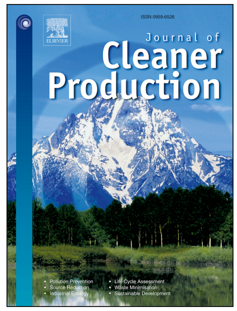
Accepted Manuscript



Energy Flows and Greenhouses Gases of EU national breads using an LCA approach

Bruno Notarnicola, Giuseppe Tassielli, Pietro Alexander Renzulli, Fabio Monforti

PII: S0959-6526(16)30629-1

DOI: 10.1016/j.jclepro.2016.05.150

Reference: JCLP 7332

To appear in: *Journal of Cleaner Production*

Received Date: 16 December 2015

Revised Date: 24 May 2016

Accepted Date: 24 May 2016

Please cite this article as: Notarnicola B, Tassielli G, Renzulli PA, Monforti F, Energy Flows and Greenhouses Gases of EU national breads using an LCA approach, *Journal of Cleaner Production* (2016), doi: 10.1016/j.jclepro.2016.05.150.

Energy Flows and Greenhouses Gases of EU national breads using an LCA approach

Bruno Notarnicola[1], Giuseppe Tassielli[1], Pietro Alexander Renzulli[1], Fabio Monforti[2]*

[1]Ionian Department of Law, Economics and Environment, University of Bari Aldo Moro, via Lago Maggiore angolo via Ancona, 74121 Taranto, Italy.

[2] European Commission, Joint Research Centre, Centre, Renewable Energy and Energy Efficiency Unit, Via Enrico Fermi 2749; T.P. 450290; 21027 Ispra (VA), Italy

**fabio.monforti-ferrario@ec.europa.eu*

Abstract

Bread represents a staple food in many parts of the world including Europe. Depending on the region of origin and the respective cultural heritage bread is made with different ingredients and is consumed in various forms. This work consists of an environmental sustainability assessment of 21 different types of bread, representing a wide spectrum of typologies of such food consumed across the European Union, via a Life Cycle Assessment approach. The embedded energy and equivalent greenhouse gas emissions of each type of bread were estimated, from cradle to bakery gate, by considering a mass, a nutritional value and a price based functional unit. Overall, the results have highlighted the variability of the embedded energy and the equivalent GHG emissions associated to the consumption of the 21 kinds of bread rooted in the cultural environment EU countries. When considering a functional unit of 1kg of bread, the Cumulative Energy Demand results range from 9 MJ/kg to 32.9 MJ/kg. The Global Warming Potential indicator has a minimum value of 0.5 $kgCO_{2eq}$/kg and a maximum of 6.6 $kgCO_{2eq}$/kg. For a functional unit amounting to a 100kcal provided by the consumption of bread, the Cumulative Energy Demand results vary from 0.33 MJ/100kcal to 0.93 MJ/100kcal whilst the Global Warming Potential indicator varies from 0.019 $kgCO_{2eq}$/100kcal to 0.135 $kgCO_{2eq}$/100kcal. For a functional unit amounting to the quantity of bread purchased with 1€ (weighted according to the purchasing price of each nation in the European Union), the Cumulative Energy Demand results vary from 1.197 MJ/€ to 3.708MJ/€ whilst the Global Warming Potential indicator varies from 0.15 $kgCO2_{eq}$/€ to 0.376 $kgCO2_{eq}$/€.

The study has pinpointed the importance of evaluating food, in terms of environmental sustainability, with more than one type of functional unit in order to account not only for the bread's nutritional purposes but also the need to satisfy social, cultural, hedonistic and other qualitative functions. Specifically, when using a mass based functional unit, the less impactful results involve bread types with simple recipes, based essentially on flour, yeast and water. By assessing the breads with an energy based functional unit, bread types which also contain vegetable oils and small amounts of animal based ingredients result as more carbon and energy friendly. The use of a price based functional unit indicates that the higher priced bread types, manufactured with more expensive ingredients that are produced in an environmentally efficient manner, are the more sustainable ones. Overall, for many types of bread, the energy consumption during the production phase, in particular the baking process, represents a hot spot and is dependent on the size and shape of the bread. Furthermore, the efficiency of ingredient production (in terms of material and energy use and in terms of the respective yields of each nation in the European Union), such as that of milk and flour, also influences the sustainability of the bread types.

Keywords: Bread, bread production; Life Cycle Thinking; LCA; Sustainable agri-food chains; Food production and consumption.

Highlights:

- Embedded energy and greenhouse gas emissions have been assessed for 21 types of bread.

- Mass, nutritional value and price based functional units have been used.

- Energy consumption in the production phase represents a hot spot for most bread types.
- Efficiency of ingredient production, bread shape and size influence the results.
- The importance of using different functional units for food LCA has been highlighted.

1 Introduction

Bread is one of the oldest prepared nourishments and represents a staple food in many parts of the world, including Europe. It is eaten in various forms during meals of the day or as a snack and it is even used as an ingredient for other more complex types of food.

In its simplest form bread is made with some form of cereal flour (mostly wheat flour, less often rye and other cereals) that is mixed into dough that is cultured with yeast, allowed to rise, and finally baked in an oven. Often however other bread ingredients, depending on the region of origin and the respective cultural heritage, are used such as dried fruit, seeds and milk derived products. This leads to the production of a large variety of bread that is consumed daily around the world, each type with different characteristics including nutritional and economic values. Such food diversity makes a complex challenge for the computation of meaningful data for environmental burden indicators describing impacts associated to food consumption.

The purpose of this work is that of comparing the environmental sustainability of a selection of different types of bread, representing a wide spectrum of typologies of such food consumed across the European Union (EU). Specifically, in this study, in order to provide a snapshot of the possible range of variability of two key environmental impact indicators associated to bread consumption, namely embedded energy and equivalent greenhouse gas (GHG) emissions, 21 kinds of bread rooted in the cultural environment of 21 EU countries were selected and investigated via a Life Cycle Assessment approach (LCA) (Notarnicola et al. 2012).

Currently there are no extensive comparative studies concerning the environmental sustainability of bread produced in different regions. LCA studies on bread found in literature, specifically regarding GHG emissions and energy use, concern bread production in a single nation (e.g. Espinoza-Orias et al. 2011, Williams et al. 2010, Grönroos et al. 2006). Other complete bread LCAs, concerning various impact categories associated to bread production, compare different scales of production (Andersson & Ohlsson 1999, Braschkat et al. 2003) including the use of conventional and organic wheat, or compare generalised bread production with that of other foods (Narayanaswamy et al. 2005), or compare bread wheat production to that of other food crops (Audsley and Wilkinson 2012, Williams 2006 & 2010). In these studies the functional unit (FU) is a mass based one that does not consider the nutritional value or the economic value of the bread. Whilst a FU based on nutritional value represents a specific quality of a staple food such as bread, an economic based FU unit, that relates environmental impacts to the production of a specific amount of income or monetary value (Cerutti et al. 2013), can also be used to represent an integrated measure of quantity and quality of the bread types. In fact, some bread types are consumed on festive occasions and hence they do not have a nutritional function alone (in terms of carbohydrate intake), but their function also involves satisfying other qualitative and hedonistic values (Notarnicola et al. 2012). Specifically, a price based FU, as pointed out by van der Werf and Salou (2015), is well suited for accounting for these qualitative aspects.

The present study is different from the existing literature in that it aims at highlighting the variability of the above mentioned impact indicators related to the production of the different EU bread types by considering not only the mass but also the energy content and the economic value of each bread. At the same time this study aims at identifying the hotspots of the life cycle of the different analysed EU breads, including aspects concerning wheat imports and food wastage and losses occurring in the supply chain, in order to create valuable information for decision making concerning possible solutions for technological improvement and sustainable behavioural changes.

2 The breads

In the framework of their participation in EXPO 2015 exhibition, 19 Member States of the European Union identified a traditional bread recipe and made it available to visitors to the EU Pavilion on its website (EXPO 2015). These 19 traditional bread recipes, together with another two recipes from two EU countries not present at EXPO (Bulgaria and Latvia) were used as the basis of the present study for estimating the energy flows and the green-house gas (GHG) emissions associated with their preparation following an LCA approach similar to the method used for assessing the 'basket of products' (Notarnicola et al. 2014).

It is worth noticing that these types of bread (

Table 1) are not necessarily the ones most consumed in each country, some of them are even quite atypical and usually reserved for special occasions or particular moments of the day (breakfast, snacks and so on). For this reason, extrapolating the data found in this study to the whole bread consumption in the country would not be correct. Nevertheless, results can help to provide a further estimate of the overall variability and uncertainties associated with the evaluation of energy implications in food consumption.

All the bread recipes entailed the use of bread wheat (common wheat) flour with the exception of the Latvian, Lithuanian, Estonian and Polish bread for which rye flour was used. However, the remaining ingredients of each recipe varied greatly from a few other constituents to many more complex ones (see Table 3).

Table 1 - The different EU bread types.

Type of bread					
1	*Austrian wheat buns - Kaisersemmel*	*8*	*Greek flat bread - Pita*	*15*	*Dutch raisins buns - Krentenbollen*
2	*Belgian sweet bread - Cramique*	*9*	*Hungarian salty buns - Pogácsa*	*16*	*Polish sourdough rye bread - Chleb Žytni Razowy*
3	*Bulgarian ceremonies round bread- Pogacha*	*10*	*Irish wholemeal and baking soda bread*	*17*	*Romanian Easter cheese bread - Pasca*
4	*Czech braided rolls - Houska*	*11*	*Italian flat bread - Focaccia*	*18*	*Slovak walnut horseshoes - Bratizlawsky Rożok*
5	*Estonian grated bread - Vaukhoore*	*12*	*Latvian parboiled rye bread - Salinata Rudzu Rupjmaize*	*19*	*Slovenian braided heart loaf - Pleteno Srce*
6	*French sourdough bread - Baguette*	*13*	*Lithuanian sourdough dark rye Rugine Duona*	*20*	*Spanish snack - Pan con Tomate*
7	*German crossed-shaped bread - Breitzel*	*14*	*Maltese sourdough bread - Hobż Malti*	*21*	*British Devon scones*

3 LCA approach and assumptions

In order to calculate the energy flows and GHG emissions related to the selected EU bread types, process-based life cycle inventory models were developed, following an LCA "from-cradle-to gate" approach.

The consistency of the data sources was checked by adopting a process-based LCA approach that leads to the creation of inventories for each single life cycle phase. The approach used was one already implemented in a previous study (Notarnicola et al 2015a). Specifically each inventory was built based on the appropriateness of the data to the present study in order to guarantee the coherence between the processes. The hypothesis ad assumptions therefore are the same for all products/ingredients and the inventories gathered from various sources have been modified and adapted to these hypothesis and assumptions.

The reference system considers the artisan production of the above listed different bread types, with the ideal business model reference of a family owned bakery operating on the local market.

The importance of using different FUs in LCA has often been highlighted in literature (van der Werf and Salou 2015), also when dealing with dietary and nutritional issues (Heller et al. 2013, Kägi et al. 2012, Smedman et al. 2010).

In order to compare fully the environmental sustainability of the different types of bread, including aspects concerning their nutritional and the economic value, functional units (FUs) pertaining to the mass, energy content and price of the bread were selected for the assessment, namely:

i. FU defined as 1 kg of bread ready to be sold in an artisan bakery.
ii. FU defined as 100kcal of energy provided by the consumption of bread sold in an artisanal bakery
iii. FU defined as the amount of bread that can be purchased for consumption from an artisanal bakery for the "weighted" price of 1€. Such price value, for each respective EU nation, is weighted according to the Eurostat Comparative Price Levels of final consumption by private households including indirect taxes (ratio between Purchasing power parities –PPPs- and market exchange rate for each country), in order to account for the purchasing power of the different EU nations (Eurostat 2015). This ratio is shown, in relation to the EU average (EU28 = 100%), in
iv. Table 2 together with the weighted value of the 1€ purchasing price. Such weighted value represents the amount that needs to be spent, in a specific nation, in order to purchase what on average has a value of 1€ in the EU.
v. Table 2 also details the effective purchasing price per kg of each bread, in each EU nation, the corrected (weighted) price of each bread according to the purchasing power of each nation and the nutritional energy content of each bread type.

Table 2 – Data concerning the national comparative price levels of the EU nations, the weighted value of a 1€ purchasing price, the effective prices of each EU bread type and the respective nutritional energy content.

EU Nation (bread type)	National comparative price level for the year 2014 (%)	Weighted value of a 1€ purchasing price (€)	Effective purchasing price of each bread (€/kg)	Weighted purchasing price of bread (€/kg)	Nutritional energy content of each bread (kcal/100g)
Austria (wheat buns)	106.8	1.068	3.97	3.72	253
Belgium (sweet bread)	109.2	1.092	9.16	8.39	302
Bulgaria(ceremonies round bread)	48.4	0.484	3.49	7.21	287
Czech Republic (braided rolls)	64.2	0.642	3.49	5.43	359
Estonia(grated bread)	79.4	0.794	7.33	9.23	289
France (sourdough bread)	107.8	1.078	2.63	2.44	237
Germany (crossed-shaped bread)	101.5	1.015	5.44	5.36	283
Greece (flat bread)	86.2	0.862	3.77	4.37	250
Hungary (salty buns)	57.1	0.571	11.75	20.57	427
Ireland (wholemeal soda bread)	120.7	1.207	5.91	4.90	243
Italy (flat bread)	101.9	1.019	3.35	3.28	277
Latvia(parboiled rye bread)	72	0.72	4.39	6.10	231
Lithuania (sourdough dark rye bread)	64	0.64	3.15	4.92	241
Malta (sourdough bread)	82.5	0.825	3.06	3.71	234
Netherlands (raisins buns)	110.7	1.107	7.36	6.65	271
Poland (sourdough rye bread)	55.8	0.558	2.18	3.91	218
Romania (Easter cheese bread)	54.3	0.543	11.31	20.83	356
Slovakia (walnut horseshoes)	68.6	0.686	6.48	9.44	384
Slovenia (braided heart loaf)	82.6	0.826	5.65	6.84	316
Spain (snack)	92.7	0.927	5.18	5.58	204
United Kingdom (Devon scones)	121.6	1.216	8.25	6.79	336

The effective bread purchasing prices illustrated in

Table 2 were estimated using the cost of the quantities of each bread ingredient and the preparation and baking energy costs. The prices of the ingredients were estimated using the Eurostat detailed average prices of consumer goods (Eurostat 2016a) together with data from the national statistics databases of the EU member states. In some cases, when data was not available from these databases, the price was estimated for each nation by considering the price of an ingredient from the same supermarket chain in each EU nation. The energy prices were obtained from the Eurostat Energy price statistics for industrial consumers (Eurostat 2016b). The sum of the ingredient and energy costs was assumed to represent 30% of the final price (Boulangerie 2011). Hence this sum was scaled up accordingly in order to approximate the final effective purchasing bread prices.

The system boundaries (Figure 1) consider a cradle-to-gate approach. For each stage of the life cycle, the process-based life cycle inventories were developed for the selected products. System boundaries cover the agricultural stage of each product, the storage of cereals, wheat/rye milling, the production and processing of other ingredients different from flour, the logistics, the packaging production (whenever possible) and the bread production. Food losses throughout the life cycle were also accounted for as well as waste management.

The ISO 14040-44 series recommends that economic allocation is to be used as a last resort compared to other approaches, however, physical allocation, especially in systems that entail the production of large quantities of by-products with low economic value (such as the case of wheat production systems), can assign a large share of the impacts to by-products and not to the main product which is the real driving force of the product system under analysis (Ardente & Cellura 2012). In such cases economic allocation can be an effective manner of partitioning the environmental impacts between the various by-products. Another appropriate allocation procedure, potentially applicable to this study, is the one based on the Cereal Unit (Brankatschk & Finkbeiner 2014) which however is still not sufficiently updated in terms of conversion factors for the EU. Hence, for the present study, the allocation of environmental impacts during bread production was solved on an economic basis (e.g. wheat-straw and skimmed milk-cream allocation, see Figure 2).

The ingredients that represented less than 5% of the total mass of all ingredients of each bread recipe were excluded from the calculations unless specific life cycle inventory data were available. Table 3 lists all ingredients considered for the LCA.

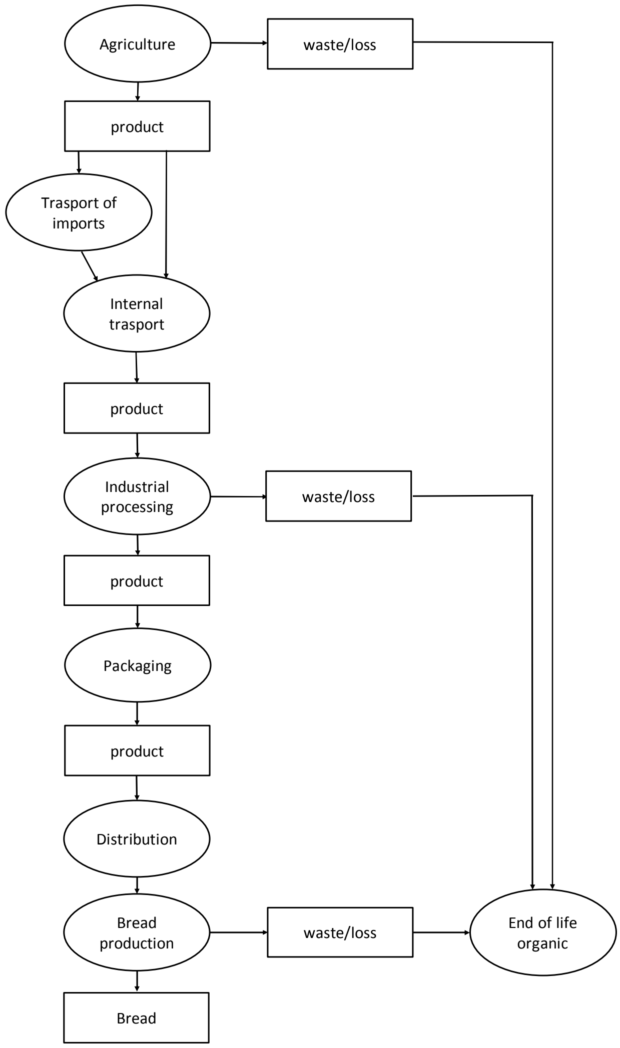


Figure 1 – The system boundaries of the bread lifecycle considered in this study.

As regards to the fertiliser use in the agricultural stage of each product, emissions of N_2O from managed soils and CO_2 emissions from lime and urea application have been estimated according to the IPCC methodologies (IPCC 2006a). By applying the calculation suggested by the IPCC guide, the ammonia emissions to air and the nitrate leaching in the soil were also estimated. It is assumed that all nitrogen that volatises converts to ammonia, and that all nitrogen that leaches is emitted as nitrate. Phosphorus emission that reaches freshwater is estimated as 5% of the phosphorus applied through fertilisers (Blonk, 2014).

The modelling of animal based ingredients (milk derived products and eggs) was carried out according to Blonk Consultants' (2014) approach, which includes accounting for feed production, animal enteric fermentation and of manure management according to the indications of the IPCC (2006b).

Logistics was modelled in terms of international trade, distribution and retail. International trade data (taken from the Eurostat database for the year 2014) was considered only for wheat since it represents by far the major ingredient, in terms of mass, of all bread types. The impacts were considered only for the international trade originating from the countries that represented the source of at least 90% of the total national wheat imports. Distribution was assumed to occur in terms of transport of raw materials/ingredients by lorry from the manufacturer to a regional distribution centre and additional transport by lorry from the centre to the retailer. The total distance travelled was assumed to be 500 km for the products used for the bread production. Refrigerated transport was modelled with a 20% increase in fuel consumption (Lalonde et al. 2013).

Packaging was included for some ingredients such as butter (aluminium foil), cheese (cardboard and polyethylene packaging) and sugar (paper packaging).

The final weight of the different bread types was estimated in the following way: firstly for each ingredient of the recipe, the humidity percentage was identified (Ciraolo et al. 1998). By multiplying the weight of the ingredient by its humidity percentage, the total humidity was obtained. A 30% humidity loss is assumed during baking. The final weight of bread was calculated by subtracting the lost moisture from the initial weight of the ingredients. For the baking process, energy consumption of the oven is related to the mass of bread and to cooking time (defined in each specific bread recipe).

Foreground data were sourced from literature and direct industry sources. Background data were mainly taken from the Agri-footprint and Ecoinvent v.3 (Frischknecht et al. 2007) databases.

The impact categories chosen are Cumulative Energy Demand v 1.08 and Global Warming. The category Cumulative Energy Demand (CED) reports the consumption of primary energy in terms of MJ (Hischier et al. 2010). For Global warming, the characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) was selected for the development of characterisation factors. Factors are expressed as Global Warming Potential for a 100 year time horizon (GWP100), in kg carbon dioxide equivalent/kg emission (IPCC, 2007).

4 Life Cycle Inventory of the breads

This section describes the inventories of the types of bread, based on the application of the hypotheses, assumptions and data described in the previous paragraphs.

The ingredients used for the various recipes, the respective amounts and the weight of the final bread are shown in Table 3. The inventories of main ingredients, namely flour and dairy products, are specific for the production countries. The inventories of the other ingredients are referred to the EU-27 average situation.

As regards to wheat/rye production, the environmental datasets for each (producing and exporting) country was built using different data sources such as the IFA (2012) database, which provides data on the fertiliser consumption per country, the FertiStat (2004) database which provides data on the specific consumption of fertilisers in the cultivation of wheat for different countries and the FAOSTAT (2014) database which was used to obtain the yields of grain per hectare in the various countries. The country of origin of the cereal and the distances from importing countries are considered for the estimation of logistics. The grinding of wheat/rye occurs in the country of production of the bread; therefore the electricity mix is differentiated by country. Data for the production of wheat flour from dry milling are taken from Renzulli et al. (2015) while those related to rye flour are taken from Agrifootprint database. Data related to bread production are taken from Espinoza-Orias et al. (2011).

The inventory of milk production was built for each country starting from data concerning production yields (obtained from the FAOSTAT database). The livestock system considered includes the following features: growth of calves and steers for 2 years before the first birth, a birth every 14 months, a productive life of 6 years, an annual replacement rate of 25%, the sale of surplus calves and out-of-production cows for slaughtering. For Eastern countries extensive breeding was assumed. For each cow the Net Energy intake (metabolisable energy minus the heat increment) required for maintenance, milk production, loose housing, gestation was calculated and then converted in gross energy (N.R.C. 2001). This was carried out in order to estimate the feed need and to accomplish the Tier2 method for the calculation of enteric methane emissions and CH_4, N_2O and NH_3 emissions from manure management (IPCC 2006b). Furthermore specific electricity mix and production losses were included for each country. The different milk yields for the year 2013, the net energy and emissions, expressed per head per year, are shown in Table 4 for the various countries.

The life cycle of milk includes, in addition to the rearing phase, also the industrial production and distribution phases, whose data were obtained respectively from Fantin et al. (2012) and Notarnicola et al. (2014).

As regards dairy products, the production cycle initially includes milk skimming. Raw milk is allowed to stand so that a part of the natural fat separates by floating: the fat has a specific weight lower than that of water and it gradually collects on the surface of the milk, while the emulsion is broken. The mass, which is recovered by skimming, takes the name of cream and contains about 60% water and 30-40% fat. For the purpose of this LCA study, an economic allocation was used for that part of the process leading to the joint production of cream and skimmed milk with percentages respectively of 17.9% and 82.1%. Cream and skimmed milk are the basis for the production of butter, cheese and milk powder. Mass balances for the production of these products are given in Figure 2. Inventory data for the various production phases are taken from Djekic et al. (2014).

Table 5 illustrates the LCI data sources of the agriculture or production stages of the other ingredients. The agricultural datasets that were sourced from literature or from databases were revised in order to adapt them to the previously reported methods and assumptions.

For the estimation of the energy consumption, occurring during the artisan bread production, bibliographical research was carried out and, among the different references, a figure of higher consumption compared to an industrial production was chosen (Jensen et al 2014; Espinoza-Orias et al 2011). The bread production consisted of dough preparation and kneading, mixing with other ingredients, followed by the proofing and finally the baking. Such operations were assumed to involve 0.54 kWh of electrical energy and 1 MJ of thermal energy during 1 hour of baking of 1 kg of bread (Kulak et al. 2015). This figure was then compared to the masses and to the cooking time of the 21 breads. The data underlying these estimates are reported in Table 6. In addition to the energy consumption during baking, heat consumption was also estimated for the heating of water that is normally added warm to the mixture, so as to dissolve the yeast.

Table 3 – The ingredients of the 21 bread types.

Ingredients	**Unit**	**Countries**																						
		AT	BE	BG	CZ	EE bread	EE ingr.	FR	DE	EL	HU	IE	IT	LV	LT	MT	NL	PL	RO	SK	SI	ES bread	ES ingr.	UK
wheat flour	g	800	430	350	1,000			650	1,000	400	250	450	800			450	500		1,000	1,000	1,000	33		370
rye flour	g					210								1,280	2,225			1,050						
bread	g						300																60	
butter	g		85	60			28		80		120						40		250		100			85
cheddar cheese	g										90													
cream	g						309				113								250					10
cream cheese	g																		500					
egg yolk	g										15													
eggs	g	62	62	123	123							123					123		369	185				62
fat	g																			350				
honey	g											8			64				50					
jam	g						262																	20
mashed boiled potato	g										100													
milk	g		214	120	500				260			350					275		300		400			175
milk powder	g																			40				
olive oil	g									14			140									6	2	
raisins	g		250														350		100	25				
salt	g	20	5	5	10	3		10	34	11	3	5	45	20	20	10	10	7	1	10	18	2	1	1
sugar	g	15	45	50		10	71		15				20	60	75		60		125	450	40	1		42
tomatoes	g																						30	
vegetable oil	g	20			250														9					
water	g	430		120		108		400	260	250			700	660	1,130	290		700		370		29		
yeast	g	30	25	9	25	10		20	42	10	1		4	60		11	15		25	50	40			14
total weight of ingredients	**g**	**1,377**	**1,115**	**837**	**1,908**	**341**	**970**	**1,080**	**1,691**	**685**	**693**	**936**	**1,709**	**2,080**	**3,514**	**761**	**1,373**	**1,757**	**2,979**	**2,480**	**1,598**	**70**	**93**	**779**
final weight of bread (kg)	**kg**	**1.20**	**1.01**	**0.72**	**1.71**	**0.30**	**0.97**	**0.93**	**1.50**	**0.59**	**0.61**	**0.80**	**1.46**	**1.83**	**3.07**	**0.65**	**1.23**	**1.50**	**2.62**	**2.28**	**1.44**	**0.06**	**0.09**	**0.70**
Form and number		**12 rolls**	**1 loaf**	**1 loaf**	**12 rolls**		**serves 4-6**	**3 loaves**	**14 buns**	**8 pitas**	**15 buns**	**1 loaf**	**2 focaccias**	**1 loaf**	**1 loaf**	**1 loaf**	**12 buns**	**2 loafs**	**8-10 people**	**50 pieces**	**1 loaf**		**2 slices**	**15 scones**

Table 4 – Data concerning milk yields in 2013, Net Energy and emissions (per cow per year) for the various EU countries.

Countries	Milk Yield	Net Energy	Net Energy/Yield ratio	Emissions				
				enteric emission	manure management			
				CH_4	CH_4	N_2O - direct emission	N_2O - indirect emission	NH_3
	kg	MJ	MJ/kg	kg	kg	kg	kg	kg
Belgium	7,547	37,249	4.94	112.97	21.00	0.98	0.42	15.14
Bulgaria	3,978	24,595	6.18	79.68	11.00	0.80	0.34	12.37
Czech Republic	7,644	37,526	4.91	113.69	11.00	0.98	0.42	15.18
Estonia	7,898	38,247	4.84	115.59	11.00	0.99	0.42	15.27
Germany	7,293	36,524	5.01	111.06	21.00	0.97	0.41	15.04
Hungary	6,869	35,319	5.14	107.89	12.00	0.96	0.41	14.88
Ireland	4,800	26,936	5.61	85.84	21.00	0.82	0.35	12.68
Netherlands	7,644	37,524	4.91	113.69	21.00	0.98	0.42	15.18
Romania	3,771	24,007	6.37	78.13	12.00	0.80	0.34	12.29
Slovakia	6,405	32,751	5.11	101.13	11.00	0.91	0.38	14.00
Slovenia	5,392	29,866	5.54	93.54	13.00	0.88	0.37	13.61
United Kingdom	7,758	37,849	4.88	114.54	21.00	0.98	0.42	15.22

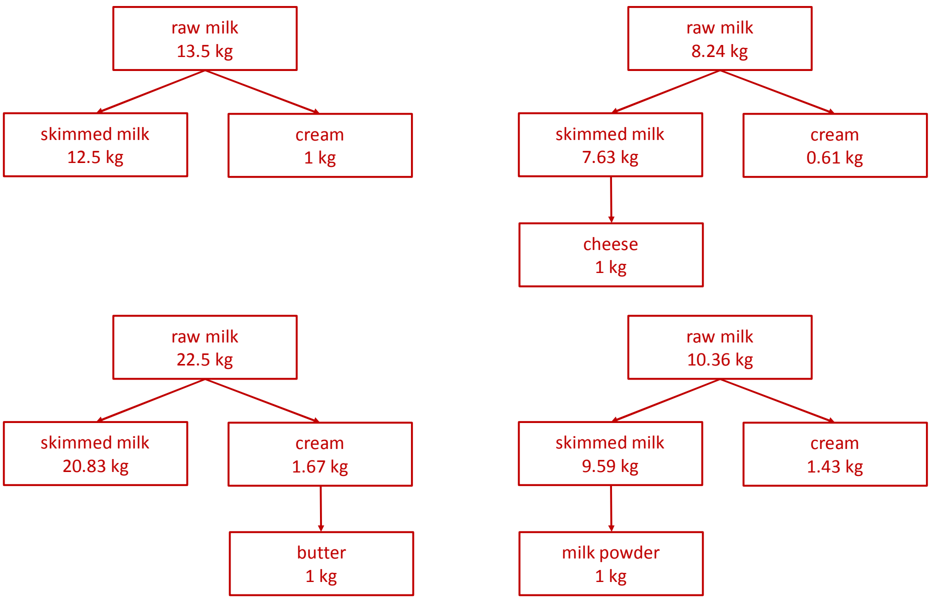


Figure 2 – Mass balance of the production of dairy products used for the bread production.

Table 5 – Overview of LCI datasets concerning the agriculture/production phase of the different bread ingredients.

Representative products	Activities	Data source
Yeast	- Yeast production	Dunn et al. (2012); COFALEC (2015)
Salt	- Process “Sodium chloride, production mix, at plant, dissolved RER”	ELCD database
Sugar	- Sugar beet cultivation - Production of sugar from sugar beet	Agri-footprint
Olive oil	- Olive cultivation - Extra virgin olive oil production from olives milling - Bottling extra virgin olive oil	Notarnicola et al. (2013)
Sunflower oil	- Production of sunflower seeds - Crude sunflower oil production from crushing (solvent process) - Refining sunflower oil	Agri-footprint
Potatoes	- Potatoes cultivation	Agri-footprint
	- Storage of fresh potatoes for fresh consumption	EPD (2012)
Honey	- Honey production	Kendall et al. (2013)
Jam	- Agricultural cultivation of strawberries - Production of jam: International Food Safety Consultancy - Guide to jam production unit	Ribaudo (2011) IFSC (2015)
Raisins	- Agricultural cultivation of grape - Production of raisin	Ribaudo (2011) Thompson (2000)
Tomatoes	- Tomato cultivation	Ecoinvent v3
Beef fat	- Beef cattle breeding - Slaughtering beef cattle for the production of beef meat - Beef fat processing	Agri-footprint
Eggs	- Laying hens breeding	Agri-footprint

Table 6 – Data used for the estimation of energy consumption during bread production (referred to the recipe).

	heat for heating water(MJ)	baking time (m)	mass (kg)	electric energy for baking (kWh)	heat in bread production (MJ)
Austria	0.05	60	1.20	0.65	1.20
Belgium	0.02	40	1.01	0.36	0.67
Bulgaria	0.03	40	0.72	0.26	0.48
Czech	0.06	30	1.71	0.46	0.85
Estonia	0.04	60	0.30	0.16	0.30
France	0.05	30	0.93	0.25	0.47
Germany	0.06	16	1.50	0.22	0.40
Greece	0.08	2	0.59	0.01	0.02
Hungary	0.00	20	0.61	0.11	0.20
Ireland	0.04	35	0.80	0.25	0.46
Italy	0.08	20	1.46	0.26	0.49
Latvia	0.23	60	1.83	0.99	1.83
Lithuania	0.13	60	3.07	1.66	3.07
Malta	0.03	40	0.65	0.24	0.44
Netherlands	0.03	20	1.23	0.22	0.41
Poland	0.08	60	1.50	0.81	1.50
Romania	0.03	40	2.62	0.94	1.75
Slovakia	0.03	15	2.28	0.31	0.57
Slovenia	0.05	30	1.44	0.39	0.72
Spain	0.00	20	0.06	0.01	0.02
UK	0.02	10	0.70	0.06	0.12

5 Energy flows and greenhouse gas emissions of the breads – results

This section illustrates the results concerning the total Cumulative Energy Demand indicator and the Global Warming Potential indicator of each type of bread, derived respectively from the calculation of the energy flows and the calculation of the GHG emissions. These results were calculated for a mass based FU, for a nutritional energy value FU and for a price based FU (Figure 3).

When considering a functional unit of 1kg of bread, the Cumulative Energy Demand results range from 9.1 MJ/kg to 32.9 MJ/kg. The value for this indicator, for 'average' EU bread, calculated in a previous study (Notarnicola et al. 2015a), amounted to 16.1 MJ/kg. The Global Warming Potential indicator has a minimum value of 0.5 $kgCO_{2eq}$/kg and a maximum of 6.6 $kgCO_{2eq}$/kg. These results are in line with those found in literature which mainly concern types of bread with simple recipes based on flour, yeast, salt and water. For example, in Kulak's et al. study (2015), which considers the lifecycle of bread types from several alternative food networks, the GWP (excluding the effects of consumer transports) ranges from 0.6 to 1.7 $kgCO_{2eq}$/kg; similarly the Non-renewable-resources indicator values range between 6 to 21.5 MJ/kg. In Andersson and Ohlsson (1999) the primary energy indicator ranges from 13.5 MJ/kg for an industrial bakery to 6.5 for a local bakery, whilst the GWP ranges from 0.9 $kgCO_{2eq}$/kg of the industrial bakery to 0.62 $kgCO_{2eq}$/kg of the local bakery. In the study of Espinoza-Orias et al. (2011) the carbon-footprint of white bread amounts to 0.8 $kgCO_{2eq}$/kg whilst that of wholemeal bread amounts to approximately 0.75 $kgCO_{2eq}$/kg. In Braschkat's et al. (2003) study, where different baking, milling and agricultural practices are evaluated via an LCA, the energy demand indicator ranges from 4 MJ/kg for an industrially baked bread to 6 MJ/kg for an bread baked in a small bakery whilst the GWP ranges from 0.41 $kgCO_{2eq}$/kg (industrial) to 0.58 $kgCO_{2eq}$/kg (small bakery) excluding all transports.

In the present study (Figure 3), for a FU amounting to a 100kcal provided by the consumption of bread, the Cumulative Energy Demand results vary from 0.33 MJ/100kcal to 0.93 MJ/100kcal whilst the Global Warming Potential indicator varies from 0.019 $kgCO_{2eq}$/100kcal to 0.135 $kgCO_{2eq}$/100kcal.

When considering a functional unit representing the amount of bread purchased with 1€ (weighted according to the purchasing price of each EU nation), the Cumulative Energy Demand results vary from 1.197 MJ/€ to 3.708MJ/€ whilst the Global Warming Potential indicator varies from 0.15 $kgCO_{2eq}$/€ to 0.376 $kgCO_{2eq}$/€.

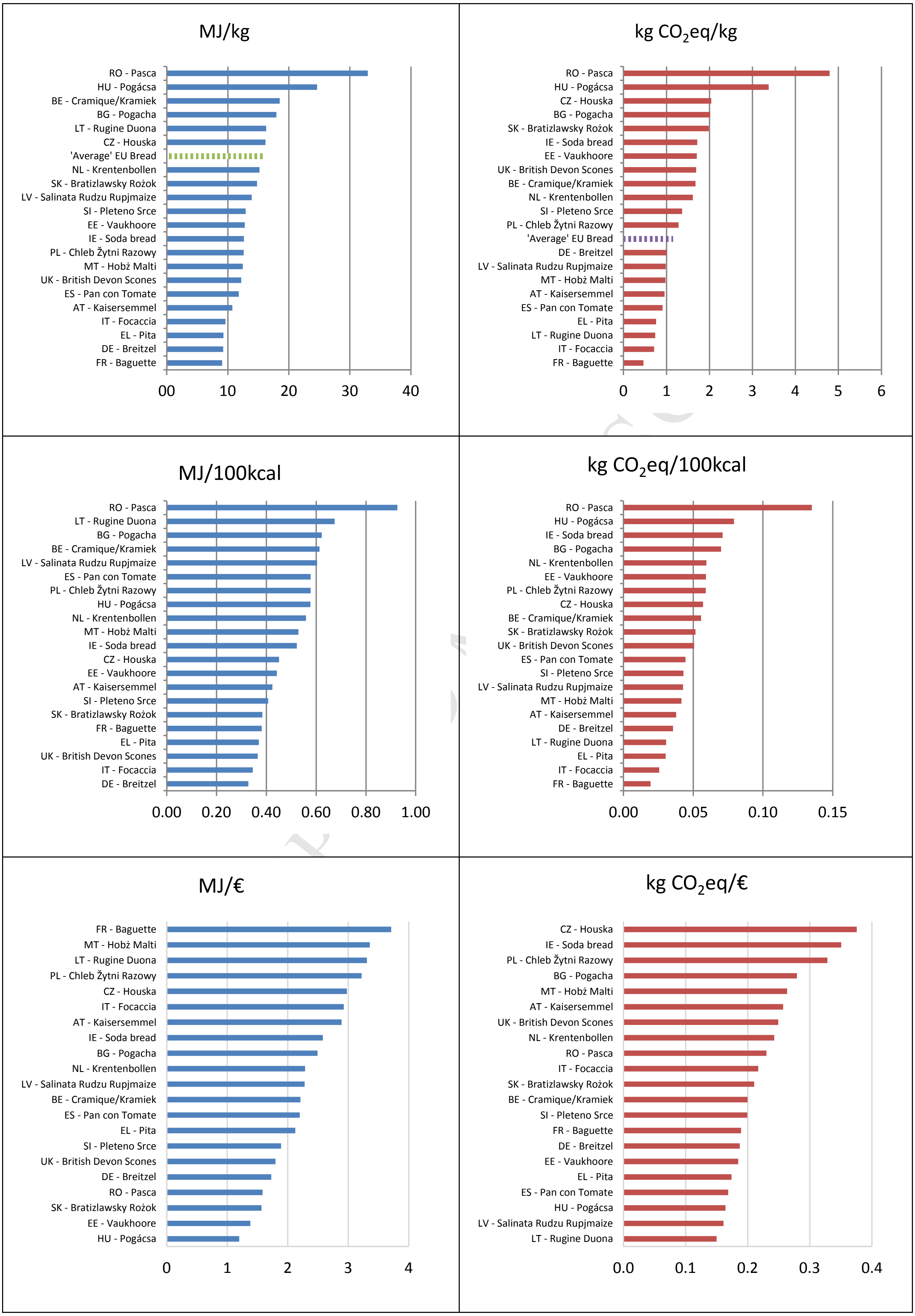


Figure 3 – Indicator values of the Embedded energy (left) and equivalent GHG emissions (right) of the 21 types of traditional bread (calculated using mass, nutritional energy and price based functional units).

6 General interpretation of the results

Figure 3 highlights that, when considering a mass based FU, bread types having more environmental impact are those that are characterised by recipes with animal-based products such as eggs, milk, cream, butter and cheese. This is due to the high energy consumption in the manufacturing phase and to the use of animal-derived ingredients associated to the emissions of CH_4 and N_2O occurring during the animal breeding and manure management. In fact, the Romanian Pascã and Hungarian Pogácsa breads, that could be considered more as pies rather than breads due to the content of animal products including cheese, are by far the more burdening breads for both indicators. On the other hand the bread types characterised by simpler recipes entailing the use of water, flour and yeast result as the more energy and carbon friendly (e.g French baguette).

In general Figure 3 also highlights that for an energy based FU (defined as 100 kcal of energy provided by the consumption of bread), the breads with the simplest recipes, such as the French baguette (essentially composed of water, yeast, salt and wheat flour), are still among the less burdening ones. However, types of bread with higher nutritional energy contents (see

Table 2) also containing vegetable based ingredients or small amounts of animal based ingredients such as milk tend to perform better when compared to the mass based FU scenario.

The Romanian Pascã, when assessed via an energy based FU, even though it is among the breads with a higher nutritional energy content, remains the worst performer. This is due to a less efficient production of milk (contained in most ingredients), as a result of the low milk yields and Net Energy use (see the Romanian ratio between Net Energy and milk yield in Table 4) and also due to a low wheat yield (3.27tons of wheat per cultivated hectare - FAOSTAT 2014).

On the whole, for a price based FU (bottom part of Figure 3), the results tend to indicate that the more sustainable bread types are those with the highest prices that thus contain more expensive ingredients (animal based ones) and can be considered more 'high-end' bread types. Even though the Romanian Pascã is the most expensive bread, it is not the most sustainable one due to the above mentioned inefficient wheat and milk based ingredient production. The Hungarian Pogácsa bread, which is the second most expensive bread, on the other hand is based on milk ingredients deriving from a more efficient milk production (see Table 4) and from a higher wheat yield (4.12t/ha). For this reason it is the most sustainable in terms of embedded energy and is the third best in terms of contribution to global warming.

An analysis of the most burdening ingredients of the different breads (see Figure 5) indicates that for the Austrian, French, Greek, Italian, Latvian, Lithuanian, Maltese and Polish bread flour is the most contributing ingredient to the Cumulative Energy Demand indicator, with a range between approximately 30% to 80%. On the other hand, animal-based ingredients contribute the most to the same indicator of the Belgian, Bulgarian, Estonian, German, Hungarian, Irish, Dutch, Romanian, Slovenian and British bread, with a share ranging from 25% to 75% in the case of bread comprising substantial amounts of butter or cheese.

The agricultural stage (see Figure 4), here defined as the operations related to the FU occurring from the cradle to the gate of the farm, as often indicated in agri-food LCA literature (Notarnicola et al. 2015b), is a critical life cycle phase primarily due to the use of pesticides and fertilisers responsible for a large energy use and, in the case of fertilisers, also for GHG emissions.

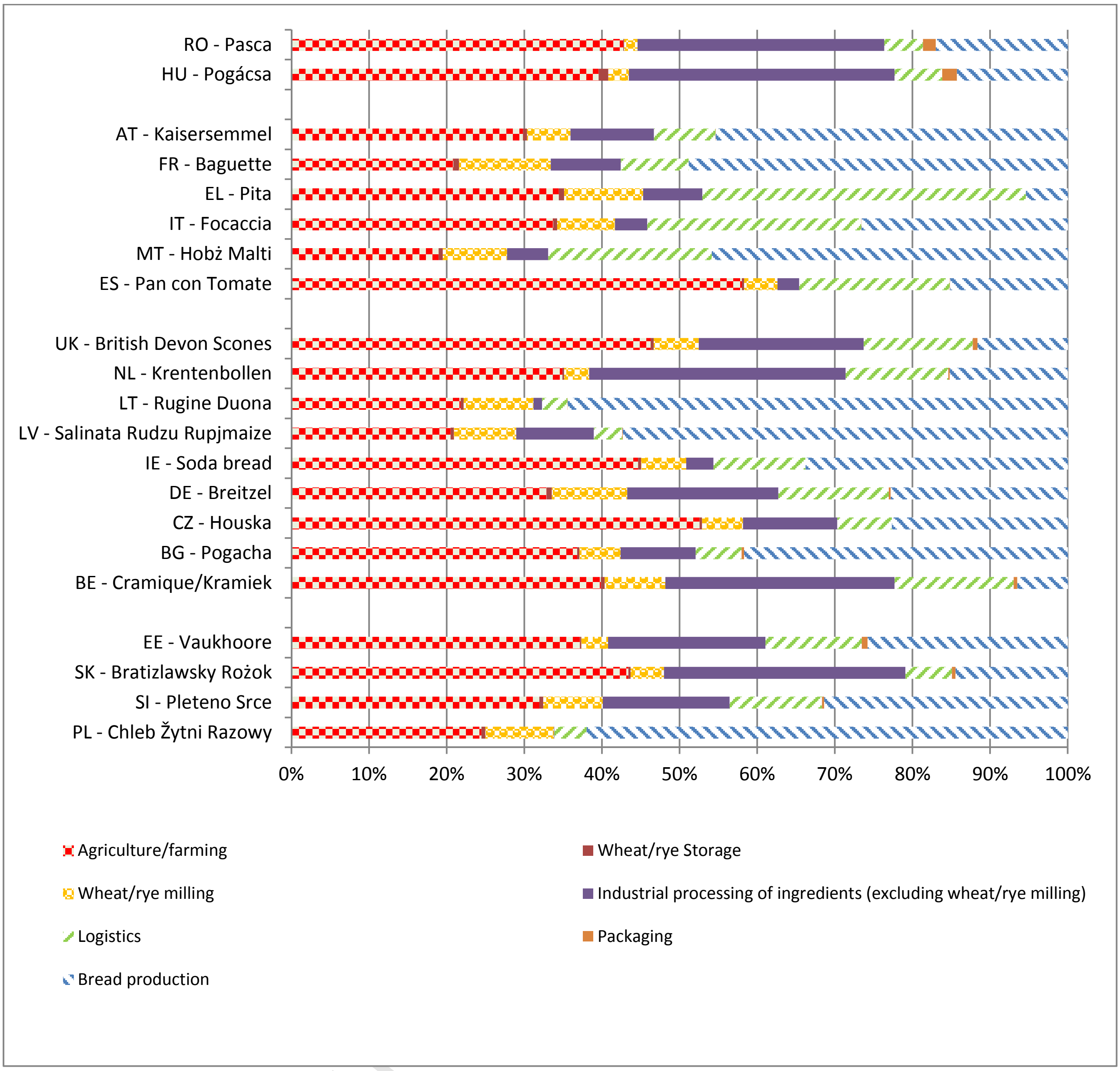


Figure 4 – Share of embedded energy of the 21 types of traditional bread (subdivided for each production step).

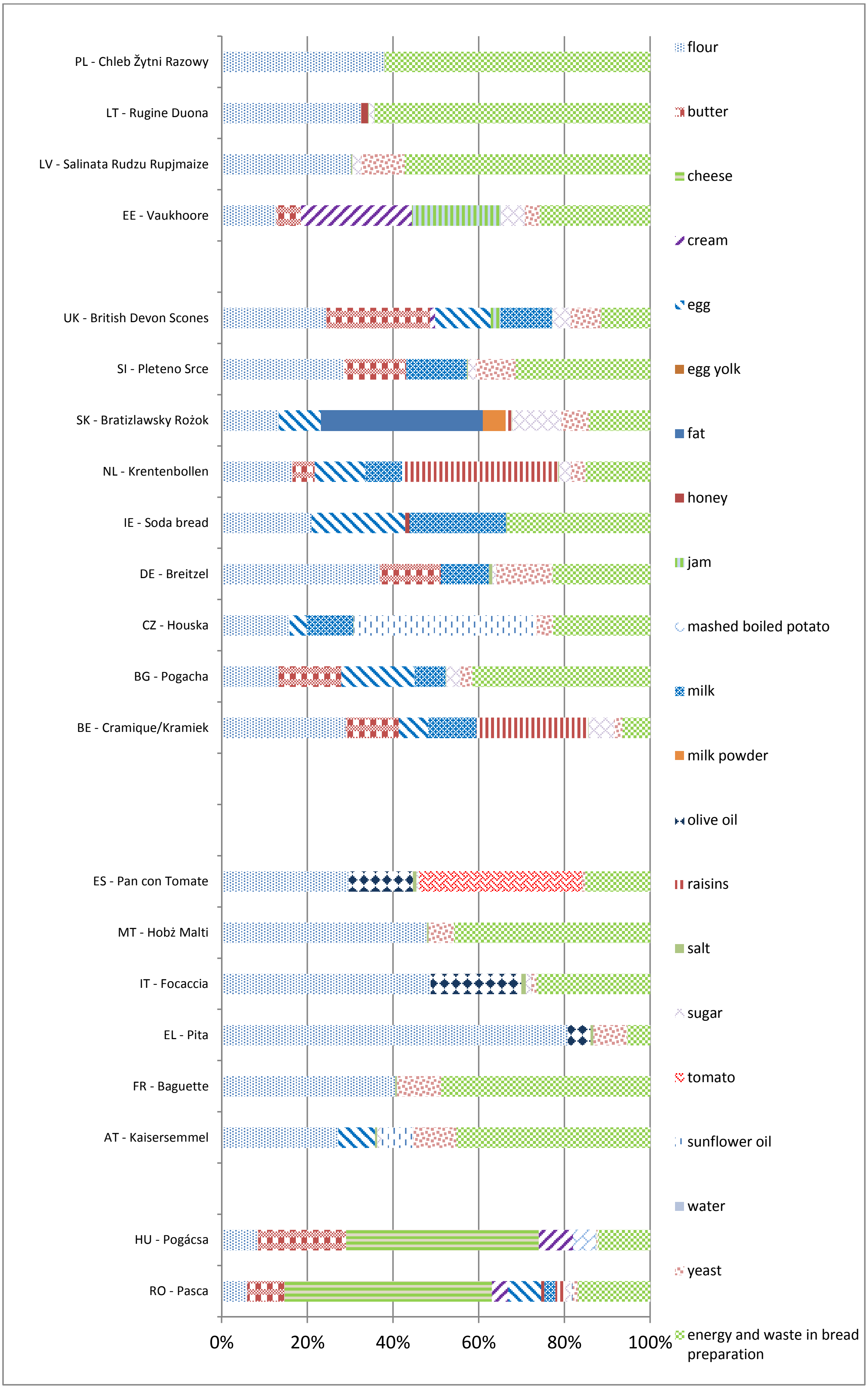


Figure 5 – Share of embedded energy of the 21 types of traditional bread (with respect to the single ingredients and the final bread preparation).

6.1 Specific interpretation of the results per bread categories

For a more detailed discussion of the environmental assessment of the bread types, the results have been grouped together in terms of:

i) breads types that contain wheat and that have a ‘simple’ recipe with little or no animal based ingredients (Figure 6),
ii) more ‘elaborate’ bread types containing animal based ingredients (excluding the above discussed Romanian Pascã and Hungarian Pogácsa bread) (Figure 7) and,
iii) bread types containing rye flour (Figure 8).

6.1.1. Simple bread types

Among the bread types based on simple recipes (Figure 6), when assessed with a mass based FU, the French Baguette, the Greek Pita and the Italian Focaccia are the more sustainable ones. In the case of the French bread this is due mainly to an electricity mix based on nuclear power and a wheat production that entails very high yields (7t/ha). The Greek bread and Italian bread are based on less efficient wheat systems, with lower yields, and also use small amounts of olive oil as ingredients. However their shape reduces the energy consumption during the baking processes. In fact, the form of each bread can also influence the energy use: small buns or elongated flat shaped bread will tend to have a larger surface area exposed in the oven during baking and hence require less energy for the evaporation of the liquids from the dough. This is why flat bread such as the Italian Focaccia and the Greek Pita have a smaller share of the embedded energy attributable to baking.

The inclusion in the Austrian recipe of one egg gives the Kiasersemmel bread, when assessed with a mass based FU, a slightly more impacting environmental profile when compared to the above mentioned bread types, which is slightly counterbalanced by a higher Austrian wheat yield. The Spanish bread performs worst in terms of embedded energy and is second last in terms of GHG emissions primarily due to the inclusion of tomato among the ingredients. The Maltese bread is also among the least sustainable in terms of the two impact categories, mainly because of the burden associated to the large national wheat imports and because of its respective energy consumption during baking which is influenced by the form of the bread which is that of a round loaf (as opposed to multiple rolls of the Austrian bread or the flat shapes of the other breads).

When assessed with a nutritional based FU, since this group of bread types have similar nutritional values (see

Table 2), the results are similar to those entailing a mass based FU.

The results concerning a price based FU differ from the previous ones principally due to the higher prices of the Greek Pita and Spanish bread when compared to the others. The lower prices of the French Baguette and Maltese Hobż Malti make these breads the worst in terms of embedded energy. Again the use of electric energy in the life cycle of the French bread, based on an electricity mix centred on nuclear power, makes the baguette third best in terms GHG emissions.

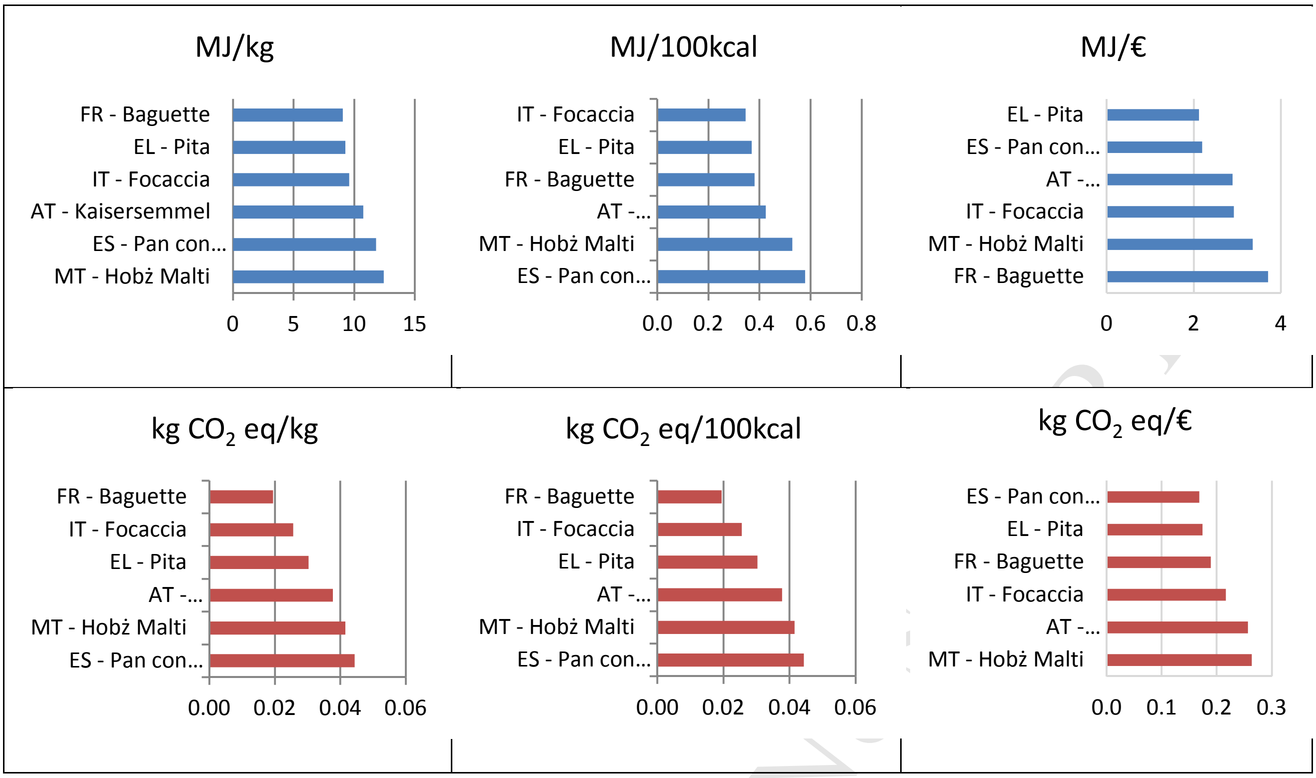


Figure 6 – Indicator values of the Embedded energy (top) and equivalent GHG emissions (bottom) of the 'simple' bread types (calculated using mass, nutritional energy and price based functional units).

6.1.2. Elaborate/festive bread types

Among the elaborate bread types, the German Bretzel is the more sustainable one in terms of both of the impact indicators, for all FUs. This is because of a recipe which is based primarily on wheat flour and milk products which are produced in a very efficient manner. Specifically, the yield of German wheat production is particularly high (7.45t/ha) and the milk yields are also above average and involve a lower Net Energy use when compared to other EU nations (see Table 4). Furthermore the shape of the bread is that of small buns which, as mentioned above, reduces the baking energy.

Similarly the shape and size of the British scones, the high wheat yields and efficiency of the British milk production system make such bread one of the most sustainable in terms of CED for all FUs. However the large use of milk and other animal based ingredients (over 42% of total ingredient mass) make it less sustainable in terms of GHG emissions for all of the FUs.

The Czech and the Bulgarian breads score badly on both indicators, for all functional units. Specifically the Bulgarian bread production involves inefficient wheat (3.98t/ha yield) and milk production (see Table 4) together with a low nutritional value and the shape of a single loaf. The Czech bread, on the other hand, is served as small rolls and thus has a lower baking energy requirement, but nonetheless is penalised by the agricultural impacts associated with the use of sunflower oil (13% mass of all ingredients) and eggs together with a low price (see

Table 2). A high nutritional value of this bread gives it a medium ranking in terms of CED for the nutritional energy based FU.

The relatively low nutritional value of the Dutch and Belgian bread types and the impact resulting from the use of raisins ranks them poorly in terms of CED and GWP when using a nutritional energy based FU and in terms of CED when using a mass based FU. The use of milk derived products produced efficiently (see Table 4) makes these two breads more virtuous in terms of GHG emissions calculated with a mass based FU.

The Slovenian and Slovak breads are ranked in-between the best and worst performers with the exception of the results concerning the economic based FU. In this case the relatively high price of the Slovak bread and its high nutritional energy value ranks it among the more sustainable in terms of CED. Similarly the relatively high price of the Slovenian bread and its relatively simple recipe based on milk, flour and a small amount of butter ranks it among the more sustainable in terms of GHG emissions.

The Irish bread is produced with flour from a wheat system that has the highest yield (8.69t/ha). This places this type of bread third best in terms of CED for a mass based FU. In all other cases this bread scores badly due to the use of milk which is produced inefficiently (see Table 4), to a low nutritional energy value and price and to the shape of a single loaf. Furthermore the ingredient humidity level is 50% which increases the overall energy use. In fact, for many types of bread, the energy consumption during the production phase, in particular the baking process, represents a hot spot (see Figure 4). The energy used in baking (see Table 6) depends partially on the amount of liquid (Table 3) in the dough that will have to evaporate during baking. In fact, breads that have an initial humidity level of the ingredients that is below 40% (water content), such as the Slovakian, British, Dutch, German, Czech, Belgian and Slovenian breads, have an average baking time of 23 minutes. The other bread types with an ingredient humidity level higher than 40%, which in some cases is as high as 50%, have an average baking time of 43 minutes.

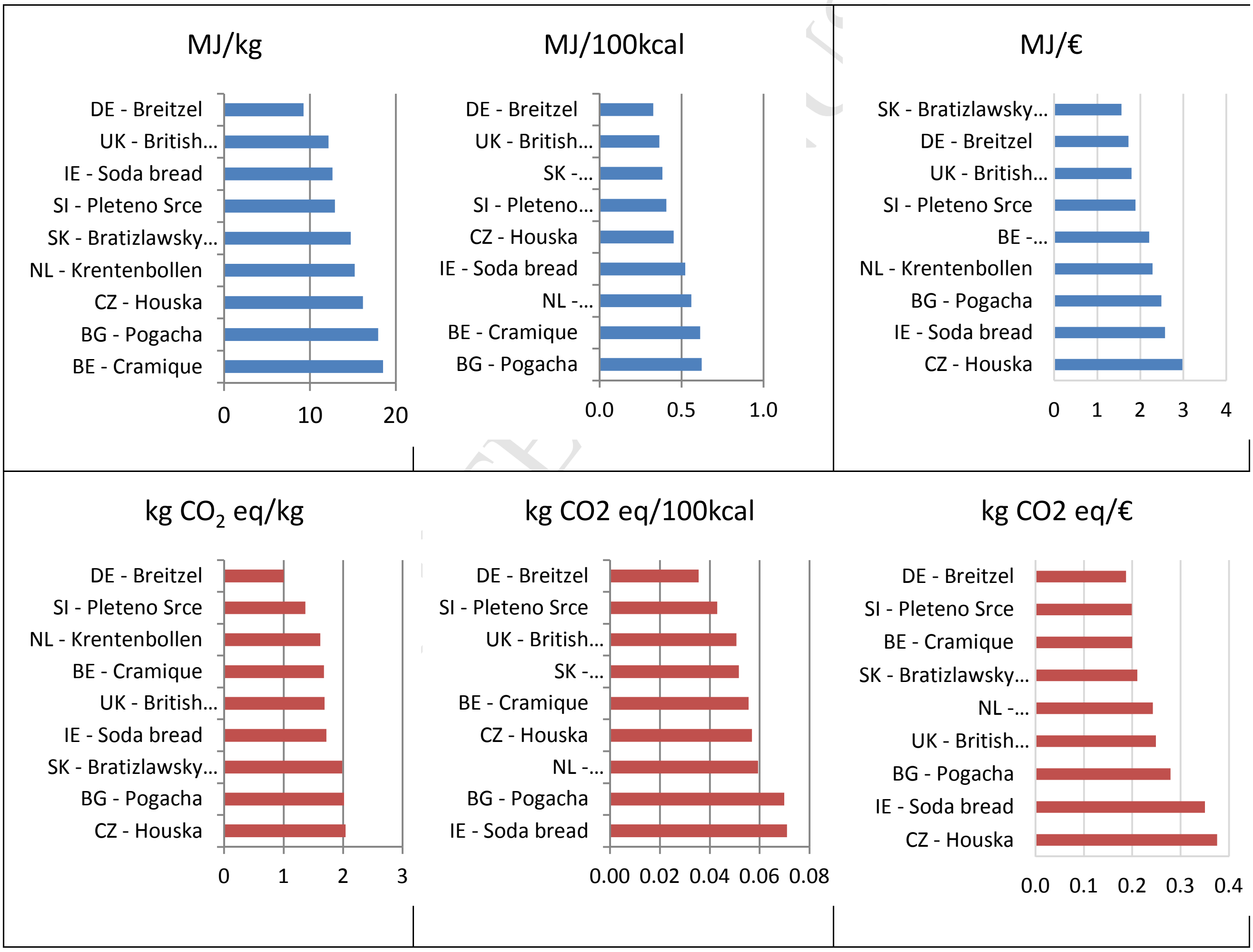


Figure 7 – Indicator values of the Embedded energy (top) and equivalent GHG emissions (bottom) of the 'elaborate' bread types (calculated using mass, nutritional energy and price based functional units).

6.1.3. Rye bread types

Among the rye based bread types the Polish Latvian and and Lithuanian breads have similar recipes essentially based on rye flour and water. The Estonian bread on the other hand also includes animal based ingredients (cream and butter), jam and sugar that are added to the rye bread once it has been baked. This inclusion of unbaked ingredients in the bread serving size, implies that the energy consumption associated to the baking process of the Estonian bread is considerably lower than that of the other bread types (Figure 4). This lower energy consumption together with a greater nutritional energy content and a higher price make the Estonian bread particularly sustainable in terms of CED in the case of all 3 FUs used for the assessment (Figure 8). However, the presence of animal based ingredients ranks this bread higher in terms of GHG emissions independently of the FU used.

The Polish, Latvian and Lithuanian all have similar ingredient humidity levels, nutritional energy contents and impacts deriving from transport and agricultural lifecycle activities (Figure 4). However Lithuania has an electricity mix based on nuclear energy which implies a higher use of primary energy and a low production of GHG for the electrical energy production. This ranks the Lithuanian bread as the worst in terms of CED and best in terms of global warming potential independently of the FU used for the assessment.

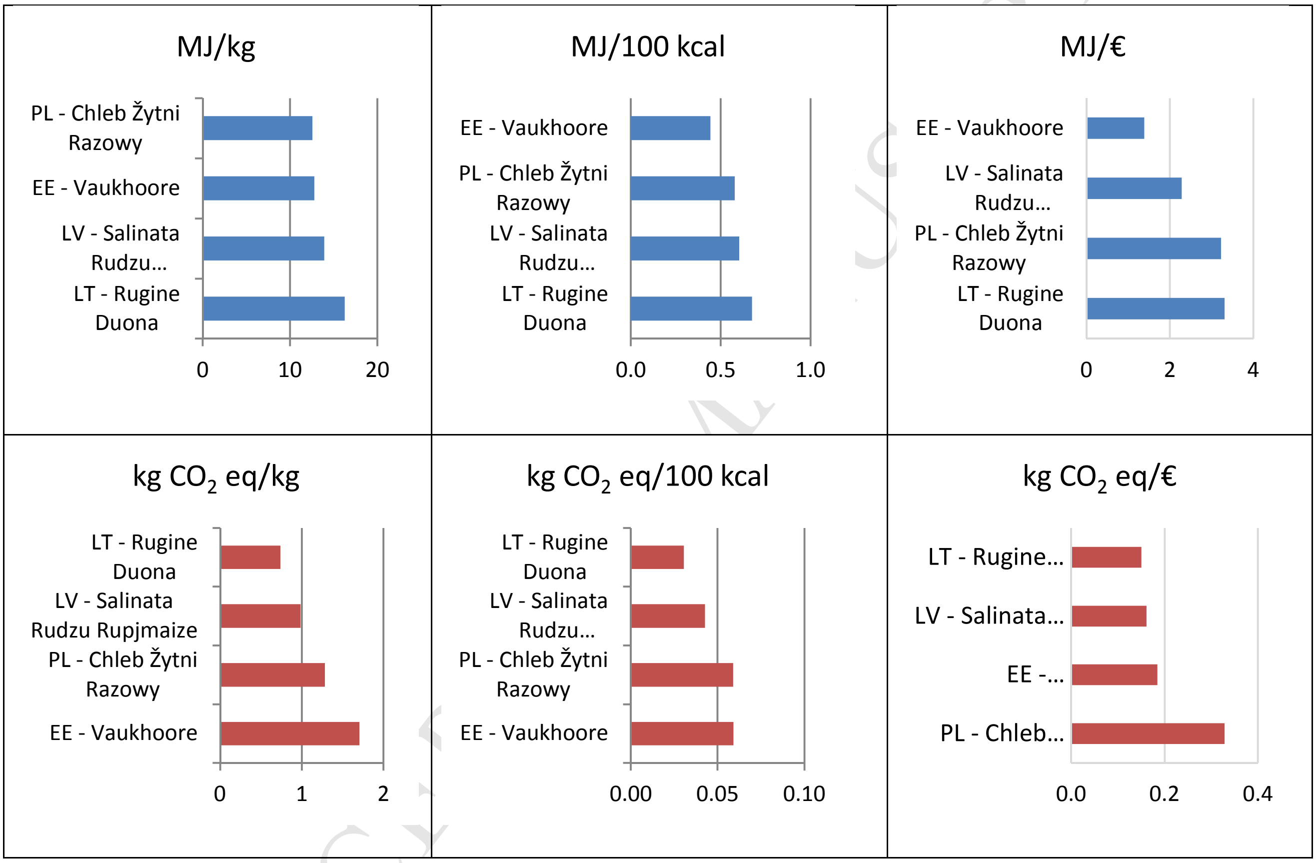


Figure 8 – Embedded energy (top) and equivalent GHG emissions (bottom) of the rye based bread types (calculated using mass, nutritional energy and price based functional units).

Conclusions

The results have highlighted the variability of the embedded energy and the equivalent GHG emissions associated to the consumption of 21 kinds of bread rooted in the cultural environment of 21 EU countries.

In general, the agricultural phase associated with the lifecycle of the bread, as often highlighted in literature, is the most burdening phase due primarily to the use of pesticides and fertilisers. Also the actual baking of the bread resulted as a particularly impacting lifecycle phase whose energy consumption can be affected by the humidity level of the dough and the size and shape of the bread. Furthermore, the overall impact associated with the EU bread type can also depend greatly on the national electricity mix, the national imports of the cereal used to make the bread flour and the efficiency of ingredient production (in terms of material and energy use and in terms of the respective yields of each EU nation), such as that of milk (and other derived ingredients) and flour.

In this study the use of a nutritional energy based FU and a price based FU provided results that differed from those obtained with a mass based FU. Specifically, when using a mass based functional unit, the more sustainable results regard bread types of the Mediterranean area with simple recipes, based essentially on flour, yeast and water. By assessing the breads with an energy based functional unit the more sustainable environmental profile shifts towards the bread types which also contain vegetable oils and small amounts of animal based ingredients. The use of a price based FU indicates that the higher priced bread types, manufactured with more expensive ingredients that are produced in an environmentally efficient manner are more sustainable.

The results obtained with mass and energy based FUs prove interesting especially if dealing with staple foods, such as bread, whose function is essentially that of providing a large fraction of the energy and nutrients required daily. In view of this it seems that, in environmental and nutritional terms, the more sustainable breads are those whose main ingredients are flour, yeast, vegetable oils and liquids such as milk and those that have a shape that reduces the baking time, for example small rolls or flat shaped breads. This study, however, does not consider the protein content of the breads which is also important from a nutritional point of view and therefore could be a future extension of the present work. Furthermore, the results obtained with a price based FU can be interesting especially if dealing with more a sophisticated bread that is not solely consumed for nutritional purposes on a daily basis but rather is consumed on festive occasions to satisfy social, cultural, hedonistic and other qualitative needs. In such cases the more sustainable bread types are the most expensive ones, containing more environmentally impacting animal based ingredients produced in the most environmentally efficient manner.

References

Andersson K. & Ohlsson T. (1999). Life Cycle Assessment of Bread Produced on Different Scales. Int. J. LCA 4 (1) pp. 25 – 40.

Ardente, F., & Cellura, M. (2012). Economic allocation in life cycle assessment. Journal of Industrial Ecology, 16(3), pp.387-398.

Audsley E. and Wilkinson M. (2012). Using a model-based LCA to explore options for reducing national greenhouse gas emissions from crop and livestock production systems. In proc. of 8th Int. Conference on LCA in the Agri-Food Sector, France.

Boulangerie (2011). Le portal des artisans. Dossier Boulangerie Net: "Le prix de la baguette: La vérité" 2011. Retrieved from: http://www.boulangerie.net/forums/bnweb/prixbaguette.php on March 10th 2016.

Blonk Consultants (2014). Agri-footprint Description of data. V 1.0. Retrieved from: www.agri-footprint.com/assets/Agri-Footprint-Part2-Descriptionofdata-Version1.0.pdf

Brankatschk, G., & Finkbeiner, M. (2014). Application of the Cereal Unit in a new allocation procedure for agricultural life cycle assessments. Journal of Cleaner Production, 73, pp.72-79.

Braschkat, J., Patyk, A., Quirin, M. & Reinhardt, G. (2003). Life cycle assessment of bread production - a comparison of eight different scenarios. In proc. of 4th International Conference Life Cycle Assessment in the Agri-food sector, Denmark.

Cerutti A., Bruun S., Donno D., Beccaro G.L. & Bounous G. (2013).Environmental sustainability of traditional foods: the case of ancient apple cultivars in Northern Italy assessed by multifunctional LCA. Journal of Cleaner Production 52 pp.245-252.

Ciraolo L., Giaccio M., Morgante A., Riganti V., 1998. Handbook of commodity science. Monduzzi Editore. Bologna. Italy.

COFALEC (2015). Confederation of EU yeast producers. Carbon Footprint of Yeast produced in the European Union (downloaded from http://www.cofalec.com/app/download/11531047823/20120327155707_Yeast_Carbon_Footprint_COFALEC_(english+version).pdf?t=1426066498. On the 22nd March 2015).

de Beaufort-Langeveld A. S. H., Bretz R., van Hoof G., Hischier R., Jean P., Tanner T. and Huijbregts M. A. J. (2003). Code of Life-Cycle Inventory Practice. SETAC. Retrieved from: www.setac.org.

Djekic I., Miocinovic J., Tomasevic I., Smigic N., Tomic N. (2014). Environmental life-cycle assessment of various dairy products. Journal of Cleaner Production Vol.68 (2014), pp.64-72.

Dunn J.B., Mueller S., Wang M., Han J. (2012). Energy consumption and greenhouse gas emissions from enzyme and yeast manufacture for corn and cellulosic ethanol production. Biotechnol Lett., 34 (12):2259–2263.

EPD (2012). PCR 2012:08; CPC 2131 – PCR for frozen vegetables, pulses and potatoes. Ver. 1.0, 2012-08-28. The International EPD System.

Espinoza-Orias N., Stichnothe H. & Azapagic A. (2011). The carbon footprint of bread. The International Journal of Life Cycle Assessment, Volume 16, Issue 4, pp. 351-365.

Eurostat (2015). Purchasing power parties 2014 data. Retrieved from http://ec.europa.eu/eurostat/web/purchasing-power-parities/data/main-tables on October 26th 2015.

Eurostat (2016a). Detailed averaged prices 2012-2014. Retrieved from http://ec.europa.eu/eurostat/web/hicp/methodology/detailed-average-prices on March 10th 2016.

Eurostat (2016b). Energy price statistics. Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics#Natural_gas_prices_for_industrial_consumers on March 10th 2016.

EXPO (2015). European Union participating member states. http://europa.eu/expo2015/participating-eu-member-states

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G. and Spielmann M. (2007). Overview and Methodology. Ecoinvent report No. 1, v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org.

Fantin V., Buttol P., Pergreffi R., & Masoni P. (2012). Life cycle assessment of Italian high quality milk production. A comparison with an EPD study. Journal of Cleaner Production Vol.28, pp.150-159.

FAOSTAT, 2014. Food and Agriculture Organization of the United Nations. Statistics Division. Available at: http://faostat3.fao.org/home/E.

FertiStat, 2004. Fertilizer use by crop statistics. Availble at: http://www.fao.org/ag/agp/fertistat/fst_fubc_en.as

Grönroos J., Seppala J., Voutilainen P., P. Seuri, Koikkalainen K. (2006). Energy use in conventional and organic milk and rye bread production in Finland. Agriculture, Ecosystems and Environment 117 (2006), pp. 109–118.

Heller, M. C., Keoleian, G. A., & Willett, W. C. (2013). Toward a life cycle-based, diet-level frame-work for food environmental impact and nutritional quality assessment: A critical review. Environmental Science and Technology, 47(22), 12632–12647.

Hischier R., Weidema B., Althaus H.-J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S., Jungbluth N., Köllner T., Loerincik Y., Margni M. and Nemecek T. (2010) Implementation of Life Cycle Impact Assessment Methods. Ecoinvent report No. 3, v2.2. Swiss Centre for Life Cycle Inventories, Dübendorf.

IFA (2012). Database of the International Fertilizer Industry Association available at http://ifadata.fertilizer.org/ucSearch.aspx.

IFSC (2015). International Food Safety Consultancy – A guide to jam production unit (downloaded from http://www.international-food-safety.com/pdf/A%20Guide%20To%20A%20Jam%20Production%20Unit.pdf on the 23rd March 2015).

IPCC (2006a). N2O emissions from managed soils and CO2 emissions from lime and urea application (IPCC Chapter 11), Vol.4, pp.1–54.

IPCC (2006b). Emissions from livestock and manure management. IPCC Guidelines for National Greenhouse Gas Inventories. Chapter 10, Vol. 4.

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Jensen J.K., Arlbjørn J.S. (2014). Product carbon footprint of rye bread. Journal of Cleaner Production 82 (2014), pp. 45-57.

JRC (2014). Methodology for building LCA-compliant national inventories of emissions and resource extraction. Report EUR 26871. European Commission, Joint Research Centre, Institute for Environment and Sustainability. European Union, 2014.

Kägi, T., Zschokke, M., & Dinkel, F. (2012). Nutrient based functional unit for meals. Paper presented at the 8th international conference on LCA in the agri-food sector, St-Malò, France.

Kendall A., Yuan J, Brodt S.B. (2013). Carbon footprint and air emissions inventories for US honey production: case studies. Int J Life Cycle Assess (2013) 18, pp.392–400

Kulak M., Nemecek T., Frossard E., Chable V., Gaillard G. (2015). Life cycle assessment of bread from several alternative food networks in Europe. Journal of Cleaner Production 90 (2015) 104-113.

Lalonde S., Nicholson A., Schenck R. (2013). Life Cycle Assessment of Beer in Support of an Environmental Product Declaration. Report retrieved from http://iere.org/wp-content/uploads/2013/10/IERE_Beer_LCA_Final.pdf

Narayanaswamy V., Van Berkel R., Altham J., and McGregor M. (2005). Application of life cycle assessment to enhance eco-efficiency of grains supply chains. In proc. of 4th Australian LCA Conference, Australia.

Notarnicola B., Sala S., Castellani V., Tassielli G., Renzulli P.A., Goralczyk M., (2015a). Environmental Impact of the European Food Basket using LCA. Proceedings of the International conference on Life Cycle Assessment as reference methodology for assessing supply chains and supporting global sustainability challenges: LCA for “feeding the planet and energy for life”. Stresa, 06-07th October 2015 - Milano, Expo 2015, 08th October 2015. ENEA, Roma, 2015. ISBN 978-88-8286-321-0

Notarnicola B. Salomone R., Petti L., Renzulli P.A., R. Roma, A.K. Cerutti (2015b). Life Cycle Assessment in the agri-food Sector - Case Studies, Methodological Issues and Best Practices. Switzerland: Springer International Publishing.

Notarnicola B., Tassielli G., Renzulli P.A. (2014) A structural analysis of EU food consumption: Selection of representative products for the basket and analysis of the environmental impacts by LCA. Technical report. European Commission, Joint Research Centre, Institute for Environment and Sustainability.

Notarnicola B., Tassielli G., Renzulli P.A. (2013). Data variability in the LCA of olive oil production. Proceedings of the VII Conference of the Italian LCA Network. Milan, 27-28th June 2013, pp.29-35.

Notarnicola B., Tassielli G., Renzulli P.A. (2012), Modeling the Agri-Food Industry with Life Cycle Assessment. In: Curran M.A. Life Cycle Assessment Handbook. pp.159-184, New York: Wiley.

N.R.C., 2001. Nutrient Requirements of Dairy Cattle. 7th revised edition. National Academy Press, Washington, D.C., USA.

Pre Consultants (2015). SimaPro Life Cycle Analysis version 7.2 (software). Amersfort, The Netherlands.

Renzulli P.A., Bacenetti J., Benedetto G., Fusi A., Ioppolo G., Niero M., Proto M., Salomone R., Sica D. and Supino A. (2015). “Life Cycle Assessment in the Cereal and Derived Products Sector”. In: Notarnicola B. Salomone R., Petti L., Renzulli P.A., R. Roma, A.K. Cerutti, eds., Life Cycle Assessment in the agri-food Sector. Springer International Publishing Switzerland.

Ribaudo F. (2011). Handbook of agriculture. Hoepli, Milan, Italy.

Smedman A., Lindmark-Månsson H., Drewnowski A. and Modin Edman A.K. (2010). Nutrient density of beverages in relation to climate impact . Food Nutr Res Vol. 54.

Thompson, J.F. (2000). Tunnel Dehydration (PDF). Pages 224-227 in: Raisin Production Manual. University of California, Agricultural and Natural Resources Publication 3393, Oakland, CA.

van der Werf H.M.G. and Salou T. (2015). Economic value as a functional unit for environmental labelling of food and other consumer products. Journal of Cleaner Production 94 (2015) pp.394-397.

Williams A., Audsley E. and Sandars D. (2010). Assessing ideas for reducing environmental Burdens of Producing Bread Wheat, Oilseed Rape and Potatoes in England and Wales using simulation and system modelling. International Journal of Life Cycle Assessment, Volume 15, Number 8, 2010, pp. 855-868.

Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk