Journal of Cleaner Production 186 (2018) 430–449

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Comparative life cycle assessment of cooking appliances in Italian kitchens

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A R T I C L E I N F O

Article history:
Received 11 October 2017
Received in revised form
22 February 2018
Accepted 13 March 2018
Available online 14 March 2018

Keywords:
Cooking appliances
Food cooking
Environmental impact assessment
Life cycle assessment
Energy consumption

A B S T R A C T

The paper aims to analyse and compare the environmental performances of the most widely used cooking appliances (the induction hob vs. the gas hob) considering a typical Italian scenario in terms of food, family and social habits. Cooking appliances are subject to energy labelling, and they represent the most impacting system inside households. This study was performed in accordance with the international standard, ISO 14040/14044, by using an attributional Life Cycle Assessment (aLCA). The functional unit is defined as the "preparation of a complete homemade meal (lunch) for 20 years consumed by a four-member family in Italy". This study shows the dominance, in terms of environmental impact, of the induction hob with respect to the gas hob for most of the selected midpoint indicators. In particular, the induction hob accounts for more than 60% of the climate change and ozone depletion impact categories and more than 70% of the metal depletion category. The same trend is also noticed in the end-point categories (human health, ecosystem qualities and resources) and for the Cumulative Energy Demand indicator. Based on the experimental evidence of this work, the use phase is the most important due to the different energy carriers (natural gas vs. electrical energy). This finding is the result of the nature of the energy carrier (the electricity grid mix) in the Italian scenario, which is mainly based on non-renewable sources. In addition, concerning the production phase of the two appliances, the induction hob shows a relevant dominance in terms of the human toxicity and metal depletion impact categories due to the use of rare metals and coppers in the cooktop part manufacturing. The outcomes obtained from this study may be used by household manufacturers to improve the performance and design solutions of their appliances as well as by end users in their selection of cooking technologies.

1. Introduction

Cooking appliances such as ovens, hobs and range hoods have been subjected to European (EU) energy labelling and eco-design requirements since 2015. Looking at the European energy consumption reports, household appliances represent the highest impacting system after space and water heating. This category excludes appliances for auxiliary cooking, e.g., microwave ovens, kettles, coffee makers, etc. (EC, 2013; EC, 2014a). As a consequence, the need for investigating the environmental consequences of appliances over the whole life cycle represents a significant issue and is also in accordance with the recommendations contained in the recent Circular Economy Action Plan (EC, 2014b; EC, 2015), which encourages the reduction of the environmental load of these products and the adoption of strategies for its reduction. According to the EUROSTAT definition, the products belonging to the cooking appliances are electric cookers with and without ovens, separate electric ovens, gas-only cookers, combined gas-electric cookers, and solid fuel-fired cooking stoves (EUROSTAT, 2013). Among these, by analysing statistical data (Palmer et al., 2013), electric and gas cookers were found to be the most used, and data coming from the cooking appliance producers confirm that they are intensively used in daily meal preparation. For this reason, the community interest in the environmental impact of the preparation of homemade meals has been growing over time.

Data regarding sales and production confirm the relevance of this sector. Germany, Italy, Spain and France are the main

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https://doi.org/10.1016/j.jclepro.2018.03.140
0959-6526/

producers of domestic electric hobs, and approximately 12 million units are produced at the EU level (EU-25), while for gas cooking appliances, nearly 50% of their production inside the EU is represented by the UK and Italy, and approximately 2.7 million units are produced at the EU level (EU-25) (BIO Intelligence Service, 2011a). Italy is one of the European countries in which the two technologies are present. Whereas gas equipment is commonly used for meal preparation, induction hobs represent a brand-new technology in Italy. Therefore, a comparison of these technologies may shows interesting outcomes and supports responsible choices by consumers. Gas hobs are widespread in Italian kitchens due to the availability and low cost of natural gas compared with the cost of electrical energy. Induction hobs are a growing cooking technology due to their high efficiency in terms of both energy consumption and cooking performance (Villani and Presutto, 2012).

The Life Cycle Assessment (LCA) literature about household appliances is broad, e.g., TV sets (Hischier and Baudin, 2010), air conditioners (Grignon-Massé et al., 2011), cooker hoods (Bevilacqua et al., 2010) refrigerators (Ma et al., 2012), kettles (Ayoub and Irusta, 2014) and vacuum cleaners (Gallego-Schmid et al., 2016). Now, with the advent of the IoT (Internet of Things), such analyses have been coupled with the use of smartphones as household appliances auxiliaries for management, monitoring and additional aspects (e.g., recipes, alarms, etc.) (Andrae and Vaija, 2017). Several authors have used LCAs to compare and analyse the differences between products or production processes. As an example, regarding product technologies, Vignali (2017) has analysed different domestic boilers, Scharnhorst et al. (2006) have compared different mobile phone generations and Andrae (2015) have compared different office computing systems. However, few of these investigations were focused on cooking appliances such as induction or gas hobs. The study conducted by Pina et al. (2015) analysed the influence, in environmental terms, of five different induction hob configurations; this study had a very specific objective, and for this reason, it excluded from the analysis the electronic boards, as well as the use and maintenance phases, focusing only on those components affected by mechanical design. In line with the objectives of that study, the environmental analysis of the use phase was excluded, thus limiting the research due to the highly significant importance of this phase in the entire product life cycle impact. The long product lifetime and the relatively high energy consumption create, indeed, a massive environmental impact, and therefore, their quantification becomes interesting. The study of Elduque et al. (2014) analysed the environmental burden created by the electronic boards of an induction hob; in this case, the analysis was limited to this specific element of the product, and consequently, the study does not allow for a clear picture of the environmental impact related to the meal cooking with hobs. Jungbluth (1997) presented a comparison of different cooking alternatives by means of an LCA. In particular, attention was focused on the energy vector used to produce the heat needed to cook by means of a gas stove and an oven using natural gas or liquefied gas, an electric range and oven, a microwave oven and a wood stove in Switzerland. This study presents a very interesting analysis; however, this paper is now nearly 20 years old, and consequently, in addition to a supersized database and method used to model and to quantity a product's environmental impact, the evolution of technologies makes the results not applicable for current cooking solutions.

The current work attempts to overcome these limits and has the objective to analyse the environmental performance of the most commonly used cooking appliances (the induction hob vs. the gas hob). This study uses the guidelines outlined by the attributional LCA (aLCA) approach. The aLCA system modelling approach has been chosen with the aim to make a comparative analysis of both types of equipment by using the inputs and outputs attributed to the functional units of a product system (Baitz, 2016). In this case, the attributional approach allows for the estimation of the environmental load of the two cooking alternatives in the same scenario, highlighting the differences in the results (e.g., climate change). This study does not consider the effect in terms of environmental impacts caused by the replacement of one technology (e.g., a gas hob) with a new one (e.g., an induction hob), which is a typical consequential life cycle analysis.

The goal of this analysis is to provide another decisional support parameter in the selection of the most sustainable system for meal preparation and to create consumer awareness of the technology used for food cooking, which is considered one of the most important points of heat/energy consumption in residential buildings. This analysis has been performed considering a typical Italian scenario in terms of food, family and behaviours. Whereas the hobs belong to energy using product category, the use phase assumes a relevant role and was modelled using real consumption data that have been directly derived from measured product test cases.

2. Methods

According to the normative (ISO, 2006a; ISO, 2006b), an attributional LCA comparison analysis requires a clear and fair definition of the goal and scope of the study (Schmidt Rivera et al., 2014). In particular, the comparison is made on two products capable of fulfilling the same function (what), for the same time period (when) and for the same quantity of food (how much) (EC, 2016). The functional unit selected for the comparison is defined as "the preparation of a complete homemade meal (lunch) for 20 years that would be consumed by a four-member family in Italy". The "typical" Italian meal represents the average amount of food consumed on a normal working day by an average Italian family. Specifically, the meal is composed of the following:

- 350 gr of pasta (spaghetti);
- 100 gr of tomato sauce as a condiment;
- One (1) omelette made out of three (3) eggs; and
- Four (4) boiled zucchini.

This menu can be prepared by the following procedure:

- Boil approximately 3 L of water in a large pot; once the water boils, place 350 gr of spaghetti into the water and let it cook for approximately 10 min;
- Cook four slices of tomato in a small pan for 20 min;
- Cook 3 eggs in a small pot for 5 min; and
- Boil approximately 1 L of water in a medium pot, and then place 4 zucchini into the water and let them cook for 5 min.

A large heat supply is needed for the pasta, while both the vegetables and the tomato sauce require a medium heat flow. The eggs could be easily cooked using a small heat supply. Thus, the preparation of such a meal implies the use of a cooking area equipped with at least four heat sources.

Obviously, the Italian and the Mediterranean cultures in general are characterised by a large variety of "typical" meals; however, the one previously described appropriately represents the food habits of Italy (Guerrero et al., 2010; Nuvoli, 2015; Renna et al., 2015; Sahyoun and Sankavaram, 2016).

The functional unit refers to a lifespan of 20 years, which considers Italian family traditions and behaviours in the current situation. This is a typical scenario in which the family members (usually four persons) remain together until the children move out for work or studies (university, etc.) (Scabini, 2000; Saraceno, 2004). The lifespan of 20 years is below the minimum reference study period (from 30 to 50 years) used for the refurbishment and renovation measures of buildings, houses and appliances (BS-EN, 2011; EBC, 2014). This means that only one cooking system shall be included in the analysis, without any replacement or substitution. This statement is confirmed by the study of the European Commission on Lot23 (domestic and commercial hobs, including grills when they are incorporated in the cookers) in which an average lifespan of between 15 and 20 years appears reasonable for both technologies (BIO Intelligence Service, 2011b).

Two different scenarios have been taken into account to cover different behaviours and situations of Italian families: (i) occasional and (ii) intensive use of domestic cooking equipment for meal preparation:

– Scenario 1: the proposed “typical” meal is prepared three (3) times per week (approx. 160 meals/year);
– Scenario 2: the proposed “typical” meal is prepared five (5) times per week (approx. 260 meals/year).

The system boundaries are defined considering the current social and cultural conditions in Italy.

The material extraction and manufacturing phases for the production of the two cooking appliances are included in the LCA analysis because the different technologies have different impacts in the overall analysis. Foods described in the definition of the typical meal are not considered as part of the life cycle inventory because, as a matter of fact, their impact is independent with respect to the cooking technology.

The use phase is included in the LCA analysis since the impacts of the two technologies carrying out the activities described in the functional unit are different considering. The use phase involves the medium (electricity vs. natural gas) used in the two technologies and the emissions (e.g., carbon dioxide) related to the combustion of natural gas. Concerning the medium, natural gas is a fossil fuel typically used for heating and cooking systems in Italian private homes. The natural gas supplied to the Italian network is mainly imported from several countries (Russia, Libya, Algeria, the Netherlands and Norway). On the other hand, with regards to electricity, Italy depends on imports of fossil fuels, which are transformed into electricity in national thermal power plants or electricity directly imported from France and Switzerland. In the case of electricity, the contributions of renewable sources (hydroelectric, solar, wind, biomass, etc.) to the Italian grid mix are limited (approx. 17% in 2017) (EUROSTAT).

The end-of-life (EoL) phase is included in the LCA analysis and has been modelled following the 100:0 approach (Allacker et al., 2017). In this case, the recycling of scrap generated by the production system has not been part of the product system, and no credits have been given for subsequent recycling. The choice of this approach was derived from a high level of practicality, as it does not require one to estimate the impact due to recycling of product at EoL nor change of the product's inherent properties. Burdens have been included for the landfill process for the remaining fraction of materials. The fraction of material flowing directly to disposal has been derived considering the typical recycling rate for several material classes as indicated in IEC/TR 62635 (2012).

Aspects that are outside the limits of the system include (i) the transport phase and (ii) the maintenance phase. As the geometric dimensions and physical characteristics of the different cooking solutions as well as the geographical location and distribution of markets and supply centres are expected to be the same for the different technologies, the transportation phase from the manufacturing sites to the distribution centres and finally to each house is not included in the analysis. Moreover, literature reviews in different industrial and production contexts highlight how the transportation of raw materials from extraction points to manufacturing sites can be neglected (Elduque et al., 2014).

As the two technologies are expected to be free of maintenance across a lifespan of 20 years, the maintenance and service phases are not included in the analysis (as per the maintenance and service plan provided by the manufacturer of the two cooking appliances). A summary of the system boundary is illustrated in Fig. 1.

In addition to this system boundary definition, a cut-off criteria based on material “mass” has been chosen for the analysis of each system. In particular, components made of certain materials whose masses account for less than 1% of the overall mass of the same material have been neglected in the inventory data collection. Even though a material “mass” cut-off criterion is frequently used in this kind of analysis, it is considered a poor indicator (Suh and Huppes, 2002). Materials, particularly metals, are relevant in terms of the resource depletion impact categories (midpoints), and they cannot be ignored from this analysis. In any case, the effect of the material “mass” cut-off in the resource depletion indicator has been investigated with a sensitivity analysis. A change of $\pm1\%$ in the input values for the main adopted metals gives a change of approx. $\pm0.85\%$ for the outcomes related to the metal depletion category.

The environmental impacts have been calculated according to the following life cycle impact assessment (LCIA) methods:

– ReCiPe midpoint - Hierarchist (H) version - Europe (Goedkoop et al., 2009; Huijbregts et al., 2017);
– ReCiPe end-point - Hierarchist (H) version - Europe H/A - with the average weighting set (A) (Goedkoop et al., 2009; Huijbregts et al., 2017); and
– Cumulative Energy Demand (CED) (Jungbluth and Frischknecht, 2010; Frischknecht et al., 2015).

Since this study is directed towards the food/meal cooking and its equipment, the energy, materials and natural resources are of primary importance. To address these perspectives, this study uses midpoint impact categories connected to the Human Health (HH) and Resources (RA) end-point impact categories as well as the Human Health (HH) Ecosystem Quality (ED) and Resources (RA) end-point damage categories from the ReCiPe method (Goedkoop et al., 2009; Huijbregts et al., 2017). The climate change impact category within the ReCiPe midpoint (H) method includes all the greenhouse gases specified in the Kyoto Protocol using the global warming potential values from the IPCC Fourth Assessment Report with a 100-year time horizon (IPCC, 2007). The cumulative energy demand (CED) method (Jungbluth and Frischknecht, 2010; Frischknecht et al., 2015) is used, additionally, as a single-issue indicator to evaluate the energy demand associated with a product's life cycle.

The default ReCiPe midpoint/end-point method perspective used is the Hierarchist (H) version refers to the normalisation values of Europe. Perspective H is based on the most common policy principles with regards to the 100 [year] timeframe (as referenced in the ISO 14044:2006 standards on LCA).

SimaPro 8.05.13 (Prè Sustainability, 2016) has been used as the LCA software tool for the analysis, and the EcoInvent database (version 3.1) has been used as a supporting inventory database.

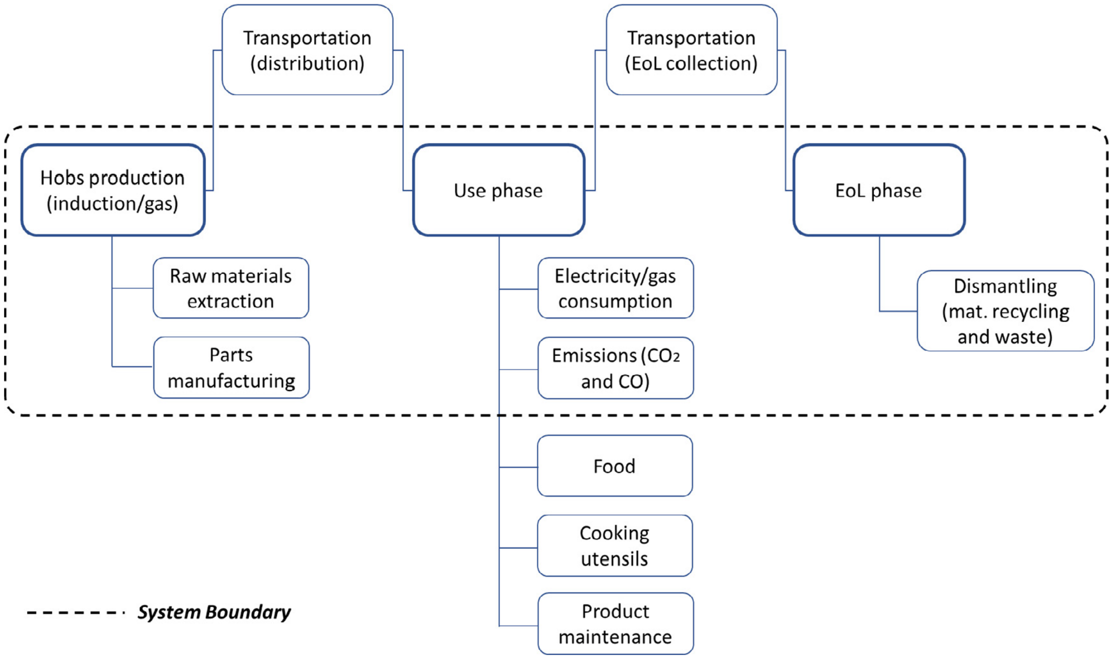


Fig. 1. System boundary.

3. Inventory data

In this section, all information (input/output) used for the LCAs of the different cooking systems is reported. The two cooking technologies are described in terms of equipment (product description) as well as their energy and resource consumptions. It is relevant to note that the "*Allocation, recycled content System Model*" (Alloc, rec) has been chosen. The "*Allocation, recycled content System Model*" together with the "*Allocation, default content System Model*" (Alloc, def) represent the two available allocation systems for attributional LCAs. Both models are based on the same methodological decisions, namely, the use of average supply and the use of partitioning as the method to allocate burdens and credits when dealing with the conversion from multi-product datasets to a single-product dataset. A substantial difference is given by the fact that the "Alloc, rec" model does not take into account any benefits related to the recycling of a material. Practically, recyclable materials are available burden-free to recycling processes, which means that secondary materials carry only the impacts derived from the recycling process. In other words, no credit is given to the waste producer for the recycling or re-use of their products (Nicholson et al., 2009; PRé Sustainability, 2016).

3.1. Product description

As mentioned in the introduction, the current research work aims to compare different cooking appliances using the LCA methodology. More specifically, the functional unit is carried out by the following reference flows: A gas hob made out of four (4) gas cookers (Fig. 2(a)). An induction hob made of four (4) cooking zones (Fig. 2(b)).

3.1.1. Gas hobs

The gas hob has four different cooking spots. The most common configuration includes a larger cooking spot, two medium spots and one small spot.

This technology is widely used in Italy due to the easy access to gas as well as its lower cost compared to that of electricity. The hob essentially consists of a metal plate that functions as frame, upon which four cooking spots are mounted. A steel grid is placed over each the cooking spot to allow for the cooking pots to be positioned right over the cooking spots. Each cooking spot is comprised of a flame-spreader, a cap, a main body, a thermocouple and a control knob. The main bodies of the spots and the flame-spreaders are made out of die casting aluminium, while the other parts are made out of different materials (mainly metals). In addition, the electric cables and the piping are included in the analysis. Further specifications of the components, related materials and manufacturing processes for the gas hob are shown in Table 1 of Appendix A.

3.1.2. Induction hobs

The induction hob deploys a different technology. Basically, below the glass-ceramic cooktop, there is an electronically controlled coil of copper. When the power is turned on, constantly changing electric current flows through the coil and produces above it a magnetic field that terminates at the bottom of a ferromagnetic pot placed above the hob.

This fluctuating magnetic field indirectly produces heat by inducing an electric current flow in the pot (an eddy current). Thus, there are considerable differences in both the bill-of-materials (BoM) and in their manufacturing processes. As with the gas hob, the induction hob also has four different heating points of different sizes: one large zone, two medium size zones and one small zone. Table 2 of Appendix A illustrates the components, related materials and manufacturing processes of the induction hob. It is clearly identifiable that there is a massive amount of copper, which is used to form the induction coils and the power cables. Moreover, there are also a number of electronic components (an electronic board and a touch control board) that are not required for the gas hob.

Fig. 2. Four-burner gas hob (a) and four-plate induction hob (b).

3.2. Inventory data collection for the raw material extraction and manufacturing phases

Life cycle inventories collect all the relevant data for the product under analysis. In the present work, data related to common materials and processes have been derived from commercial life cycle inventory databases (the background data), while data related to specific materials and processes have been derived from interviews with the manufacturers and suppliers or from direct measures in laboratories (the foreground data). Available data from manufacturers allow for the preparation a list of assemblies, sub-assemblies, components, materials and masses including the main manufacturing processes (e.g., rolling, drawing, coating, etc.).

For the gas hob, all the raw material data and all the manufacturing process data, excluding the high-pressure die casting process (HPDC), are derived from the EcoInvent v.3.1 database, and they represent, therefore, background data. Foreground data have been collected for the high-pressure die casting process by direct interviews with the suppliers of manufacturing company. The HPDC process presents, indeed, specific and customised characteristics that are applied for the production of the burner main bodies and the flame-spreaders. In this case, data collected from the HPDC supplier included (i) the heating energy used for the melting process, (ii) the electrical energy used for parts and metal handling, processing and trimming, (iii) the oil consumption necessary for the lubrication of the die, (iv) the water used for cooling the parts, (v) the air emissions associated with the furnace and (vi) the process waste.

For the induction hob, raw material data and manufacturing process data, excluding data related to the glass-ceramic cooktop, are derived from the EcoInvent v.3.1 database and represent therefore background data. Foreground data have been collected by direct interviews with the hob manufacturer for the glass-ceramic cooktop, which represents approximately 25% of the weight of the entire hob, and it can be considered therefore to be a key component of the product.

The electronic board and the touch control board (related to the induction hob) have been modelled using the background data present in the EcoInvent v.3.1 database and by applying the methodology proposed by Eldoque et al. (2014), i.e., by measuring the quantity and the weight of each electronic component inside the two boards. The BoMs of the two boards are reported in Tables 3 and 4 of Appendix A, which include the dataset used for modelling the boards. In addition, due to the high power rating required for the induction hob operation, the electric wires have been modelled using the background data present in the EcoInvent v.3.1 database, using a thicker wire diameter (2.5 mm). These data can be considered to be conservative, due to the fact the copper percentage considered in the modelled component is higher than the amount present in the product.

Inventories related to raw material extraction and manufacturing phases are presented in Tables 1 and 2 of Appendix A for the gas hob and for the induction hob, respectively. Tables 3 and 4 of Appendix A present the inventories related to electronic and touch control boards contained in the induction hob, respectively.

Concerning the geographic reference of the data used, most of the dataset refers to an unspecified location in the world (GLO) for the materials and manufacturing processes. This choice derives from the fact that the locations from where the primary materials originate or where the manufacturing processes occur are not clearly defined. Indeed, the manufacturer is a world trading company that produces and sells its products in different geographic areas.

3.3. Inventory data collection for the use phase

Data related to the energy consumption of the hobs during their use phases have been directly measured by experimental tests and then modelled using background data present in the EcoInvent v.3.1 database. Two separate experimental tests have been carried out, one for each product. The same procedure has been followed for both products. In practice, after setting up the measuring equipment, natural gas (methane) and electrical energy consumption have been measured and recorded. As mentioned before, the largest cooker has been used to boil the water and cook the pasta, while the medium ones have been used to cook the tomato sauce and the zucchini, and the smallest one has been used to cook the omelette. Each test has been conducted at a different time, meaning that only one cooker was on at a time. In the case of the gas hob, the methane consumption has been

Table 1
Electrical energy and gas consumption for the two cooking appliances.

Food	Burner size	Induction hobs		Gas hobs	
		Electricity consumption [kWh]	Cooking time [min]	Methane consumption [m3]	Cooking time [min]
Spaghetti	Rapid	0.24379	14	0.03701	24
Sauce	Semi-rapid	0.06033	9	0.00895	15
Zucchini	Semi-rapid	0.12091	12	0.02238	18
Omelette	Auxiliary	0.02303	6	0.00597	10

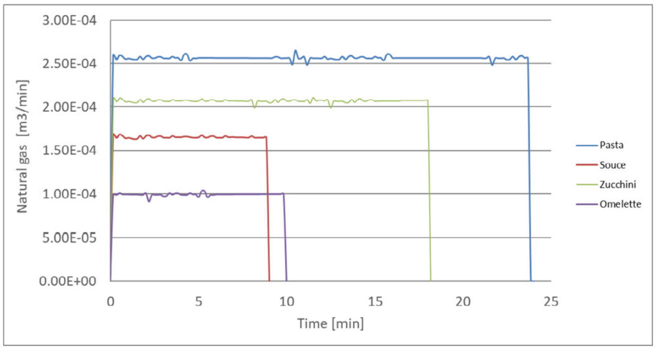


Fig. 3. Gas consumption for the four different foods.

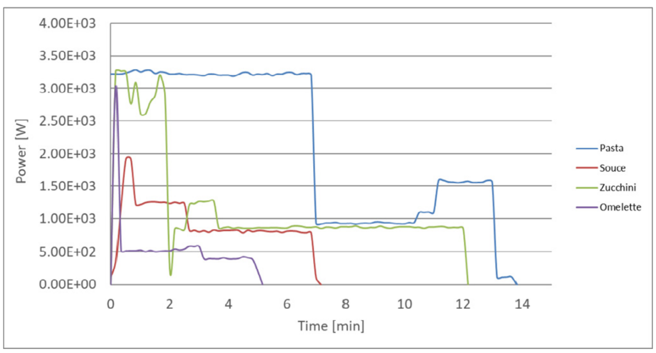


Fig. 4. Electrical energy consumption for the four different foods.

measured by constantly monitoring the gas flow rate [m^3/sec] using a specific flowmeter, while for the induction hob, the unitary power consumption [W/sec] has been measured with a specific power meter. The experimental tests have been carried out in constant ambient temperature of 25 Celsius grade. Table 1 illustrates the consumption values and relative cooking times for both case studies.

Whereas the gas hob allows the user to calibrate the heating outcome at different levels, the induction hob is less flexible and can accommodate up to nine different heating powers. In the graph below (Fig. 3), the trend of methane consumption is illustrated. It is clear that in the case of gas hob, the heating control has been used at its full power for the whole test. Obviously, the same function could have been accomplished by using half of the power (medium); however, it would require a larger period of time, which is not realistic considering the real modelled scenario. Analysing the energy consumption graph of the induction hob (Fig. 4), it is possible to see that the power demand has been calibrated according to the actual need. Looking at the blue line, which represents the energy consumption for

Table 3
CO2 and CO emissions for the gas hob.

Rapid burner		Semi-rapid burner		Auxiliary burner	
CO2 [ppm]	CO [ppm]	CO2 [ppm]	CO [ppm]	CO2 [ppm]	CO [ppm]
12513	97	10836	84	10449	81

preparing the pasta, it is possible to see that the power consumption drastically decreases at certain point and then remains almost constant until the end. This trend is the result of the fact that once the water is boiling, there is no need to keep the power at its maximum, and instead, a lower power output leads to a more suitable cooking condition. Stand-by energy consumption has been neglected from the analysis considering that the induction hob shuts off completely after 1 min of inactivity. During the standby phase, the energy consumption is negligible (approx. 0.00016 kWh).

Table 2 summarises the results from the use phase and compares both products with the two delineated use scenarios. Obviously, the consumption in Scenario 2 is larger than that in Scenario 1; however, the overall influence on the life cycle impact is not predictable without assessing the impacts from the other life stages.

Considering the background data for the two energy carriers, the Italian (IT) reference has been chosen (for both the electricity grid mix and natural gas):

- Natural gas (methane) - Natural gas, low pressure {IT}| market for | Alloc Rec, S
- Electrical energy - Electricity, low voltage {IT}| market for | Alloc Rec, S

In addition, for the gas hob, the combustion of natural gas has been modelled by using experimental tests performed by the hob manufacturers in accordance with the specific standard (UNI EN 30-1-1:2011). Natural gas combustion includes carbon dioxide and carbon monoxide emissions as described in Table 3.

3.4. Inventory data collection for the EoL phase

The inventory related to the EoL phase is presented in this subsection. All components have been modelled with the "*Allocation, recycled content System Model*". Burden-free processes are made visible in the EcoInvent v. 3.1 database using "empty" processes. Burdens have been included for the landfill process for the remaining fraction of materials. The burdens for the remaining fraction of materials have been derived starting from the typical recycling rates for material classes contained in IEC/TR 62635 (2012). Table 4 contains the EcoInvent v. 3.1 datasets used to model recyclable material classes (Aluminium, Steel, PA, PE, PP, PS, and Copper), the related recycling rates are derived from statistical

Table 2
Specific electrical energy and gas consumptions in the two defined life cycle scenarios.

	Scenario 1 (20 years, 3 times per week)		Scenario 2 (20 years, 5 times per week)	
	Induction hob [kWh]	Gas hob [m3]	Induction hob [kWh]	Gas hob [m3]
Spaghetti	760.64	115.47	1267.73	192.45
Sauce	188.24	27.92	313.73	46.54
Zucchini	377.23	69.82	628.72	116.37
Omelette	71.86	18.62	119.76	31.04
Tot.	*1397.97*	*231.47*	*2329.95*	*386.41*

Table 4
EoL modelling for different materials used in the hobs.

Material class	EcoInvent 3.1 dataset	Recycling rate (%)	Disposal rate (%)
Aluminium	Aluminium (waste treatment) {GLO}| recycling of aluminium | Alloc Rec, S	95	5
Steel	Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Alloc Rec, S	95	5
PA (Nylon)	Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Alloc Rec, S	94	6
PE (Polyethylene)	PE (waste treatment) {GLO}| recycling of PE | Alloc Rec, S	94	6
PP (Polypropylene)	PP (waste treatment) {GLO}| recycling of PP | Alloc Rec, S	94	6
PS (Polystyrene)	PS (waste treatment) {GLO}| recycling of PS | Alloc Rec, S	94	6
Copper	Used cable {GLO}| market for | Alloc Rec, S	24	76

data (IEC/TR 62635, 2012) and the remaining fractions of product components are directed to disposal.

Disposal treatments have been used to model the remaining fraction of recyclable material classes and for the un-recyclable glass-ceramic cooktop (Glass cullet, Cement, Ceramic tile) (Bonifazi and Serranti, 2006):

- Waste electric and electronic equipment {GLO}| market for | Alloc Rec, S has been used to model the landfilling of the remaining fractions of the recyclable materials;
- Waste concrete {GLO}| market for | Alloc Rec, S and Inert waste, for final disposal {GLO}| market for | Alloc Rec, S has been used to model the landfilling of the glass-ceramic top components.

4. Results

In this section, the outcomes are reported and discussed (Section 4.1), including references to the literature in this field. All the selected indicators are analysed including the contribution of each life cycle phase and the effect of each item on the final results. Uncertainty and sensitivity analyses are presented (Section 4.2) to describe the robustness of the results and to identify how much the uncertainty related to the most significant data input affects the environmental impact categories.

4.1. Results discussion

The results are displayed both graphically (from Figs. 5–11) and numerically (Tables 5 and 6) for the analysed environmental indicators as follows.

The results show the life cycle impacts of a gas hob and an induction hob for the given functional unit. The environmental impacts have been expressed by means of the ReCiPe impact assessment method both at the midpoint and the end-point levels. The results, after characterisation, are fundamental to understand the contributions of each cooking technology to the selected impact categories, whereas the end-point results have been given to express the results from a wider perspective highlighting the burdens to Human Health, the Ecosystems and Resource consumption. Moreover, this study includes the analysis of two different use scenarios that were adopted to simulate different users' behaviour and habits.

In accordance with previous literature reports (Boustani et al., 2010; Song et al., 2012; Elduque et al., 2014), it is possible to observe the relatively low importance of the EoL phase in comparison to the other life cycle stages.

Looking at Figs. 5 and 6, it is possible to note the contributions at the midpoint level of both technologies for each impact category for the first and second scenarios, respectively. The two graphs show, at a glance, a notable dominance in terms of the environmental burdens of the induction hob as it presents higher impacts in all seven categories chosen for this aim. The results related to scenario 2 (Fig. 6), which expresses the impacts deriving from a more intense use phase, demonstrate how the trend in all midpoint categories is practically equal to the result of scenario 1.

From this general overview, a closer look has been given to

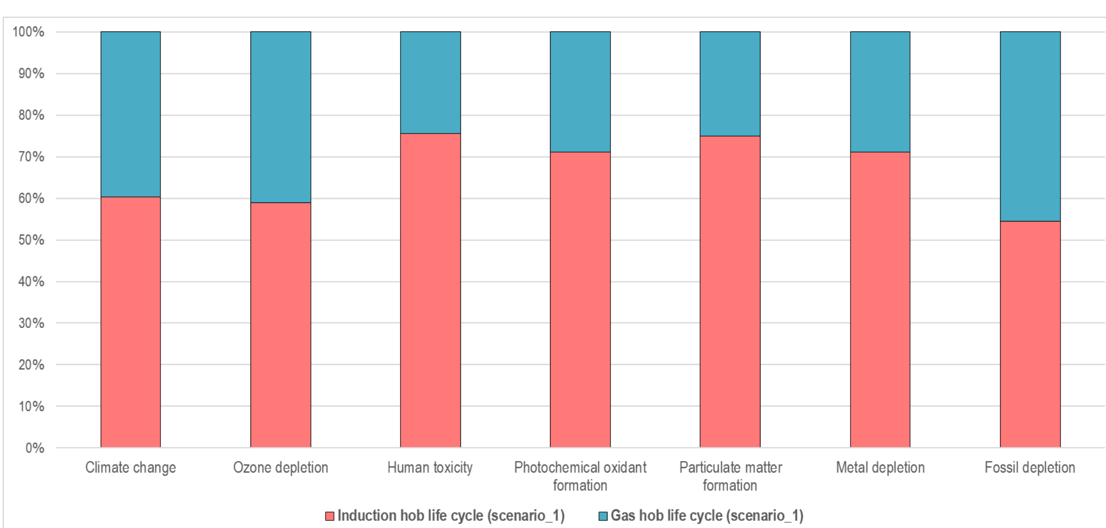


Fig. 5. Environmental impact comparison (ReCiPe midpoints) between the gas hob and the induction hob for life cycle scenario 1.

Table 5
Gas hob environmental impact assessment for both life cycle scenarios.

Impact category	Unit	Scenario 1							Scenario 2						
		Production		Use		EoL		Total	Production		Use		EoL		Total
Method: ReCiPe Midpoint (H) V1.12/Europe Recipe H															
Climate change	kg CO2 eq	6.06E+01	9%	5.92E+02	91%	1.09E-01	0%	6.52E+02	6.06E+01	6%	9.86E+02	94%	1.09E-01	0%	1.05E+03
Ozone depletion	kg CFC-11 eq	4.19E-06	5%	8.41E-05	95%	7.49E-09	0%	8.83E-05	4.19E-06	3%	1.40E-04	97%	7.49E-09	0%	1.44E-04
Human toxicity	kg 1,4-DB eq	1.61E+02	87%	2.36E+01	13%	6.83E-02	0%	1.85E+02	1.61E+02	80%	3.94E+01	20%	6.83E-02	0%	2.00E+02
Photochemical oxidant formation	kg NMVOC	2.74E-01	26%	7.79E-01	74%	3.65E-04	0%	1.05E+00	2.74E-01	17%	1.30E+00	83%	3.65E-04	0%	1.57E+00
Particulate matter formation	kg PM10 eq	2.44E-01	50%	2.44E-01	50%	2.59E-04	0%	4.89E-01	2.44E-01	37%	4.07E-01	62%	2.59E-04	0%	6.52E-01
Metal depletion	kg Fe eq	9.31E+01	95%	4.51E+00	5%	7.76E-03	0%	9.77E+01	9.31E+01	93%	7.51E+00	7%	7.76E-03	4%	1.01E+02
Fossil depletion	kg oil eq	1.52E+01	6%	2.30E+02	94%	2.85E-02	0%	2.45E+02	1.52E+01	4%	3.84E+02	96%	2.85E-02	0%	3.99E+02
Method: ReCiPe Endpoint (H) V1.12/Europe Recipe H/A															
Human Health	yr	2.61E-04	22%	9.09E-04	78%	2.68E-07	0%	1.17E-03	2.61E-04	15%	1.51E-03	85%	2.68E-07	0%	1.78E-03
Ecosystems	yr	5.80E-07	11%	4.86E-06	89%	1.02E-09	0%	5.44E-06	5.80E-07	7%	8.10E-06	93%	1.02E-09	0%	8.69E-06
Resources	$	9.16E+00	19%	3.84E+01	81%	5.26E-03	0%	4.75E+01	9.16E+00	13%	6.39E+01	87%	5.26E-03	0%	7.31E+01
Method: CED															
Non-renewable	MJ	7.39E+02	6%	1.08E+04	94%	1.53E+00	0%	1.16E+04	7.39E+02	4%	1.81E+04	96%	1.53E+00	0%	1.88E+04
Renewable	MJ	8.79E+01	63%	5.07E+01	37%	1.51E-01	0%	1.39E+02	8.79E+01	51%	8.44E+01	49%	1.51E-01	0%	1.73E+02
Total	MJ	8.27E+02	7%	1.09E+04	93%	1.68E+00	0%	1.17E+04	8.27E+02	4%	1.81E+04	96%	1.68E+00	0%	1.90E+04

Table 6
Induction hob environmental impact assessment for both life cycle scenarios.

Impact category	Unit	Scenario 1							Scenario 2						
		Production		Use		EoL		Total	Production		Use		EoL		Total
Method: ReCiPe Midpoint (H) V1.12/Europe Recipe H															
Climate change	kg CO2 eq	9.59E+01	10%	8.94E+02	90%	1.33E+00	0%	9.91E+02	9.59E+01	6%	1.49E+03	94%	1.33E+00	0%	1.59E+03
Ozone depletion	kg CFC-11 eq	8.09E-06	6%	1.18E-04	93%	1.62E-07	0%	1.26E-04	8.09E-06	4%	1.97E-04	96%	1.62E-07	0%	2.05E-04
Human toxicity	kg 1,4-DB eq	4.07E+02	71%	1.65E+02	29%	1.04E+00	0%	5.74E+02	4.07E+02	60%	2.76E+02	40%	1.04E+00	0%	6.84E+02
Photochemical oxidant formation	kg NMVOC	5.82E-01	22%	2.01E+00	77%	5.17E-03	0%	2.60E+00	5.82E-01	15%	3.35E+00	85%	5.17E-03	0%	3.94E+00
Particulate matter formation	kg PM10 eq	4.03E-01	28%	1.05E+00	72%	2.37E-03	0%	1.46E+00	4.03E-01	19%	1.76E+00	81%	2.37E-03	0%	2.16E+00
Metal depletion	kg Fe eq	2.16E+02	90%	2.46E+01	10%	7.05E-02	0%	2.41E+02	2.16E+02	84%	4.10E+01	16%	7.05E-02	0%	2.57E+02
Fossil depletion	kg oil eq	2.62E+01	9%	2.68E+02	91%	3.75E-01	0%	2.94E+02	2.62E+01	6%	4.46E+02	94%	3.75E-01	0%	4.73E+02
Method: ReCiPe Endpoint (H) V1.12/Europe Recipe H/A															
Human Health	yr	5.24E-04	24%	1.64E-03	76%	3.20E-06	0%	2.17E-03	5.24E-04	16%	2.74E-03	84%	3.20E-06	0%	3.27E-03
Ecosystems	yr	9.46E-07	11%	7.69E-06	89%	1.23E-08	0%	8.64E-06	9.46E-07	7%	1.28E-05	93%	1.23E-08	0%	1.38E-05
Resources	$	1.98E+01	30%	4.60E+01	70%	6.71E-02	0%	6.58E+01	1.98E+01	20%	7.67E+01	79%	6.71E-02	0%	9.65E+01
Method: CED															
Non-renewable	MJ	1.34E+03	9%	1.39E+04	91%	1.79E+01	0%	1.52E+04	1.34E+03	5%	2.31E+04	94%	1.79E+01	0%	2.45E+04
Renewable	MJ	1.26E+02	6%	2.07E+03	94%	7.75E-01	0%	2.20E+03	1.26E+02	4%	3.46E+03	96%	7.75E-01	0%	3.58E+03
Total	MJ	1.47E+03	8%	1.60E+04	91%	1.87E+01	0%	1.74E+04	1.47E+03	5%	2.66E+04	95%	1.87E+01	0%	2.81E+04

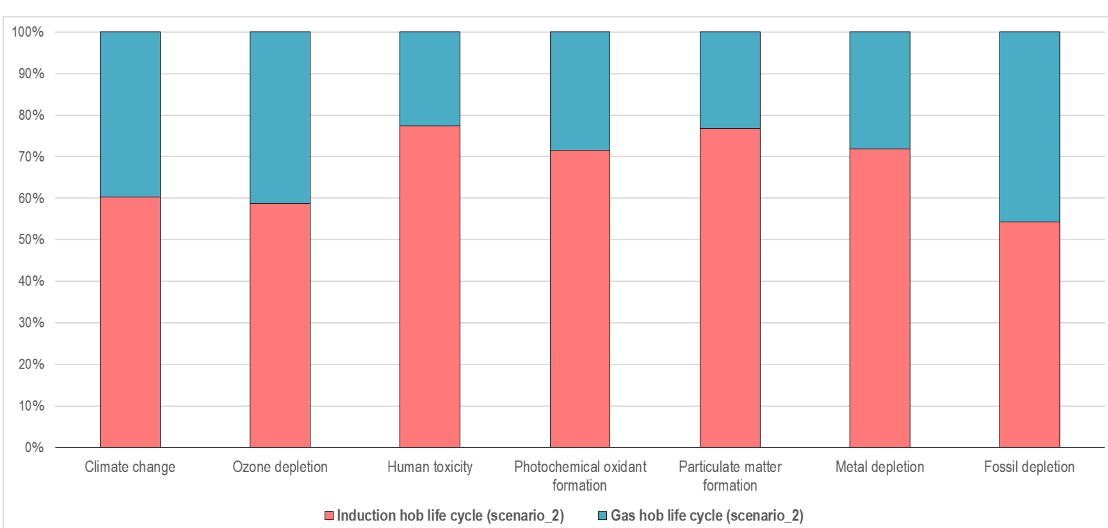


Fig. 6. Environmental impact comparison (ReCiPe midpoints) between gas hob and induction hob for life cycle scenario 2.

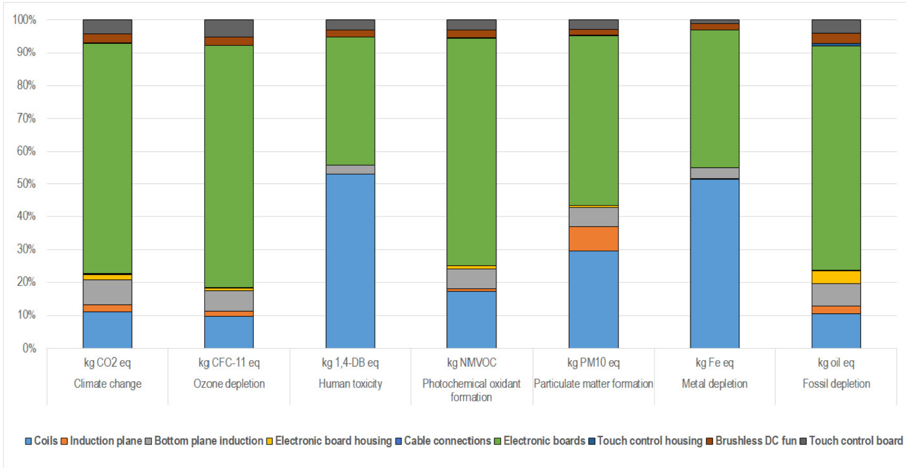


Fig. 7. Detailed analysis of the induction hob "material + manufacturing phase" for the ReCiPe categories [kg CO2 eq.].

climate change and ozone depletion impact indicators. As shown in Figs. 5 and 6, within this set of indicators, the induction hob presents a slight dominance of approximately 60% for both scenarios. In particular, the impact breakdowns of the different lifecycle phases show how the use phase accounts for more than 90% of the total impact (Tables 5 and 6).

Considering another set of indicators comprising human toxicity, photochemical oxidant formation and particulate matter formation, the dominance of the induction hob is more significant and ranges between 70% and 80% for both scenarios. In detail, a difference is noticed for the impact breakdowns of the life cycle phases. For example, considering the human toxicity indicator in the first scenario the production phase contributes approximately 87% for the gas technology and approximately 71% for the induction technology.

This difference is even more acute for the metal depletion indicator, where the hob production phase accounts for 95% and 90% of this indicator for the gas and induction technologies, respectively. One more interesting aspect related to the production phase is the value of the metal depletion indicator in the two cases: 93.15 [kg Fe eq.] (Gas) vs. 215.94 [kg Fe eq.] (Induction). These values lead to an important result related to the induction technologies. As shown in Fig. 7, the largest impacts in almost all categories are associated with (i) the production of the electronic boards and (ii) the production of the coils.

In detail, analysing the electronic boards used in the induction hob, the main contribution comes from the deployment of rare materials, while analysing the coils, almost all impacts derives from the copper used as the conductive material. To evaluate the magnitude of these impacts, normalised results are presented in Fig. 8. As shown, the electronic boards and coils have larger impacts in almost all categories. Specifically, metal depletion and human toxicity present greater impacts compared with the other components.

The origins of these impacts are illustrated in Fig. 9, where the characterised results from the electronic boards are presented. This figure shows that for the previously mentioned impact categories, the "PP film-type capacitor" is the most impactful component followed by the "Diode for board" and the "Induction ring core". This outcome is expected due to the large deployment of precious metals used in these electronic components.

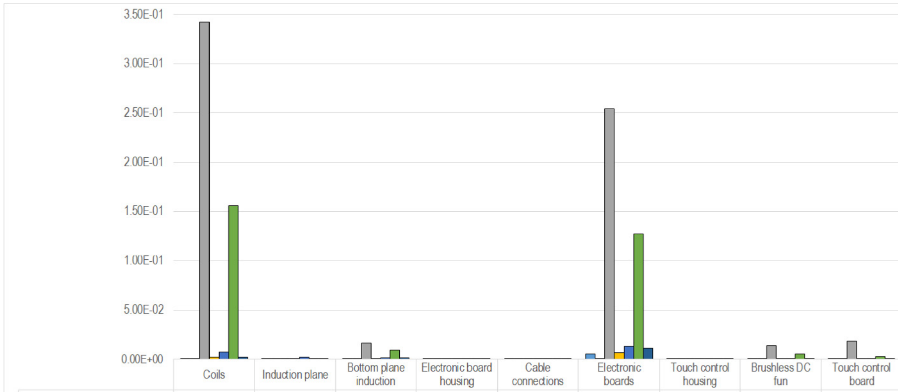
Fig. 10 shows results from the ReCiPe end-point analyses of both technologies in both scenarios. Again, this figure shows a dominance by the induction hob compared with the gas technology for the three end-point categories (Human Health, Ecosystems and Resources). Considering the Resources indicator, a slight dominance is noticed (approximately 57%), while for the Human Health indicator, a larger share is seen (approximately 65%). In both scenarios, the most important contributor to the life cycle impacts is the use phase (Tables 5 and 6).

Fig. 11 displays the results from the CED assessment. The CED is considered to be one of the key indicators, and its goal is to calculate the total primary energy input for the generation of a product, taking into account the pertinent front-end process chains. This indicator is considered to be of primary importance in this context, due to the large use these products are subjected to during their life cycle. In both scenarios, the largest share of the total impact is attributed to the induction hob. This is mainly due to the energy demand required during the use phase, particularly considering the number of non-renewable sources characterising the Italian energy grid mix. Still on this subject, the profile of the electrical energy (Italian grid mix) used for the induction hob technology is an interesting aspect to argue. As highlighted in the introduction, currently, the Italian grid mix is mainly characterised by fossil fuels. Even though the current share of renewable energy is below the 20%, the trend has significantly increased in the past two decades, and it is expected to growth even more due to the energy development plan and national/communitarian incentives. For this reason, the environmental profile related to the use phase of induction hobs seem overestimated by using the current energy scenario, and it can potentially lead to lower environmental impacts compared with the gas hob technology.

4.2. Sensitivity analysis

A sensitivity analysis of the environmental impacts was conducted with the following assumptions:

1 A variation in the input materials for the hob production phase in the range of ±10%
2 A variation in the use phase energy demand in the range of ±10%
3 The use of two extreme cases for the EoL phase:
  a) 100% material recycling and 0% landfill (optimistic)
  b) 0% material recycling and 100% landfill (pessimistic)



	Coils	Induction plane	Bottom plane induction	Electronic board housing	Cable connections	Electronic boards	Touch control housing	Brushless DC fun	Touch control board
Climate change	9.51E-04	1.81E-04	6.46E-04	1.41E-04	1.01E-05	6.01E-03	2.62E-05	2.21E-04	3.62E-04
Ozone depletion	3.55E-05	5.63E-06	2.30E-05	3.21E-06	2.30E-07	2.71E-04	5.96E-07	9.08E-06	1.87E-05
Human toxicity	3.42E-01	6.99E-04	1.70E-02	3.34E-04	2.39E-05	2.54E-01	6.20E-05	1.41E-02	1.89E-02
Photochemical oxidant formation	1.77E-03	8.92E-05	5.87E-04	1.01E-04	7.24E-06	7.12E-03	1.88E-05	2.39E-04	3.01E-04
Particulate matter formation	7.98E-03	2.00E-03	1.65E-03	1.48E-04	1.06E-05	1.40E-02	2.75E-05	4.92E-04	7.50E-04
Metal depletion	1.56E-01	8.25E-04	9.74E-03	2.46E-05	1.76E-06	1.27E-01	4.56E-06	5.65E-03	3.38E-03
Fossil depletion	1.77E-03	3.88E-04	1.16E-03	6.03E-04	4.31E-05	1.16E-02	1.12E-04	5.24E-04	6.78E-04

Fig. 8. Normalised results from ReCiPe midpoints for the induction hob.

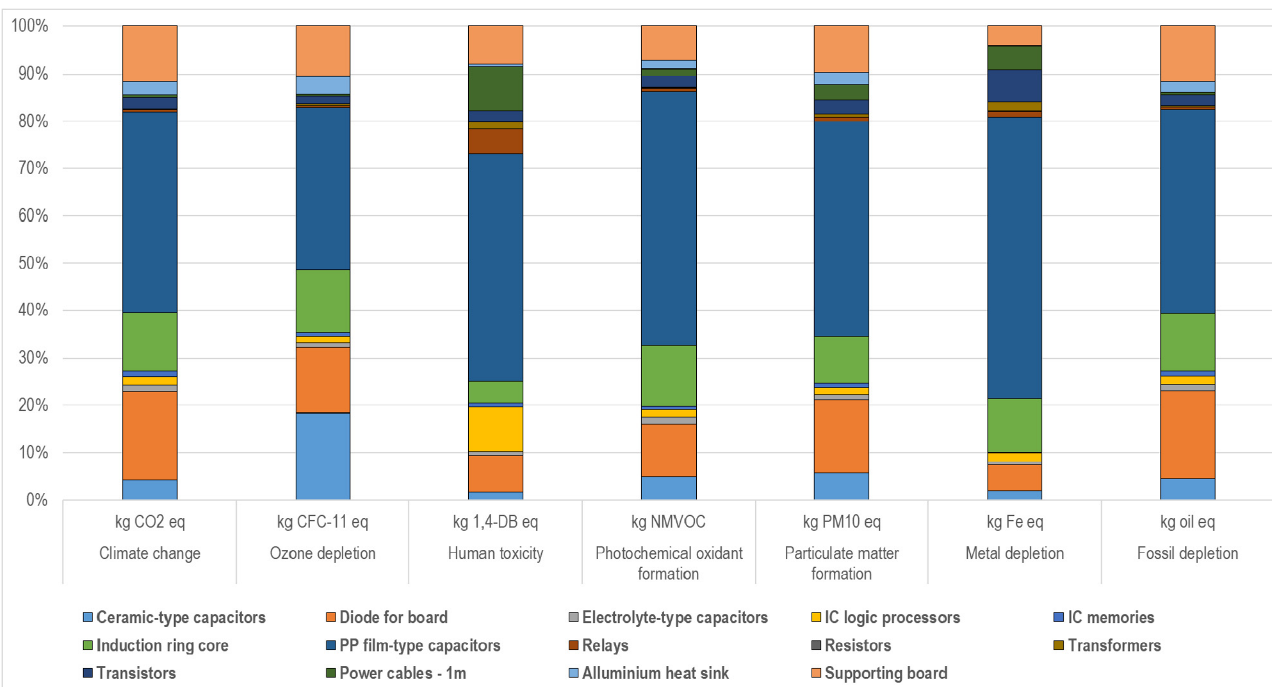


Fig. 9. Detailed characterised results of the electronic boards in the induction hob for each category (ReCiPe midpoints).

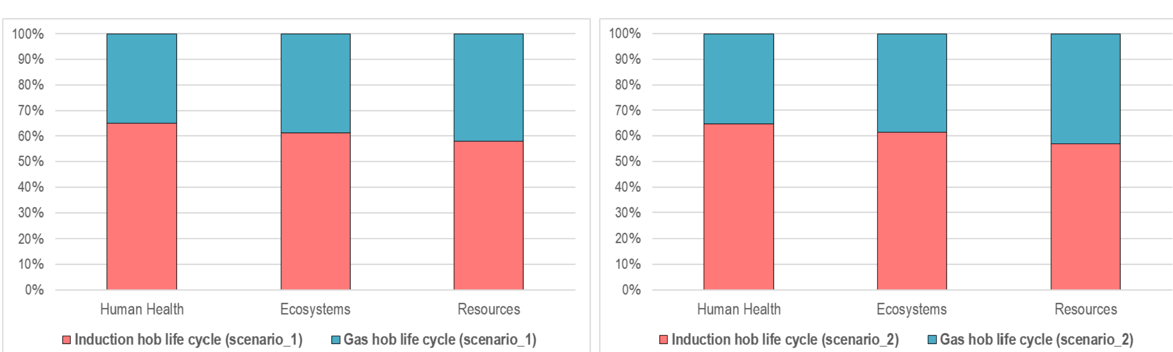


Fig. 10. Environmental impact comparison (ReCiPe end-points) between the gas hob and the induction hob for life cycle scenario 1 (left) and life cycle scenario 2 (right).

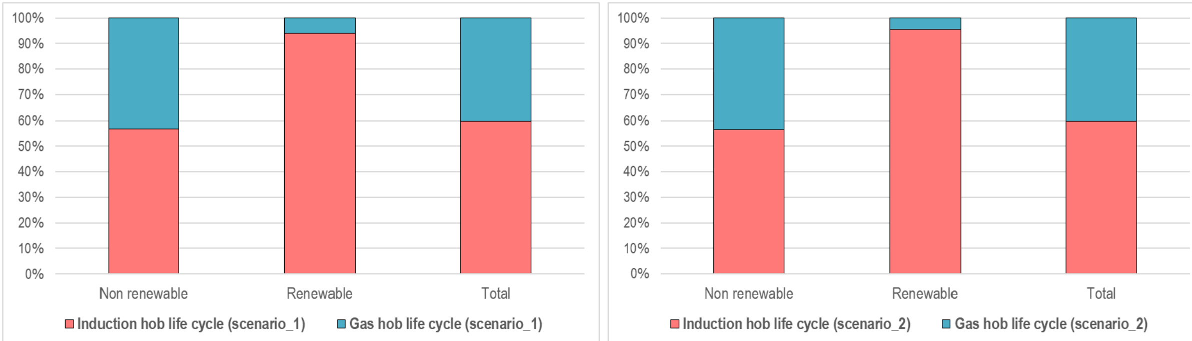


Fig. 11. Environmental impact comparisons (CED) between the gas hob and the induction hob for life cycle scenario 1 (left) and for life cycle scenario 2 (right).

Table 7
Sensitivity analysis for the gas hob life cycle in scenario 1.

Impact category	Unit	Baseline	Material variation (±10%)	Energy demand variation (±10%)	100% material recycling	100% product landfilling
Method: ReCiPe Midpoint (H) V1.12/Europe Recipe H						
Climate change	kg CO2 eq	652.32	±0.78%	±8.30%	−0.38%	0.04%
Ozone depletion	kg CFC-11 eq	0.00	±0.32%	±8.68%	−0.03%	0.14%
Human toxicity	kg 1,4-DB eq	184.66	±8.00%	±1.26%	−0.63%	0.30%
Photochemical oxidant formation	kg NMVOC	1.05	±2.42%	±6.88%	−0.44%	0.06%
Particulate matter formation	kg PM10 eq	0.49	±4.69%	±4.75%	−0.90%	0.08%
Metal depletion	kg Fe eq	97.66	±8.70%	±0.46%	−0.13%	0.01%
Fossil depletion	kg oil eq	245.43	±0.46%	±8.56%	−0.05%	0.15%
Method: ReCiPe Endpoint (H) V1.12/Europe Recipe H/A						
Human Health	yr	0.00	±2.06%	±7.20%	−0.52%	0.01%
Ecosystems	yr	0.00	±0.91%	±8.19%	−0.35%	0.05%
Resources	$	47.54	1.76%	±7.46%	−0.13%	0.13%
Method: CED						
Total	MJ	11715.64	±0.55%	±8.49%	−0.05%	0.15%

Table 8
Sensitivity analysis for the induction hob life cycle in scenario 1.

Impact category	Unit	Baseline	Material variation (±10%)	Energy demand variation (±10%)	100% material recycling	100% product landfilling
Method: ReCiPe Midpoint (H) V1.12/Europe Recipe H						
Climate change	kg CO2 eq	991.08	±0.97%	±8.27%	−0.53%	0.33%
Ozone depletion	kg CFC-11 eq	0.00	±0.65%	±8.55%	−0.02%	0.10%
Human toxicity	kg 1,4-DB eq	573.70	±6.64%	±2.80%	−0.60%	0.55%
Photochemical oxidant formation	kg NMVOC	2.60	±2.21%	±7.19%	−0.28%	0.07%
Particulate matter formation	kg PM10 eq	1.46	±2.70%	±6.74%	−0.16%	0.12%
Metal depletion	kg Fe eq	240.59	±8.24%	±1.01%	−0.58%	0.02%
Fossil depletion	kg oil eq	294.36	±0.90%	±8.34%	−0.29%	0.10%
Method: ReCiPe Endpoint (H) V1.12/Europe Recipe H/A						
Human Health	yr	0.00	±2.37%	±7.04%	−0.48%	0.29%
Ecosystems	yr	0.00	±1.10%	±8.16%	−0.52%	0.30%
Resources	$	65.85	±2.93%	±6.53%	−0.22%	0.08%
Method: CED						
Total	MJ	17447.36	±0.85%	±8.38%	−0.24%	0.08%

Considering the first assumption (variation of input materials for the hob production phase in the range of ±10%), it is possible to assess both the influence of the hob production phase and the cut-off rule.

Considering the second assumption, it is possible to account for the influence of the use phase, which includes the variations in food preparation both for food types and required times.

Considering the last assumption, it has the intent to assess the influence of the EoL phase in these two extremist cases. The findings of the sensitivity analysis are shown in Tables 7 and 8.

Looking at the material variation, for most of the considered categories, the effects on the life cycle results are less than 3%. The only two categories that account for a higher value are human toxicity and metal depletion. In particular, the metal depletion category is sensitive to the variation in the material mass (8.70% for the gas hob and 8.24% for the induction hob). This result is in line with the expectation due to the large use of metals and the toxic effect of some of the metals (e.g., heavy metals) used in these products. In addition, these results validate the cut-off criteria used within this approach.

The variation in the energy demand (both gas and electricity) represents the most important aspect in the final environmental assessment. Excluding the human toxicity and metal depletion categories, all the other categories are subjected to a considerable variation. In particular, the CED indicator, which is the most sensitive to the energy demand, is affected by more than 8%. This trend is found in both the gas and the induction hobs.

The results of the two limit conditions presented for the EoL are presented in the last two columns of Tables 7 and 8 for the gas hob and induction hob, respectively, for scenario 1. Looking at these results, the EoL does not have an important effect on the product environmental assessment, and the sensitivity analysis confirms this statement. The results presented in Table 8 (the induction hob) look more sensitive to the EoL scenario due to the higher impact of the rare metals used in the electronic boards.

5. Conclusions

The present study illustrates the environmental performance of two different cooking facilities: the gas hob vs. the induction hob. In addition to the use of different raw materials and manufacturing processes for these two products, these two technologies adapt different energy carriers (electricity vs. gas) as well as different energy transformations, which implicitly lead to different operating efficiencies.

From a general perspective, the gas hob performs better than the induction hob in the Italian context.

Analysing the life cycle phases, it emerges that the hob production phase represents a weak point for the induction hob. Given the current product configurations, from an environmental point of view, the use of certain materials (such as rare metals) determines the higher impacts. Looking at the use phase, in such long-lasting products, the electrical energy source plays a key role. Indeed, the use phase represents more than 90% of some particular indicators, such as climate change and ozone depletion. Another interesting outcome is the negligible impacts of the EoL phase.

Despite the fact that the introduction of the induction hob in the global market occurred a decade ago, its considerable market share has only been achieved in recent years due to their steadily improving energy efficiency. Apart from the environmental focus, in Italy, the cost of electricity compared to that of gas has always fostered the adoption of the gas hob instead of the induction hob. As demonstrated in this work, at the present time, gas hobs are still more efficient in term of environmental impacts.

This outcome is largely influenced by the many factors that were included in this study. The first factor was the type of food selected in the analysis. In fact, despite that the food itself is outside the system boundaries, the power required to cook it is actually defying the use phase. A different type of food would lead to a different amount of power consumed. In addition to the food itself, the lifestyle of the Italian family is changing, meaning that they formerly cooked at home more often than they do now. Thus, the actual use phase might be less intensive for the same product life expectancy.

Another important point is the generation of electricity by external sources, which can be coupled with the induction hob. Practically, the generation of the electric power used for cooking by photovoltaic panels offsets the impacts related to the electricity production. The categories such as climate change and ozone depletion would show lower impacts due to the different supply of energy.

Another external influence, with a similar outcome, is the effect of the modification of the Italian grid mix. As described, the transition to a more renewable energy generation grid mix largely affects the results of this study. The use of a different energy grid mix, which includes a higher rate of renewable energy sources (photovoltaic, wind power, cogeneration, etc.), leads to an important reduction in the environmental impacts of this technology. This is the case in northern European countries (e.g., Norway and Denmark) where their share of renewable sources is higher than those of southern European countries such as Italy. As mentioned above, the impacts on the climate change and ozone depletion categories decrease for the induction hob, whereas the environmental profile of the gas hob remains unchanged.

As technological development advances, the overall energy conversion efficiency the induction hob improves as well. The replacement of electronic components with those having better performance increases the efficiency of the induction hub leading to lower electricity consumption. The same trend is not observed in gas hob devices. In fact, the gas technology is largely accepted and well known in the global market, and no further research and development actions are currently being undertaken to improve its efficiency.

In addition to the improvement of its overall efficiency, the introduction of more electronic devices, or in general the dominance of electronic devices to the detriment of mechanical devices, leads to a shorter lifetime for the induction hub. As occurs in other markets, the lifetime bottleneck is usually represented by the electronic components, which have the shortest lifespan among all the components of the product. This phenomenon has a negative effect from an environmental point of view, favouring the gas hob technology. Therefore, whether a lifetime of 20 years for induction units is a reasonable figure is perhaps open to question. Induction hobs are more complex, in terms of the number of parts and technology, than either conventional electric or gas hobs. It would not be surprising if a lifetime more similar to those of other consumer electrical products (approximately 10–15 years) was actually realised.

In conclusion, this study demonstrates the environmental validity of the gas hob cooking technology in comparison with the established induction hob technology considering the cooking process of a typical Italian meal for a medium-sized family.

Future work will be dedicated to the analysis of the evolving energy scenario and market changes that will include a larger use of renewable energy. Indeed, in future scenarios, the shift from fossil fuels to renewable sources will increase the benefit of using an electricity-consuming product such as the induction hob in comparison with the gas hob. In addition, evolving energy costs and market trends will also affect the life cycle costs of both technologies, and a correlation with environmental indicators can increase the consumers' awareness in the selection of the most sustainable system considering not only environmental indicators but also economic factors.

Appendix ALife cycle Inventory for *Hobs production* phase

Table 1
LCI of gas hob system.

Reference flow: gas hob 1 [pcs]								
Assembly name	Component name	Q.ty[pcs]	Material	Data sources Background (B) Foreground (F)	Corresponding dataset in EcoInvent 3.1	Manufacturing process	Data sources Background (B) Foreground (F)	Corresponding dataset in EcoInvent 3.1
Hob grill	Grills	2	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 650 kN press, single stroke
				B (EcoInvent 3.1)		Welding (MIG)	B (EcoInvent 3.1)	Welding, arc, steel
				B (EcoInvent 3.1)		Degreasing	B (EcoInvent 3.1)	Degreasing, metal part in alkaline bath
				B (EcoInvent 3.1)		Enamelling	B (EcoInvent 3.1)	Enamelling
	Rubber feet	8	Synthetic Rubber (EVA)	B (EcoInvent 3.1)	Ethylene vinyl acetate copolymer	Injection moulding	B (EcoInvent 3.1)	Injection moulding
Flame-spreaders	Ausiliario	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	High pressure die casting	F (supplier direct interview)	–
				B (EcoInvent 3.1)		Machine working: Dressing	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Semirapido	2	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	High pressure die casting	F (supplier direct interview)	–
				B (EcoInvent 3.1)		Machine working: Dressing	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Rapido	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	High pressure die casting	F (supplier direct interview)	–
				B (EcoInvent 3.1)		Machine working: Dressing	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
Caps	Ausiliario	1	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 3500 kN press, single stroke
				B (EcoInvent 3.1)		Enamelling	B (EcoInvent 3.1)	Enamelling
	Semirapido	2	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 3500 kN press, single stroke
				B (EcoInvent 3.1)		Enamelling	B (EcoInvent 3.1)	Enamelling
	Rapido	1	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet metal drawing	B (EcoInvent 3.1)	Deep drawing, steel, 3500 kN press, single stroke
				B (EcoInvent 3.1)		Enamelling	B (EcoInvent 3.1)	Enamelling
Main bodies	Ausiliario	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	High pressure die casting	F (supplier direct interview)	–
				B (EcoInvent 3.1)		Machine working: Dressing	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Semirapido	2	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	High pressure die casting	F (supplier direct interview)	–

				B (EcoInvent 3.1)		Machine working: Dressing	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Rapido	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	High pressure die casting	F (supplier direct interview)	–
				B (EcoInvent 3.1)		Machine working: Dressing	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
Gas taps	Main body	4	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Machine working: Turning and drilling	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Valve body	4	Copper	B (EcoInvent 3.1)	Copper	Machine working: Turning and drilling	B (EcoInvent 3.1)	Metal working, average for copper product manufacturing
	Nut	4	Brass	B (EcoInvent 3.1)	Brass	Machine working: Turning and drilling	B (EcoInvent 3.1)	Brass removed by turning, average, conventional
	Bottom brackets	4	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Sheet rolling	B (EcoInvent 3.1)	Sheet rolling, aluminium
				B (EcoInvent 3.1)		Machine working: Drilling	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Screw TORX M4x8	16	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed	Machine working: Turning	B (EcoInvent 3.1)	Steel removed by turning, average, computer numerical controlled
				B (EcoInvent 3.1)		Zinc plating	B (EcoInvent 3.1)	Zinc coat, pieces
	Cable clips	4	PA (Nylon)	B (EcoInvent 3.1)	Nylon 6	Injection moulding	B (EcoInvent 3.1)	Injection moulding
	Tap brackets	4	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 650 kN press, single stroke
Thermocouples	Probe	4	Chrome (90% Ni – 10% Cr)	B (EcoInvent 3.1)	90% Ni – 10% Cr	NA	–	–
	Body	4	Copper	B (EcoInvent 3.1)	Copper	Machine working: Turning	B (EcoInvent 3.1)	Metal working, average for copper product manufacturing
	Cables	4	Wire in Copper and Insulation/Jacket in PVC	B (EcoInvent 3.1)	Cable, unspecified	NA	–	–
Spark-plugs	Spark-plug	4	Ceramic	B (EcoInvent 3.1)	Sanitary ceramics	NA	–	–
	Cables	4	Wire in Copper and Insulation/Jacket in PVC	B (EcoInvent 3.1)	Cable, unspecified	NA	–	–
	Spring	4	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed	Wire drawing, cutting and bending	B (EcoInvent 3.1)	Wire drawing, steel
Metal plate	Plate	1	Stainless Steel	B (EcoInvent 3.1)	Steel, chromium steel 18/8, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 38000 kN press, single stroke
	Screw TORX M4x8	8	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed	Machine working: Turning	B (EcoInvent 3.1)	Steel removed by turning, average, computer numerical controlled

(*continued on next page*)

Table 1 (*continued*)

Reference flow: gas hob 1 [pcs]

Assembly name	Component name	Q.ty[pcs]	Material	Data sources Background (B) Foreground (F)	Corresponding dataset in EcoInvent 3.1	Manufacturing process	Data sources Background (B) Foreground (F)	Corresponding dataset in EcoInvent 3.1
				B (EcoInvent 3.1)		Zinc plating	B (EcoInvent 3.1)	Zinc coat, pieces
	Caps	6	PA (Nylon)	B (EcoInvent 3.1)	Nylon 6	Injection moulding	B (EcoInvent 3.1)	Injection moulding
	Plate protection	1	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 38000 kN press, single stroke
				B (EcoInvent 3.1)		Zinc plating	B (EcoInvent 3.1)	Zinc coat, pieces
	Brackets	4	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 650 kN press, single stroke
				B (EcoInvent 3.1)		Zinc plating	B (EcoInvent 3.1)	Zinc coat, pieces
	Screw M2,9 × 16	8	Stainless Steel	B (EcoInvent 3.1)	Steel, chromium steel 18/8,	Machine working: Turning	B (EcoInvent 3.1)	Chromium steel removed by turning, average, computer numerical controlled
Knobs	Knobs	4	Acrylonitrile-butadiene-styrene (ABS)	B (EcoInvent 3.1)	Acrylonitrile-butadiene-styrene copolymer	Injection moulding	B (EcoInvent 3.1)	Injection moulding
	Reinforcement	4	Carbon steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 650 kN press, single stroke
				B (EcoInvent 3.1)		Zinc plating	B (EcoInvent 3.1)	Zinc coat, pieces
	Metal inserts	4	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Machine working: Turning	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Rubber feets	4	Synthetic Rubber (EVA)	B (EcoInvent 3.1)	Ethylene vinyl acetate copolymer	Injection moulding	B (EcoInvent 3.1)	Injection moulding
Piping	Main hose	1	Carbon steel	B (EcoInvent 3.1)	Steel, low-alloyed	Sheet bending	B (EcoInvent 3.1)	Drawing of pipe, steel
				B (EcoInvent 3.1)		Welding (MIG)	B (EcoInvent 3.1)	Welding, arc, steel
	Screw TORX M4x8	3	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed	Machine working: Turning	B (EcoInvent 3.1)	Steel removed by turning, average, computer numerical controlled
				B (EcoInvent 3.1)		Zinc plating	B (EcoInvent 3.1)	Zinc coat, pieces
	Rapido hose	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Aluminium impact extrusion	B (EcoInvent 3.1)	Impact extrusion of aluminium, cold, initial surface treatment
	Semirapido hose	2	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Aluminium impact extrusion	B (EcoInvent 3.1)	Impact extrusion of aluminium, cold, initial surface treatment
	Ausiliario hose	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Aluminium impact extrusion	B (EcoInvent 3.1)	Impact extrusion of aluminium, cold, initial surface treatment
Electric cables	Electric cable	1	Wire in Copper and Insulation/Jacket in PVC	–	Cable, three-conductor cable	NA	–	–
	Bands	1	PA (Nylon)	B (EcoInvent 3.1)	Nylon 6	Injection moulding	B (EcoInvent 3.1)	Injection moulding
	Transformer cable	2	Wire in Copper and Insulation/Jacket in PVC	–	Cable, unspecified	NA	–	–
	Transformer	1	Different materials	–	Transformer, low voltage use	NA	–	–

Table 2
LCI of induction hob system.

Reference flow: induction hob 1 pcs								
Assembly name	Component name	Q.ty [pcs]	Material	Data sources Background (B) Foreground (F)	Corresponding dataset in EcoInvent 3.1	Manufacturing process	Data sources Background (B) Foreground (F)	Corresponding dataset in EcoInvent 3.1
Glass-ceramic top		1	Glass-ceramic	F (manufacturer direct interviews)	–	Melting, Pressing and moulding, Sintering	F (manufacturer direct interviews)	–
Support brackets		7	Stainless Steel	B (EcoInvent 3.1)	Steel, chromium steel 18/8, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 650 kN press, single stroke
Bottom plane		1	Carbon Steel	B (EcoInvent 3.1)	Steel, low-alloyed, hot rolled	Sheet drawing	B (EcoInvent 3.1)	Deep drawing, steel, 3500 kN press, single stroke
						Zinc plating	B (EcoInvent 3.1)	Zinc coat, pieces
Electronic board housing		1	PolyPropylene (PP)	B (EcoInvent 3.1)	Polypropylene, granulate	Injection moulding	B (EcoInvent 3.1)	Injection moulding
Touch screen housing		1	PolyPropylene (PP)	B (EcoInvent 3.1)	Polypropylene, granulate	Injection moulding	B (EcoInvent 3.1)	Injection moulding
Cable connection		1	PolyPropylene (PP)	B (EcoInvent 3.1)	Polypropylene, granulate	Injection moulding	B (EcoInvent 3.1)	Injection moulding
Cooling fan		2	Various materials	B (EcoInvent 3.1)	Fan, for power supply unit, desktop computer	N.A.	–	–
Main coil (210 mm)	Electrical Insulator top sheet	1	Potassium Aluminium Silicate (Mica)	F (manufacturer direct interviews and literature)	–	N.A.	–	–
	Springs	2	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Machine working: Wiring	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Sensor	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Sheet rolling	B (EcoInvent 3.1)	Sheet rolling, aluminium
				B (EcoInvent 3.1)		Laser cutting	B (EcoInvent 3.1)	Laser machining, metal, with YAG-Laser, 200W power
	Diode	1	Diode	B (EcoInvent 3.1)	Diode, glass-, for through-hole mounting	NA	–	NA
	Coil	1	Copper	B (EcoInvent 3.1)	Copper	Wire drawing, cutting and bending	B (EcoInvent 3.1)	Wire drawing, copper
	Cables	2	Wire in Copper and Insulation/Jacket in PVC	B (EcoInvent 3.1)	High power cable	N.A.	–	–
	Plastic support	1	Low Density Poly ethylene (LDPE)	B (EcoInvent 3.1)	Polyethylene, low density, granulate	Injection moulding	B (EcoInvent 3.1)	Injection moulding
	Ferrite elements	8	Ferrite	B (EcoInvent 3.1)	Ferrite	NA	–	–
	Electrical Insulator bottom sheet	1	Potassium Aluminium Silicate (Mica)	F (manufacturer direct interviews and literature)	N.A.	–	–	–
	Bottom cover	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Sheet rolling	B (EcoInvent 3.1)	Sheet rolling, aluminium
				B (EcoInvent 3.1)		Laser cutting	B (EcoInvent 3.1)	Laser machining, metal, with YAG-Laser, 200W power
Medium coils (180 mm)	Electrical Insulator top sheet	1	Potassium Aluminium Silicate (Mica)	F (manufacturer direct interviews and literature)	N.A.	–	–	–
	Springs	4	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Machine working: Wiring	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing

(*continued on next page*)

Table 2 (*continued*)

Reference flow: induction hob 1 pcs

Assembly name	Component name	Q.ty [pcs]	Material	Data sources Background (B) Foreground (F)	Corresponding dataset in EcoInvent 3.1	Manufacturing process	Data sources Background (B) Foreground (F)	Corresponding dataset in EcoInvent 3.1
	Sensor	2	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Sheet rolling	B (EcoInvent 3.1)	Sheet rolling, aluminium
				B (EcoInvent 3.1)		Laser cutting	B (EcoInvent 3.1)	Laser machining, metal, with YAG-Laser, 200W power
	Diode	2	Diode	B (EcoInvent 3.1)	Diode, glass-, for through-hole mounting	NA	–	NA
	Coil	2	Copper	B (EcoInvent 3.1)	Copper	Wire drawing, cutting and bending	B (EcoInvent 3.1)	Wire drawing, copper
	Cables	4	Wire in Copper and Insulation/Jacket in PVC	B (EcoInvent 3.1)	High power cable	N.A	–	–
	Plastic support	2	Low Density Polyethylene (LDPE)	B (EcoInvent 3.1)	Polyethylene, low density, granulate	Injection moulding	B (EcoInvent 3.1)	Injection moulding
	Ferrite elements	16	Ferrite	B (EcoInvent 3.1)	Ferrite	N.A.	–	–
	Electrical Insulator bottom sheet	1	Potassium Aluminium Silicate (Mica)	F (manufacturer direct interviews and literature)	N.A.	–	–	–
	Bottom cover	2	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Sheet rolling	B (EcoInvent 3.1)	Sheet rolling, aluminium
						Laser cutting	B (EcoInvent 3.1)	Laser machining, metal, with YAG-Laser, 200W power
Small coil (140 mm)	Electrical Insulator top sheet	1	Potassium Aluminium Silicate (Mica)	F (manufacturer direct interviews and literature)	N.A.	–	–	–
	Insulation sheet	1	Ceramic fibres	B (EcoInvent 3.1)	Sanitary ceramics	N.A.	–	–
	Springs	2	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Machine working: Wiring	B (EcoInvent 3.1)	Metal working, average for aluminium product manufacturing
	Sensor	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Sheet rolling	B (EcoInvent 3.1)	Sheet rolling, aluminium
				B (EcoInvent 3.1)		Laser cutting	B (EcoInvent 3.1)	Laser machining, metal, with YAG-Laser, 200W power
	Diode	1	Diode	B (EcoInvent 3.1)	Diode, glass-, for through-hole mounting	N.A.	–	–
	Coil	1	Copper	B (EcoInvent 3.1)	Copper	Wire drawing, cutting and bending	B (EcoInvent 3.1)	Wire drawing, copper
	Cables	2	Wire in Copper and Insulation/Jacket in PVC	B (EcoInvent 3.1)	High power cable	N.A	–	–
	Plastic support	1	Low Density PolyEthylene (LDPE)	B (EcoInvent 3.1)	Polyethylene, low density, granulate	Injection moulding	B (EcoInvent 3.1)	Injection moulding
	Ferrite elements	6	Ferrite	B (EcoInvent 3.1)	Ferrite	N.A.	–	–
	Electrical Insulator bottom sheet	1	Potassium Aluminium Silicate (Mica)	F (manufacturer direct interviews and literature)	N.A.	N.A.	–	–
	Bottom cover	1	Aluminium alloy	B (EcoInvent 3.1)	Aluminium, cast alloy	Sheet rolling	B (EcoInvent 3.1)	Sheet rolling, aluminium
						Laser cutting	B (EcoInvent 3.1)	Laser machining, metal, with YAG-Laser, 200W power

Table 3
LCI for the electronic board (through-hole technology) induction hob.

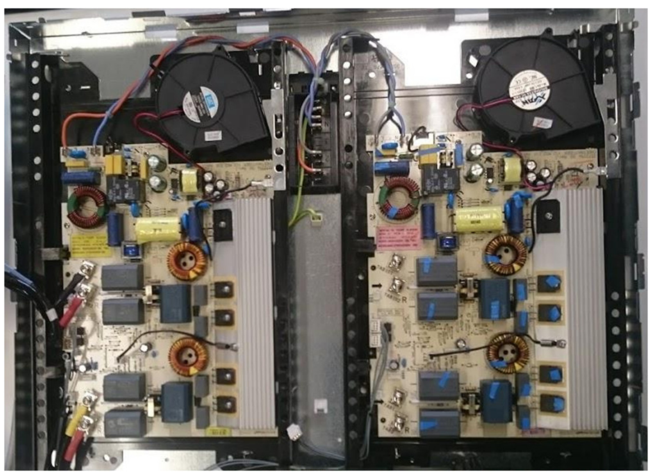
Electronic board picture	Component name	Q.ty [pcs]	Tot. Weight [gr]	Data source	Corresponding dataset in EcoInvent 3.1
	Polypropylene film capacitors (different types - MKP, MKPH, MKP Y2, etc.)	32	392	B (EcoInvent 3.1)	Capacitor, film type, for through-hole mounting
	Ceramic capacitors (KSC)	4	12	B (EcoInvent 3.1)	Capacitor, tantalum-, for through-hole mounting
	Electrolytic Capacitors (RJ3)	12	12	B (EcoInvent 3.1)	Capacitor, electrolyte type, < 2 cm height
	Transistors (RJH60F7)	8	8	B (EcoInvent 3.1)	Transistor, wired, small size, through-hole mounting
	Inductors ring core	6	146	B (EcoInvent 3.1)	Inductor, ring core choke type
	Transformers	6	36	B (EcoInvent 3.1)	Transformer, low voltage use
	Diodes	8	40	B (EcoInvent 3.1)	Diode, glass-, for through-hole mounting
	Resistors	20	1	B (EcoInvent 3.1)	Resistor, wirewound, through-hole mounting
	Relays	2	20	B (EcoInvent 3.1)	Switch, toggle type
	IC logic processors	4	2	B (EcoInvent 3.1)	Integrated circuit, logic type
	IC memories	4	1	B (EcoInvent 3.1)	Integrated circuit, memory type
	Supporting board	1	80	B (EcoInvent 3.1)	Printed wiring board, for through-hole mounting, Pb free surface
	Copper wires 2,5 mm (Wire in	4	80	B (EcoInvent 3.1)	Copper
	Copper and Insulation/Jacket in PVC)		8	B (EcoInvent 3.1)	Polyvinylchloride, bulk polymerised
	Aluminium heat sinks (200*250*20)	2	500	B (EcoInvent 3.1)	Aluminium, cast alloy

Table 4
LCI for touch control board (surface mount technology - SMT) of induction hob.

Touch control board picture	Component name	Q.ty [pcs]	Tot. Weight [gr]	Data source	Corresponding dataset in EcoInvent 3.1
	SMD Capacitors	33	0.2	B (EcoInvent 3.1)	Capacitor, for surface-mounting
	SMD Transistors	93	0.2	B (EcoInvent 3.1)	Transistor, surface-mounted
	SMD Resistor	38	0.2	B (EcoInvent 3.1)	Resistor, surface-mounted
	SMD Piezo Transducer	1	NA	B (EcoInvent 3.1)	Neglected
	SMD Filter	1	NA	B (EcoInvent 3.1)	Neglected
	IC memory	1	0.1	B (EcoInvent 3.1)	Integrated circuit, memory type
	IC logic processor	1	0.4	B (EcoInvent 3.1)	Integrated circuit, logic type
	Leds	13	0.2	B (EcoInvent 3.1)	Light emitting diode
	Inox platelets and springs	18	8	B (EcoInvent 3.1)	Steel, chromium steel 18/8
	Segment displays	6	5	B (EcoInvent 3.1)	Liquid crystal display, unmounted
	SMT board	1	8	B (EcoInvent 3.1)	Printed wiring board, for surface mounting, Pb free surface

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