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Evaluation of environmental impacts in the catering sector: the case of pasta

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A B S T R A C T

Despite its enormous size and economic value, there is currently scant information on environmental impacts from the catering sector. At the same time, the awareness of and preferences for environmentally sustainable food preparation and consumption are growing. In general, two catering approaches are practised: cook–serve and deferred. In the former, food is cooked and immediately served to consumers while the latter allows for the food to be prepared at times and places completely different from consumption. This study, based in Italy, focuses on environmental impacts of deferred catering with the aim of evaluating different options for food preparation and distribution, to help identify environmentally sustainable solutions. For these purposes, the case of pasta, one of the most popular foods worldwide, is considered. Two main types of deferred system (cook-warm and cook-chill) and cooking technologies (pasta cookers and range tops) used in the catering sector are evaluated. The results suggest that cooking in pasta cookers saves up to 60% of energy and 38% of water compared to range tops and therefore reduces by 34–66% the impacts associated with pasta preparation. The environmental impacts of pasta cooking could also be reduced by using gas rather than electric appliances as the impacts of the latter are higher by 13–98%. In the current study, pasta cooking is the major hotspot in both the cook-chill and cook-warm chains. Overall, the impacts from the cook-chill chain are 17–96% higher than from the cook-warm system, mainly because of the use of refrigerants and higher consumption of energy.

1. Introduction

Catering is a complex system involving both people and equipment in the preparation and serving of food. Such systems transform a diverse combination of inputs into desired outputs (Smith and West, 2003). A commonly accepted definition of the term “catering” or “food service” is “the provision of food and beverages away from home” (Davis et al., 1998). Traditionally, catering has been divided into the “cost food service sector” or “contract catering”, which, broadly speaking, refers to not-for-profit catering activities, and the “profit sector” (Smith and West, 2003). The former includes catering outlets for business, education and health care, while the latter comprises profit-orientated establishments such as restaurants, fast-food chain outlets, cafes, takeaways, pubs, leisure and travel catering outlets (Bourlakis and Weightman, 2004).

In general, two catering approaches are practised: conventional or cook–serve and deferred (Ciappellano, 2009). In the former, food is cooked and immediately served to consumers with all stages of food preparation occurring in a few hours before the food is served and consumed. This is typically the case in restaurants and canteens. The deferred system, on the other hand, allows for the food to be prepared at times and places completely separate from consumption: here, the food preparation and cooking are carried out in centralised kitchens, from which the prepared meals are distributed to consumers (e.g. hospitals, schools, companies, etc.). The time difference between the preparation in the catering centre and the consumption can be several hours, days or even months, depending on the method used to preserve the food. Three main types of deferred system can be distinguished: the cook-warm, cook-chill and cook-freeze chains (Williams, 1996; Ciappellano, 2009; Risteco, 2006a); however, the latter is less common (Risteco, 2006b). In cook-warm chains, the food is distributed at a

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temperature of 65 °C (to avoid the risk of microbial growth) and the consumption should occur within 2 h after cooking (Ciappellano, 2009; EpiCentro, 2012). The cook-chill system is defined as "a catering system based on the full cooking of food followed by fast chilling and storage in controlled low-temperature conditions above the freezing point, usually 0–3 °C" (Evans et al., 1996). The cooking process in the cook-chill system ensures the destruction of vegetative stages of any pathogenic micro-organisms (Evans et al., 1996).

The contract catering sector in Europe employs over 600,000 people and delivers over 6 billion meals each year (FERCO, 2014). This equates to 67 million consumers served every day, or one in four meals eaten outside the home (FERCO, 2014). In Italy alone, for example, the contract catering sector is worth €6.2 billion to which the health care sector (hospitals, nursing homes) contributes 34%, the education sector 30% and catering for business the remaining 36% (ANGEM, 2014).

Yet, despite its enormous size and economic value, there is currently scant information on environmental impacts of the catering sector. At the same time, the awareness of and preferences for environmentally sustainable practices for food preparation and consumption are growing. This is largely driven by the need to reduce costs but also to gain a market advantage by attracting environmentally conscious consumers (Baldwin et al., 2011). Therefore, in an attempt to contribute towards a better understanding of environmental impacts in the catering sector, this study focuses on the deferred system with the aim of evaluating different options for food preparation and distribution, to help identify environmentally sustainable solutions. As an example, the study considers pasta, one of the most popular foods worldwide. The focus is on cook-chill and cook-warm chains; as mentioned earlier, the cook-freeze approach is not as common and is thus not considered. While the findings are specific to the pasta, they could be applicable to some other foods as the technologies and approaches used in the catering sector are similar. The outcomes of such analysis could be helpful to food-service providers in planning more sustainable catering activities as well as to consumers in choosing more sustainable food providers.

2. Methodology

Life cycle assessment (LCA) has been used to estimate the environmental impacts of pasta cooking and distribution to consumers, following the ISO 14040/44 methodology (ISO, 2006a,b). The goal of the study and the data used are detailed in the sections below, together with the assumptions.

2.1. Goal and scope of the study

The aim of this study is twofold:

i) to evaluate the environmental impacts associated with the preparation (cooking) of pasta in professional kitchens and compare different cooking technologies used most commonly in the catering sector; and
ii) to compare the impacts of the cook-warm and the cook-chill chains in the deferred catering system.

The following cooking technologies are considered:

- pasta cookers: electric, gas and liquefied petroleum gas (LPG); and
- range tops (hobs): gas, electric, infrared and induction.

The stages typically involved in the cook-warm and cook-chill chains are outlined in Fig. 1. Following food preparation, the cook-chill approach involves blast chilling (at 0–3 °C for a maximum of 90 min), portioning and packaging, refrigerated storage (at 0–3 °C, for a maximum of five days), refrigerated transportation (at 0–3 °C) and regeneration or reheating (at 70 °C for 2 min). In the cook-warm method, cooked food is portioned and packaged and transported at ambient temperature to the point of consumption.

As can be seen from Fig. 1, the following activities are included in the study:

- pasta cooking;
- for the cook-chill chain: blast chilling, refrigerated storage, refrigerated transportation to the consumer and regeneration (reheating) of pasta; and
- for the cook-warm chain: ambient transport to the consumer.

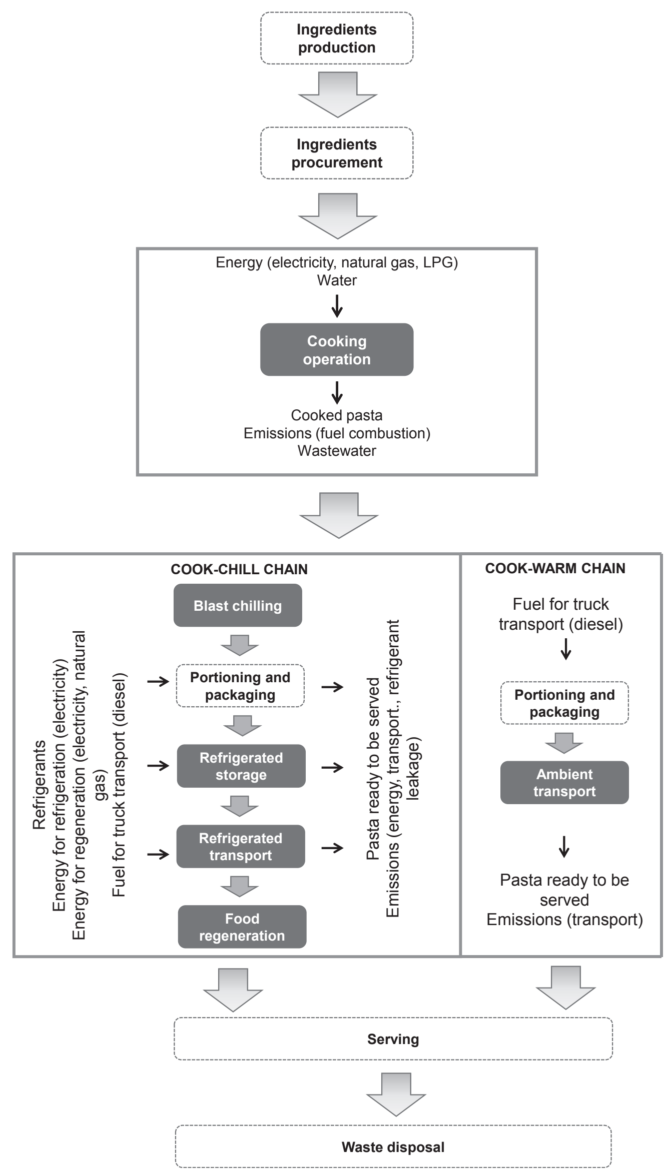

Fig. 1. System boundary considered in the study. [Activities in the dashed white boxes are excluded from the system boundary.]

The environmental impacts of the production of pasta, which is common to all cooking methods and chain management approaches, are excluded from the study. Similarly, the packaging, food serving and post-consumer waste management are not considered as they are present in both the cook-warm and cook-chill chains. The impacts of the manufacture of pasta cookers and range tops are not considered as their contribution over the life time would be negligible.

The functional unit is defined as the "preparation and distribution of 1 kg of cooked pasta". Spaghetti is considered as an example but a similar catering approach and findings would apply to other types of pasta. To obtain 1 kg of cooked pasta, 444 g of dry pasta is needed. The study is based in Italy where the deferred system with cook-warm and cook-chill chains is very common (Risteco, 2006c).

2.2. Inventory data

This section specifies the assumptions and data used in different life cycle stages, starting with the cooking and followed by cook-chill and cook-warm chains, respectively.

2.2.1. Cooking stage

The inventory data for cooking the pasta in cookers and range tops are summarised in Tables 1 and 2, respectively. As can be seen, the following inputs and outputs are considered:

- water to cook the pasta;
- energy required to heat the tap water to 100 °C;
- energy required to cook dry pasta for 8 min (time based on pasta producers' specification and Marti et al. (2013));
- water vapour produced during cooking;
- wastewater disposed of after the cooking, assuming municipal wastewater treatment; and
- CO_2, CH_4, CO and NOx emissions from natural gas pasta cookers and range tops.

The emissions of particulate matter and sulphur dioxide generated during pasta cooking are excluded as they are very low (Buonanno et al., 2009; Zhang et al., 2010; EPA, 2008).

The data have been obtained from various sources, including scientific literature, manufacturers' specifications, legislation and personal communication with a cooking centre. Background data have been sourced from Ecoinvent v. 2.2 (Frischknecht et al., 2007) and ILCD (Wolf et al., 2012).

The energy needed to boil the water (E_{heat}) and to cook the pasta (E_{cook}) given in Tables 1 and 2 has been calculated according to equations (1) and (2), respectively:

$$E_{heat} = \frac{q \times \Delta T \times c_p}{\eta \times C} \quad (\text{kJ/kg}) \tag{1}$$

$$E_{cook} = \frac{P \times t}{C} \quad (\text{kJ/kg}) \tag{2}$$

where:

q the amount of water needed to cook the pasta (l)
ΔT the difference between the initial temperature of the water (14.5 °C) and the boiling temperature (100 °C)
c_p specific heat of water (4.186 kJ/kg °C)
η cooking efficiency of the appliances, defined as the ratio of the energy transferred to the water to the energy consumed by the appliance
P power rating of pasta cooker or range top (kW)
t time to cook pasta (8 min or 480 s).
C capacity of pasta cooker or a pot used on range tops.

The above variables have been obtained as follows:

- Power rating (P) and capacity (C) for pasta cookers: a range of data have been collected from manufacturers of commercial pasta cookers dominating the catering market (for data points, see Fig. 2).
- Power rating (P) for range tops: using manufacturers' data, the power rating has been identified for each type of range tops dominating the market (see Table 3). These values have been classified according to the different burner size shown in Table 3. In cases where for the same burner size a range of power ratings were found (electric and infrared range tops), the energy needed to cook pasta has been estimated assuming the minimum value for that burner size category as the energy they provide is sufficient for the specified amount of water (and pasta); in any case, if using burners with a higher power rating,

Table 1
Inventory data for 1 kg of cooked pasta prepared in pasta cookers.

Unit[a]		Electric	Gas	LPG	Data sources
Inputs					
Water[b]	kg	4.44	4.44	4.44	Manufacturers' specification[c]
Heating energy[d]	MJ	1.02[e]	1.97	1.97	FSTC (1999), CEN (2005),[c] Manufacturers' specification[c]
Cooking energy[f]	MJ	0.52[e]	0.82	0.82	Marti et al. (2013),[c] Manufacturers' specification[c]
Outputs					
Water vapour	kg	0.22	0.18	0.18	See Appendix A for details
Wastewater	kg	1.99	2.01	2.01	Marti et al. (2013),[c] FSTC (1999)[c]
BOD	g	0.60	0.60	0.60	Presidente della Repubblica (2011)
CO_2	g	–	156.62[g] (151.61–162.78)	176.15[g] (172–183.16)	IPCC (2006)
CH_4	mg	–	2.80[g] (0.84–8.4)	2.80[g] (0.84–8.4)	IPCC (2006)
CO	g	–	0.08[g] (0.05–0.12)	0.14[g] (0.08–0.19)	EMEP/EEA (2013)
N_2O	mg	–	0.28[g] (0.08–0.83)	0.28[g] (0.08–0.83)	EMEP/EEA (2013)
NO_x	g	–	0.14[g] (0.07–0.56)	0.14[g] (0.08–0.19)	EMEP/EEA (2013)

[a] All units per 1 kg of cooked pasta.
[b] The mass of water is related to the mass of dry pasta which is cooked at a ratio of water:pasta = 10:1 (Marti et al., 2013; Ruini et al., 2013).
[c] Data shown in the table calculated based on the original data from these sources. For data from manufacturers see Fig. 2.
[d] Energy needed to bring water to boil from the tap water temperature of 14.5 °C (the latter sourced from Metropolitana Milanese SPA, 2012).
[e] The Italian electricity mix is assumed.
[f] Energy required to cook dry pasta for 8 min.
[g] Default value reported in the respective references with the minimum and maximum values shown in brackets.

Table 2
Inventory data for 1 kg of cooked pasta prepared on range tops.

	Unit[a]	Power rating available on the market as specified in Table 3						Data sources
		Minimum				Maximum		
		Electric	Infrared	Induction	Gas	Induction	Gas	
Inputs								
Water[b]	kg	4.44	4.44	4.44	4.44	4.44	4.44	FSTC (2002)[,c]
Heating[d] energy	MJ	2.89[e]	2.74[e]	1.77[e]	3.06	1.77	3.06	CEN, 2005[,c]; Manufacturers' specification[c]
Cooking[f] energy	MJ	0.71[e]	0.71[e]	0.71[e]	0.71	1.18	1.62	Marti et al. (2013)[,c]; Manufacturers' specification[c]
Outputs								
Water vapour	kg	0.17	0.18	0.28	0.16	0.47	0.44	
Wastewater	kg	3.72	3.71	3.61	3.73	3.42	3.52	Marti et al. (2013)[,c]
BOD	g	1.12	1.11	1.08	1.12	1.03	1.06	Presidente della Repubblica (2011)
CO_2	g	–	–	–	210.47[g] (204.4–219.5)	–	262.61[g] (254.2–272.9)	IPCC (2006)
CH_4	mg	–	–	–	3.92[g] (1.13–11.3)	–	4.73[g] (1.4–14)	IPCC (2006)
N_2O	mg	–	–	–	0.38[g] (0.11–1.13)	–	0.47[g] (0.14–1.4)	EMEP/EEA (2013)
NOx	g				0.19[g] (0.09–0.75)		0.23[g] (0.12–0.94)	EMEP/EEA (2013)
CO	g				0.11[g] (0.07–0.16)		0.14[g] (0.08–0.2)	EMEP/EEA (2013)

[a] All units per 1 kg of cooked pasta.
[b] The mass of water is related to the mass of dry pasta which can be cooked at a ratio of water:pasta = 10:1 (Marti et al., 2013; Ruini et al., 2013).
[c] Data shown in the table calculated based on the original data from these sources. For data from manufacturers, see Table 3.
[d] Energy needed to bring water to boil from the tap temperature of 14.5 °C (the latter sourced from Metropolitana Milanese SPA, 2012).
[e] The Italian electricity mix is assumed.
[f] Energy required to cook dry pasta for 8 min.
[g] Default value reported in the respective references with the minimum and maximum values shown in brackets.

Table 3
Power rating of range tops assumed in the study.

Types of range top[a]	Power rating according to manufacturers (kW)	Classification of range tops by FSTC (2002) according to power rating (kW)
Electric (min–max)	1.5–4.0[b]	<4.7
Electric infrared (min–max)	2.1–3.4[c]	<4.7
Electric induction (min)	3.5	<4.7
Electric induction (max)	5	>4.7 and <7.6
Gas (min)	1.5	<4.7
Gas (max)	10	>7.6

[a] 'Min' and 'max' refers to the minimum and maximum burner size available on the market.
[b] 1.5 kW used in the calculations.
[c] 2.1 kW used in the calculations.

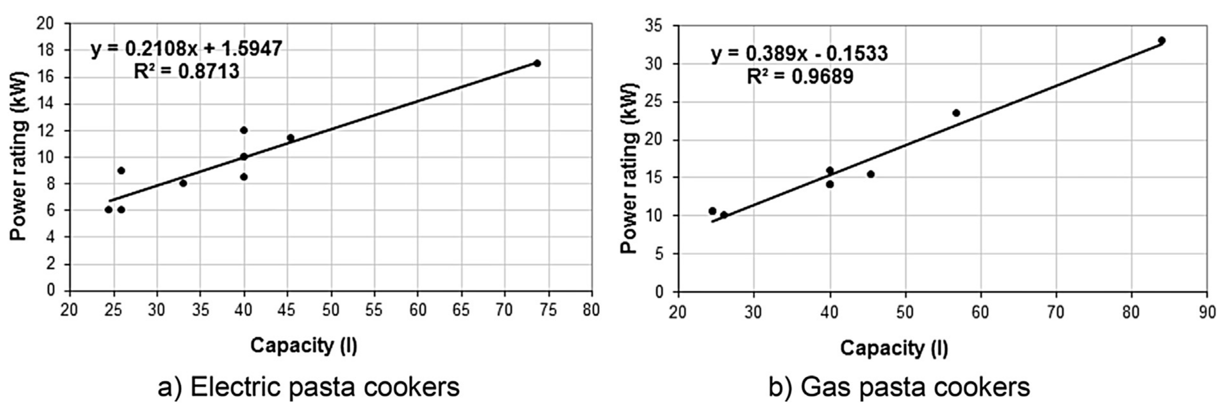

Fig. 2. The relationship between capacity (water volume) and power rating for electric and gas pasta cookers estimated using manufacturers' data. [Note that some of the points overlap so that there are more data than visible in the graphs.]

the power input can be reduced to the minimum needed for cooking to save energy.

- Cooking efficiency (η): data on the efficiencies of the appliances have been obtained from literature (see Table 4).
- The amount of water needed to cook the pasta (q): a relationship between the power rating of the appliances and the associated amount of water has been defined as follows. For pasta cookers, an equation describing the relationship between power rating and water capacity has been defined using manufacturers' specification (see Fig. 2). In the base case, the mean capacity has been assumed; the influence of different cooker sizes on the environmental impacts of cooking is explored through a sensitivity analysis later in the paper. For the range tops, the amount of water to cook the pasta is related to the capacity of pasta pots (C) and has been determined according to the size of the burners as shown in Table 5.

Table 4
Efficiencies of cooking appliances.

	Cooking efficiency (%)[a]	Source
Pasta cooker – electric	97.4	Average from FSTC (1999)
Pasta cooker – gas/LPG	50	CEN (2005).[b]
Range top – electric	55[c]	Museo Energia (2013); Manufacturer[d]
Range top – infrared	58[c]	Museo Energia (2013); Manufacturer[d]
Range top – induction	90[c]	Museo Energia (2013); Manufacturer[d]
Range top – gas	52[c]	CEN (2008).[b]

[a] Cooking efficiency is assumed to be constant for all sizes of pasta cookers and top ranges.
[b] Minimum requirement.
[c] The data refer to an aluminium pot. The sizes of the pots vary based on the power of the burner. The diameter of pots ranges between 24 cm and 40.6 cm and it is optimised for the power of the burner (FSTC, 1999; CEN, 2008; Manufacturer[d].
[d] Confidential.

Table 5
Capacity of pasta pots according to the classification of range tops by FSTC (2002) based on the power rating.

Power rating of range tops (kW)	Capacity of pasta pot (l)
<4.7	4.54
>4.7 and <7.6	9.07
>7.6	13.15

Furthermore, a two-cycle cooking process has been assumed for pasta cookers.[1] This means that part of the water used to cook pasta in the first cooking cycle is re-used to cook another batch of pasta, with the addition of freshwater to compensate for water losses through evaporation and absorption by pasta. The energy required to heat the water to the boiling point is lower for the second cycle, since the temperature of the water in the cooker is higher than in the first cycle (see Appendix A for estimates). Thus, the water use, heating energy and wastewater have been averaged over the two cycles and these data have been used for the LCA modelling (see Table 1 and Appendix A).

For the range tops, a single-cycle cooking process has been assumed as common practice since the quantity of pasta cooked is smaller than in past cookers. However, the influence on the results of reusing water in the second cycle is examined through a sensitivity analysis later in the paper.

The power ratings for both the pasta cookers and range tops have been used in a conservative manner by assuming the highest power value and the maximum capacity.

2.2.2. Cook-chill chain

As shown in Fig. 1, following pasta cooking, the cook-chill chain involves blast chilling, refrigerated storage, refrigerated transportation and regeneration (or reheating) of pasta. The data and assumptions for these stages are described in the following sections.

2.2.2.1. Blast chilling. Following a similar approach as for the cooking appliances described in the previous section, technical data for a representative sample of commercial blast chillers dominating the market have been collected to define a relationship between the capacity and power rating for these appliances (see Fig. 3). Like the cooking energy, the energy requirement for blast chilling has been estimated based on the power rating and capacity of blast chillers in Fig. 3 and the time of 1 h[2] needed to cool the pasta to 3 °C:

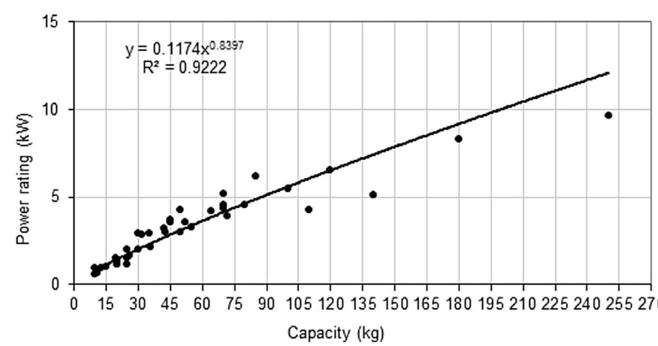

Fig. 3. The relationship between the capacity and power rating of blast chillers estimated using data from manufacturers.

$$E_{chill} = \frac{P_{chill} \times t_{chill}}{C_{chill}} \quad (\mathrm{kJ/kg}) \tag{3}$$

where:

E_{chill} energy required to cool 1 kg of cooked pasta to 3 °C.
P_{chill} power rating of the blast chiller (Fig. 3) (kW).
t_{chill} time required to cool the pasta (1 h, based on a real case).
C_{chill} capacity of the blast chiller (kg).

These results are shown in Table 6 for the mean capacity of the chiller, with a sensitivity analysis exploring later in the paper the influence of different chiller sizes on the environmental impacts from this stage. Note that the estimated energy for blast chilling of 50 kWh/t of product (Table 6) agrees well with the range of 70–130 kWh/t reported by Duiven and Binard (2002) for blast freezing, taking into account that the energy consumption is higher for the latter than the former.

The refrigerant used in blast chillers is assumed to be R404A and the LCA data for its manufacture are based on the study by Bovea et al. (2007). The expected leakage of refrigerant is 5–10% per year[2] so that an average value of 7.5% has been assumed. The

Table 6
Inventory data for blast chilling.

	Amount
Energy consumption (Wh/kg$_{cooked\ pasta}$)	50[a]
Refrigerant load (mg/kg$_{cooked\ pasta}$)	60[b]
Refrigerant leakage (mg/kg$_{cooked\ pasta}$)	4.5[b]

[a] Estimated using eqn. (3) and the relationship in Fig. 3, assuming the mean power rating for blast chillers. The Italian electricity mix is assumed.
[b] Source: personal communication with Professor Savvas Tassou, Brunel University.

[1] Personal communication with an Italian cooking centre.
[2] Personal communication with Professor Savvas Tassou, Brunel University.

amount of refrigerant leaked during the time needed to chill the pasta (1 h) has been estimated assuming that the blast chiller is switched on for 8 h per day over 254 working days per year, as shown in Table 6.

2.2.2.2. Refrigerated storage and transport. Cooked pasta can be stored in refrigerators from one to five days. Two types of refrigerant have been considered for the refrigerated storage – R404A and ammonia – assuming an annual leakage of 15% (DEFRA, 2008). The energy consumption during the storage is assumed at 0.26 Wh/kg h (DEFRA, 2008). Table 7 shows the estimates for these parameters for different storage time.

The data for refrigerated transport are summarised in Table 8. In the base case, the chilled pasta is assumed to be transported to the consumer by a 20–28 t fully-loaded truck over an average distance of 50 km; the return trip is also considered, assuming an empty truck. Shorter (1 km) and longer (100 km) distances as well as different vehicle sizes are considered within a sensitivity analysis. The life cycle inventory data for transport have been sourced from Ecoinvent (Frischknecht et al., 2007) but have been modified to include the additional amount of fuel (and the emissions) used by the refrigeration unit as well as the production and leakage of refrigerants, with the latter assumed at 22.5% of the annual charge (DEFRA, 2008; UNEP, 2003). The LCA data for the production of different types of refrigerant used for refrigerated transport (R404A, R134A, R410A) have been sourced from Bovea et al. (2007).

2.2.2.3. Regeneration (reheating). The following appliances have been considered for reheating: gas and electric combination oven, which are the most-widely used appliances in professional kitchens (Rohatsch et al., 2007) and microwave ovens, which are increasingly used in establishments where fast heating is required as well as in the hospitality industry (Rohatsch et al., 2007). The energy consumption for reheating shown in Table 9 has been estimated based on the oven pre-heating requirements, equal to 15% of the total energy needed for reheating in combination ovens (FSTC, 2002), the heating time of 7 min for combination and 65 s for microwave ovens (Rohatsch et al., 2007) and the temperature of 70 °C that must be reached to avoid bacterial contamination (Ciappellano, 2009). The CO_2 and CH_4 emissions associated with gas combustion have been calculated using the IPCC emission factors (IPCC, 2006) while N_2O, CO and NOx emissions have been estimated according to EMEP/EEA (2013).

Table 9
Inventory data for pasta regeneration (reheating) for different oven sizes.

	Small	Medium	Large
Combination oven – gas			
Pre-heating energy (kJ/$kg_{cooked\ pasta}$)	10.96	7.35	6.02
Heating energy (kJ/$kg_{cooked\ pasta}$)	73.04	49.00	40.16
CO_2 (g/$kg_{cooked\ pasta}$)	5	3.16	2.59
CH_4 (µg/$kg_{cooked\ pasta}$)	84	56	46
N_2O (µg/$kg_{cooked\ pasta}$)	8	6	5
NOx (mg/$kg_{cooked\ pasta}$)	5	3	2
CO (mg/$kg_{cooked\ pasta}$)	2	2	1
Combination oven – electric			
Pre-heating energy (kJ/$kg_{cooked\ pasta}$)	5.48[a]	4.20[a]	4.11[a]
Heating energy (kJ/$kg_{cooked\ pasta}$)	36.52[a]	28.00[a]	27.39[a]
Microwave oven			
Energy (kJ/$kg_{cooked\ pasta}$)	13.81[a]	13.04[a]	

[a] The Italian electricity mix is assumed.

2.2.3. Cook-warm chain

In this chain, after the cooking stage, the food is transported to the point of use in insulated trucks (Fig. 1). The Ecoinvent database has been used to estimates the impacts from the transport, making the same assumptions for the truck size and distances as for the refrigerated transport (see Section 2.2.2.2).

2.3. Sensitivity analysis

To test the robustness of the results and investigate the effect of key assumptions, the following parameters have been considered within the sensitivity analysis:

i) Pasta cooking
- the size of the pasta cookers and range tops: the capacity and power rating have been varied based on the respective relationships in Fig. 2; note that the mean values are assumed in the base case; and
- emissions from fuel combustion: minimum and maximum emission factors for natural gas and LPG combustion defined by IPCC (2006) and EMEP/EEA (2013) have been considered, first by assuming all minimum and then all maximum values (see Tables 1 and 2);

ii) Cook-chill and cook-warm chains
- the size of blast chillers (cook-chill): the capacity and power rating have been varied using the relationship in Fig. 3; note that the mean values for power rating (6.5 kW) and capacity (120 kg) are assumed in the base case;

Table 7
Inventory data for the refrigerated storage.[a]

	Number of days				
	1	2	3	4	5
Energy consumption (kWh/$kg_{cooked\ pasta}$)	0.006[b]	0.012[b]	0.019[b]	0.025[b]	0.031[b]
Refrigerant load (mg/$kg_{cooked\ pasta}$)	5.48	10.96	16.44	21.92	27.40
Refrigerant leakage (mg/$kg_{cooked\ pasta}$)	0.82	1.64	2.47	3.29	4.11

[a] Based on data from DEFRA (2008).
[b] The Italian electricity mix is assumed.

Table 8
Inventory data for refrigerated transport.

	Fuel consumption (l/km)	Refrigerant charge (g/km)	Refrigerant leakage (g/km)
Truck 3.5–20 t	0.32	0.05	0.01
Truck 20–28 t	0.38	0.06	0.01
Truck> 28 t	0.42	0.07	0.02

- refrigerant type for refrigerated storage (cook-chill): ammonia (R404A is assumed in the base case) and;
- refrigerant type for refrigerated transport (cook-chill): R134A and R410A (as above, R404A is assumed in the base case).
- the size of trucks: 3.5–20 t and >28 t, with 20–28 t assumed in the base case; and
- transport distance: 1 km and 100 km (50 km in the base case).

3. Results

The environmental impacts have been estimated using the midpoint ReCiPe method (Goedkoop et al., 2009). The following impact categories are considered: climate change (CC), ozone depletion (OD), human toxicity (HT), photochemical oxidants formation (POF), terrestrial acidification (TA), freshwater eutrophication (FE), terrestrial, freshwater and marine ecotoxicity (TE, FEc and ME, respectively), metal and fossil fuel depletion (MF and FD). Moreover, for the cooking operation only, the water footprint has also been estimated following the Pfister et al. methodology (2009).

SimaPro V7.3.2 has been used for the LCA modelling and estimation of the impacts. The water footprint has been calculated using the CCaLC software tool V3.3 (CCaLC, 2014).

The results are presented in the following sections, first for cooking in pasta cookers and the range tops, and then for the cook-chill and cook-warm chains.

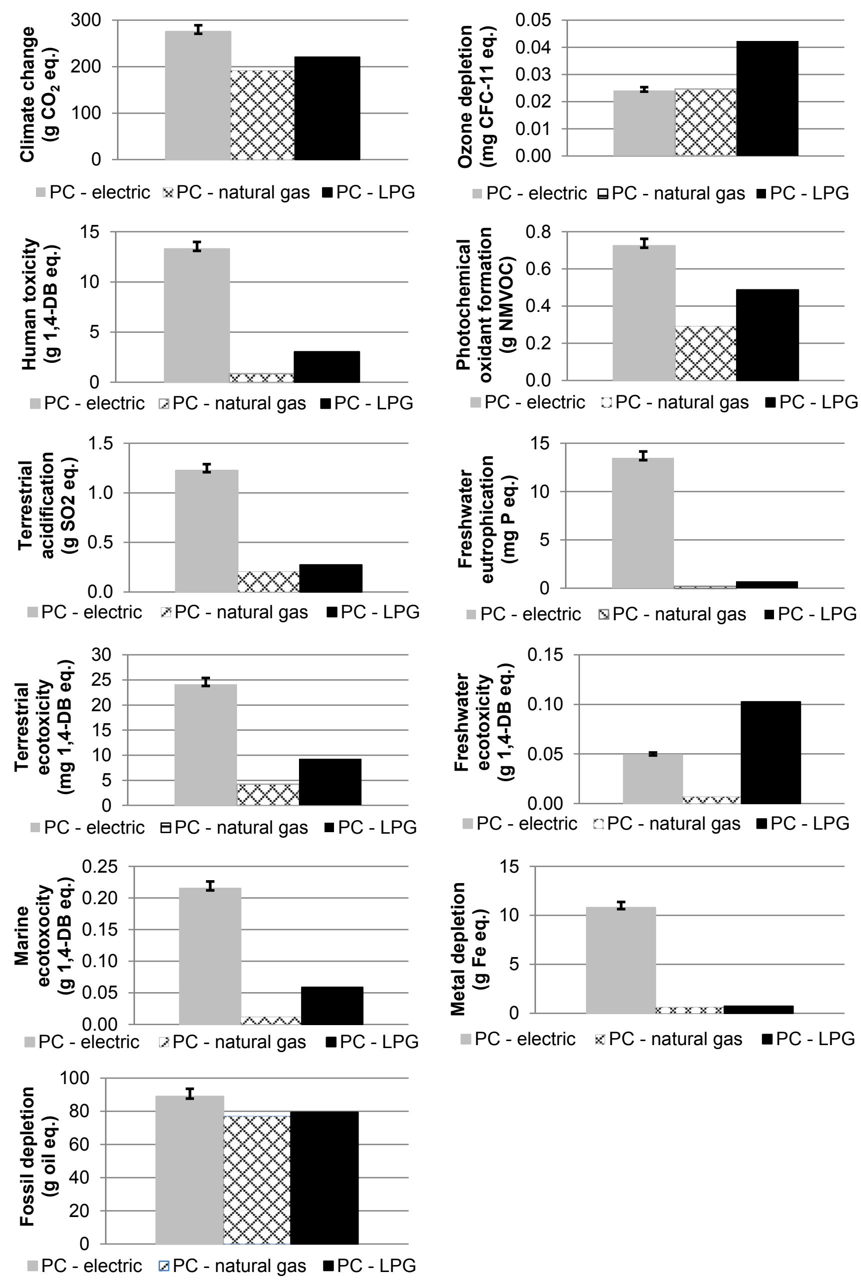

Fig. 4. Environmental impacts of cooking in different types of pasta cooker (PC). [All impacts expressed per 1 kg of cooked pasta, assuming the mean size of pasta cookers estimated using the relationship in Fig. 2. The height of the columns represents the mean values. The error bars for electric pasta cookers represent the variation in impacts related to different size of the cookers. The error bars for the other two types of cooker not shown as the variation is <0.35%.]

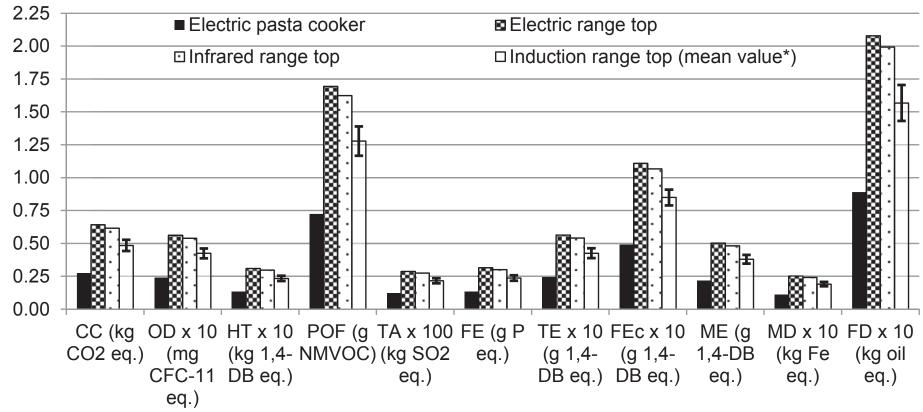

Fig. 5. Comparison of environmental impacts of electric pasta cookers and range tops. [All impacts expressed per 1 kg of cooked pasta. *Mean values represented by the height of the columns correspond to the average of the minimum and maximum power rating for induction range tops. The error bars show the impacts for the minimum and maximum power rating. The results for all other appliances correspond to the minimum power rating as explained in Section 2.2.1. Impacts nomenclature: CC: climate change; OD: ozone layer depletion; HT: human toxicity; POF: photochemical oxidant formation; TA: terrestrial acidification; FE: freshwater eutrophication; TE: terrestrial ecotoxicity; FEc: freshwater ecotoxicity; ME: marine ecotoxicity; MD: metal depletion; FD: fossil fuel depletion.]

3.1. Pasta cooking

As can be seen in Fig. 4, pasta cookers using natural gas are environmentally the best and electric cookers the worst option, with the difference between them ranging from 13% for fossil fuel depletion to 98% for freshwater eutrophication in favour of gas cookers. This is due to a relatively high contribution (21%) of coal and oil in the Italian electricity mix (based on 2011 data from ISPRA (2012) and IEA (2014)). The exception is ozone depletion, for which the electric cookers are slightly better (by 2.5%) because of the emissions of halons used for fire retardants in gas pipelines. This impact is, on the other hand, highest for LPG cookers, being twice as high as for the electric appliances because of the production of offshore oil used in the life cycle of LPG. LPG cookers are also the worst option for freshwater ecotoxicity which is over 10 times higher than for the natural gas devices, owing to water discharge from the LPG production process.

Figs. 5 and 6 compare pasta cookers and range tops using electricity and natural gas, respectively. As can be inferred from Fig. 5, electric cookers are overall the best option compared to the electric range tops, with their impacts being on average 43% lower compared to the induction and 57% lower relative to the electric range tops. The latter appear to be environmentally least sustainable, while the induction range tops represent the second best option after electric cookers, particularly when the lowest power rating is assumed.

Like the electric cookers, gas cookers also outperform gas range tops (Fig. 6), with the savings in environmental impacts ranging from 34% for the climate change impact and ozone layer depletion to 66% for photochemical oxidants formation.

If, on the other hand, a two-cycle cooking process is assumed for range tops as for the pasta cookers, these results would change (not shown in figures): the environmental benefits from the use of pasta cookers relative to range tops would decrease. Electric cookers would still represent the best option compared to the electric range tops, with their impacts being on average 31% lower compared to the induction and 37% lower relative to the electric range tops. Gas cookers would outperform gas range tops with the environmental savings between 18% for the climate change impact and ozone layer depletion and 58% for photochemical oxidants formation.

Varying the air emissions (see Tables 1 and 2) from gas combustion for the gas-based equipment affects only three impact categories, as shown in Fig. 7. While the overall effect on the climate change impact is small (~6%), terrestrial acidification and photochemical oxidant formation range widely (by ~130% and ~170%, respectively), with a much greater variation found for the gas than

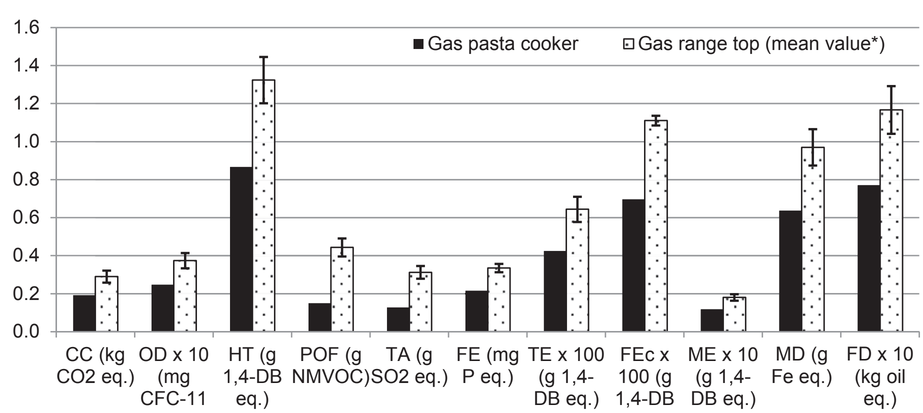

Fig. 6. Comparison of environmental impacts of pasta cookers and range tops using natural gas. [All impacts expressed per 1 kg of cooked pasta. For impacts nomenclature, see Fig. 5. *Mean valued represented by the height of the columns correspond to the average of the minimum and maximum power rating for gas range tops. The error bars show the impacts for the minimum and maximum power rating. The results for gas pasta cookers correspond to the minimum power rating as explained in Section 2.2.1.]

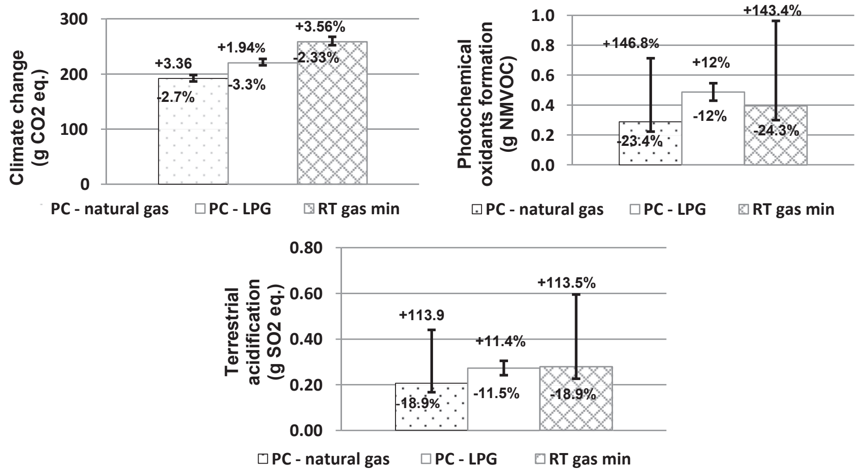

Fig. 7. Environmental impacts of pasta cookers (PC) and range tops (RT) for the three categories affected by the changes in emissions from combustion of natural gas. [All impacts expressed per 1 kg of cooked pasta. The height of the columns corresponds to the average air emissions from combustion of natural gas shown in Tables 1 and 2. The error bars show the variation in the result assuming minimum and maximum values for the emissions. RT gas min: minimum power rating for gas range tops of 1.5 kW. NMVOC: non-methane volatile organic compounds.]

LPG devices. This is mostly due to NOx, which have a broader emissions range for natural gas than for LPG.

Therefore, based on the results of this study, it can be concluded that gas pasta cookers are the best option for most impacts, including the water footprint. The latter, given in Fig. 8, is estimated at 0.75 l eq. per 1 kg of cooked pasta for pasta cookers, compared to 1.21 l eq. for the range tops. However, assuming a two-cycle cooking process for the range tops, there would be no difference in the water footprint relative to pasta cookers.

Finally, the environmental impacts of pasta cooking could be reduced by using a lid on the cooking appliances. This was not considered in this study as their use in professional kitchens is not a regular practice, for both cost reasons (lids are sold as an optional accessory for pasta cookers) and for the convenience of cooking staff.

3.1.1. Comparison of results with literature

Only one study was found in the literature that considered the carbon footprint of pasta cooking in the catering sector (Barilla, 2013), estimating that 620 g CO_2 eq./kg of dry pasta is emitted when using gas appliances and 1300 g CO_2 eq. for electric devices (the exact type of appliances was not specified). This compares well with the CC value for cooking estimated in the present study of 432 g CO_2 eq./kg of dry pasta for the gas cookers and the average value of 1307 g CO_2 eq./kg of dry pasta for the electric range tops. These values are equivalent to 192 g CO_2 eq. and 581 g CO_2 eq. per kg of cooked pasta, respectively, as presented in the previous section (see Figs. 4 and 5, respectively).

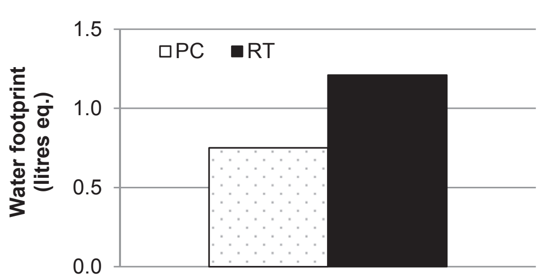

Fig. 8. Water footprint of cooking for pasta cookers (PC) and range tops (RT). [Expressed per 1 kg of cooked pasta. The water footprint considers only the amount of tap water required to cook pasta so that the impact is the same across the different types of pasta cookers and range tops, respectively.]

It is also interesting to put the results in perspective with respect to the contribution of pasta cooking to the impacts of the whole life cycle of pasta, when its production is also taken into account. There are several sources of data for the latter but they are mainly available for the carbon footprint and the values range widely, from 500 to 898 g CO_2 eq./kg of dry pasta (Bevilacqua et al., 2007; Federal Environment Agency, 2010; Röös et al., 2011; Barilla, 2013). Therefore, depending on the carbon footprint of pasta production considered, the contribution of cooking would range from 46% to 59%.

Only one study was found that considered impacts other than the carbon footprint (Barilla, 2013), estimating ozone depletion at 0.11 mg CFC11 eq./kg of dry pasta, acidification at 3.41 g SO_2 eq. and eutrophication at 4.82 g PO_4 eq. Based on these and the current study's results, the contribution of cooking to the life cycle of pasta (excluding the impacts from the cook-warm and cook-cold distribution) would be approximately 26% for ozone depletion and negligible for the other two impacts.

3.2. Cook-chill chain

The results for the cook-chill chain are presented in Fig. 9, also showing the impacts of pasta cooking for context; as an example, the results are shown for pasta cookers. As can be observed from the figure, for most impact categories the contribution of cooking is much higher than of the other stages in the chain. This includes CC (67–77% of the total, depending on the pasta cooker used), TA (62–67%), FD (74–89%) and POF (64–72%). After cooking, blast chilling is the second highest contributor to the impacts, causing 18–19% of CC, 13–64% of FE, 12–47% of MD and 13–28% of TA, largely owing to the electricity used for chilling. The variation in the results is due to the different size of the chiller assumed (Fig. 9), ranging from 0.81 to 12.11 kW as well as the different options in the cook-chill chain.

Unlike the other impacts, ozone depletion is largely due to blast chilling which contributes 73–87% to the total, with the rest being from cold storage of pasta. As this is due to the refrigerant (R404A), a sensitivity analysis has been carried out to examine the effect on the results if ammonia is used instead for cold storage. The findings in Fig. 10 suggest that the use of R404A leads to higher impacts for all the categories, except for TA which is lower for R404A by 7.7% because of the greater effect of ammonia leakage on this impact.

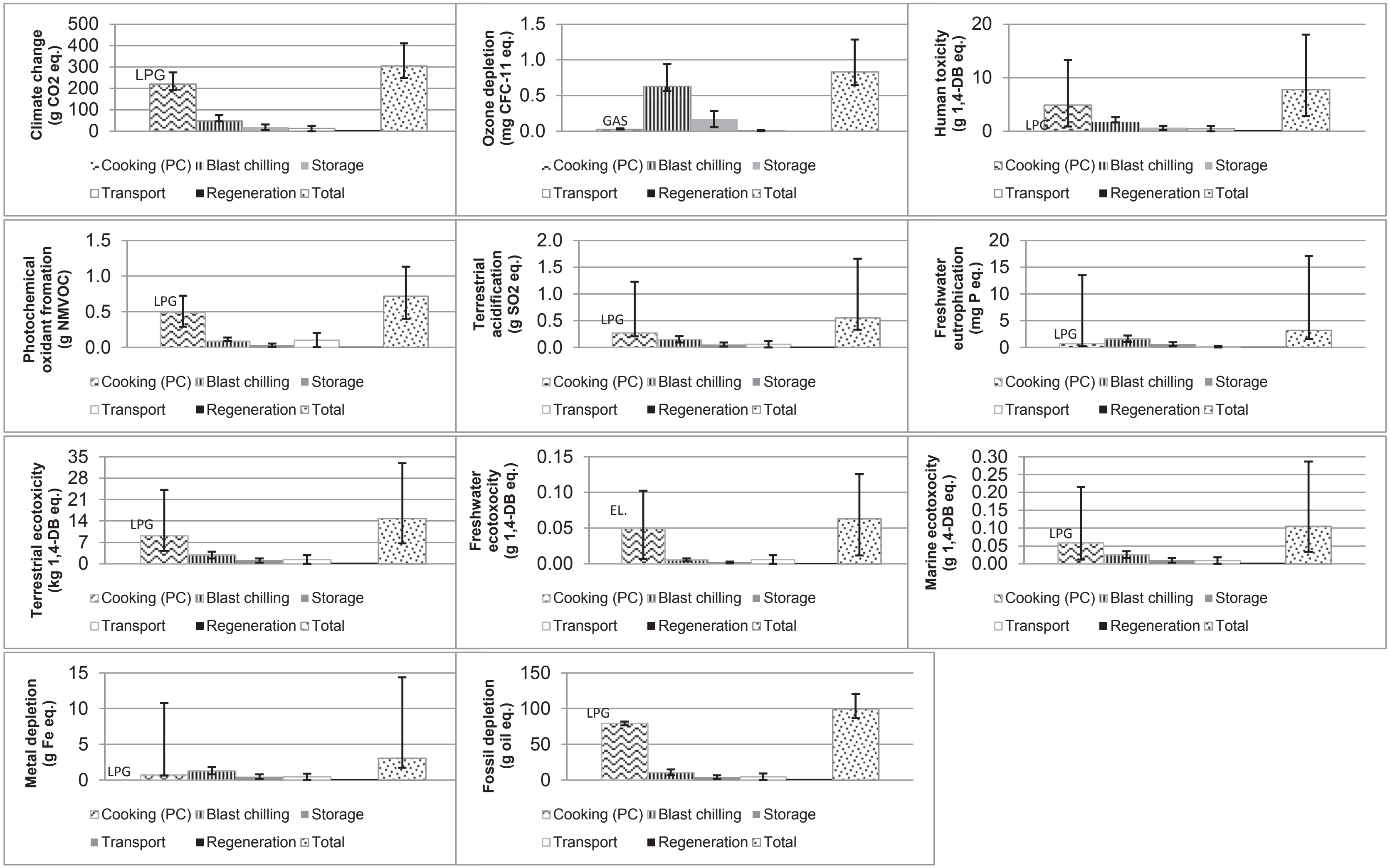

Fig. 9. Environmental impacts of the cook-chill chain. [All impacts expressed per 1 kg of cooked pasta. The height of the columns and the error bars represent, respectively: for cooking, the type of pasta cooker as indicated in the figure with the impacts in between the best (minimum) and worst (maximum impact) cooker option assuming maximum power rating for all cookers; for blast chilling, the mean size (6.5 kW), minimum (0.81 kW) and maximum (12.11 kW); for refrigerated storage with R404A, the mean (3 days), minimum (1 day) and maximum (5 days) storage time; for transport by a 20–28 t truck with R404A refrigerant: the average (50 km), minimum (1 km) and maximum (100 km) distance considered; for regeneration: the average value for gas, electric combination and microwave ovens (no error bars).]

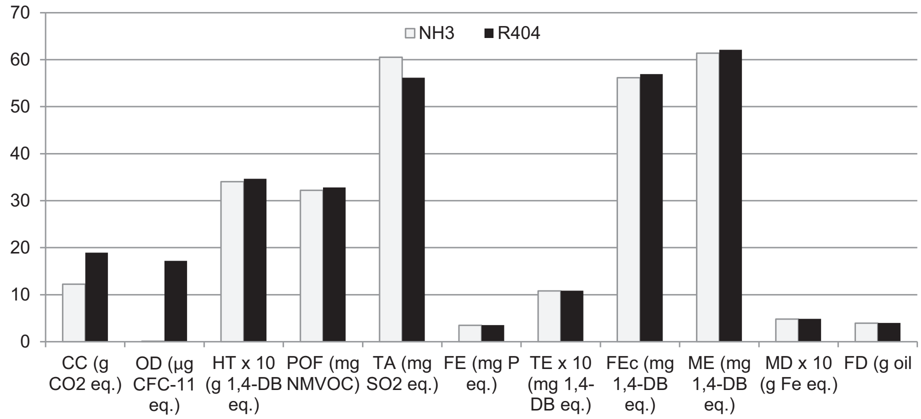

Fig. 10. Comparison of the impacts for refrigerated storage using NH_3 and R404 as refrigerants. [For impacts nomenclature, see Fig. 5. The results refer to a three-day storage.]

The greatest variation is found for CC and OD which are 55% and more than 100 times higher, respectively, for R404A than ammonia. All other impact categories differ by less than 2%.

The contribution of refrigerated transport is small (0.02–7.5%) across the impact categories, except for POF to which is adds 14% for a distance of 50 km and 18% for 100 km. These findings are consistent with other food-related studies which also found that the contribution of refrigerated transport per functional unit is small (e.g. Eide, 2002; Fritsche and Eberle, 2009; Gunady et al., 2012). Nevertheless, to test the robustness of the results for transport, a sensitivity test has been performed assuming different sizes of trucks and the type of refrigerant used during transportation. The results in Fig. 11 indicate that while the influence of the latter is negligible (<1%), the size of the truck affects the impacts of the transportation much more: they increase by 30–40% when a 3.5–20 t truck is used relative to the 20–28 t vehicle and decrease by up to 19% for a >28 t truck. The latter is due to bigger vehicles being more efficient, consuming less fuel per kilogram of product transported.

The effect of pasta regeneration (reheating) on the impacts is also small (0.06–4.5%). This appears to be in contrast with the findings by Schmidt Rivera et al. (2014) who identified reheating of a ready-made meal in an electrical oven as one of the hotspots in the life cycle. Moreover, in their analysis of the carbon footprint of bread, Espinoza-Orias et al. (2011) found toasting (effectively, reheating) to be one of the hotspots. These differences in the results could be explained by a much higher energy consumption for reheating assumed in these two studies because of the lower efficiency of domestic ovens and toasters compared to industrial ovens considered in the current work; a further reason could be a difference in the assumptions for reheating. Furthermore, unlike these studies, the current research assumes a full load of the ovens, thus further increasing the efficiency of energy consumption. Overall, the most environmentally efficient are gas ovens which are best for seven out of 11 impacts, followed by the microwave ovens with the lowest CC, OD, POF and FD (Fig. 12). Electric ovens are the worst option across all the impact categories.

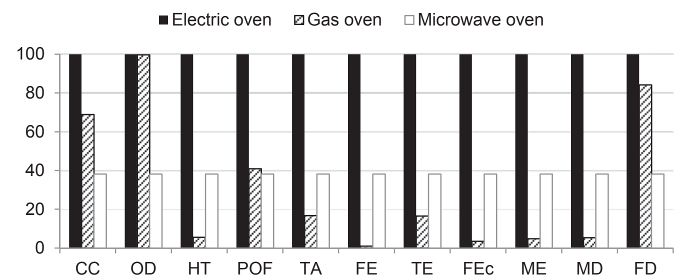

Fig. 12. Relative impacts of different ovens for pasta regeneration (reheating). [For impacts nomenclature, see Fig. 5. The results refer to the mean oven size.]

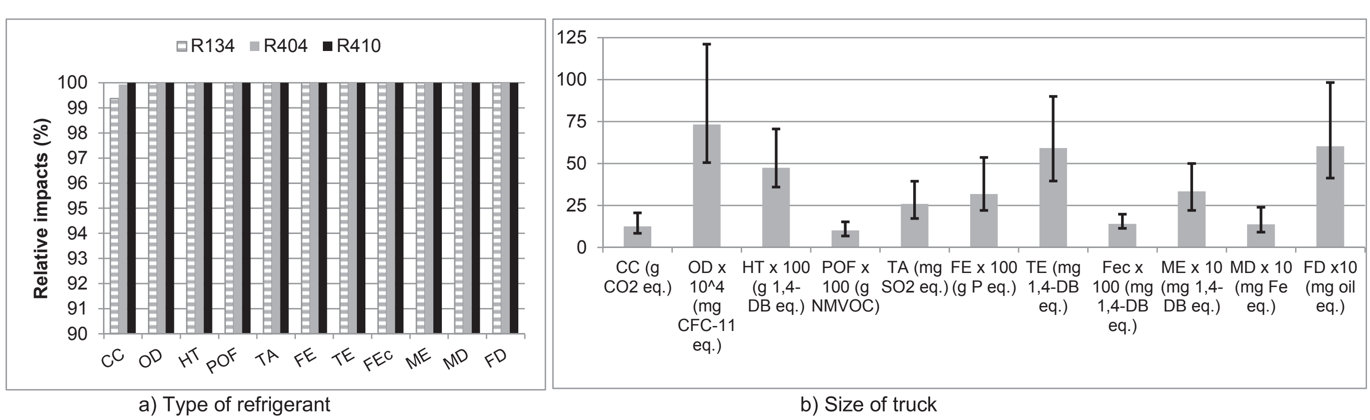

Fig. 11. The relative impacts of refrigerated transport using different refrigerants and the effect on the impacts of the size of truck. [For impacts nomenclature, see Fig. 5. The results refer to a distance of 50 km.]

3.2.1. Comparison of results with literature

As there is a lack of studies related to the catering sector, it is not possible to compare the obtained results with literature. Nonetheless, some studies taking into account the cold chain for food products have been carried out. For example, Gunady et al. (2012) assessed the CC impact associated with the supply chain of three unprocessed foods which require refrigeration along their life cycle. They found that post-farm activities, which include packaging and refrigerated storage, accounted for 16–35% of the total CC. Another study undertaken by Coley et al. (2009) indicated that the packing and refrigerated storage (and some administration activities) as responsible for approximately 24% of the CC impact related to farm products. Even though the cited studies considered different kinds of product and life cycle stages (agriculture vs. processing) compared to the current study, there is a good agreement of the CC results for the contribution of the 'cold stages' to the whole chain: in the present work, the blast chilling and cold storage are estimated to contribute on average 22% to the climate change impact.

3.3. Cook-warm chain

This chain, in addition to pasta cooking, comprises only one other stage – ambient transportation of pasta in insulated trucks; as the pasta is delivered warm to the consumption point, there is no need for reheating. The impacts are summarised in Fig. 13 assuming the use of pasta cookers as an example. Unsurprisingly, the majority of the impacts (79–100%) are from cooking with the contribution of transport being a little bit higher than in the cold chain, but still small: 0.09–9% across all the impact categories, except for POF to which is adds 16.7% for a distance of 50 km and 21.3% for 100 km. Many other studies of ambient transport of food have also found that this stage does not influence the impacts (e.g. Fusi et al., 2014; Espinoza-Orias et al., 2011).

The total impacts from the cook-warm and cook-chill chains are compared in the next section.

3.4. Comparison of cook-chill and cook-warm chains

As indicated in Fig. 13, all the impacts from the cook-warm chain are lower than from the cook-chill system, ranging from 17% and 30% lower FD and FE, respectively, to 96% lower OD.

Although neither chain is influenced by transportation, it is still interesting to compare the impacts from refrigerated and ambient transport used in the two respective chains. As expected, the environmental performance of the refrigerated transport is worse, particularly for CC owing to the increase in diesel fuel required for the refrigeration unit and the refrigerant leakage as well as OD because of the emission during the production of the refrigerant.

Therefore, the results of this study would suggest that the cook-warm chain is environmentally more sustainable than the cook-chill system. However, the latter tends to generate less food waste as only the amount of food which is actually required is reheated (Risteco, 2006a). According to a study carried out in some schools in Turin, Italy (Risteco, 2006c), the average percentage of first dishes (including pasta) not served, and therefore wasted, is 27.5%. Therefore, (possibly) avoiding waste through the adoption of the cook-chill chain, the impacts would be reduced because of the lower amount of pasta used and less waste that needs to be treated and disposed of. A similar conclusion was reached by Schmidt Rivera et al. (2014) in their study of ready-made meals, finding that the amount of waste is overall lower in the cold chain, leading to the lower overall impacts. Note that waste was not considered in this study as the impacts of pasta are not included in the system boundary, so that the inclusion of waste would not be congruent with the goal of the study.

Furthermore, the cook-chill chain provides more flexibility in terms of food preparation, allowing preparation of meals at any point in the day rather than just a few hours before the meal time, five days a week instead of seven (Risteco, 2006a). Moreover, the productivity tends to be higher in the cook-chill chain, with the number of meals prepared per day per chef being significantly greater (Clark, 1997). In addition, the cook-chill systems allow for wider menu choices with less skilled staff and reduced equipment needs (Smith and West, 2003). All these factors lead to increased efficiency and reduced costs, particularly labour (Clark, 1997; Risteco, 2006a; Marzano and Balzaretti, 2011) (Fig. 14).

Another important variable that should be taken into account when comparing different catering systems is the quality of meals delivered, both sensorial and nutritional. However, there are no conclusive findings on this with studies reporting conflicting results. For example, Light and Walker (1990) claim that the cook-hot-hold system results in damage to the quality of food, while Williams (1996) suggests that under normal operating conditions, with hot-holding limited to less than 90 min, vitamin retention is better than in a cook-chill chain. These aspects should therefore be investigated more fully in future research.

4. Conclusions

This work has studied different cooking technologies available in the food-service sector with the aim of identifying opportunities

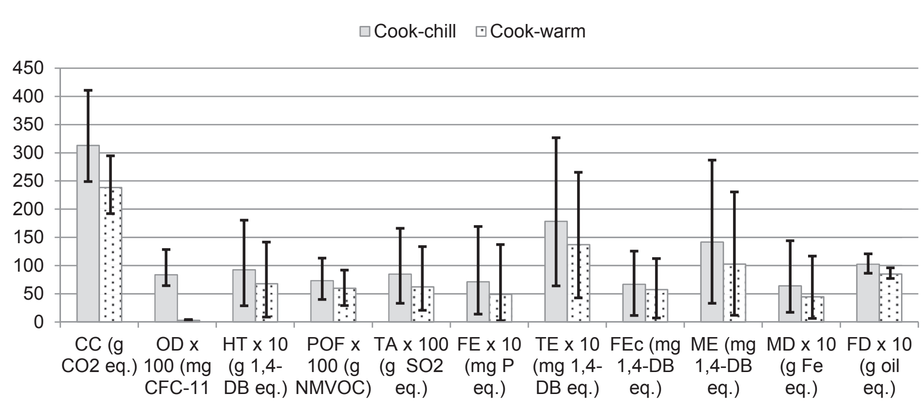

Fig. 13. Comparison of the cook-chill and cook-warm chains. [For impacts nomenclature, see Fig. 5. The height of the columns represents the mean values for all appliances and other parameters considered and the error bars show the minimum and maximum impacts based on the variations considered in the paper.]

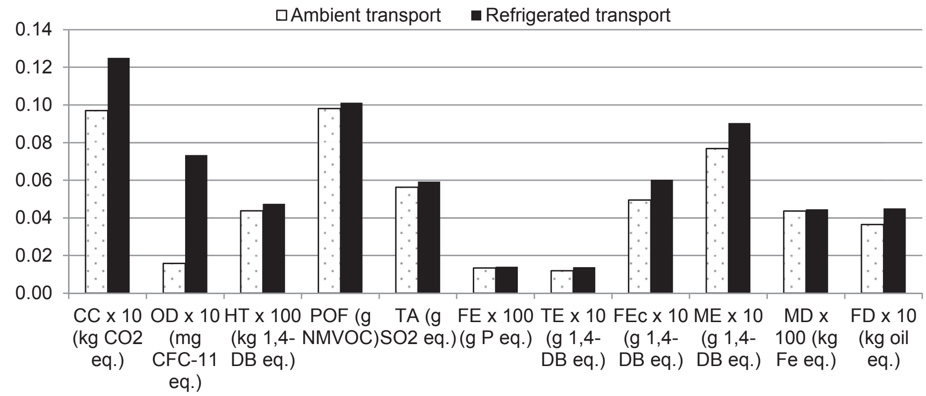

Fig. 14. Comparison of ambient transport in the cook-warm and refrigerated transport in the cook-chill chains. [All impacts expressed per 1 kg of cooked pasta. For impacts nomenclature, see Fig. 5. The results refer to a distance of 50 km and a truck of 20–28 t.]

for improving its environmental performance. The focus of the study has been on pasta, one of the most popular foods worldwide. The following cooking technologies have been considered: electric, gas and LPG pasta cookers and gas, electric, infrared and induction range tops. The second aim of the study has been the evaluation of the environmental impacts of the two deferred systems predominant in the food-service sector, namely the cook-chill and cook-warm chains. The study is based in Italy.

The results suggest that cooking in pasta cookers saves up to 60% of energy and 38% of water compared to range tops and therefore reduces by 34–66% the impacts associated with pasta preparation. Nevertheless, it should be noted that pasta cookers and range tops serve different purposes: the latter are manly used for preparation of smaller meal quantities, making them suitable for à-la-carte business in restaurants or in hospital kitchen; pasta cookers, on the other hand, are used when much larger amounts of food need to be cooked.

The environmental impacts of pasta cooking could also be reduced by using gas rather than electric appliances as the impacts of the latter are higher by 13–98%. A further improvement would be achieved by using a lid on the cooking appliances. However, their use in professional kitchens is not a regular practice, for both cost reasons and for the convenience of staff.

Pasta cooking is the major contributor to the environmental impacts in both the cook-chill and cook-warm chains. In the former, blast chilling is the main cause of ozone depletion and the second highest contributor to all other impacts. The contribution of refrigerated transport and storage is small, except for photochemical oxidant formation, for which the former contributes 14–18%, depending on the distance considered. The ambient transport used in the cook-warm chain influences photochemical oxidant formation, contributing 17–21% to the total.

Overall, the results of this work indicate that the cook-chill chain has 17–96% higher environmental impacts than the cook-warm system. This is mainly due to the use of refrigerants and higher consumption of energy. Therefore, the cook-warm approach appears to be environmentally a more sustainable option under the conditions considered in this study.

However, the choice of the 'best' chain would depend on many other factors, including flexibility, efficiency, costs, convenience and food quality, the consideration of which was beyond the scope of this paper. It is therefore recommended that these parameters be considered in future studies.

Acknowledgements

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Appendix

Table A.1
Water loss for different pasta cookers.

	Water losses (l/kg cooked pasta)	
	Electric cooker	Gas/LPG cooker
Water absorbed by pasta	0.550	0.550
Water associated with foam (generated during cooking)	0.097	0.097
Water vapour	0.220	0.180
Water loss while draining pasta (5%)	0.220	0.220
Total loss (refill for the 2nd cycle)	1.087	1.047

Table A.2
Data used for calculating energy requirements for water heating for different pasta cookers

	Electric cookers		Gas/LPG cookers	
	Temperature (°C)	Mass (l/kg cooked pasta)	Temperature (°C)	Mass (l/kg cooked pasta)
Water reused from the 1st cycle	100	3.353	100	3.393
Water lost in the 1st cycle and toped up in the 2nd cycle (see Table A.1)	14.5	1.087	14.5	1.047
Total water (reused and refilled water)	78.9	4.440	79.7	4.440

Table A.3
Distribution of water, heating energy and wastewater between the 1st and 2nd cycle for different pasta cookers

	Electric pasta cookers			Gas/LPG		
	1st Cycle	2nd Cycle	Average	1st Cycle	2nd Cycle	Average
Water use (l/kg cooked pasta)	4.440	1.087	2.764	4.440	1.047	2.744
Heating energy (MJ/kg cooked pasta)	1.633	0.403	1.018	3.182	0.756	1.969
Wastewater (l/kg cooked pasta)	0.317[a]	3.670[b]	1.990	0.317[a]	3.710[b]	2.014

[a] The sum of water associated with the foam (discharged to the drain) and water loss while draining pasta (see Table A.1).
[b] Total amount of water for pasta cooking (4.44 l) minus the amount absorbed by pasta (0.55 l) and lost through evaporation (0.22 l); see Table A.1 for the latter two values.

The initial temperature of water in the 2nd cycle is calculated as follows:

$$T_t = \frac{W_1 \times T_1 + W_r \times T_r}{W_t} \quad (^\circ C) \qquad (A.1)$$

where:

T_t temperature of the water in the 2nd cycle (°C)
T_1 temperature of W_1 (°C)
W_1 mass of water reused from the 1st cycle (l)
W_r mass of water refilled for cooking pasta in the 2nd cycle (l)
T_r temperature of W_r (°C)
W_t sum of reused and refilled water (l)

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