The environmental impacts of coffee consumption inter alia depend on the preparation method used by consumers. Preparation methods such as filter drip, pod machines and fully automatic coffee machines are the most common ones in Germany: 62% of the consumers use a filter drip machine to brew their coffee, 23% use filter pad machines and 15% use espresso machines such as fully automatic coffee machines or capsule systems. The aim of the different studies presented in this paper was to identify the critical environmental issues along the life cycle of coffee and to compare the different preparation methods of coffee regarding their influence on the environmental impacts. Within the Product Carbon Footprint (PCF) Pilot Project Germany, the PCF of one cup of a special type of coffee was analysed on behalf of Tchibo GmbH (Überseering, Hamburg, Germany). As the results show, the preparation by the consumer is one crucial part of the entire life cycle of coffee, making up a share of 30% of the overall emissions. Another hot spot is the cultivation of coffee beans with 55%. Concerning the use phase, research shows that environmental impacts vary significantly depending on the preparation method used by the consumer. Main drivers are differences in power consumption of the respective technologies. Furthermore, different packagings of the coffee play a decisive role. Comparing the analysed appliances and defined usage scenarios in this study, the French press and filter drip machine performed best, followed by the filter pad machine. In contrast, the environmental impacts of the analysed fully automatic coffee machine and the capsule machine were highest. The reason for this was the high power consumption, especially in the machines' sleep and standby mode. Additionally, capsule machines contribute to the environmental impacts because of the aluminium and/or plastic packaging of the capsules, automatic coffee machines because of their cleaning and rinsing programmes.

The detailed results indicate a significant savings potential in the use phase. The impacts not only depend on the specific energy efficiency of the chosen appliance but also on the usage behaviour.

Introduction

With an average consumption of 150 l per person in 2009 (German Coffee Association, 2008), coffee is the most consumed beverage in Germany. Assuming an average volume of 125 ml per cup, this figure corresponds to a daily consumption of 3.3 cups of coffee. Concerning the different preparation methods, there is a considerable trend towards espresso fully automatic and an extremely strong trend towards portioned machines (capsules and pads) according to GfK (2010). Over the last year, this segment grew by more than 15% in Germany (German Coffee Association, 2010).[1] This is partly due to an increasing number of single households and the growing demand for coffee at the touch of a button (German Coffee Association, 2010).

At the same time, in more and more households, coffee machines account for a significant proportion of the energy consumption and thereby contribute to the environmental impacts. According to a Swiss study (Bush *et al*., 2007), the energy consumption of all private coffee machines in Switzerland per year is equal to the energy consumption of 110 000 average households. In a typical Swiss household, the total energy consumption of a coffee machine has a share of approximately 4%. Depending on the installed model and on the user behaviour, the range of energy consumption is large (Bush *et al*., 2009). According to a research project of the Swiss Federal Office of Energy, about 75% of the coffee machines' energy is used for standby mode and the keep warm function (Bush and Nipkow, 2003).

[1]These machines both replace other machines and are used as additional devices. The processes run in parallel, but there is no specific data about that issue.

Lately, a number of studies have been carried out on the environmental impact of coffee preparation (such as Quack *et al.*, 2009; Stratmann *et al.*, 2009) with the aim to compare the different preparation methods and to identify possible savings potentials regarding the use phase. The various approaches were based on different methodologies: life cycle assessment (LCA), Product Carbon Footprint (PCF) and Product Sustainability Assessment (PROSA), which will be described later. The aim of the PROSA study on coffee preparation (Stratmann *et al.*, 2009) was to develop award criteria for coffee machines on behalf of the German environmental label 'Blue Angel'.

The PCF study, which actually also included other environmental impact categories than global warming potential (GWP) alone, focused on the life cycle analyses of a specific variety of coffee, the so-called 'Tchibo Privat Kaffee Rarity Machare' (Quack *et al.*, 2009). It was elaborated within the framework of the PCF pilot project (http://www.pcf-projekt.de), which aimed at developing a sound methodology for calculating product-related greenhouse gas (GHG) emissions that may be additionally used in business-to-business or business-to-end-user communications (Prieß *et al.*, 2009). The results of the PCF study reveal that the GHG emissions from coffee preparation by the consumer over the whole life cycle of one cup of coffee are a significant hot spot being responsible for about 30% of the overall emissions. Even though the contribution of the coffee preparation is lower than that of agriculture, which accounts for about 55% of the overall emissions, it is worth to have a closer look on this life cycle phase: results presented in this paper show that the environmental impacts vary significantly because of the preparation method used by the consumer and the energy efficiency of the used appliance. Concerning the reduction potential of the hot spot agriculture, further research needs to be performed on different methods of coffee cultivation in relation to gained harvests. Nevertheless, it is obvious that organic agriculture bears advantages concerning the avoidance of toxic substances (pesticides).

Description of the proceeding

Methodological approach

LCA

The LCA served as methodical background for the calculation. The goal of the LCA is to gain more information on the environmental impacts of different coffee preparation methods. To this end, these systems are compared with the aim of identifying the one with the lowest environmental impacts concerning the investigated parameters. LCA captures the most varied types of resource consumption (such as energy carriers, minerals, water) and environmental impacts in the form of impact categories (GHGs, acidification, eutrophication, etc.). Then, these impact categories are reported in relation to a functional unit. The LCA procedure is set out in detail in the ISO standards 14040 and 14044 and ideally, includes all stages of a product system (cradle to grave). Conducting a complete LCA is a complicated, costly and time-consuming process. As an alternative, a streamlined LCA can be performed. This is a simplified LCA method that aims at identifying only the major environmental impacts of a product across its life cycle and at identifying the most relevant environmental impacts that will be focused. Such a streamlined LCA has been performed within the course of the PROSA study on coffee preparation.

PCF

A PCF is the overall amount of carbon dioxide (CO_2) and other GHG emissions (such as methane, laughing gas, etc.) emitted during the life cycle of a certain product. The causes of these emissions are, for example, electricity production in power plants, heating with fossil fuels, transport operations and other industrial and agricultural processes.

The carbon footprint is quantified using indicators such as the GWP. As defined by the Intergovernmental Panel on Climate Change (IPCC, 2007), a GWP is an indicator that reflects the relative effect of a GHG in terms of climate change considering a fixed time period, such as 100 years (GWP_{100}). The GWP for different emissions can then be added up to give one single indicator that expresses the overall contribution of these emissions to climate change (kg CO_2e). A PCF can either be carried out in accordance with the standard ISO 14040/14044 or with the standard British Standards Institution Publicly Available Specification 2050 and/or the Greenhouse Gas Protocol.

PROSA

The PROSA is a method for the strategic analysis and evaluation of product portfolios, products and services (Grießhammer *et al.*, 2007). The goal is to identify system innovations and options for action towards sustainable development. To achieve this objective, the PROSA structures the decision-making processes that are necessary, reducing complexity to key elements. The PROSA spans complete product life cycles and value chains; it assesses and evaluates the environmental, economic and social opportunities and risks of future development trajectories. It calls as far as possible on existing, well-established individual tools (Megatrend Analysis, LCA, Life-Cycle Costing, etc.). Figure 1 shows the basic structure of the PROSA.

The herewith presented the PROSA study on coffee machines includes a market analysis, a streamlined LCA, a life cycle cost analysis and a benefit analysis. Furthermore, this study allows an integrative approach of processing and evaluation. Because of lack of data, a social LCA was not carried out. The focus of the results shown in this paper will be on LCA.

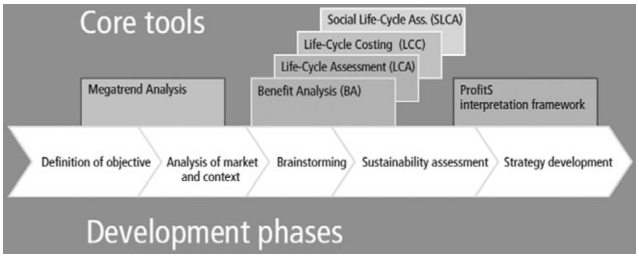


Figure 1 Basic structure of Product Sustainability Assessment.

Scope of the analyses – definition of the particular proceeding

Description of the considered methods for coffee preparation

In Europe, the shares of coffee preparation methods used are very different. In Italy, Switzerland and Portugal, espresso machines (here: fully automatic coffee machines, capsule machines and porta-filter machines) have market shares of more than 70%, whereas in Germany, Belgium and the Netherlands, the market shares of these machines represent less then 20%. However, high growth rates are recorded in these countries (Topten, 2010a).

Preparation methods such as filter drip, French press, pod machine and fully automatic coffee machine are the most common ones in Germany: 62% of the consumers use a filter drip coffee maker to brew coffee, 23% use pod machines and 15% use espresso machines such as fully automatic coffee machines or capsule systems (Stratmann *et al*., 2009). There are also households with more than one coffee machine, but there is no data available which coffee machine is used how often.

Using a *French press*, ground coffee is placed in a glass pot and hot water is poured into it. Then, an attached plunging device, which is tightly fitted to the glass pot, is pushed to the bottom of the pot, where the grounds are trapped. *Filter drip coffee makers* work according to the overflow principle, which means that they work without pressure in contrast to automatic coffee machines and some automatic single-serve coffee makers (capsules and filter pads). Coffee is brewed by means of an electronic drip machine and paper filter. Water is heated in a chamber of the machine to 90–95°C and is slowly dripped over the ground coffee. Brewed coffee is trapped in the normal glass pot and leaves the grounds in the filter. *Filter pad machines* and *capsule machines* belong to the group of *automatic single-serve coffee makers*. Using a *filter pad machine*, coffee is brewed cupwise by pressing hot water with low pressure (250 to 300 kPa) through small filter pads filled with ground coffee. *Capsule machines* work with high pressure of 900 kPa. The hot water is pressed through small aluminium/plastic capsules filled with ground coffee. *Fully automatic coffee machines* operate automatically at the touch of a button and contain a complete preparation system with mill, tamp and pumps. Coffee beans are grinded to coffee grounds and are then compressed. With a pressure of at least 900 kPa, the heated water (about 90°C) is pressed through the coffee powder. The coffee grounds are then automatically thrown into the pulp container and the brewed coffee goes directly into the provided cup/cups. Some automatic coffee machines even have an automated milk frothing, water filter and self-cleaning system. Most of the appliances can operate both with coffee powder and coffee beans.

Functional unit and function of the analysed product system

In order to calculate the environmental impacts of a service or a product, a functional unit has to be defined. It is designed to normalize all flows within the scope of the study/the analysed product. In addition, the functional unit can also be a basis for the comparison of different products – in this case, for the comparison of different preparation methods. Such a comparison is only possible when their functional unit has the same function.

The functional unit was specified as the preparation of 2000 cups of coffee (125 ml each).[2]

As already mentioned earlier, the original PCF study on coffee preparation referred to a functional unit of one cup of coffee including the coffee powder (7 g of coffee powder, 0.125 l of water). In order to present comparable data in this paper, the results were extrapolated to 2000 cups of coffee, the impact of the provision of coffee powder being marked.

System boundaries

For the analyses of the different preparation methods, the following processes were considered:

- production of the coffee machine on the basis of its material composition (no manufacturing data were available);
- use of the coffee machine for the preparation of 2000 cups of coffee in 1 year;
- production and disposal of the filter pads and capsules including their packaging; the filter paper and the packaging of the coffee beans/coffee powder
- disposal of coffee grounds and sewage.

The following processes were excluded from the system boundaries:

- cleaning and decalcification of the machines;
- disposal and/or recycling of the coffee makers;
- the cultivation of coffee as well as the provision of (cold) water and the distribution (these processes were excluded from the analysed system as they can be assumed to be comparable for the different coffee makers).

According to the strict principle of life cycle analysis, all material and energy inputs within the system boundaries sketched earlier were inventoried and traced back to natural resources.

Manufacturing of the coffee machines

The material composition and the weight of the appliances vary among each other. On the basis of expert interviews and research, the following conservative assumptions reflecting the average material composition of a typical device were made: Table 1.

Use of the coffee maker

The usage behaviour was adopted from the Topten measuring method for coffee machines (Nipkow, 2008) and based on the following assumed usage pattern:

- use of the coffee machine in factory setting concerning the time delay for an eventual automatic power down;
  - coffee machines without power down function are left in idle mode for 12 h per day, for the filter drip coffee maker, 30 min of keep warm function (hot plate) is assumed;

[2]The functional unit reflects the average coffee consumption in a German two-person household, taking into account the typical in-house consumption in Germany. About a quarter to half of the coffee consumption in Germany takes place out-of-house in cafés, at work, etc. (German Coffee Association, 2010).

Table 1 Assumptions concerning the material composition of the appliances [plastics typically used in coffee makers are ABS (acrylonitrile-butadiene-styrene copolymers), polyethylene and high-density polythylene; typical metals are steel and copper]

	Weight (in kg)	Material composition (%)	Assumed product life time (in years)	Explanations
Filter drip coffee maker	1.6	Glass (20) Plastics (50) Metal (15) Others (15)	10	
French press	0.7	Glass (45) Metal (45) Plastics (10)	20 (with three changes of the glass jar)	The energy consumption of the electric kettle to heat the water was taken into account.
Filter pad – and capsule machine	6.5	Plastics (90) Metals (10)	6	There are automatic single-serve coffee makers with a higher content of metals. Because of the small share of the impacts of the production phase (about 5%), a change of the above mentioned assumptions would not change the overall results significantly.
Fully automatic machine	11.5	Plastics (90) Metals (10)	10	Similar to the filter pad and capsule machines, there are as well fully automatic coffee machines with a higher content of metals. For the results, that is not significant. The same applies to the weight of the machines.

• twice a day, coffee is produced within 1 h (coffee period[3]);
• a total of 2000 cups of coffee with 125 ml of water each are being produced per year using a constant value of 20.[4]

Obviously, there is a large variety of possible different usage behaviours in real life. As it is not possible to consider all of them and as there are no data on the average usage behaviour, an assumption had to be made. With the help of sensitivity analyses, the range of possible different usage behaviours can be covered.

Energy consumption

For the calculation, the following annual energy consumptions are taken into account according to Bush *et al*. (2007):

• average filter drip coffee maker: 25 kWh/a (Nipkow, 2009a);
• average French press: 28 kWh/a depending on the energy consumption of the used water boiler to heat up the water;[5]
• energy efficient filter pad/capsule machine: energy consumption 78 kWh/a (Nipkow *et al*., 2010);
• very energy inefficient filter pad/capsule machine: energy consumption 218 kWh/a.

With regard to the automatic coffee machine, three different assumptions were made for the use phase:

• energy efficient appliance with integrated auto power down function: energy consumption 78 kWh/a (Nipkow *et al*., 2010);
• average appliance without integrated auto power down function: energy consumption 178 kWh/a;
• very inefficient appliance without integrated auto power down function: energy consumption 218 kWh/a.

As indicated on Topten Switzerland (Nipkow, 2009b), the calculations were made on the basis of a coffee volume of 80 ml, the values earlier were extrapolated from 80 ml to 125 ml. In order to do so, the specific energy demand for coffee brewing had to be adapted: instead of 9.13 Wh per cup respective, 20 kWh for 2000 cups (80 ml), 28.28 kWh of electricity are needed to brew the coffee – based on calculations from experts assuming an efficiency of 80% and water heating from 12 to 90°C.

Coffee preparation

The considered coffee makers use the coffee in different forms: coffee powder, filter pads, capsules or coffee beans. Depending on the brand, the capsules are composed of different compounds and materials. On the one hand, there are capsules composed only of aluminium or plastic. On the other hand, there are also capsules with a plastic housing and an aluminium lid. Some of them have an aluminium coating on the ground[6] and almost all have a filter membrane. Their secondary packaging is usually made of cardboard. In contrast to capsules, filter pads from different brands do not differ much from each other. They are made of filter paper and have nearly the same weight. Their secondary packaging is usually made of aluminium-coated packaging foil similar to the packaging of espresso beans. Regarding the capsules, two different alternatives were considered in the calculation in order to cover the range of the different material compositions. Regarding the first alternative, the capsule is entirely made of aluminium except for a small filter membrane made of sulphate pulp. As for the second alternative, the capsule is composed of a plastic housing and an aluminium lid. This composition corresponds to an average plastic

[3]The coffee period is simulated as follows: minute 0: switching on, heating up, possibly rinsing; minute 30: setting to standby, waiting for 5 s, activating; minute 60: setting to standby, waiting for 5 s, waiting for auto power down.

[4]As the measuring of the coffee production is very difficult and the differences between the appliances are minimal, the standard value of the Swiss Agency for Efficient Energy Use was used for the calculations of the automatic coffee machine, the filter pad and the capsule machine (Bush *et al*., 2009).

[5]Data on the basis of electric kettle Siemens TW 60101, electricity consumption: 0.0141 kWh per cup.

[6]Such as Dolce Gusto capsules of Nescafé; http://www.dolce-gusto.de.

Table 2 Assumptions concerning the packaging of the coffee based on average values (own measurements)

Reference	Packaging		Secondary packaging	
Unit	Grams per cup	Kilogram per 2000 cups		Kilogram per 2000 cups
Coffee beans/coffee powder in aluminium-coated bag	0.0001025	0.205		
Filter paper (filter pads)	0.2	0.4	Aluminium-coated bag	1.04
Aluminium (capsules, type 1)	1.13	2.26	Carton	3.51
Polypropylene (PP) and aluminium (capsules, type 2)	PP 3.32 Aluminium 0.3	PP 6.64 Aluminium 0.6	Carton	3.51

capsule, also covering those with an aluminium foil at the bottom instead of an aluminium lid. For both alternatives the filter paper is not taken into account.

Table 2 gives an overview of the assumptions concerning the packaging including capsules and secondary packaging.

Production and disposal of the filter pads and the capsules including their secondary packaging

For the manufacturing of pads, capsules and their secondary packaging, only the production of the materials was considered. Specific manufacturing processes as the shaping of the capsules were not taken into account because of lack of data.

The following assumptions were made with regard to the disposal:

- Aluminium-coated packaging foil: disposal in incineration plant as the aluminium content is only 0.12%. Since no data were available, a possible plastic recycling was not considered.
- Disposal of the coffee ground and the filter pads:
  - French press: waste water treatment. It was assumed that coffee grounds are treated by washing them away into sewage.[7]
  - Automatic coffee machines and filter pad machines: 77% disposal as bio-waste (90% as compost and 10% as biogas; (Umweltbundesamt, 2008), the remaining 23% are disposed of in an incineration plant.
- Disposal of the aluminium capsules:
  - It was assumed that the capsules are disposed of through the Duales System Deutschland (DSD).[8] Because of the lack of data (maybe the capsules are disposed of by household waste because of their soiling after use), and referring to experts, a recycling of 100% was suggested. The coffee ground is disposed of in an incineration plant. Credits were calculated according to the open loop system (50:50). This method of allocation considers the impacts of producing a recycled material as a percentage of virgin production and as a percentage of recycled material production. The basic idea underlying is that a portion of the impact results from upstream virgin material inception and from the recycling of materials.
- Disposal of the capsules consisting of polypropylene (PP) and aluminium:
  - If the capsules are disposed of through the DSD system, they end up either in the aluminium fraction or in the plastic fraction, depending on the colour of the plastic. As the sorting plant is not able to recognize dark plastic capsules as plastic material, they are sorted to the residual waste fraction for burning. In the plastic fraction, they are identified as PP with a probability of 80–85% and are recycled. In addition to the colour of the plastic, the position of the aluminium on the conveyor belt is important for the sorting. Depending on the position, the capsule is sorted to the aluminium or to the plastic fraction. Because of lack of data for the regranulation process and as many capsules are composed of plastic, it was assumed that they are disposed of in an incineration plant. The aluminium lids are recycled. The credit has been calculated according to the open-loop system (50:50).

As there are many different types of capsules on the market, not all available types could be covered by the study. It is possible that the environmental impacts of other types of capsules might be higher or lower.

[7]It was assumed that this is the typical user behaviour. As the disposal phase had no relevant share of the overall result, no sensitivity analysis was carried out, e.g. assuming bio-waste.

[8]German resource recovery and recycling group that has organized the nationwide collection of packaging waste arising at private households in Germany.

Results

PCF of one cup of coffee (Rarity Machare)

One motivation for the in-depth analyses of the different preparation methods of coffee were the results of the PCF pilot project that indicated the huge influence of the consumption phase within the value chain of coffee. In this study, it was shown that the carbon footprint of one cup of coffee amounted to about 59 g CO_2 equivalents. The following figure gives an overview of the considered processes within the life cycle of coffee and their related GHG emissions, the result being projected on to the average coffee consumption of a two-person household in Germany with 2000 cups of brewed coffee (125 ml each). As in this case, the coffee powder was also considered the provision of 14 kg (7 g per cup) of coffee beans is included in the results.

As illustrated in Fig. 2, 2000 cups of coffee can be assigned to a carbon footprint of 119 kg CO_2e. *Main emission drivers* are the processes occurring at the farm (such as cultivation) including therewith connected upstream processes (such as production of pesticides and fertilizers), which make up 55% of the overall GHG emissions. With a share of 36% of the overall emissions, impacts from consumption are another hot spot. These 36% include the grinding and purchasing (4%) as well as the disposal (2%). Actually, 30% of these impacts attributed to consumer behaviour are caused by coffee consumption. Consequently, the

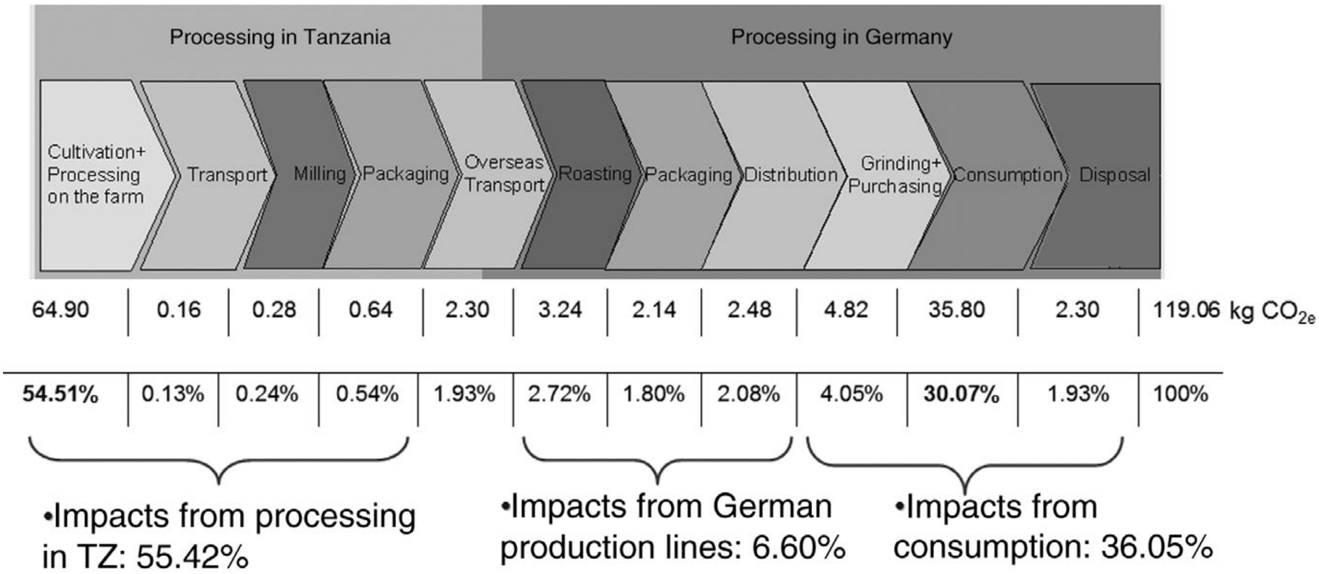


Figure 2 Overview on the life cycle phases and the CO_2e emissions of the different processes within the value chain of coffee. Functional unit: 2000 cups of coffee a 125 ml.

preparation of coffee by the consumer plays a crucial role in the carbon footprint.

Calculation of the consumption was carried out assuming a mix of preparation methods. On the basis of a general survey on coffee preparation from Dialego (2008), the mix was defined as 9% French press, 75% filter drip and 16% automatic coffee machine.[9] Furthermore, the carbon footprint of these different preparation methods was compared. The results of this comparison are shown in the next chapter. Within the PCF Pilot Project, further impact categories such as cumulated energy demand, acidification potential, eutrophication potential, etc. were calculated as sensitivity analyses. As the results of the considered impact categories do not differ significantly from the GWP, they will not be described here in detail.

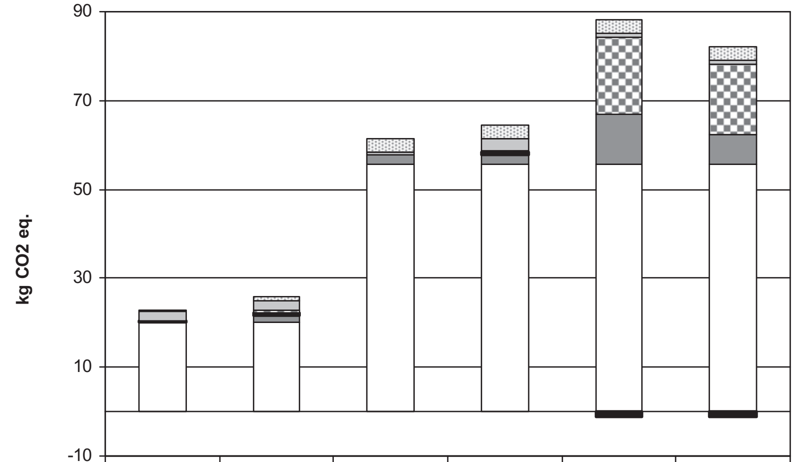
Comparison of different methods for coffee preparation

The results of the studies of Quack *et al*. (2009) and Stratmann *et al*. (2009) where different preparation methods were considered show a significant difference between the compared methods (see Fig. 3). The French press and the filter drip coffee machine have the lowest GWP. With 23 and 26 kg CO_2e, respectively, they are in the same range. The impacts of the fully automatic coffee machine and the filter pad machine are significantly higher (62 resp. 65 kg CO_2e). Capsule machines have the highest GWP of between 81 and 87 kg CO_2e. The production of the capsules as well as their disposal cause significant GHG emissions that impair the overall result of the capsule machines. It must be added that the assumptions made concerning the disposal favoured the recycling of the capsules; worse scenarios may be possible in real life. Hence, capsule machines using capsules consisting of plastic and aluminium have the highest GWP. Although the production and disposal of the capsules add significantly to the overall result, the use of the capsule machine still dominates the result with a share of 64% to 69%. By contrast, the capsules' contribution to the overall emissions is 20% for the production and 8% to 13% for the disposal. Considering all preparation methods, the use phase is the most important phase of the life cycle, with GHG emissions resulting from electricity consumption of the used appliances (coffee maker or electric kettle). In contrast to this, manufacturing and disposal phase only play a subordinate role.

Depending on the respective usage scenario (as for example, the chosen time intervals between the coffee preparations without switching off the device), considerable differences exist. Besides the purchase of an energy efficient appliance, an energy efficient use is therefore a prompt and easy way for consumers to reduce the energy consumption of coffee preparation. In one unpublished study (D. Quack *et al*., unpublished), different user behaviours were considered and analysed regarding their influence on the environmental impacts. The results show that the contribution of an efficient and an inefficient usage scenario to the overall result varies between 63% and 94%. Both usage scenarios consider the preparation of four cups of coffee per day, according to the Topten Measuring method. For the inefficient usage scenario, it was assumed that the user will keep the coffee machine in on mode for the whole day; for the efficient usage scenario, however, it was assumed that the user will turn the coffee machine off directly after the preparation of the coffee. These results show that up to 37% of the energy consumption can be reduced by consumer behaviour.

In order to analyse the high results of an automatic coffee machine in detail and to show the range of power consumption of different appliances on the market, Fig. 4 displays the GWP of an

[9]Average appliance without integrated auto power down function.



	French Press	Filter drip coffee maker	Fully automatic coffee	Pad filter machine with credit	Capsule machine (PP+Alu) with credit	Capsule machine (100% Alu) with credit
Manufacturing of the coffee makers	0.3	0.8	3.2	3.0	3.0	3.0
Production of the packaging of the filter pads/capsules/coffee	2.1	2.1	0.6	2.9	1.0	1.0
Production of the filter pads/capsules	0.0	0.8	0.0	0.3	17.4	15.9
Disposal of the packaging of the filter pads/capsules	0.4	0.4	0.1	0.6	-1.3	-1.3
Disposal of the filter pads/capsules/coffee ground	0.02	1.7	2.1	2.2	11.3	6.8
Use of the coffee makers	20.1	20.1	55.5	55.5	55.5	55.5

Figure 3 Global warming potential of different preparation methods for coffee. Functional unit: 2000 cups of coffee.

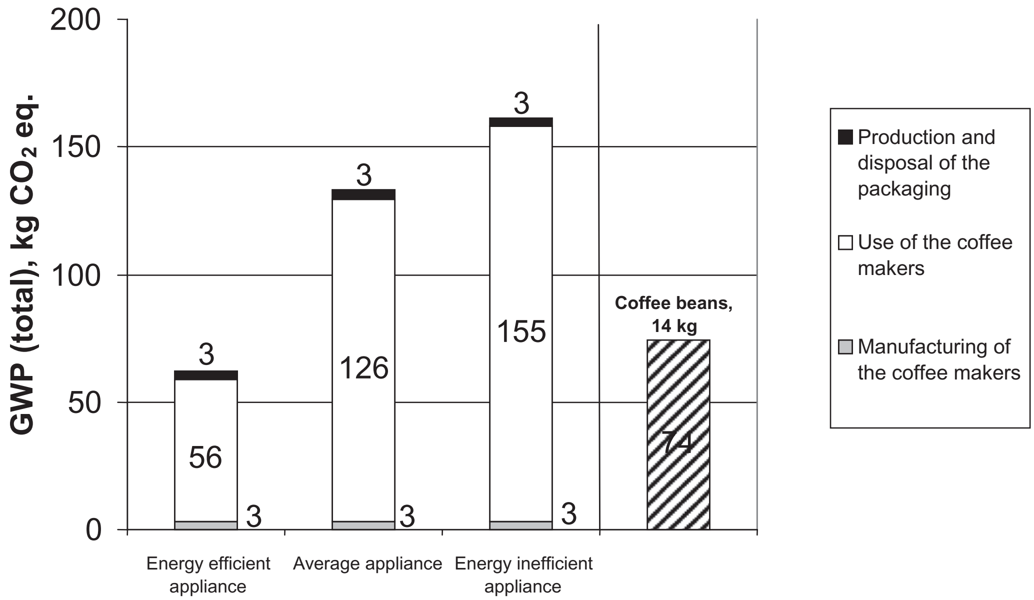


Figure 4 Global warming potential (GWP) of an energy efficient, an average and an inefficient fully automatic coffee machine. Functional unit: 2000 cups of coffee. The last column to the right shows the GWP of 14 kg of coffee beans, the amount that is necessary to make 2000 cups of coffee being attributable to cultivation, distribution and processing (the greenhouse gas emissions of the coffee beans refer to the Product Carbon Footprint study Quack *et al.*, 2009).

Table 3 Share of the life cycle phases on the global warming potential of different fully automatic coffee machines

	Energy efficient appliance (%)	Average appliance (%)	Energy inefficient appliance (%)
Manufacturing of the fully automatic coffee machine	5	2	2
Use of the coffee machine	89	95	96
Production and disposal of the packaging	6	3	2

energy efficient, an average and an inefficient fully automatic coffee machine (the assumptions of the appliances are described earlier).

On the one hand, the figure confirms that the use phase has the largest share of the GWP in comparison with the production of the coffee machines and the production and disposal of the coffee grounds. On the other hand, it also highlights the relevance of the efficiency of the fully automatic coffee machine for the overall GHG emissions of 2000 cups of coffee. It is striking that the cultivation, processing and distribution of the coffee beans contribute less (for average and inefficient machines) or only slightly more (for efficient coffee machines) to the GWP than the use of the coffee makers.

Depending on the used appliance, the contribution of the production phase to the overall GHG emissions ranges between 2% and 5% (see Table 3). With a contribution of 2% to 6%, the production and disposal of the packaging respective the coffee grounds fall within the same range. With a share of 89% to 96%, the highest impacts are caused by the use phase. Moreover, the result shows that the GWP varies significantly because of the energy efficiency of the fully automatic coffee machine. Even if an energy efficient appliance is used, however, the use phase has a share of 89% of the GWP (96% if an inefficient coffee machine is used). Today, there are several energy efficient coffee machines available with an annual energy consumption of about 40 kWh, which is significantly less then the 78 kWh per year assumed in the calculation earlier. This energy demand leads to a reduction of 45% of the overall GWP in comparison with an appliance with an energy consumption of 78 kWh per year (34 resp. 62 kg CO_2e.)

Conclusions and recommendations for consumers

The herewith presented analyses showed that the preparation of coffee is – at the example of GWP – connected to, more or less, environmental impacts depending on the method chosen for coffee preparation, the user behaviour and the efficiency of the appliance used for coffee preparation: it was unanimously demonstrated that the use phase of a coffee machine contributes most to the overall GHG emissions of its life cycle. Still, most consumers are not aware of the possibility to influence the environmental impacts of their coffee machine be it by purchasing an efficient appliance or using it efficiently.

When buying a coffee machine, consumers should make sure that the chosen model has an integrated auto power down function, switching the appliance from idle mode to standby mode after less then 1 h. Coffee machines with a hard off switch can be operated even more economically by switching it off directly after coffee preparation at the touch of a button. We would like to add that consumers may obtain further information at Internet platforms such as Topten International Group (Topten IG, 2010c), Topten Switzerland (Topten CH, 2010b) and Ecotopten (EcoTopTen, 2010) that contain a number of well-grounded recommendations concerning the choice of efficient appliances. Particularly efficient and climate-friendly coffee machines can additionally be labelled with the German environmental label Blue Angel.[10] Unfortunately, there are no certified products on the market yet.

Smart user behaviour may save a lot of energy, too: if the coffee machine has an automatic power down function, this should be set to 1/2 to 1 h. Note: the automatic power down function is usually set to 1 to 2 h by factory setting. With the proper setting, not only energy can be saved but also seals and pumps remain in good condition for a longer time, not being hot all of the time. Coffee machines without an automatic power down function should directly be switched off after use. For appliances with an energy saving mode (lowering the temperature of the thermo block), consumers should consult the manual or check the menu in order to verify that this function is activated. If necessary, the energy saving mode must be activated.

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