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Energy use in the EU food sector: State of play and opportunities for improvement

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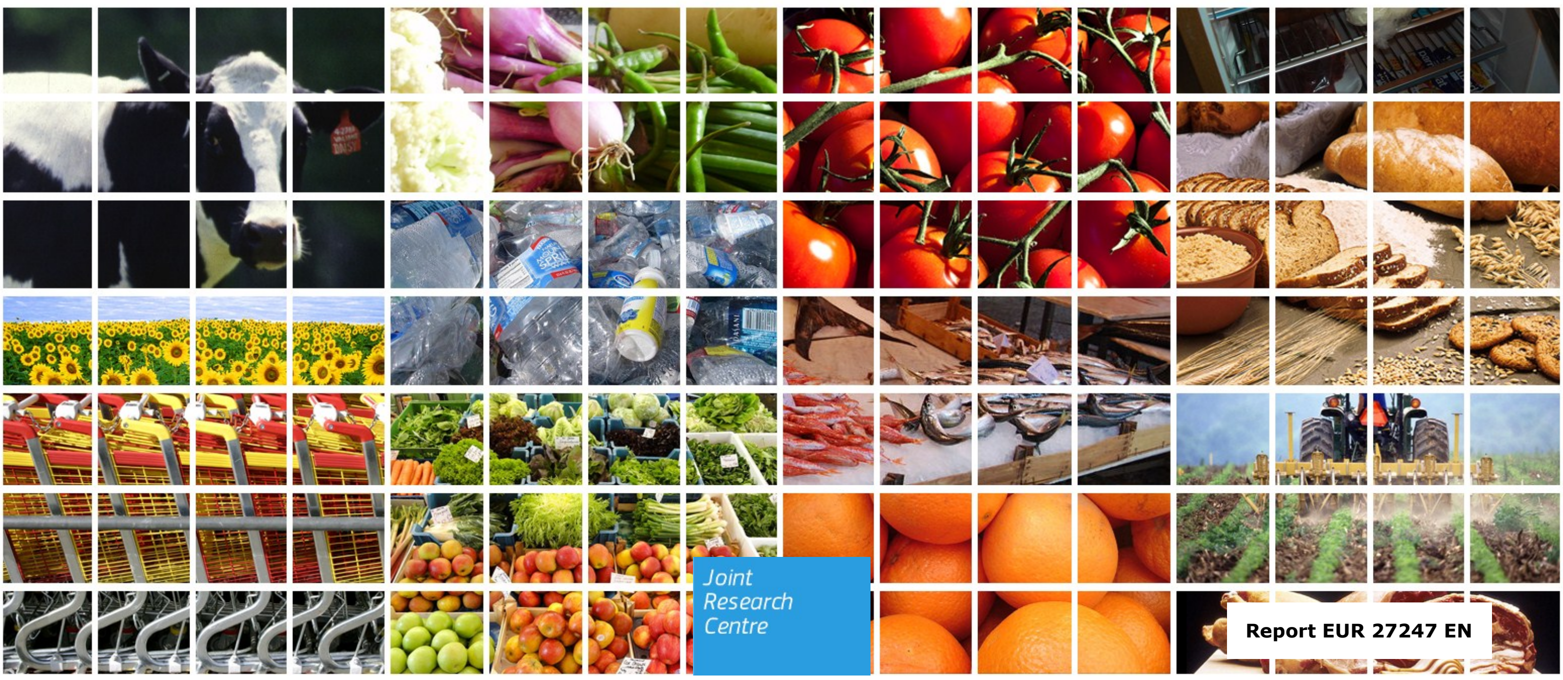

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Abstract

The amount of energy necessary to cultivate, process, pack and bring the food to European citizens' tables accounts for 17 % of the EU's gross energy consumption, equivalent to about 26 % of the EU's final energy consumption in 2013. Challenges and solutions for decreasing energy consumption and increasing the use of renewable energy in the European food sector are presented and discussed.

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Disclaimer

Executive summary

The food sector is a major consumer of energy: the amount of energy necessary to cultivate, process, pack and bring the food to European citizens' tables accounts for 17 % of the EU's gross energy consumption in 2013, equivalent to about 26 % of the EU's final energy consumption in the same year.

Agriculture, including crop cultivation and animal rearing, is the most energy intense phase of the food system—accounting for nearly one third of the total energy consumed in the food production chain.

The second most important phase of the food life cycle is industrial processing, which accounts for 28% of total energy use. Together with logistics and packaging, these three phases of the food life cycle "beyond the farm gate" are responsible for nearly half of the total energy use in the food system.

While the "end of life" phase including final disposal of food waste represents only slightly more than 5% of total energy use in the EU food system, food waste actually occurs at every step of the food chain. In 2014 the EU generated 100 million tonnes of food waste, primarily at the household level and manufacturing. Given the large amounts of energy involved in food production, reducing food waste is an important vector for improving the overall energy efficiency of the food system. Food waste also has the potential to play a role in renewable energy production as a feedstock for bioenergy production.

Different food products need very different amounts of energy per unit of mass depending on their nature, their origin and the kind of processing they have been subjected to. Refined products and products of animal origin generally need an amount of energy several times larger than vegetables, fruits and cereal products.

While the EU has made important progress in incorporating renewable energy across the economy, the share of renewables in the food system remains relatively small. Renewables accounted for just 7% of the energy used in food production and consumption in 2013 compared to 15% in the overall energy mix.

Renewables more limited penetration is largely a reflection of the high reliance of the food sector of fossil fuels. Overall, fossil fuels account for almost 79% of the energy consumed by the food sector compared to 72% of overall energy consumption. The relatively low share of renewables in the food sector is also linked to the fact that about one fifth of food consumed in the EU is imported from regions outside the EU where the renewable share is generally lower than 15%.

Building on these results, the report discusses the way ahead and highlights the main challenges to be faced in decreasing the energy use and in increasing the renewable energy share in the food sector. Sectoral literature reviews present solutions offered by science and technology and industrial case studies and EU-funded research projects show their practical application.

Although energy efficiency in agriculture production is steadily improving with direct energy consumption per hectare declining by about 1% every year in the last two decades, addressing the challenge of decoupling agriculture productivity from energy consumption and GHG emissions will require an array of responses across the food system.

Energy, especially in the form of indirect energy used for fertilisers and pesticides or irrigation, remains a crucial input for cultivation success but huge improvements are possible. More efficient fertiliser production technology and avoiding unnecessary fertiliser applications through properly designed cultivation practices are expected to complement each other and play a major role in decreasing indirect energy inputs to agriculture. In this sense, considerable experience and data exist for organic farming, no-tillage and integrated farming especially designed to minimise energy and material inputs.

European farmers are already leading the way in this transition, for example, through efforts to increase the use of renewable energy in agricultural production. Thanks to investments in farm-based renewable technologies like biogas, farmers have the potential to not only become energy self-sufficient, but also to make a major contribution to EU energy production while reducing GHG emissions.
The increasing popularity of on-farm biogas has provided 13.4 Mtoe (mega-tonne oil equivalent) of primary energy and 52.3 TWh of biogas-based electricity in the EU in 2013. Based on the National Renewable Energy Action Plan projections, by 2020 biogas could account for 1.5% of the EU's primary energy supply and 5% of overall natural gas consumption.

The EU food industry is also making important contributions to make their activities more sustainable, through both increased investment in renewable energy and energy efficiency improvements. The food industry's energy consumption from 2005-13 has declined, both in absolute terms as well as in terms of energy intensity, producing more while using less energy. Several food processing industries are also exploring the possibility of recovering the energy contained in food residues on site, through biogas production or in dedicated combined heat and power plants.

Energy efficiency in food transport is pursued through two possible pathways: improving the energy performance of the transportation systems and decreasing or optimising the amount of transportation itself. Trade-offs are also to be considered: while it is generally true that food travelling long distances embeds more energy than locally originated food, several studies reveal that the issue needs to be carefully assessed on a case-by-case approach, for example in case of vegetables. Scientific literature reports cases where efficient transportation from warm countries resulted in less energy use in comparison with vegetables locally grown in greenhouses.

Consumers also have an important role to play as everyday decisions about food consumption can effect of the amount of energy required by food by as much as a factor of four. Potential actions consumers can take to reduce their energy "food print" include: reducing meat consumption, buying locally and seasonally, as well as reducing food waste and substituting organic food when possible.

Policy design reflects the complexity of the challenge: in the EU, a large portfolio of policies and political initiatives have already been deployed and other are going to be adopted, resulting in an important combined effect for the overall energy profile of food production.

EU policies such as the Renewable Energy Directive and the Energy Efficiency Directive have helped set the stage for a transition to a more sustainable food system, but do not directly target the food production process. The EU's Common Agriculture Policy also plays an important role, in particular through incentivising investments in more sustainable farming methods, as well as the rural development programme which aims to "facilitate the supply and use of renewable sources of energy."

Introduction — Food and energy: the general view

The world demand for food will increase substantially in the next decades, due to demographic growth: world population should increase from 7.1 billion in 2013 to 9.6 billion by 2050 (United Nations Department of Economic and Social Affairs Population Division, 2013; Nellemann et al., 2009). The biggest share of population increase will take place in developing countries where life standards and incomes are also expected to improve. Better life conditions will lead to a larger per capita consumption of animal-protein (meat, milk and dairy products), vegetable oils and processed food - see Figure I.1. (McIntyre, Herren, Wakhungu & Watson, 2009a, 2009b).

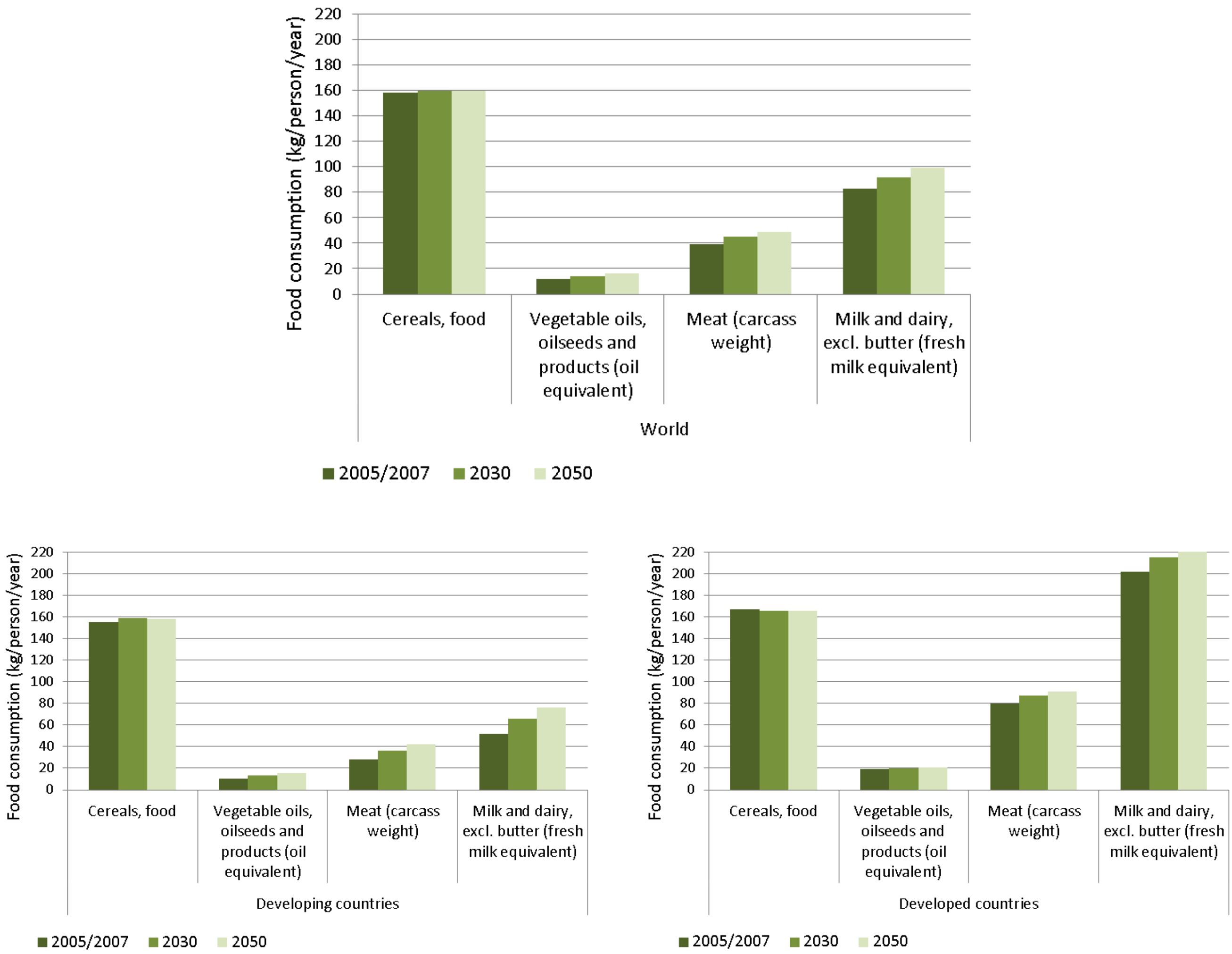


Figure I.1 Consumption projections for some groups of food products up to 2050 in the world (top panel), developing countries (left bottom panel) and developed countries (right bottom panel)(Alexandratos and Bruinsma, 2012). NB: 'Cereals food' consumption includes the grain equivalent of beer consumption and of corn sweeteners.

In Europe, the demographic growth will be smaller if compared with world's trend. The EU-28 is expected to increase from a population of about 507 million in 2013 to 526 million in 2050 (EuroStat, 2014: EuroPop 2013 — base scenario). Nevertheless, even in Europe per capita consumption of meat, oil and diary product will increase (see again Figure I.1, bottom panel), although the amount of these products currently consumed is already substantial. This global trend towards a larger world's population consuming larger amount of complex food will impact energy consumption. According to the Food and Agriculture Organization of the United Nations (FAO) (2011a), the agri-food sector currently accounts, directly or indirectly, for around 30 % of the world's total end-use energy consumption ([1]). The greenhouse gas (GHG) emissions from agri-food sector amount to about 10 Gt of carbon dioxide equivalent (CO_2e) per year, i.e. roughly one-fifth of the overall world GHG emissions in 2010 (Olivier, Janssens-Maenhout, Muntean & Peters, 2013) .

A precise accounting of energy consumed (and mis-consumed) in food production is extremely challenging. Food is a very composite entity and the amount of energy for bringing it 'from farm to fork' varies greatly from one product to another. Even when considering the same type of product, the energy 'cost' differs notably, reflecting changes on cultivation area, farming practices, efficiency of processing and storage, season of production and/or consumption, transportation needs, etc.

The food supply chain consists of several successive steps, each needing energy for its specific processes. Figure I.2 shows FAO estimates on energy shares consumed in the various food chain supply steps, in terms of world average and for high and low gross domestic product (GDP) countries ([2]).

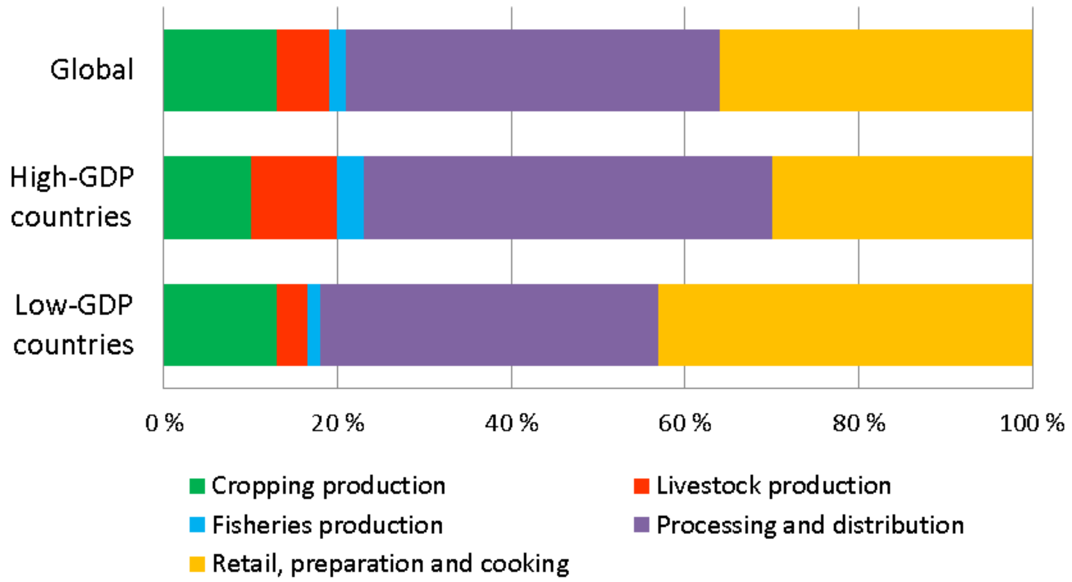


Figure I.2 Final energy consumption in the food sector and its shares for various production steps. Global (top) high-GDP (middle) and low-GDP (bottom) countries Source: (FAO, 2013a, p. 144).

Agriculture plays a similar role regardless of GDP: 20 % (low GDP) and 25 % (high GDP). The share of energy used for retail, preparation and cooking is considerably higher in low-GDP countries (about 45 %) than in high-GDP countries (30 %). Experts attribute this fact to the more inefficient (and unhealthy) cooking habits in developing countries (FAO, 2013a). A useful indicator for the energy 'cost' of food products is the sum of all energy inputs along the production chain: the so-called embedded (or embodied)

([1]) Such an estimate refers to a world average, and it is expected to be smaller for developed countries, where a larger amount of energy is consumed in industrial and service activities that are not related to agriculture and food production.

([2]) The caveat associated in such an estimate (FAO, 2011b) is worth remembering: 'It should be noted that [Figure I.2 is] indicative only and should be interpreted with care. FAO analyses were based on the range of data available, but this data was at times unreliable, incomplete and out of date since related energy [...] data as presented in the literature.'

energy. Each processing step, including end-of-life management of the product and its residues, increases the amount of energy embedded in the product

The energy embedded in food products does not account only for *direct energy* uses, such as moving a tractor, heating an oven or powering a mixer. On the contrary, it includes also *indirect energy* flows, such as the energy needed to produce and transport fertilisers or to operate irrigation systems.

Generally, the direct energy flow measures the energy inputs used at a given stage of a product or service while the indirect energy flow includes the accumulated energy inputs used to produce the inputs for a given stage of a product or service (Pelletier et al., 2011).

Chapter 1 of this report provides an evaluation of food-related energy flows in the European Union updated to 2013, including an estimate of the contribution of the different sectors and energy sources to the overall energy embedded in the most representative European food products.

The main challenges in decreasing energy use in the food sector and increasing the renewable energy share are reported and discussed in Chapter 2 (behind the farm gate) and in Chapter 3 (beyond the farm gate), together with potential solutions and strategies suggested by the scientific community.

Technology focused measures for increasing the energy efficiency of the food sector range from technological improvements (e.g. more efficient engines, optimal transport schemes) to improved farming practices (e.g. better fertiliser applications, low-tillage agriculture) and include, *indirect measures* acting on indirect energy inputs such as improvements in the water supply to irrigated crops and transformation industry.

As in other industries, the suitability of energy-efficiency measures in food production is a challenge for policy formulation: measures are subject to trade-offs and economies of scale and they should be carefully assessed before being implemented. Energy-saving measures must not affect productivity and must be appropriate to the scale of the country/region/district/industry, etc. and the scientific community is very active in exploring new methodologies and systemic approaches.

Improvements can also be achieved involving other actors. For example, *consumers* can contribute to reducing the environmental/energy impact of the sector by changing their dietary and food purchasing behaviours (i.e. buying local food, respecting seasonality, etc.), or by properly using domestic appliances or by minimising domestic food waste.

Renewable energy (RE) can substitute fossil fuels, partially or completely, in several food production steps, improving sustainability and contributing to decoupling the food costs from the oil price (see Appendix 0). Thanks to Renewable Energy Directive targets (see Chapter 4) the amount of RE in the food production in Europe will grow. On top of that, farmers and companies can directly buy RE from a specific 'green' energy supplier or even self-produce their energy, e.g. through biogas production plants or combined heat and power (CHP) units fed with agriculture residues.

Food losses and waste are a major cause for energy loss in food supply: one-third of the food is lost or wasted at the global level (FAO, 2011a), while in the EU the amount of food waste was 89 million tonnes in 2006, reached 100 million tonnes in 2014 (EC, 2015) and is expected to increase to 126 million tonnes in 2020 (BIO Intelligence Service, 2010). Experts point at mismatch between supply and demand, poor purchase planning or unconsumed cooked food as main causes of food waste.

Along with any intervention, special attention should be paid to rebound *effects* ([3]). There is a risk that investments in a single part of the plant/farm lead to lack of

([3]) According to Sorrell and Dimitropoulos (2008), the potential 'energy savings' from improved energy attention resulting in additional and unnecessary energy consumption in other sections of the same plant/farm (Ruzzenenti and Basosi, 2008; Sorrell and Dimitropoulos, 2008; Sorrell, 2007).

The International community is aware of the issue. Decreasing the amount of energy embedded in food products and/or making it more sustainable by increasing the use of renewable energy is the core of the 'energy-smart' food strategy as defined by the FAO (2011a) and more recently enshrined in the UN initiative Sustainable Energy for All (Accenture & UN-Global Compact, 2012).

In the EU, a large portfolio of policies aiming at decreasing energy consumption and increasing renewable share in the food production chain has been deployed by both European institutions and Member States and are presented in Chapter 4.

Industry operating in the European food sector has proven to be actively committed to translating measures into practical improvements and the report describes several case studies, including both EU-funded scientific projects and examples from the industry sector collected through the European Food Sustainable Consumption and Production Round Table.

efficiency are commonly estimated using basic physical principles and engineering models. However, the energy savings that are realised in practice generally fall short of these engineering estimates. One explanation is that improvements in energy efficiency encourage greater use of the services (for example heat or mobility) which energy helps to provide. Behavioural responses such as these have come to be known as the energy-efficiency 'rebound effect' or Jevons' paradox.

1. Energy flows in the food production sector in the European Union

1.1 Assessing energy flows in the food sector — literature and methodologies

The food sector is a very composite industrial sector, based on very diverse feedstock and with several specific production steps leading to the final product. Full understanding of the energy content of food products and the opportunities for energy efficiency and renewable energies is challenging, and few energy-focused comprehensive studies of the whole food sector exist. On the contrary, studies targeting a specific production step, a specific feedstock and/or a specific set of measures are relatively more common.

Among the studies covering the whole sector, the reports produced by the FAO, in the framework of the Energy-smart Food for People and Climate (ESF) Programme must be mentioned (See Figure I.2). The FAO's ESF Programme focuses on raising awareness on the dependency of global agri-food systems on fossil fuels, the implications this dependency has for food security and climate, and the potential for agri-food systems to alleviate this problem by becoming a source of renewable energy ([4]).

The US Department of Agriculture (USDA) and the Massachusetts Institute of Technology (MIT) have jointly produced a very detailed study on energy flows for the United States of America (USA)'s food sector by means of an input-output analysis. The main findings are included in Box 1. Pimentel et al. (2008), Woods et al. (2010) and Pelletier et al. (2011) have reviewed sectorial literature gathering the challenges and measures faced by these type of analysis.

In order to illustrate how sparse the scientific literature in this field is, Appendix A presents a detailed bibliometric analysis of the international literature on food and energy.

Methodological issues

Burney (2001) noticed that any energy improvement analysis should start with the assessment of direct and indirect energy flows throughout the supply chain: measures applied to larger energy flows produce more overall benefits in comparison to measures addressing niche consumption areas.

The quantitative assessment of energy flows in food systems has been traditionally carried out following two approaches (Burney, 2001): the life cycle analysis (LCA) and the input-output (IO) accounting. These two methodologies differ in both the general approach (LCA follows a bottom-up pathway while IO works in a top-down way) and the data inputs, and therefore it is not surprising that results sometimes vary, even to a large extent.

LCA seeks to assess the environmental impacts and the use of resources across the entire product life cycle, in order to identify possible room for improvements. All the steps involved in creating a certain product are analysed, starting from raw material extraction and conversion, then manufacture and distribution, to the final use and/or consumption. LCA also includes re-use, recycling of materials, energy recovery and ultimate disposal.

On the other hand, the input–output analysis is a tool that can be used to provide estimates of inputs (including energy) per unit of final product based on how various sectors of an economy are linked and exchange resources (including energy).

([4]) Full details on the FAO's ESF programme can be found on http://www.fao.org/energy/81350/en/

As a general rule, IO focuses on industrial sectors of a given economic area and can provide very precise results down to a certain level of aggregation, taking into account direct and indirect contributions. Nevertheless, IO needs to be complemented with exogenous data as far as process steps taking place outside the studied economic area are concerned.

As a major example of IO methodology application in the food sector, Canning et al. (2010) have assessed the energy flows of a large number of composite food categories in the USA, (see Box 1 for additional details), while Cao et al. (2010) have evaluated the energy flows in the Chinese agriculture sector.

On the contrary, LCA, as a product-focused methodology, takes into consideration all energy inputs along the full production (and disposal) chain, wherever these occur. LCA, however, needs detailed data on product 'history' and is very sensitive to the definition of the boundaries of the production system and to the methodology used for allocating the embodied energy among co-products or by-products.

LCA has become a very widely used tool in food energy assessment. Following the need for improving the consistency of different references, Peano et al. (2014) recently reported the ongoing effort for creating a new World Food LCA Database, ideally providing detailed data for food produced in a large number of countries and regions across the world. While methodological guidelines for food life cycle analysis have already been published (Nemecek et al., 2014), the full database is expected to be released in late 2015.

LCA remains challenging when applied to large economic sectors as apparently 'similar' products can be enormously diverse in reality (See Appendix D for a case study on European bread). In order to make sectorial LCA analysis achievable, a compromise has to be found between the representativeness of the set of products analysed and practical feasibility.

For this reason, in the framework of its coordination of the European Platform on Life Cycle Assessment (EPLCA), the Joint Research Centre (JRC) of the European Commission developed a specific EU 'basket of products' for nutrition (EC — DG JRC, 2012a, 2012b). Thanks to its LCA standardised approach, the basket allowed monitoring the food consumption patterns and its environmental impacts, including GHG emissions. For this report the analysis has been updated to 2013 and has been extended to include the embedded energy. Results are presented and discussed in next sections.

Box 1 — Energy flows in the US food system

Energy use in the US Food System is the topic covered by the ERR-94 Report of the US Department of Agriculture (Canning et al., Economic Research Service / USDA, 2010), prepared in cooperation with MIT. Energy is used throughout the entire food supply chain, from the manufacture and application of agricultural inputs such as fertilisers, for irrigation, through crop and livestock production, processing and packaging. At a later stage, energy is also used for distribution services, such as shipping and cold storage/refrigeration, preparation, disposal equipment in food retailing and food service establishments, and in the home kitchens of citizens. Dependence on energy throughout the entire food chain raises concerns about the impact of high or variable energy prices on the final price of food for the consumer, as well as about domestic food security and the country's possible reliance on imports of energy. In addition to concerns about energy/food prices and energy security, the use of energy in the food chain can also have environmental impacts, one example being carbon dioxide emissions.

A number of studies have addressed the food-related energy use in the USA. These studies generally indicate that:

- food-related energy use has remained a substantial share of the total national energy budget;
- food-related energy use of households has been the largest among the seven supply chain stages

considered (agriculture, processing, packaging, transportation, wholesale and retail, food services, households);
- food-related energy flows may have increased significantly over the last few years.

These results, however, do not explain why energy use has changed over time and do not provide a valid quantification of these changes, since the various studies rely on different data sources and different model assumptions. The added value provided by this USDA Report 94 is that it compares the estimates of energy use in 1997 and 2002 by using data exclusively from two Federal agencies and is based on the same energy flow model for each year of analysis. This harmonised approach facilitates valid comparisons of energy flows over time. This report thus provides policy-makers and analysts with information to assess which stages of the food supply chain and what industries are the largest energy users, and which stages and industries have experienced the fastest rates of energy-use growth. The report allows the identification of the factors that have influenced the increase in energy use in the food sector and also the factors that are likely to influence changes in the future.

Regarding the findings of this study, it appeared that between 1997 and 2002 the energy use per capita in the United States of America decreased by 1.8 %, while the per capita food-related energy use in the USA increased by 16.4 %. The population of the USA grew by more than 14 million over the period, increasing the total energy use by 3.3 % and increasing the total food-related energy use by 22.4 %. As a share of the national energy budget, food-related energy use grew from 12.2 % in 1997 to 14.4 % in 2002. Several economic factors can influence the use of energy throughout the US food system, such as labour and energy costs, the ability to substitute between these inputs when their costs change, the time availability of households for food-related activities and household affluence. The findings suggest that about half of the growth in food-related energy use between 1997 and 2002 is explained by a shift from human labour towards a greater reliance on energy services across almost all food categories. High labour costs in the food services and food processing industries, combined with increased consumption of prepared foods and more eating out, appear to be driving this result. The increases in food expenditure per capita and in population growth also contributed to the increase in food-related energy use over this period, with each trend accounting for roughly a quarter of the total increase.

However, the study showed the largest growth in energy use over this period, as both households and food service establishments increasingly outsourced manual food preparation and clean-up activities to the manufacturing sector. Over this period, the food processing and food service industries faced increasing labour costs, while energy prices in this period were lower and far less volatile than they have been since 2002. In agriculture, the increase in energy use in relative terms was attributed to the producers of vegetables and poultry products. The freight service industry accounted for a small share of the increase in overall food-related energy use, but a substantial share of the increase attributed to some food commodities, especially fresh fruit and poultry products.

A projection of food-related energy use suggests that food-related energy use as a share of the national energy budget grew from 14.4 % in 2002 to an estimated 15.7 % in 2007.

This study was conducted on the basis of input-output material flow analysis and measured the flows of all energy sources used in the USA to reach the final markets via three inter-connected steps:

- measurement of all known quantities of energy directly used in each domestic production activity, including household operations, organised into roughly 400 industry classifications;
- tracing the flow of energy embodied in each of the energy-using industry products throughout the production economy and into a complete accounting of final market sales;
- identification of all food-related final markets and assessment of the food-related energy embodied in all final market sales.

This analysis used data from two Federal sources: the Bureau of Economic Analysis Benchmark Input-Output Tables and the Energy Information Administration's State Energy Data System.

1.2 The JRC food basket in the 'basket of product' LCA analysis

European food consumption is complex (see also Appendix 0). and the definition of a 'reference' EU food basket is a challenging task. Indeed, the basket cannot be too detailed so the analysis can be performed within a reasonable amount of time and resources, and should contain products for which robust data accepted and validated through peer reviewing is available.

As already mentioned in section 1.1, the JRC has recently developed a battery of 'basket of products' indicators, aimed at analysing and monitoring the consumption patterns in the EU and their related environmental impacts. A specific basket of products for nutrition was then developed (EC — DG JRC, 2012a, 2012b) and a preliminary assessment of the EU food consumption impacts prepared, which already included GHG emissions but not embodied energy.

The JRC basket-of-product study has been recently revised and updated, providing a picture of the nutrition basket updated to 2013. The details are presented and discussed in next paragraphs.

1.2.1 The JRC food basket: data sources and selection methodology

The proper identification of a 'food basket' for EU food consumption that is representative of the actual consumption patterns and at the same time manageable is quite a complex issue. Depending on the extent and quality of the available data, a drastic simplification of the food consumption patterns (see Appendix 0) is generally necessary.

A detailed description of the basket definition methodology is available in JRC (2012b). In short, the authors analysed data regarding food consumption, mainly from the Eurostat ProdCom (Eurostat-ProdCom, 2015) and FAOSTAT ([5]) databases, and complemented it with specific nutrition and food consumption data from a literature survey on emerging consumption trends including data from reports on food consumption and relative environmental aspects within the EU (DEFRA, 2012; EEA, 2012; Eurostat, 2011; FAO, 2011b; Foster, Green, Bleda and Dewik, 2006; Tukker, Huppes, Guinée, Heijungs, de Koning, van Oers, Suh, Geerken, Van Holderbeke and Jansen, 2006).As a result of such an analysis, the food consumption data detailed in Table 1.1 was prepared for 2013 in the EU-27.

Representative products for each food category were then finally chosen on the basis of the following criteria:

- Amounts of a food product. Products consumed in the largest quantities were considered as potential basket products;
- Prior knowledge of the magnitude of environmental impacts of a type of food product. Certain food types, such as meat and dairy products (Foster et al., 2006), have the greatest impact, especially in terms of greenhouse gas emissions (GHG) (Tukker, Huppes, Guinée, Heijungs, de Koning, van Oers, Suh, Geerken, Van Holderbeke and Jansen, 2006), compared not only to other food products but also to all consumer goods (Gerber et al., 2013). Moreover, meat and dairy products embody a significantly higher amount of energy if compared with other food categories (Pimentel and Pimentel, 2003).
- Types of product whose consumption trend has been increasing during the last ten years, such as frozen and/or pre-cooked meals.

(5) Whenever incomplete or incongruent Eurostat data was encountered it was verified, integrated or substituted with the same data from the FAOSTAT databases regarding food and drinks.

Table 1.1 2013 consumption in the EU-27 of food categories as defined in the Eurostat ProdCom database. Source: Authors' elaboration on Eurostat, FAO and other data sets (see text)

Categories of food products	2013 consumption in EU-27 [1 000 t]
Cereal products	44996
Dairy products	67068
Oils and fats	20668
Fruit and vegetables,	36834
Meat and fish	58899
Alcoholic drinks	50659
Non-alcoholic drinks	126902
Pre-prepared meals	5013
Sugar and confectionaries	25548
Other	17353
Total	**453940**

1.2.2 JRC food basket composition

Table 1.2 shows the 17 products identified as the most representative for the nutrition basket. Table 1.3 details these products and their consumption in 2013 and defines the 'JRC food basket' It is worth noticing that, obviously, this food basket does not cover all food consumption but represents the very noticeable mass share of 61 % of the consumed food in 2013 in the EU-27 (see Table 1.1).

Table 1.2 Products selected in order to compose the JRC food basket of products and their represented product groups. Source: Authors' own analysis.

Product groups	Selected basket product
Meat and seafood	Beef, pork, poultry
Dairy products	Milk, cheese, butter
Crop-based products	Olive oil, sunflower oil, sugar
Cereal-based products	Bread
Vegetables	Potatoes
Fruit	Oranges and apples
Beverages	Coffee, mineral water, beer
Pre-prepared meals	Meat-based meals

Table 1.3 Details of the consumption and economic value of products making up the "JRC food basket" for 2013. Source: Authors' own analysis based on Eurostat, FAO and other data sources.

Basket product	Total consumption of basket product [1 000t/year]	Per-capita apparent consumption [kg/inhabitant year]	% of total per-capita apparent basket consumption	Economic value of the consumption of each basket product [million EUR/year]
Pig meat	22 449	44.7	8.1%	40 797
Beef	6 914	13.8	2.5%	30 818
Poultry	13 248	26.4	4.8%	28 444
Bread	19 136	38.1	6.9%	29 114
Milk and cream	39 326	78.2	14.2%	24 953
Cheese	9 347	18.6	3.4%	36 564
Butter	1 927	3.8	0.7%	7 193
Sugar	15 913	31.7	5.7%	11 383
Refined sunflower oil	2 661	5.3	1.0%	2 781
Olive oil	1 955	3.9	0.7%	4 490
Potatoes	36 475	72.6	13.1%	10 166
Oranges	7 012	14.0	2.5%	4 097
Apples	9 104	18.1	3.3%	5 340
Mineral water*	55 405 *	110.2 *	19.9%	11 358
Roasted coffee	1 793	3.6	0.6%	10 690
Beer*	33 553 *	66.8 *	12.1%	26 270
Prepared dishes and meals-meat based	1 502	3.0	0.5%	13 958
TOTAL	277 722	552.6	100.0%	298 415

* in litres

1.3 Energy flows and GHG emissions related to the JRC food basket

1.3.1 Methodology

As previously mentioned, a detailed analysis of the overall environmental impacts of the JRC food basket has been developed through the LCA of each product, following a harmonised methodological framework. A detailed description of the methodology applied is available in Notarnicola *et al* (2015); the main key points of the analysis follow.

System boundaries consider a cradle-to-grave approach: for each stage of the life cycle, the authors developed the process-based life cycle inventories for the selected representative products. For each product, system boundaries include the agricultural and production stage, the packaging production and disposal, the logistics - including international trade, domestic distribution and retail.
In particular, to assess the impact of retail, the following assumptions were made: product is purchased in a large store; the energy consumption of the store is allocated to the various products according to their weight (Nielsen et al., 2003); for products that require a refrigerated storage the electric energy consumption is evaluated on the basis of the volume occupied (considering the specific weight of the products) and the time spent in the store (EPD, 2012); the losses occurred in the shop undergo a waste treatment which, therefore, is charged at retail.
Food losses throughout the life cycle have also been accounted for.

The production chain has been divided into six parts, each considering one or more stages (see Table 1.4).

Table 1.4 Production parts and stages of food production chains. Source: Authors' own analysis.

Production parts	Production stages
Agriculture/breeding	• Cultivation of crops
	• Animal rearing
	• Food waste management (relevant part)
Industrial processing	• Processing of ingredients
	• Slaughtering, processing and storage of meat
	• Chilled or frozen storage
	• Food waste management (relevant part)
Logistics	• International transport of imports
	• Transport to manufacturer
	• Transport to regional distribution centre
	• Distribution
	• Transport to retailer
	• Retail
	• Food waste management (relevant part)
Packaging	• Manufacture of packaging
	• Final disposal of packaging
Use	• Transport of the products from retailer to consumer's home
	• Refrigerated storage at home
	• Cooking of the meal
End of life	• Final disposal of food waste
	• Wastewater treatment

Special care was given to assessing the quality of data used in the study on the basis of the following parameters, developing a 'pedigree' data matrix:

- time-related coverage: age of data;
- geographical coverage: geographical area from which data for unit processes has been collected;
- technology coverage: specific technology or technology mix;
- completeness: type of provided flow;
- consistency: coherence of data with the methodology and assumptions of the study.

The impact categories chosen are Cumulative Energy Demand v 1.08 and Global Warming. The cumulative energy demand is based on the method published by ecoinvent version 2.0 (Frischknecht, Jungbluth, Althaus, Doka, Dones, Hellweg, Hischier, Humbert, Margni, Nemecek and Spielmann, 2007) and adopted to be used in the SimaPro LCA software and databases (PRé Consultants, 2014). For Global warming, the characterisation factors are taken from the model developed by the Intergovernmental Panel on Climate Change (IPCC).

1.3.2 Estimates of energy embedded in the JRC basket products

Figure 1.1 shows the amount of energy embedded in the JRC food basket in units of MJ per EU citizen, broken down for the 17 products represented and their production steps. Figure 1.2 shows the same data per kilogram of product.

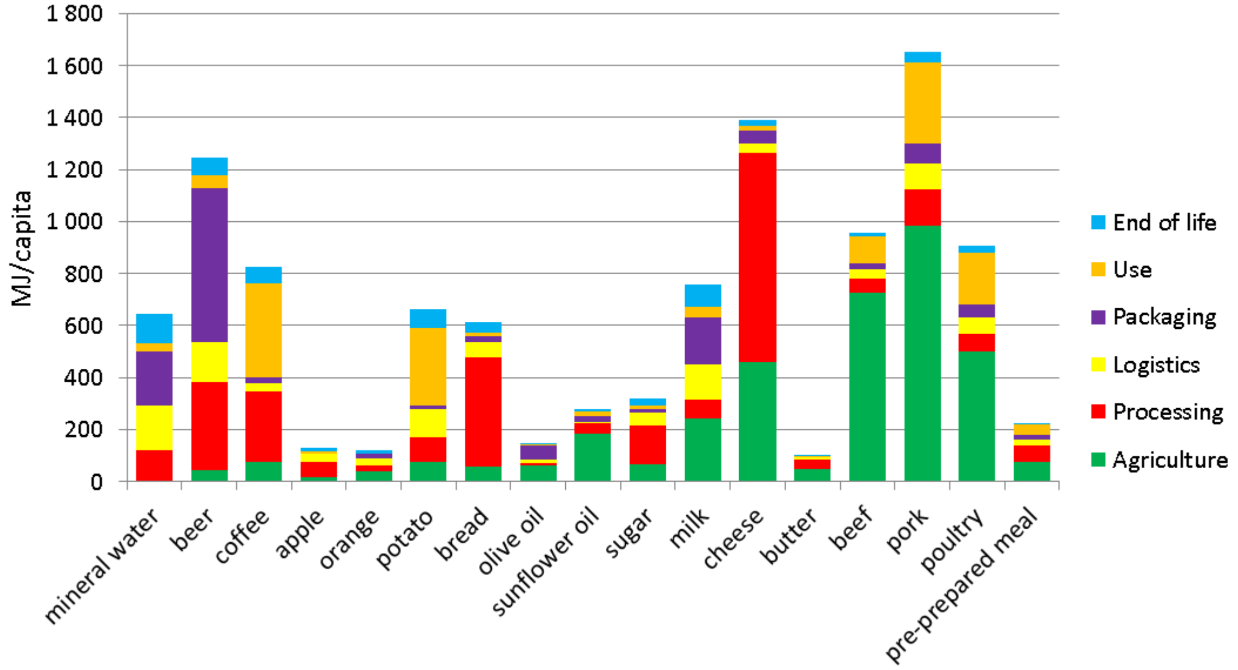


Figure 1.1 Energy embedded in the JRC food consumption basket for the average citizen, broken down for products and production steps. Units: MJ/capita. Source: Authors' own analysis.

Figure 1.2 confirms that livestock and dairy products (except milk) incorporate a substantial amount of energy (see also section 3.7), while vegetables and bread are less energy-intensive per kilogram of product. It is worth noticing that data reported for coffee refers to grains or powder of product and not to the infusion, which is prepared differently across the EU.

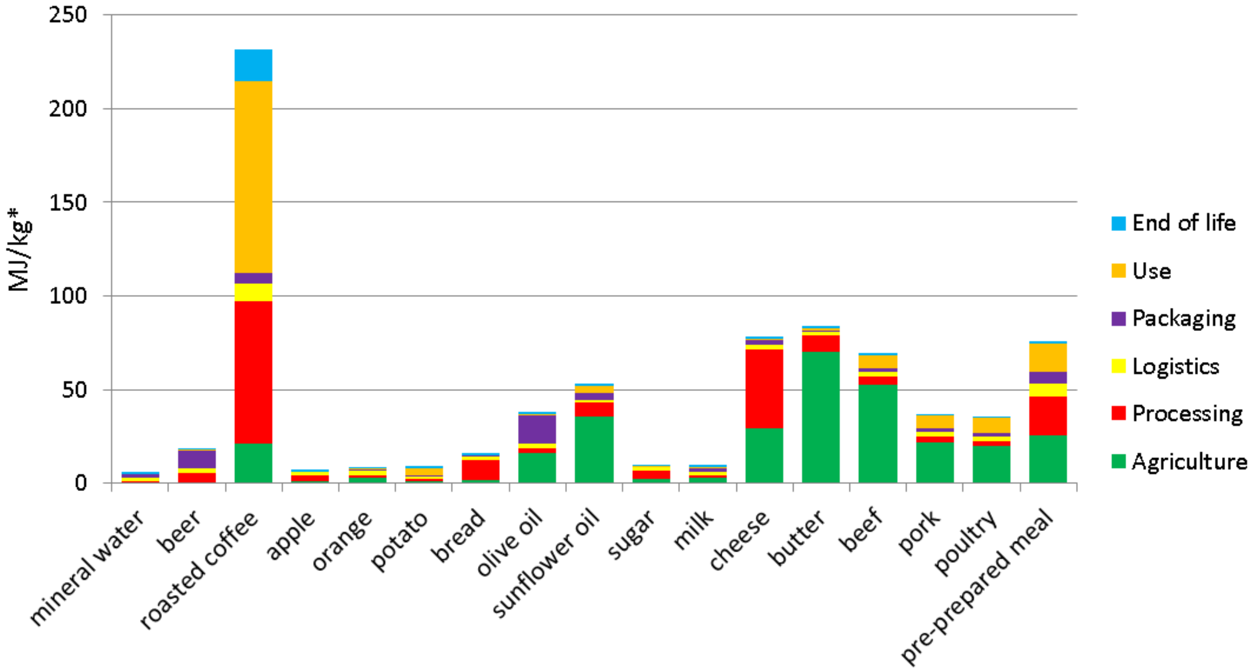


Figure 1.2 Energy embedded in the production steps and products making up the JRC food basket. * Units in MJ/kg or MJ/l (for beer, milk and mineral water). Source: Authors' own analysis.

Figure 1.3 shows the shares of energy embedded in a kilogram of each of the 17 products along the different production steps. The relative weight of production steps is very different in different products: For instance, the relevance of the agriculture step (including livestock raising) for the meat and dairy-related products is overwhelming, while packaging plays an important role in the 'bottled' products such as milk, oil, beer and mineral water.

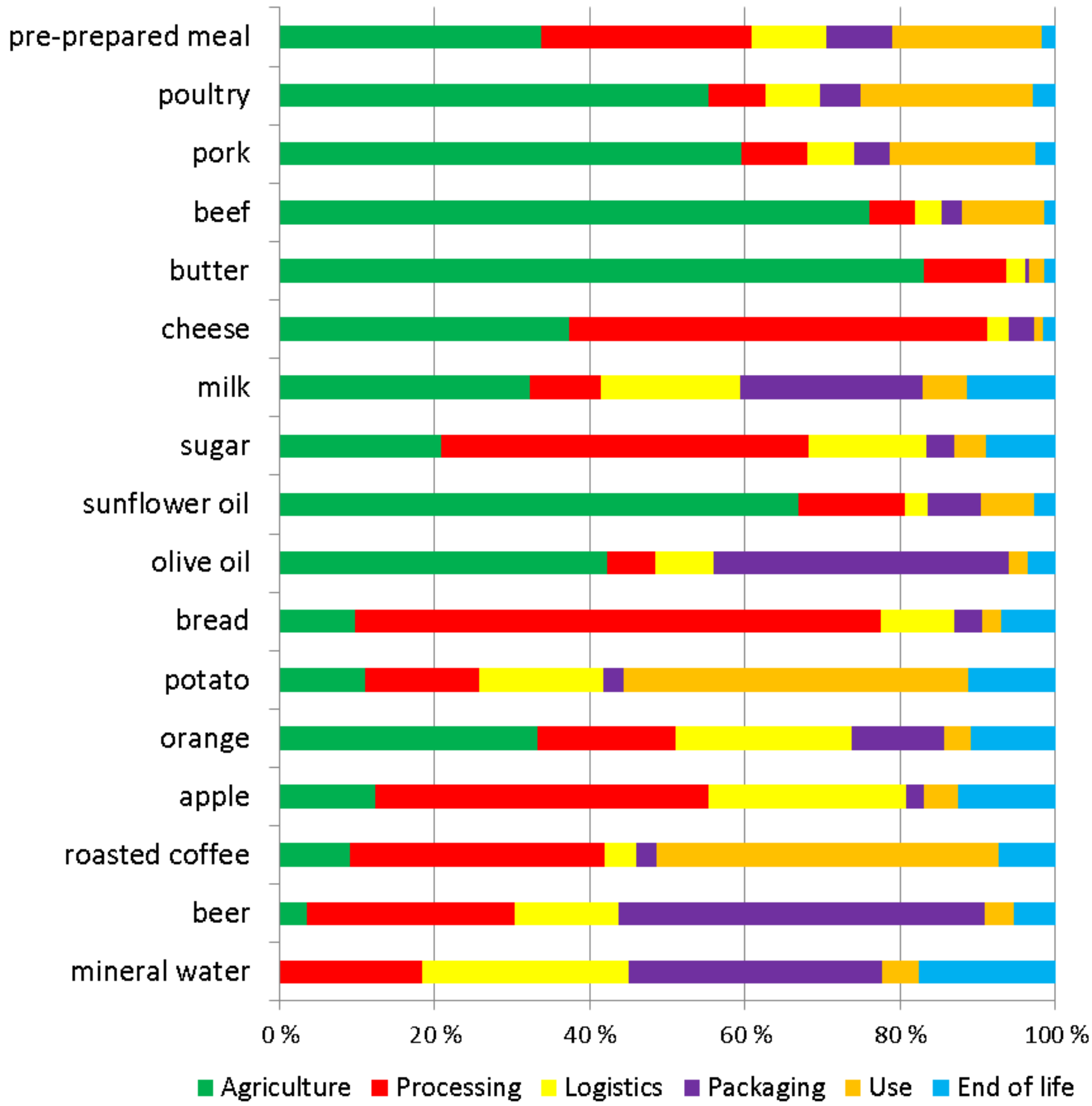


Figure 1.3 Shares of energy embedded along the production steps of a kilogram of product for the 17 products represented in the JRC food basket. Source: Authors' own analysis.

About the source of energy embedded in the JRC food basket, Figure 1.4 shows that in all the steps of the food supply chain, most of energy used is derived from fossil fuels, followed by nuclear energy. Hydro energy plays an important role in industrial processing while the energy from biomass is significant in the end-of-life stage. Figure 1.5 shows the energy sources for each of the products in the JRC food basket.

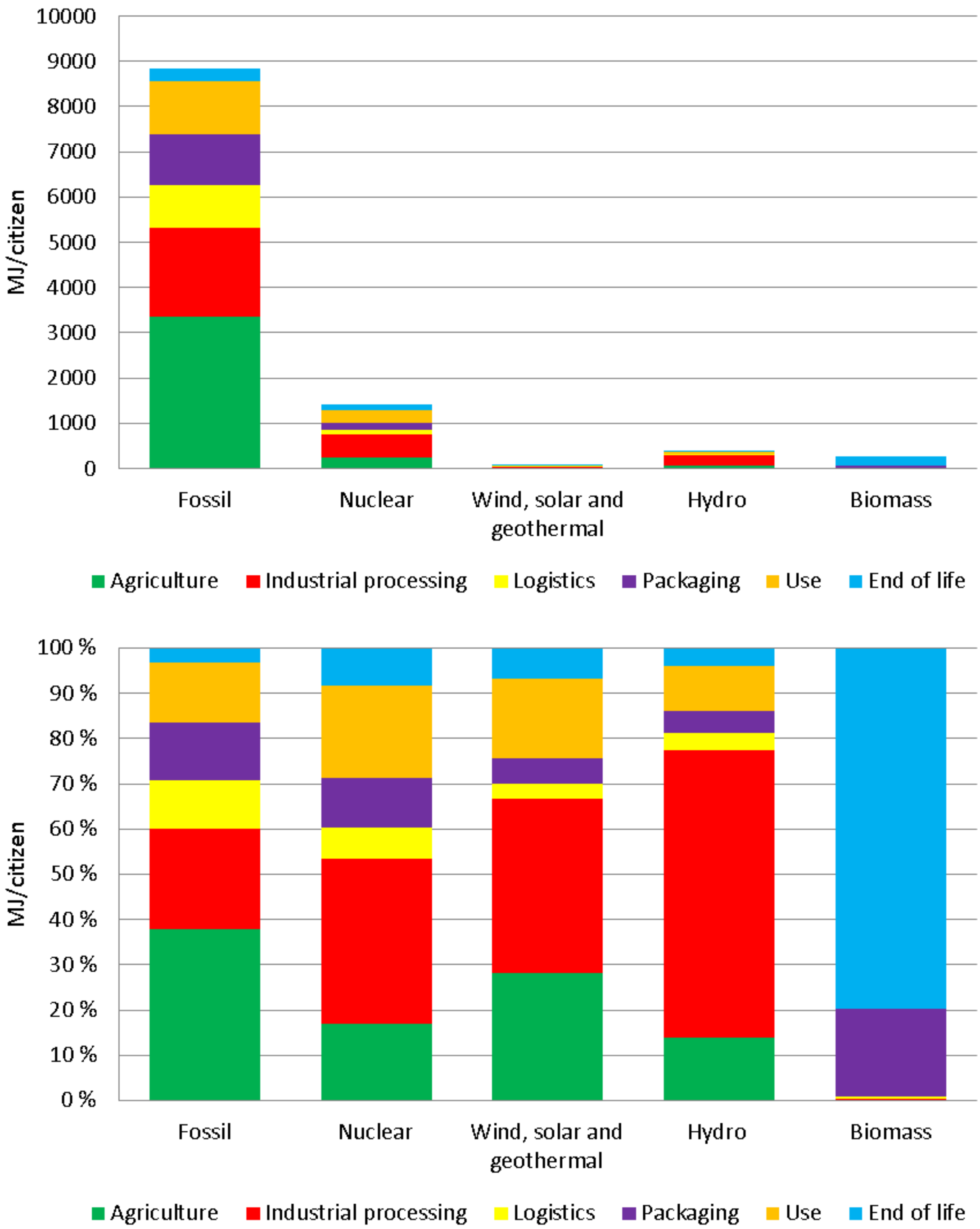


Figure 1.4 Sources of energy embedded in the JRC food basket in units of mega joules (MJ), in absolute (top panel) and relative (bottom panel) terms. Units: MJ/capita. Source: Authors' own analysis.

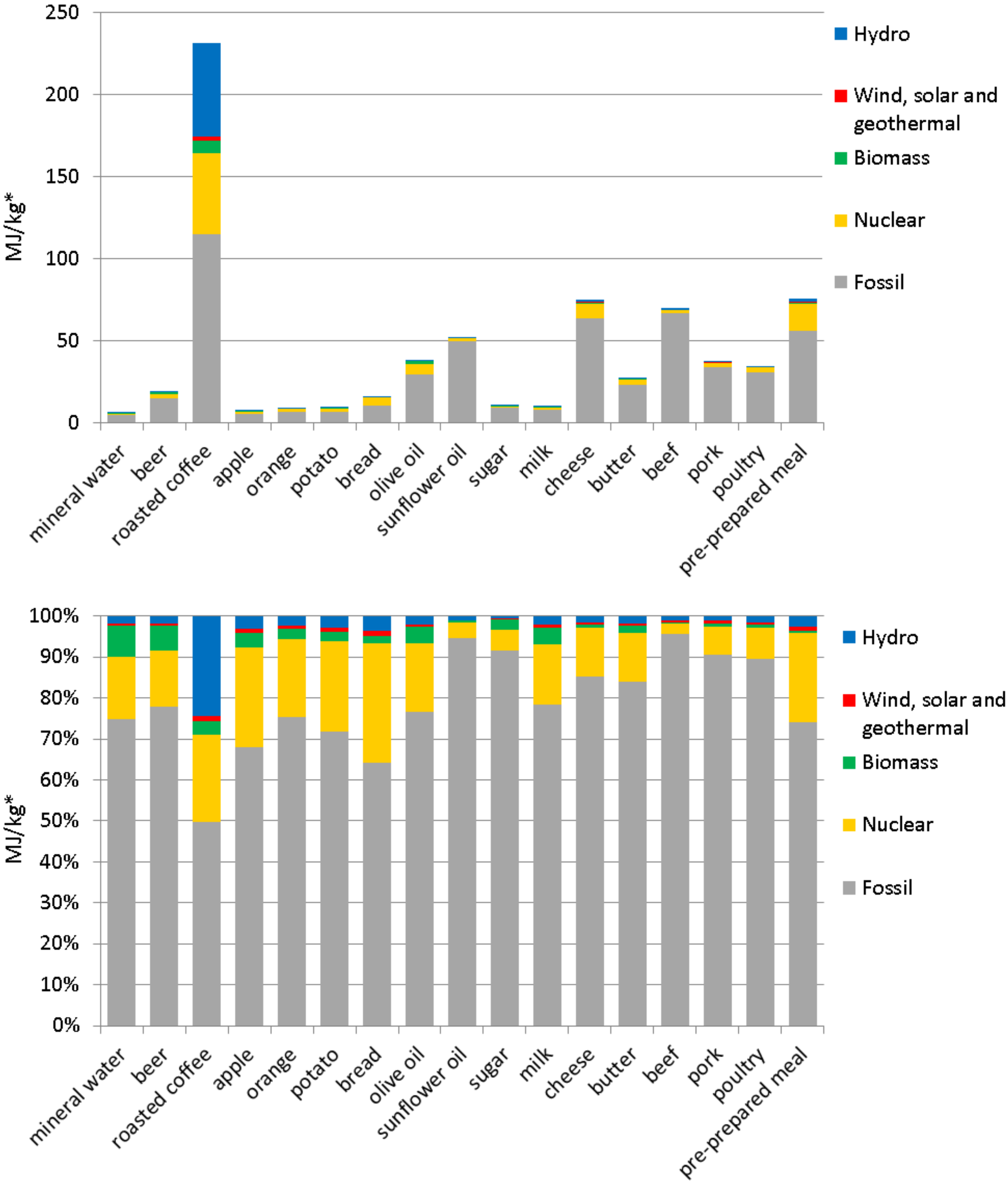


Figure 1.5 Sources of energy embedded in each of the products making up the JRC food basket in absolute (top panel) and relative (bottom panel) terms. *Units in MJ/kg or MJ/l (for beer, milk and mineral water). Source: Authors' own analysis.

1.3.3 GHG emissions from the JRC food basket

Figure 1.6 shows the GHG emissions related to the whole life cycle of the products composing the JRC food basket in units of kg of CO_{2e} per EU citizen, again broken down for the 17 products represented and their production steps. Figure 1.7 shows the same data per kilogram of product.

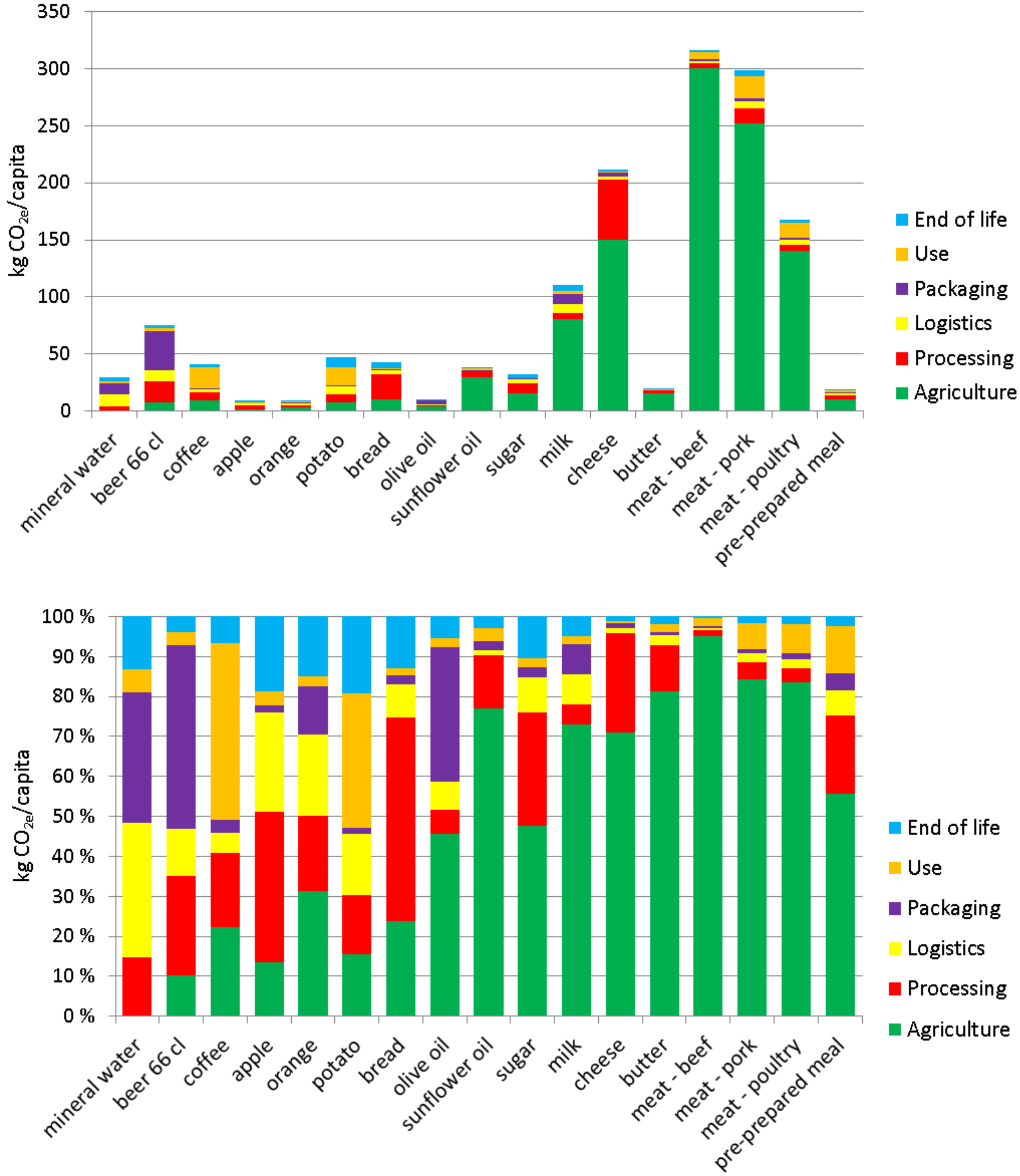


Figure 1.6 Annual greenhouse gas emissions related to the average EU citizen's consumption of the JRC food basket, detailed per product and per production step in absolute (top panel) and relative (bottom panel) terms. Units in kg of CO_{2e}/capita. Source: Authors' own analysis.

Consumption of dairy and meat products confirm its major role in GHG emissions even when emissions are estimated per kg of product (Figure 1.7), with the exception of milk.

Emissions from the agriculture/zoo-technical stage are also particularly significant for the dairy and meat products: agriculture emissions account for 73, 81 % and 71 % for milk, butter and cheese, respectively. In the case of beef, pork and poultry agriculture linked GHG emissions reach the shares of 95 %, 84 % and 84 % respectively. Not surprisingly, the same two groups of products also account for the largest absolute amounts of non-CO_2 GHG emissions (see Figure 1.7), again indicating the major role of agricultural production phase in their life cycle.

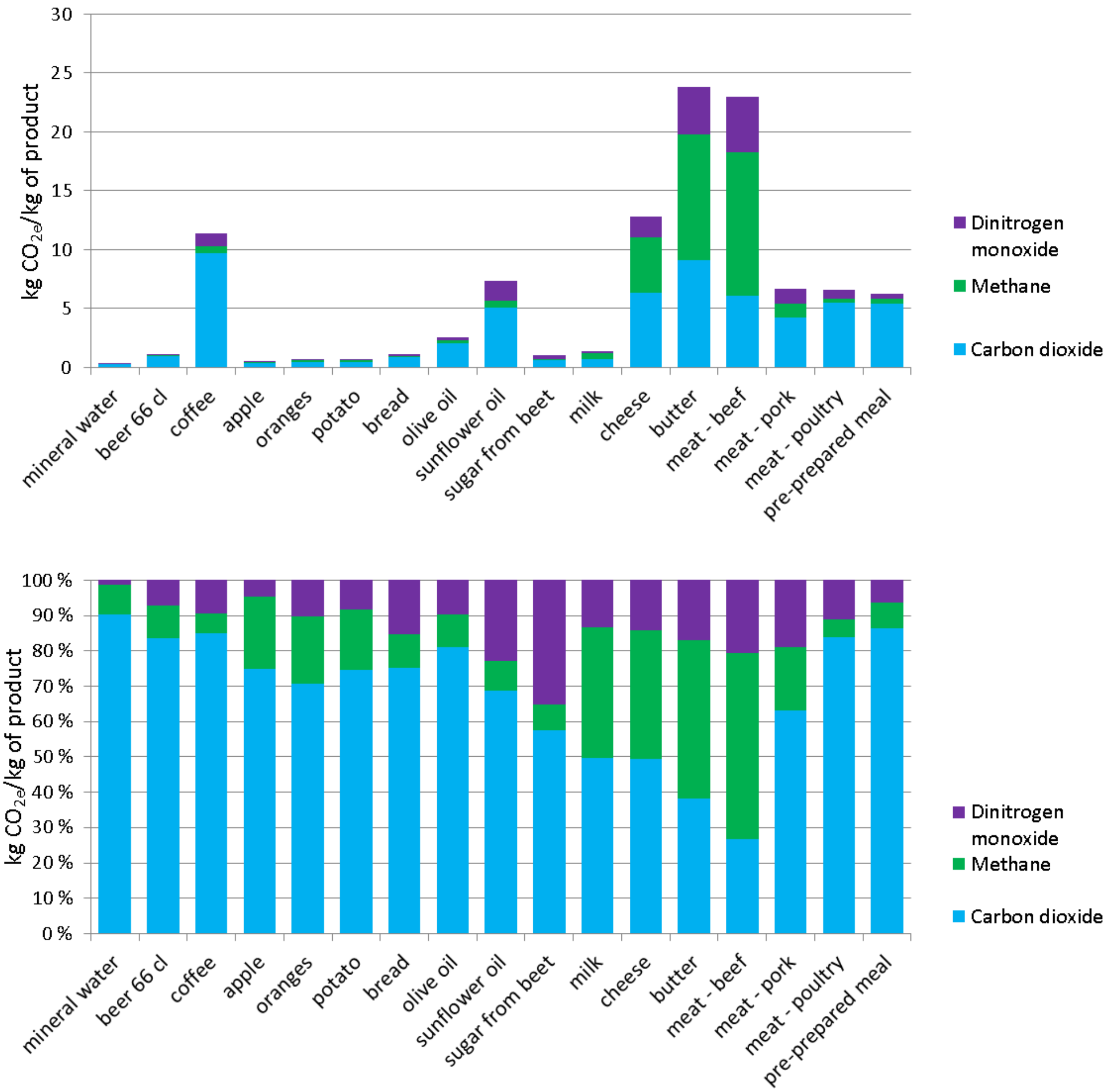


Figure 1.7 Greenhouse gas emissions per quantity of product and for type of GHG for the 17 products included in the JRC food basket in absolute (top panel) and relative (bottom panel) terms. Data in kilograms of CO_{2e}/kg of product. Source: Authors' own analysis.

1.4 Energy flows and GHG emissions along the EU-27 food supply chain

1.4.1 Energy flows along the EU-27 food supply chain

Data presented in section 1.3.2 describes the energy embodied in the JRC food basket in 2013 and its origin. However, the JRC food basket does not cover the whole food consumption in the EU-27 and so the results need to be extrapolated to estimate the energy flows across the whole EU-27 food supply chain.

Products selected for the basket were expected to represent well the product groups to which they belong. Under this assumption, the energy embodied per mass unit in the 17 sample products was supposed to be equal to the energy embodied per mass unit in all the products belonging to the same group (Table 1.2) including production steps and energy source. In the case of two or more products belonging to the same group (e.g. meat), the weighted average of the energy profiles of the sample products was considered, using consumption data from Table 1.3 as weighting coefficients ([6]). In this way, the energy embodied in the whole amount of food consumed in the EU-27 in 2013, as reported in Table 1.1, has been estimated.

However, food actually consumed does not equal the total food produced to satisfy European consumption, as wasted food in the EU has been estimated to be about 100 million tonnes per year (EC, 2015). The energy embedded in the wasted food was estimated as the weighted average of food products contained in the whole JRC food basket.

Figure 1.8 shows the results of energy flow analysis in terms of the average energy embedded in the food consumed by each EU citizen, including the amount of energy lost in food wastage, detailed per production step.

In total, an energy amount of about 23.6 GJ is embedded in the food consumed in 2013 by each European citizen, equivalent to the gross energy provided by 655 litres of Diesel fuel. Considering a population of 502.5 million people, the overall amount of energy embedded in the food consumed in EU-27 in 2013 is estimated to 11 836 PJ (283 Mtoe), equivalent to 17 % of the EU-27's gross energy consumption and 25.7 % of its final energy consumption in 2013.

Such an estimate is equal to the figure of 17% of energy consumption in the UK related to food production reported by DEFRA (2013) and it is also consistent with FAO evaluations (see Figure I.2) when applied to strongly industrialised areas.

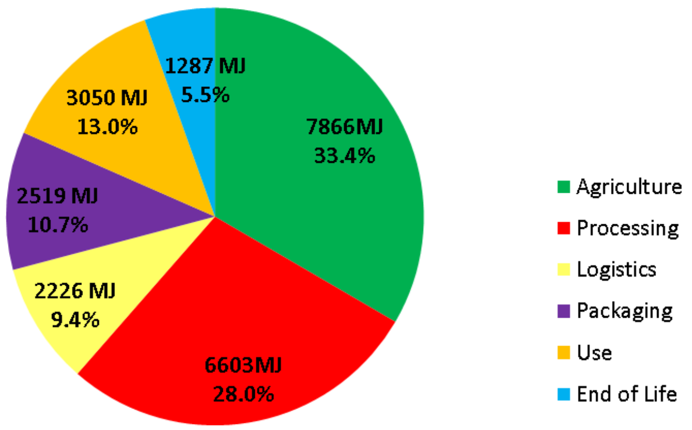


Figure 1.8 Energy embedded in the food consumed by the average EU-27 citizen, broken down by food production step. Source: Authors' own analysis([7]).

([6]) In the case of the 'other' category, the average energy content of the whole JRC food basket was assumed.

([7]) More detailed calculations indicate that retail accounts for about 12% of the average logistics energy consumption, and the rest is caused by transport Nevertheless, this estimate is subject to a large variability when applied to single products.

In Figure 1.8 it can be noted that one-third of energy embedded in food consumed in the EU-27 is related to the agricultural phase (including livestock breeding and the management of agricultural waste) followed by more than a quarter related to industrial processing. It is also important to mention that industrial processing, logistics and packaging together account for almost half of all the energy involved (see also Chapter 3 for further discussion.)

Moreover, according to Figure 1.8, about 60 % of the energy embodied in European food derives from agriculture and logistics, two sectors largely dominated by fossil fuels in which the penetration of renewable energies is still relatively small (see 2.1 and 3.3 for further details)

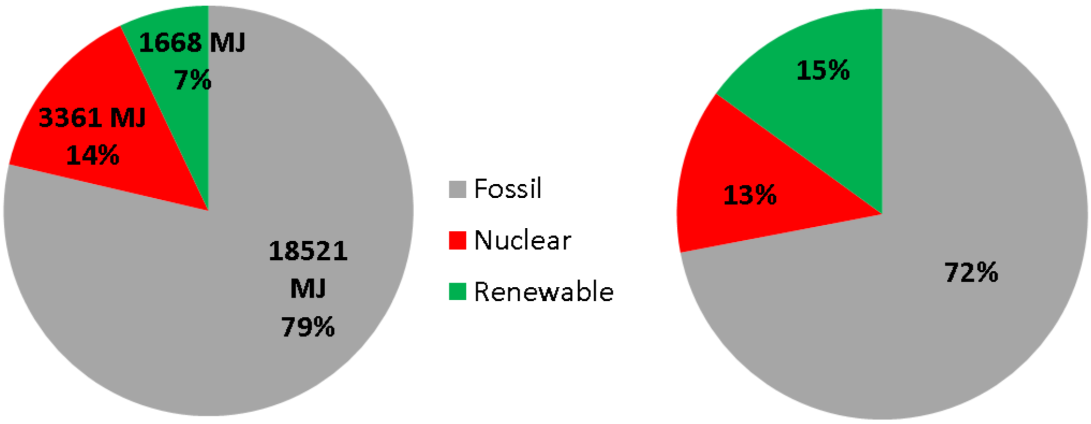


Figure 1.9 Energy embedded in the food consumed by the average EU-27 citizen in 2013, detailed per energy source (left) compared to the overall EU-27 energy consumption mix in 2013 (right). Source: Authors' own analysis and Eurostat.

Consistently, about 80 % of the total energy associated with the entire food life cycle originates from fossil fuels (Figure 1.9 left-hand side), while all renewable energy sources account for 7.1 %. The overall EU-27 energy consumption mix in 2013 (Figure 1.9 — right-hand side) shows a RE share around 15 % and a 72 % contribution from fossil fuels. Thus, while the EU has made important progress in incorporating renewable energy across the economy, the share of renewables in the food system remains relatively small. Possible solutions and pathways for improvement will be discussed in the next chapters and in particular in 2.4 and 3.2.

It is worth mentioning that not all energy associated with the food supply chain is generated within the EU borders, as relevant amounts of food and food ingredients are imported from outside the EU (see 3.3.1).

Finally, it has to be reminded that results discussed here represent the average consumption of the average product by the average citizen. Specific results are known to be extremely variable. As an example Appendix 0 summarises the LCA study of 21 types of bread produced in different EU countries: the products, equally called 'bread', embed an amount of energy ranging from 9 MJ/kg up to 37 MJ/kg, to be compared with the value of 16.1 MJ/kg of the average bread included in the JRC food basket.

1.4.2 GHG emissions along the EU-27 food supply chain

GHG emissions from the JRC food basket have been also extrapolated to the whole food consumption in EU-27 in 2013 following the same procedure described in 1.4.1

Food consumption in 2013 has led the average EU citizen to emit 2 965 kg of CO_{2e}, which is roughly equivalent to the emissions from travelling about 22 800 km by car ([8]).

Figure 1.10 illustrates how these emissions are split by supply chain production steps, revealing once again that the agricultural production phase, including animal rearing, accounts for the highest overall share of the food related GHG emissions (67.3 %).

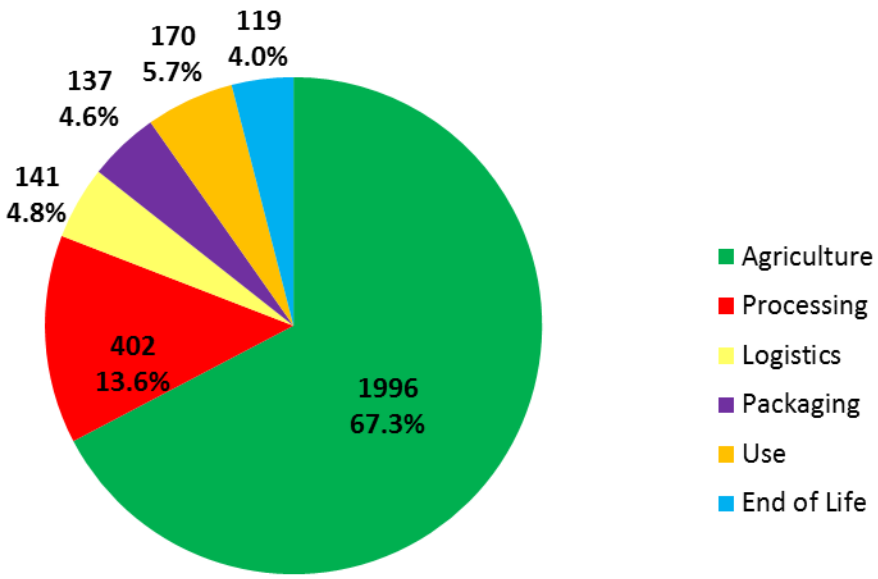


Figure 1.10 GHG emissions caused by the food consumed by the average EU-27 citizen in 2013, detailed per food production step. Units: $kgCO_2e$. Source: Authors' own analysis.

The same limitations described in the case of embedded energy hold for GHG emissions estimate: results refer to average products, behaviours and consumption patterns.

Nevertheless, the predominant role of agriculture is evident in both the case of embedded energy and GHG emissions. European farmers are aware of such a relatively high impact of their sector and are leading the way in the transition to a better energy use their daily work. Challenges and solutions for improving the energy use and the energy quality in agriculture will be the subject of next chapter.

([8]) The current target value of 130 g CO_2e/km for new cars was considered.

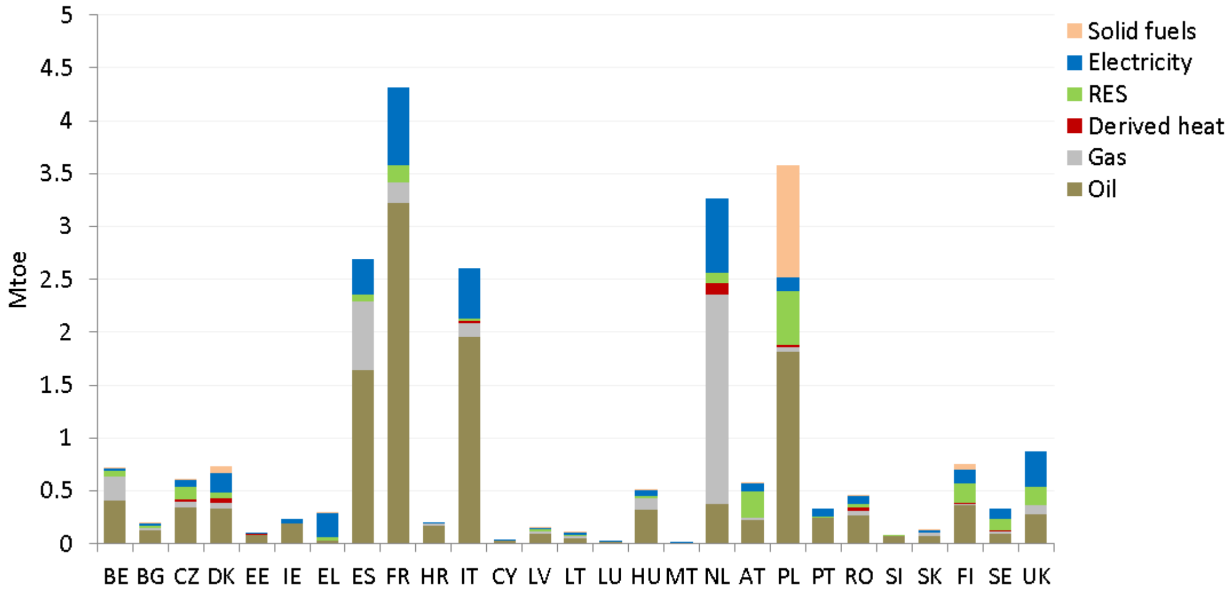
2. Energy-related challenges and solutions in food production — behind the farm gate

Agriculture and livestock are responsible for 33.4 % of the energy embedded in food consumed in the EU (Chapter 1), the largest contributing sector. Also because of an even higher share of agriculture-related GHG emissions (see Figure 1.10), the issue of agriculture decarbonisation has been very relevant in the scientific and policy debate in Europe in the last decades. This chapter provides a general picture of the state of the art and trends on energy use in the EU's agriculture sector and then discusses the main solutions for both decreasing energy consumption and increasing renewable energy shares. Examples from EU research programmes will complement the chapter.

2.1 Energy use in agriculture, livestock and aquaculture — the current situation and recent trends

The direct energy consumption of the EU agriculture sector amounted to 23.9 Mtoe (Eurostat, 2014a) in 2013, equivalent to 2.2% of EU's final energy consumption in the same year. On a national basis, direct energy consumed in agriculture accounted for a share of between 1 % and 6 % of the final energy consumption. In 2013, the direct energy mix for agriculture was largely dominated by fossil fuels, with oil and gas together accounting for almost 70 % , electricity for 16 % and renewables for 8 % The renewables share steadily increased in the last decades from the 1990 value of 2 % ([9]).

Figure 2.1 shows the current energy mix for agriculture sector in the EU-28 in absolute (top panel) and relative (bottom panel) terms (Eurostat, 2014a).



([9]) On top of the direct renewable energy use, it has to be considered that the cited 15 % contribution from electricity also partially derives from renewable sources, depending on the electricity mix evolution.

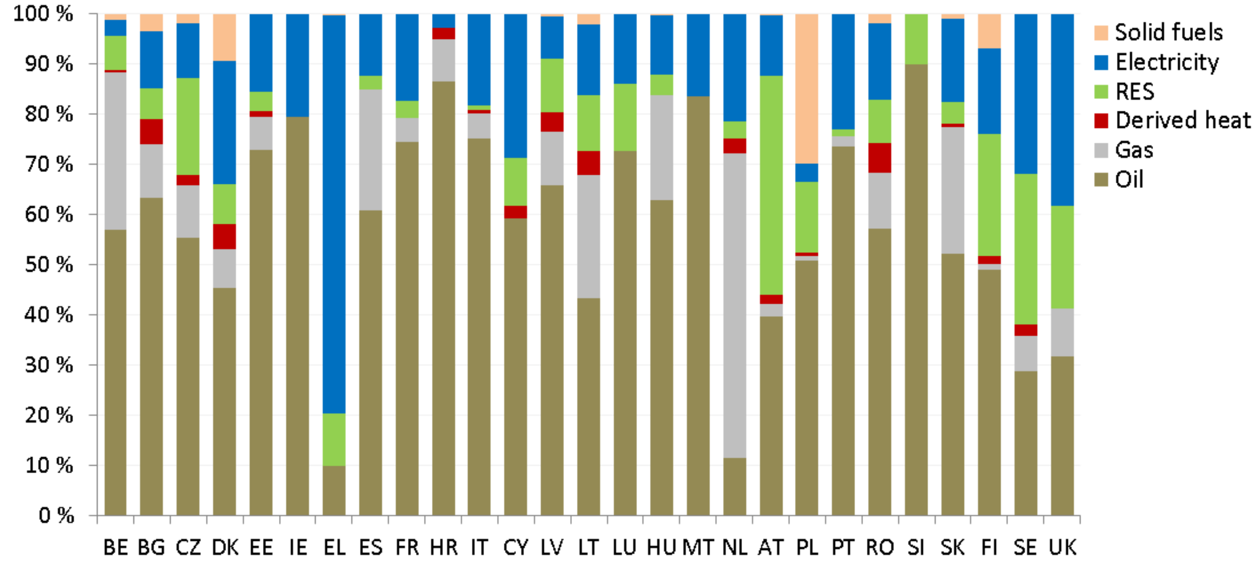


Figure 2.1: Direct energy use in the agriculture sector in the EU-28 in absolute (top panel) and relative (bottom panel) terms in 2013 (Eurostat, 2014a). NB: Data missing for Germany.

Figure 2.2 shows that both the total direct energy consumption and direct energy consumption per cultivated hectare have decreased since 1990. A general decadal trend towards a more efficient agriculture production is well visible in Europe, at least as far as direct energy consumption is concerned.

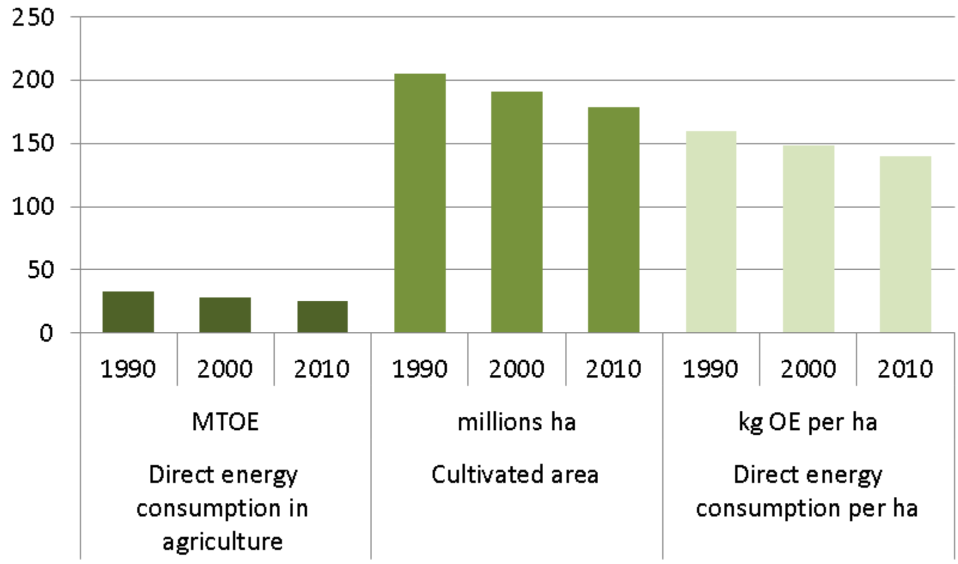


Figure 2.2 Evolution of direct energy use in the agriculture sector (left — million tonnes of oil equivalent), cultivated area (middle — millions hectares) and direct energy consumption per unit of cultivated area (right — kilograms of oil equivalent/hectare) in the EU-27 in the 1990-2010 period (Eurostat, 2014a).

Nevertheless, Gołaszewski et al. (2012) pointed out as these numbers only partially reflect the actual energy amount consumed, and several inputs are not fully allocated to the agriculture sector's energy statistics.

As an example, DEFRA estimated that in the United Kingdom and for the period 2003 – 2007, the agriculture sector consumed 2.5 times more energy indirectly than as direct energy (DEFRA, 2008). More precisely, in 2007, the most recent year for which such an analysis is available, the direct energy consumption in agriculture amounted to 839 ktoe, while 1 053 ktoe and 321 ktoe were consumed respectively for fertiliser and pesticide production, 503 ktoe for animal feed and 373 ktoe for tractors and other agricultural machinery construction.

A recent study of the US agriculture sector (Beckman, Borchers and Jones, 2013) has shown that indirect energy inputs account for about one half of the direct energy use, with fertilisers and pesticides accounting for roughly 60 % and 40 % of the indirect energy share, respectively. Pelletier et al. (2011) report the general result of indirect energy being usually larger than direct energy in intensive agriculture systems.

For Europe, an exhaustive study with detailed direct and indirect energy flows in agriculture is not available, but a dedicated study by Gołaszewski et al. (2012) following a LCA-like approach has provided results for six European countries and several kinds of crops and livestock (see Figure 2.3 and Figure 2.4).

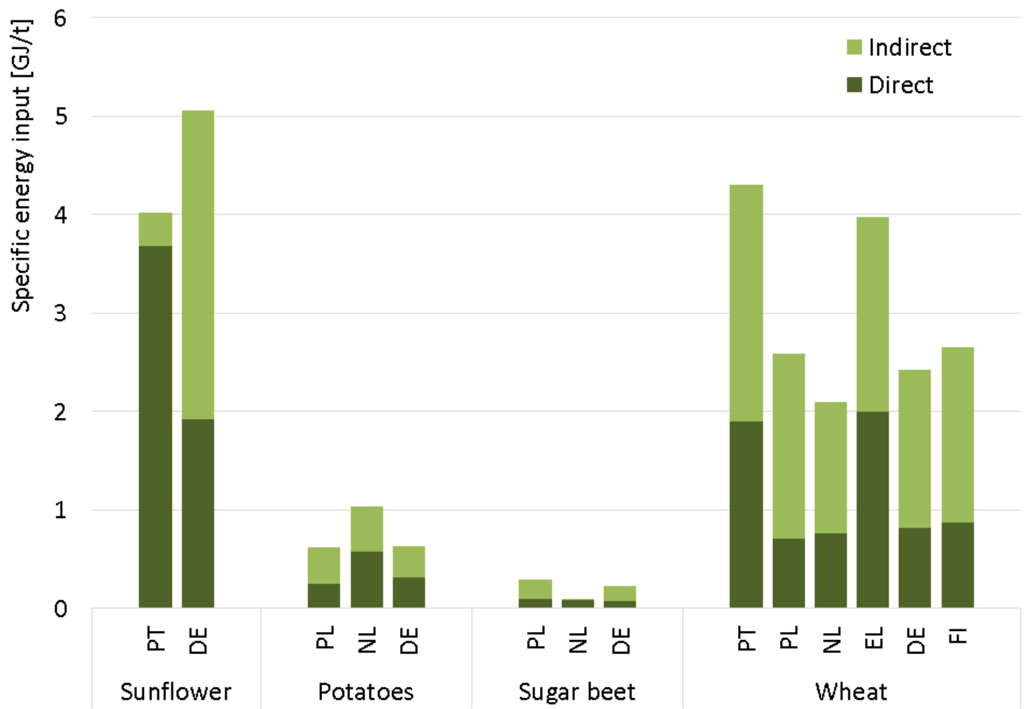


Figure 2.3 Direct and indirect energy input for four crops in different European countries. Absolute values in GJ/t of crop. Source: (Gołaszewski et al., 2012).

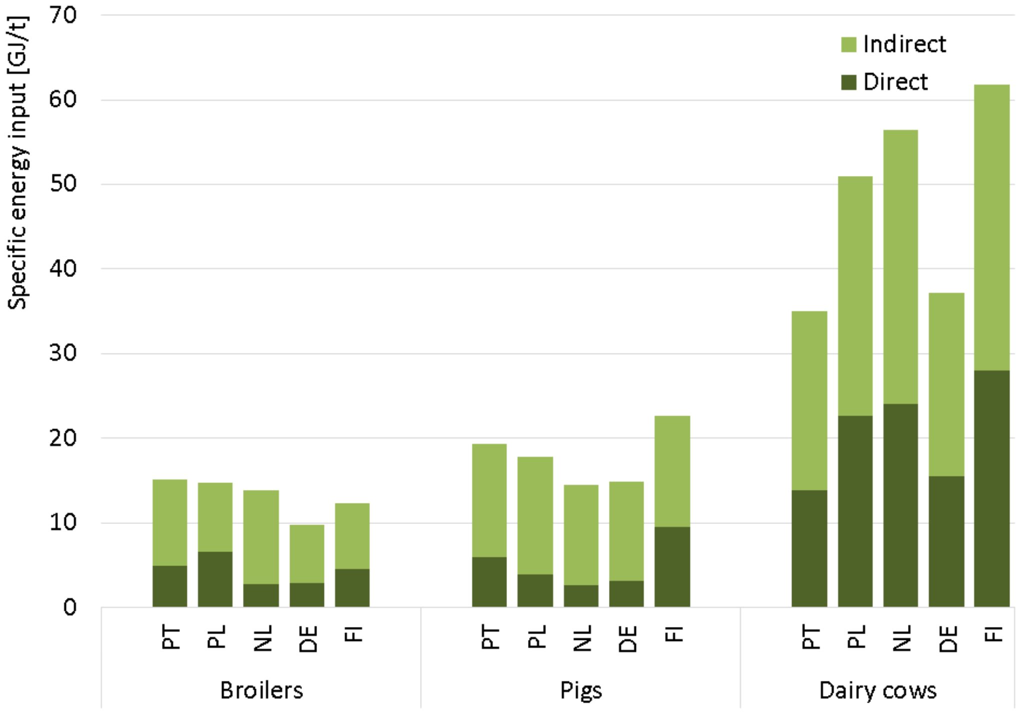


Figure 2.4 Direct and indirect energy input for three livestock categories in different European countries. Absolute values in GJ/t of product. Source: (Gołaszewski et al., 2012)

2.2 Realising energy efficiency in agriculture

Farmers are usually keen to improve energy efficiency and to save energy in order to decrease their operational costs. Besides, above a certain threshold, increased energy consumption does not necessarily translate into immediate yield benefits. Woods *et al*. (2010) have demonstrated the overall nonlinear relationship between energy inputs and crop yield, with saturation effects for high energy inputs. Nevertheless, energy remains a crucial input for cultivation success: Woods *et al.* (2010) have also shown that an energy input too small can lead to very low yields and then, perversely, to an overall higher energy demand per tonne of harvested product. The proper balance has to be found on a case-by-case basis, taking into consideration the peculiarities of each farm and cultivation system. The following sections illustrate key avenues which can be followed to improve energy efficiency in different aspects ([10]) throughout the value chain.

2.2.1 Optimising fertiliser production

Pelletier *et al.* (2011), DEFRA (2008) and several other studies identified fertilisers as a key issue in indirect agricultural energy flows. Ramírez and Worrel (2006) estimated that in 2001 the energy embedded in the global fertiliser consumption amounted to about 3 600 petajoule (PJ), i.e. about 1 % of the global energy demand. The major share of this energy, about 72 %, was needed for the production of nitrogen fertilisers. Besides, the nitrogen fertiliser industry uses fossil fuels not only as an energy source but also as a raw material: ammonia synthesis requires hydrogen gas, currently produced using natural gas, thus absorbing 3-5 % of the world's natural gas production.

([10]) For a more detailed review of best practices which can be implemented in the Agricultural sector in particular to improve energy efficiency, please refer to the Best Practice report developed by the Joint Research Centre for the Agriculture (Crop and Animal Production) sector; more information available at http://susproc.jrc.ec.europa.eu/activities/emas/agri.html

According to Fertilizers Europe (2014), the production of nitrogen-based fertilisers commonly used in Europe requires 10-14 MJ/kg, depending on the actual product with a peak of 23 MJ/kg for urea, a fertiliser very rich in nitrate. On the contrary, potash and phosphorus fertilisers are currently produced with 3 MJ/kg and 0.2 MJ/kg, respectively.

If the energy spent is referenced to the nutrient content, the differences become even more evident: nitrate fertilisers need 40-50 MJ per kg of nutrient, while potash and phosphorus fertilisers require 5 and 0.35 MJ per kg of nutrient, respectively. On average, nitrogen fertiliser production is ten times more energy-intensive than phosphorus and potassium fertilisers (Khan & Hanjra, 2009) and largely exceeds the energy requested for the actual field application of fertilisers.

Even if the energy cost of fertiliser production has declined by a factor of five in the last century (Woods *et al.*, 2010), fertilisers are still a relevant energy-demanding aspect of modern agriculture. Again according to Fertilizers Europe (2014), improved fertiliser production technology — high-energy efficiency, nitrous oxide decomposition (de-N_2O) catalysts — combined with the best agricultural management practices still enables a significant reduction in the carbon and energy footprint of crop production.

From the point of view of production, according to Ramírez and Worrel (2006), the full application of best available techniques (BAT) guidelines (see Chapter 4) in the fertiliser industry worldwide will lead to a decrease in the energy embedded in fertilisers of 19 % globally. Supply volume effects and the competitive advantage of technical improvements will also decrease energy consumption in fertiliser production. However, physical limits exist: the energy embedded in nitrogen fertilisers cannot be lower than about 24 MJ/kg nutrient (see again Ramírez & Worrell, 2006). For this reason, in the long term, avoiding unnecessary fertiliser applications through properly designed cultivation practices will be the most effective strategy.

2.2.2 Energy saving cultivation practices

In heavily mechanised agriculture systems, machinery use is an important direct energy consumer. Farm mechanisation includes tractors, equipment for cultivation and planting, and harvesters, together with machinery and equipment used for irrigation, livestock production, grain drying and storage.

The Conservation Agriculture (CA) concept (FAO, 2013c, 2015b) aims at reducing the energy and environmental burden related to farm mechanisation, fertiliser applications and other energy intensive practices.CA includes several significant changes in farming practices such as conservational tillage or no-till planting practices ([11]) (Ashworth, Desbiolles and Tola, 2010; Baker *et al*., 2006; Derpsch and Friedrich, 2009), integrated pest management ([12]), plant nutrient management (EurAgEng, 2010), weed and water precision farming (Sims, 2011), and controlled traffic farming (EurAgEng, 2010).

([11]) In no-tillage practices seeders need to penetrate surface organic mulch and deposit the seed and fertiliser at the correct depth.

([12]) As an example, AAB (2010) reports that about 50 % of all pesticides applied in traditional agriculture do not reach the intended target.

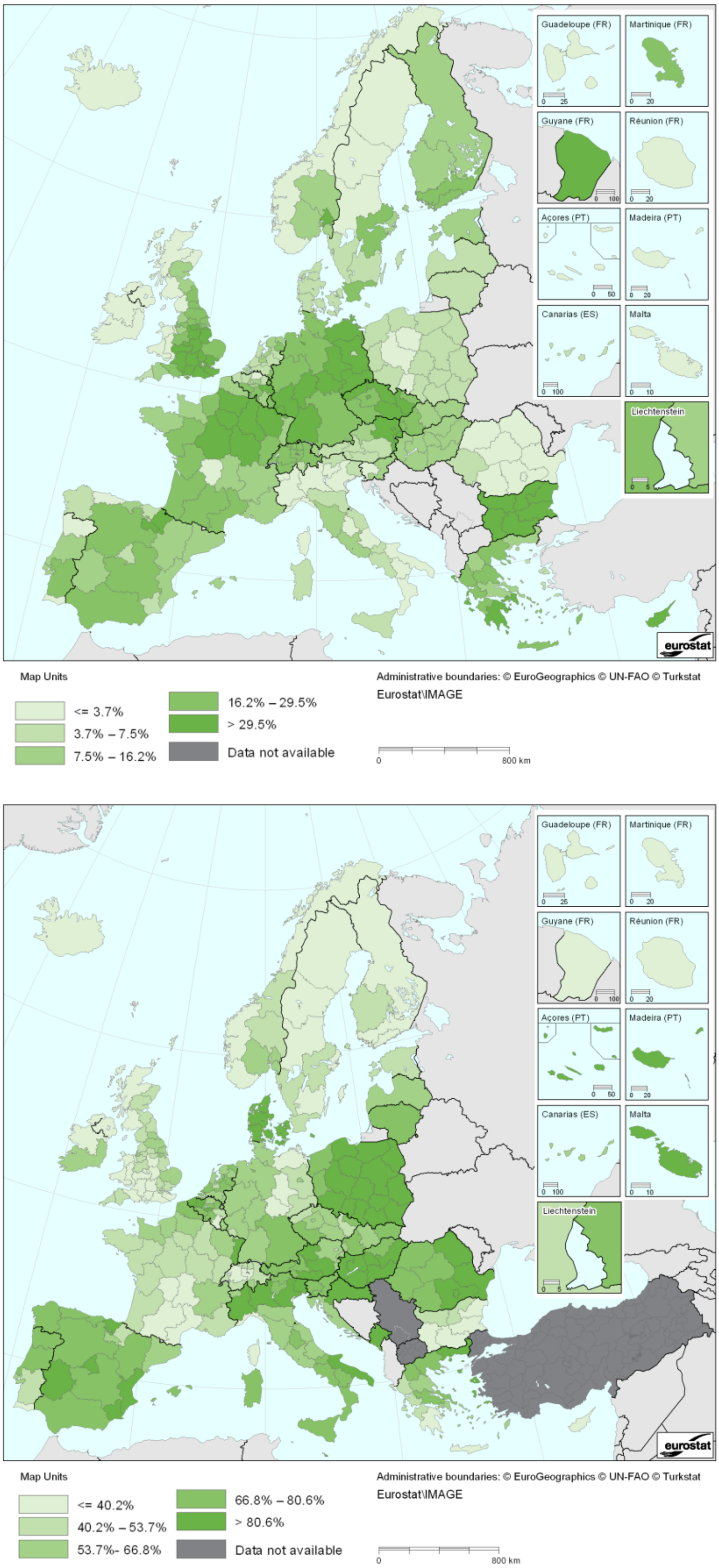


Figure 2.5 Share of arable land for which conservation tillage (top panel) or no-tillage (bottom panel) practices were applied in 2010. Data for NUTS-2 regions. Source: (Eurostat, 2015).

Several actions included in CA result in consistent energy savings, especially in the case of tillage systems. For instance, Mileusnic *et al*. (2010) have measured a decrease in tractor fuel consumption ranging between 40 % and 60 % when comparing each other traditional, limited and no-tillage corn and wheat cultivations in Serbia.

According to the FAO (2013c), the adoption of the CA concept could result in a further carbon sequestration into the soil at the rate of about 0.5 t/ha/year, could reduce the labour and energy requirements by about 50 % and could lead to noticeable fuel and machinery cost savings. Globally, in 2010 about 117 million ha out of a total of 1 390 million ha of arable land were cultivated under CA approach, with some farms already practising it for over 30 years. Over the past 20 years, the global rate of transformation from tillage-based farming to CA has been some 5.3 million hectares per annum, increasing in the last decade to 6 million ha/year (FAO, 2013c).

Integrated Arable Farming Systems (IAFS) also contribute to evident energy savings (Bailey *et al*., 2003). IAFS include several concurrent measures known to reduce agronomic inputs (conservation tillage, use of disease-resistant cultivars, rational use of pesticides, target application of nutrients) and to diversify crops (shift from intensive monoculture to crop rotation, promotion of biodiversity through the management of field margins and non-agricultural vegetation) (Alluvione, Moretti, Sacco and Grignani, 2011). IAFS have proved effective in decreasing both direct and indirect energy inputs, but the actual amount of energy savings varies notably. For instance, Bailey *et al.* (2003) have compared four different rotations (involving wheat, potatoes, oilseed rape and other crops) in six UK locations: for some, energy savings reached up to 8 %, while others have shown very little or no energy improvements at all. In another context, IAFS and low-input (LI) integrated farming were compared on the field with conventional production in a wheat-maize-soybean-maize rotation in Northern Italy (Alluvione *et al*., 2011). In this case, energy savings exceeded 30 %, especially thanks to decreased fertilisation rates, balanced crop-nutrient removal and the adoption of minimum tillage.

Several studies have compared the energy consumption of organic crop production to integrated and conventional agriculture, targeting different areas and products. For example, Zafiriou *et al.* (2012), Michos *et al.* (2012) and Kavargiris *et al.* (2009) have analysed differences in energy input between conventional, integrated and organic farming in Greece for asparagus, peach orchards and vineyards. In two of three cases (peach and vineyards), organic farming has shown energy advantages, while for asparagus the differences were not statistically significant. Pimentel (2006) also found that in the case of organic corn production fossil energy inputs per unit of energy output were 31 % lower than conventional production, and 17 % lower in the case of organic soybean production.

As a general rule, organic farming appears to be significantly better from the energy point of view (Alonso and Guzmán, 2010; Gomiero, Paoletti and Pimentel, 2008), mainly because of a different approach to fertiliser use. However, exceptions are found across geographical areas and crops (see for example Astier *et al*., 2014). The lower yields obtained by organic crop production can result, in some cases, in a negative impact on the energy use per tonne of product.

Eurostat and DG AGRI (2013) declare that the share of arable land subject to organic cultivation is steadily increasing, from 3 % in 2003 to 5.2 % in 2010 in the EU, although it is quite unevenly geographically distributed (see Figure 2.6).

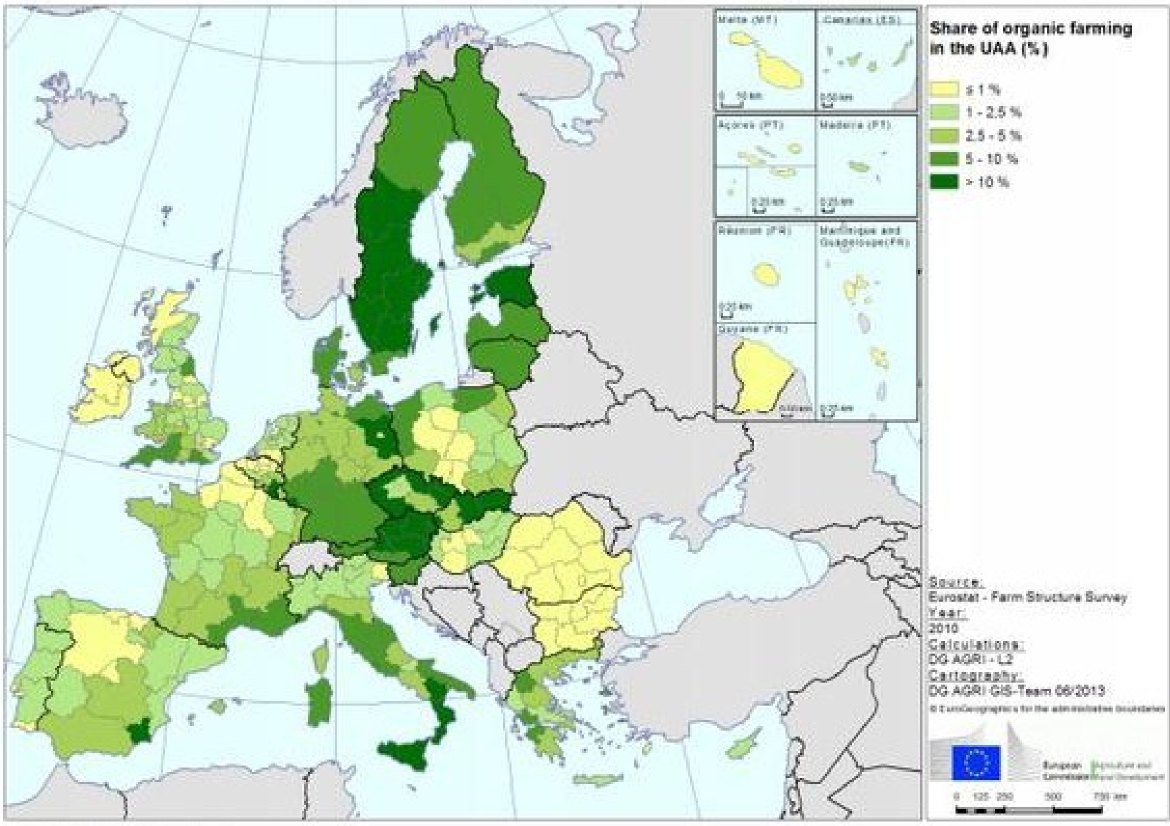


Figure 2.6 Share of organic farming on arable land in 2010. Data for NUTS-2 regions. UAA: utilised agricultural area. Source: (Eurostat — DG AGRI, 2013).

2.2.3 Further improving water use

Water use in agriculture is crucial. This sector globally accounts for almost 70 % of the water withdrawals (FAO 2013) and many crops require intensive irrigation. Animal products, and especially beef, are particularly water demanding: for instance, the production of one kilogram of beef requires more than 15 000 litres of water (Hoekstra, Chapagain, Aldaya and Mekonnen, 2011; Pimentel *et al*., 1997), including water indirectly consumed through animal forages and grain intakes (see Box 2 on the water-food-energy nexus for more detail). Irrigation needs can change considerably from one year to another, depending on weather conditions, and largely differ in different climate areas.

In the case of Europe, Figure 2.7 shows the amount of irrigation withdrawal per cultivated hectare in three recent periods for the EU Member States for which at least two sets of water consumption data were available. Regional differences are evident and, although a decreasing trend could be observed for the majority of countries, a clear tendency towards an increasingly efficient irrigation water use is far from evident.

Intensive need for water provisions implies important energy needs, especially for irrigation but studies have shown that improvements in the irrigation systems could lead to important energy savings. For instance, optimising pump sizes to take into consideration the peak (two to three months per year) and off-peak water requirements can be an effective measure: Moreno *et al*. (2009) have developed a methodology to estimate features and efficiency curves of optimal pumping stations, while up to 35 % energy savings in irrigation systems have been reported by Jiménez-Bello *et al.* (2010) and by Moreno *et al*. (2010) after an irrigation plan rotating among two or more sectors of the irrigated area, was put in place in a test area.

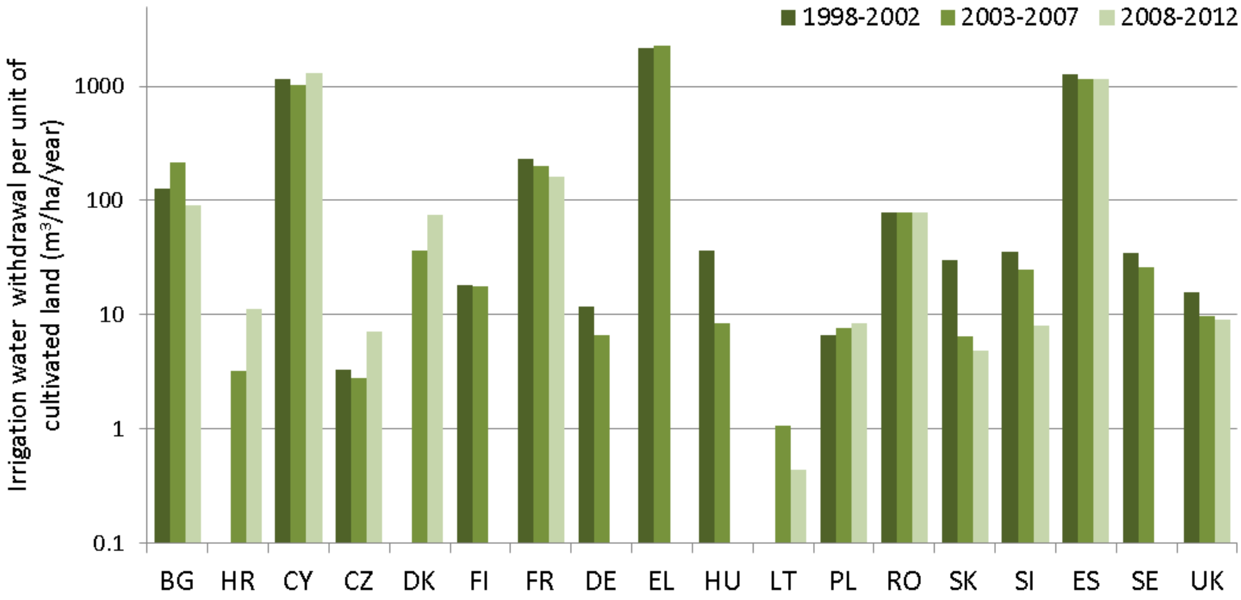


Figure 2.7 Irrigation water withdrawals per unit of cultivated area in 18 EU Member States in the period 1998-2012. Units in m^3/ha/year. Data from AQUASTAT(FAO, 2015a).

Even so, the existence of important trade-offs between water savings and energy efficiencies have been reported, for example by Rodrigues-Diaz *et al*. (2011). In the case discussed, an agricultural district in Andalusia, the energy needs and its costs boosted after the modernisation of the irrigation systems from a traditional open channel network to a more water-efficient, on-demand pressurised system. Although the amount of water withdrawn for irrigation to farms was considerably reduced, the maintenance costs increased up to 400 %. The new pumping pressurized systems caused higher energy needs that the previous gravity – based systems.

Again, in arid or semi-arid areas, diversification of water sources is often considered a viable solution for assuring a more continuous water supply. But even this measure does not necessarily end up with a better energy profile. As an example, Martin-Gorriz *et al.*(2014) demonstrated that the use of desalinated seawater for irrigating the highly water-stressed areas in Southern Spain is expected to lead to a substantial increase in the overall energy content of the products.

Finally, Diotto *et al.* (2014) also investigated the energy embodied in the irrigation equipment, considering both surface pivot and drip systems. Starting from the Australian test case developed by Jacobs (2006), a full model was developed, allowing the comparison of the irrigation systems under a wide range of surrounding conditions.

2.2.4 Better livestock feeding

High-quality proteins and nutrients provided by livestock come at the price of a much higher energy embodied in comparison with crop products (see also Chapter 1). According to Woods *et al.* (2010), animal feed accounts for a share of between 70 % and 90 % of the total energy embedded in the raw livestock products, while the rest reflects the energy spent on animal husbandry. In this situation, energy-efficiency measures must target feed crop production: improving feed conversion efficiency and avoiding wastage are the main ones. Clearly, energy-saving measures applied in agriculture will positively impact the energy content of livestock products too. Moreover, some additional strategies have been proved to be useful, such as the use of organic residues in the form of biogas to close the energy cycle in stables and farms. This will be discussed in further detail in section 2.4.

2.3 Fishery and aquaculture

The energy consumed in the fishery sector (including aquaculture) amounted to 45 PJ in the EU-28 in 2012, equivalent to almost 5 % of the direct energy consumed in the agriculture sector in the same year. The fishery sector has suffered a constant shrinkage in the last decades and Eurostat (2014b) reports a total catch of 4.4 million tonnes in the EU for 2012, equivalent to just 60 % of the total catch in 1995.

Even so, the EU fishery fleet is still very important, with a total gross tonnage of 1.64 million tonnes and about 82 000 ships. Spain, Italy, Greece, France, Netherlands and Portugal have fishing fleets larger than 100 000 gross tonnage and altogether provide 60 % of the EU-28's fleet.

Tyedmers (2004) estimated that direct fuel energy inputs typically accounts for between 75 % and 90 % of the energy use in the sector and it is largely provided by fossil fuels. Tyedmers (2004) also evidences the energy use per unit of catches is increasing over time. Possible causes are the decrease in abundance of the closest targeted fisheries resources, pushing fleets to longer travels and the increase in the size, power and technical sophistication of fishing vessels. Even though, fishery products remain very competitive in terms of embodied energy per calories provided when compared with, for example, meat. It is also worth noticing that besides the energy directly employed for vessel movements, an important share of energy provided by fules (in some cases reaching 40 %) is commonly employed for jigging and freezing the catches directly on board as a pre-processing step of the food production chain (see again Tyedmers, 2004).

Box 2 — The food-water nexus and its energy implications

The food-water nexus and its energy implications has become an important topic at the same time for research, for the international, national and regional organisations/agencies, and for all the players in the water and energy fields (both private and public, operators and stakeholders). Water, energy and food are essential for human well-being and sustainable development. Global projections generally indicate that the demand for freshwater (surface water and ground water), energy and food will increase significantly over the next decades due to population growth, economic development, international trade, urbanisation, diversification of diets (e.g. more meat consumption means more water use), cultural/technological changes and climate change.

According to the FAO (2014), agriculture presently uses 70 % of total global freshwater withdrawals and is the largest user of water. Water is used for agriculture production and along the entire agri-food chain. The food production and supply chain consumes about 30 % of total global energy (FAO 2011a).

Energy is required to produce, transport and distribute food, as well as to extract, pump, lift, collect, transport and treat water. Cities, industry and other sectors, such as tourism, use more and more water, energy and land resources. This is associated with problems of environmental degradation, competition for water and in some cases, resource scarcity. As demand grows, there is increasing competition over natural resources between agriculture, fisheries, livestock, forestry, mining, transport and other sectors, with impacts on livelihoods and the environment that are sometimes difficult to predict.

This situation is expected to become more problematic in the future as it is estimated that 60 % more food will need to be produced in order to feed the world in 2050. In addition, global energy consumption is projected to grow by up to 50 % by 2035 (IEA 2010). Total global water withdrawals for irrigation are projected to increase by 10 % by 2050 (FAO, 2011b).

As an example to illustrate the complexity of the water-food-energy nexus, especially in some tropical countries where large dams are still being built, large-scale water infrastructure projects may have positive impacts, producing hydropower and providing water storage for irrigation and urban uses. But these might come at the expense of downstream ecosystems and agricultural systems, and with social implications such as resettlement. In the same way, growing bioenergy crops or biomass in an irrigated agriculture scheme may improve the energy supply, but may also result in increased competition for land and water resources and present risks to food production. At the global level as well as in the EU, there are thus links between water, food and energy that may sometimes result in synergies, but also in conflicts and in the necessity of trade-offs between different sectors or interest groups.

For example, in Asia, the Green Revolution and the introduction of groundwater pumps have transformed irrigated agriculture and became a key factor in the food security of countries such as India, Pakistan and China. However, groundwater pumping has accelerated the depletion of water resources and aquifers. Food production has become increasingly vulnerable to energy prices, often resulting in the farmers' dependency on energy subsidies or public support mechanisms. At the same time, farmers sometimes have no other option than to pump water, since services provided by public irrigation agencies are often of poor quality and may prioritise energy production. The solution commonly proposed is to revise tariff and metering systems and to improve the pumps' technical efficiency. Regarding this issue, a nexus perspective can help us to understand the wider implications for water, energy and food, and broaden the scope of interventions to include: water demand management, investment frameworks to publicly fund improved surface irrigation, groundwater management, irrigation technologies and agricultural practices, as well as food procurement and trade policies. These interventions are likely to have an impact on the drivers and pressures that have led initially to over-pumping. Water pricing is an essential component of water and energy policies, both in the EU and elsewhere.

In this general context, the water-energy-food nexus has emerged as a key concept to describe the complex and interrelated nature of our global resource systems on which we depend to achieve different, often competing development goals. In practical terms, it offers a coherent approach to natural resource management, taking into account social, economic and environmental goals. Food-water-energy nexus interactions are complex and dynamic and cannot be studied in isolation due to the variety of objectives, drivers and local conditions.

Even if it is obvious that, in the EU, water, food and energy has to be assessed at national, regional and the watershed level and that there are huge variations in the quantification of the starting point (for example, between EU Member States such as Ireland and the United Kingdom on one side, Cyprus and Malta on the other side, and in between regions such as Andalusia and Central Finland), a water-energy-food nexus approach allows:

- a description of interactions about how we use and manage resource systems, describing interdependencies, constraints and synergies;
- the development of the capacity to identify, assess and analyse food-water-energy nexus interactions and the implications that any change — policy decisions, large-scale investments or changes in agricultural practices — may have beyond the intended objective and scale;
- a prioritisation of response options.

In addition to the inclusion of a broader process of stakeholder dialogue, the overall approach should include data analysis, scenario development and response options with the corresponding impact analysis.

Regarding the EU's food imports and exports, the analysis of the food sector links with water and energy should consider not only the water footprint of EU-made food products but also of food products imported into the EU.

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2.4 Opportunities for renewables in agriculture

2.4.1 Renewable energy in the EU energy mix

Following the legal framework established by the Renewable Energy Directive, renewable energy (RE) is rapidly entering the EU energy mix reaching 14.15 % of final energy consumption in 2012 ([13]) and estimated 15 % ([14])in 2013 in the EU-28 (see Figure 2.8). In 2012 RE consumption share amounted to 16.5 % in the heating/cooling sector, 25.4 % in the electricity sector and 5.35 % in the transport sector. The renewable energy used in the heating/cooling sector accounted for more than half of the total renewable energy consumed in 2012. The most significant growth of the renewable shares until 2012 occurred in the electricity sector, with an increase of 10.6 percentage points from the 2005 baseline year, which corresponds to almost 75 % of the planned share of electricity from RE for 2020. .

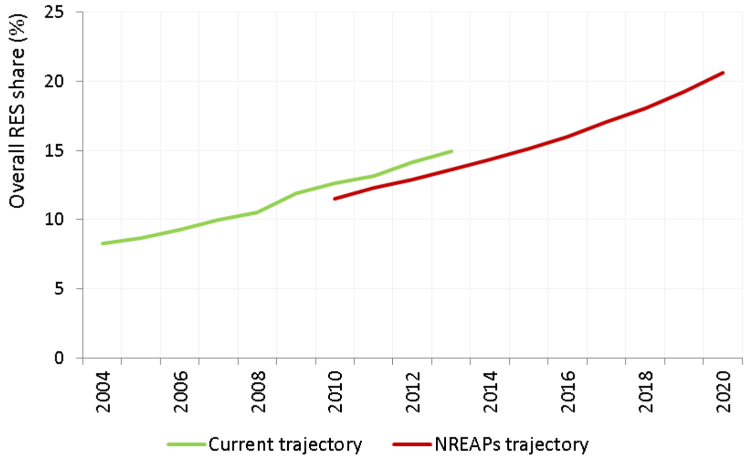


Figure 2.8 Current and projected overall share of renewable energy sources (RES) in the EU-28. Source: Eurostat, Progress Reports ([15]) and NREAPs ([16])

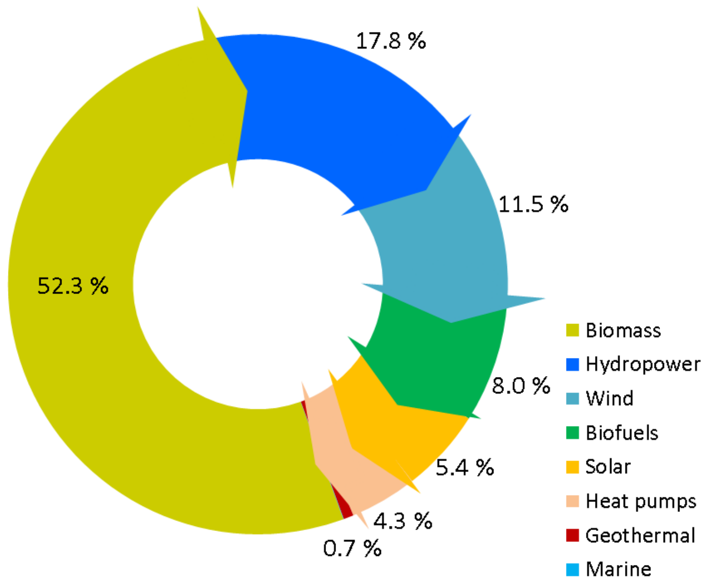


Figure 2.9 Contribution of renewable energy sources in RES mix in the EU-28, 2012. Source: Renewable energy progress reports.

([13]) Based on the last published Progress Reports (see e.g., next footnote).
([14]) Eurostat 2013 Shares Results http://ec.europa.eu/eurostat/web/energy/data/shares
([15]) Biannual reports to the European Commission on progress in the promotion and use of energy from renewable sources following Article 22 of the Renewable Energy Directive (Banja et al., 2013).
([16]) According to the Renewable Energy Directive (2009/28/EC), the expected deployment of renewable energy was detailed by Member States in their National Renewable Energy Action Plans (NREAPs) (Banja, Monforti-Ferrario and Scarlat, 2013; Szabó et al., 2011).

Biomass was the main source of renewable energy in the EU-28, with a contribution of almost 54 % to the total renewable energy used in 2013 ([17]) (Figure 2.9). Photovoltaic (PV) and wind have expanded rapidly in the last decade, accounting for nearly 65 % of additional renewable electricity produced between 2011 and 2012.

In the heating/cooling sector, the increase of biomass covered almost 80 % of the additional renewable energy consumed in this sector between 2011 and 2012. Other sources, such as solar thermal, geothermal and heat pumps, accounted for a small but gradually increasing share in heat consumption in the EU-28, reaching considerable levels in some Member States.

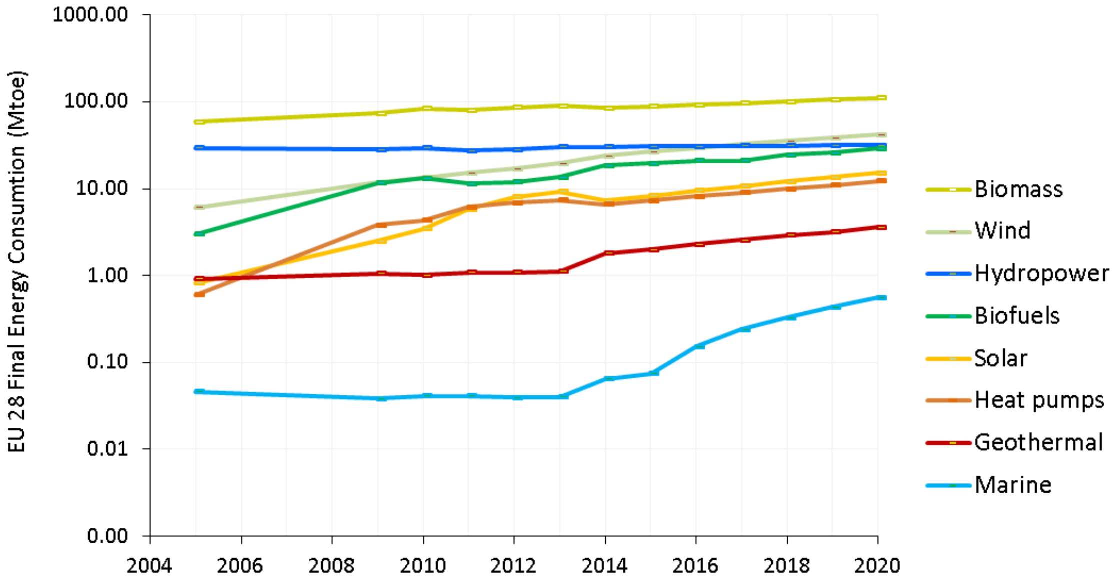


Figure 2.10 Current and projected development of renewable energy sources in the EU-28. Source: Progress Reports and NREAPs.

Biomass will remain the major source of renewable energy until 2020 (see Figure 2.10), with a share decreasing to 45.1 % from the 2005 figure of 59.2 %. Newer technologies, such as wind, are expected to overcome traditional technologies like hydropower, reaching a 17.2 % share of the RE provided in 2020. Other technologies, such as solar photovoltaic, solar thermal and geothermal, will account for smaller shares — 2.9 %, 2.7 % and 1.5 % respectively, but assuring a very high penetration in electricity consumption. Biofuel use is expected to reach a share of 11.7 % in the total renewable energy mix in 2020.

The overall push for renewable resources will drag the whole food sector towards a higher share of renewable use through, for instance, the use of more renewable electricity, an increased use of renewable heat or biofuels in machinery operations and transport.

On top of this, the food sector can itself make a valuable contribution for reaching the EU objectives for RE consumption. According to (FoodDrinkEurope, 2012b) huge opportunities for a targeted implementation of renewable energies into specific processes of the supply chain exist. Some examples of food sector-specific pathways to more sustainable energy uses can be found in the next paragraph.

([17]) Data source: EEA report " Renewable energy in Europe – approximated recent growth and knock on effects" - http://www.eea.europa.eu/publications/renewable-energy-in-europe-approximated

2.4.2 Opportunities for RE use in agriculture

Bardi *et al.* (2013) have pointed to some key agriculture processes in which RE could be increasingly used. For instance, photovoltaic-fed electric tractors are being tested under different conditions. Concept models have already been developed, providing the same performance level as the fossil-fuel-powered traditional machinery although the duration of the batteries and their recharging time with PV modules remain an issue. Other studies (Joshua, Vasu and Vincent, 2010; Rao, Mathapati and Amarapur, 2013) have tested prototypes of small-scale PV pesticide sprayers in the field and shown their practical feasibility, especially suitable for developing countries.

Fertilisers are currently mostly obtained through catalysis from atmospheric nitrogen with hydrogen gas usually originating from 'stripping' hydrogen atoms to hydrocarbons (usually natural gas or syngas from coal). Instead, it is in principle possible to use 'renewable' hydrogen, obtained by the electrolysis of water through renewable electricity. Early studies (Dubey, 1977; Grundt, 1982) have demonstrated the technical feasibility of a complete 'wind to ammonia' production chain that is currently reaching economic maturity (Morgan, McGowan, Manwell and Center, 2011; Reese and Massie, 2008), even if the electrolytic hydrogen is sometimes still more expensive than the hydrogen obtained from fossil hydrocarbons.

A more radical approach to renewable fertiliser production has been recently proposed and tested at laboratory scale by Licht *et al.* (2014). Licht *et al.* investigated an electrochemical pathway in which ammonia is produced by the direct electrolysis of air and steam in a molten iron salt environment, without the need to create hydrogen and avoiding the use of large amounts of fossil fuel for its synthesis.

2.4.3 RE co-production in the farm system

Renewable energy production associated with farming has become more and more popular in the developed world. According to USDA's On-Farm Renewable Energy Production Survey (OFREPS, 2011), in 2007, about 1 420 US farms reported at least a wind turbine installed (of which 1 405 were smaller than 100 kW), 121 reported a methane digester, 7 968 reported solar panels (of which 7 236 solar PV and 1 835 solar thermal) for an average installed capacity of 4.5 kW per farm. For EU-27 in 2008, Pedroli and Langeveld (2011) reported a total on-farm production of final energy from renewable sources of 11.8 Mtoe: 8.0 Mtoe of electricity (mostly consisting of wind energy sold outside the farm) and 3.8 Mtoe of heat mostly used for the farm's own consumption. According to their NREAPs' consistent scenario, on-farm RE production in 2020 in the EU-27 could reach 35.9 Mtoe of electricity and 6.1 Mtoe of heat.

Solar energy production for internal farm uses was soon identified as a major opportunity for sustainable farming and for sustainable agriculture-based social structures (Campen, Guidi and Best, 2000) and it remains a promising and developing sector, also thanks to the recent massive decrease of PV panel costs (Jäger-Waldau, 2014). Additionally, some of the farm infrastructures (e.g. shelters, storage, etc.) are naturally suitable for an integrated production of solar-origin electricity and/or heat and, depending on the farm size, they could provide opportunities for a fully self-sustained farm electricity production.

Table 2.1 (Xiarchos and Vick, 2011) summarises the possible uses of solar energy (both to produce electricity and heat) inside the farm system.

Solar-based water desalinisation appears as a suitable solution for farming, especially in arid and semi-arid areas (Gude, Nirmalakhandan, Deng and Maganti, 2012; Kalogirou, 1998; Salata and Coppi, 2014).

The kinetic energy provided by wind has been used for centuries for water pumping, and nowadays all kinds of renewable electricity can play a large role in irrigation systems (see also Table 2.1). Gopal *et al*. (2013) provide examples of water pumping systems that can be redesigned in order to include storage, helping to match the different time scales of the demand for water (peaked in a given period of a few months but otherwise quite uniform) with the intermittent supply of wind and solar electricity.

Table 2.1 Possible uses of locally generated solar energy in the farming system (Xiarchos and Vick, 2011).

		Fields	Livestock	Other
Water pumping	PV	Wells, ponds, streams, irrigation	Wells, ponds, streams	Domestic uses
Building needs	PV		Security and task lighting, ventilation, feed or product handling equipment, refrigeration	Battery charging, task lighting, ventilation fans, air-conditioning needs, refrigeration
	SH		Air cooling, air/space heating, water heating	Domestic uses of solar heat
Farm and ranch	PV	Feeder/sprayer, irrigation sprinkler controls, security and task lighting	Electric fences, feeder/sprayer	Electric fences, invisible fences, battery charging, compressor for fish farming, fans for crop drying, greenhouse heating
	SH			Crop drying, greenhouse heating

Another major opportunity for renewable energy self-production in farming is offered by onsite anaerobic digestion of livestock and agriculture residues. Biogas produced in this way could be either exploited on-site, or be sold on the market thus complementing farmers' revenues. Moreover, biogas can be upgraded to biomethane to allow its injection into the natural gas grid or its use as a vehicle fuel.

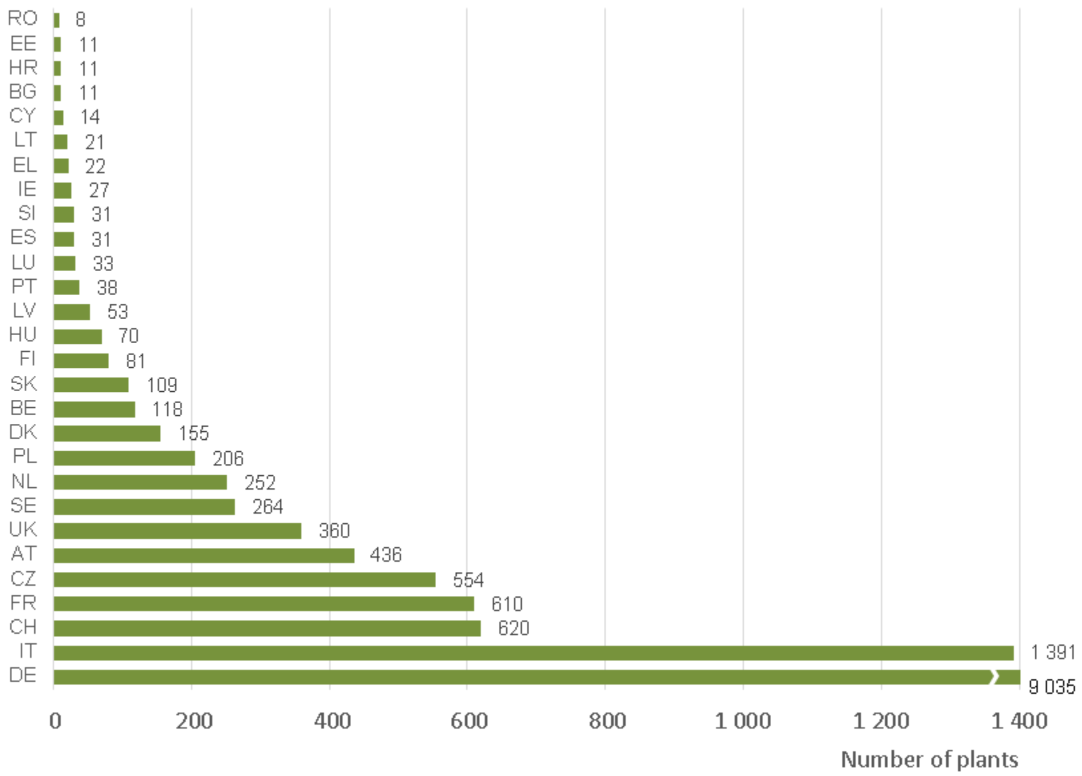


Figure 2.11 Operational biogas plants in the EU-28 in 2013. Source: (EBA, 2014).

Biogas production is quite popular in Europe: The EurObserv'ER Biogas Barometer (EurObserv'ER, 2014) states that 13.4 Mtoe of biogas primary energy was produced in 2013 in the European Union and reports a production of 52.3 TWh of biogas-based electricity ([18]). Moreover, the European Biogas Association (EBA, 2014) also provides the number of more than 14 500 biogas facilities installed in the EU by 2013 with an overall total installed capacity of 7 857 MW_{el} (see Figure 2.11).

The expansion of the biogas sector is also part of several national strategies for achieving the goals of the Renewable Energy Directive. The EBA states that the biogas production target in the National Renewable Energy Action Plans amounts to approximately 28 billion m^3 natural gas equivalent to be compared with the actual production of 14 billion m^3 of natural gas equivalent in 2013. Biogas production will then double until 2020 finally accounting for 1.5 % of the European Union's primary energy supply and 5 % of its overall natural gas consumption. Such an amount of biogas will also provide benefits in terms of security of supply and a reduced energy dependence from imports.

According to the EBA, in 2013 there were 282 bio-methane plants in the EU with a total production capacity of 1.3 billion m^3 of biomethane. Injection in the gas distribution network of biomethane is a reality in 11 European countries (AT, CH, DE, DK, FI, FR, LU, NL, NO, SE, UK) while vehicles are fuelled with biomethane (either pure or blended with natural gas) in 12 European countries (AT, CH, DE, DK, FI, FR, HU, IS, IT, NL, SE and UK).

But the biogas sector could expand even more: the Green Gas Grid Project (Brijder, Dumont and Blume, 2014; more information on the project in paragraph 2.5) estimates that the maximum theoretical biomethane potential in the EU-27 is in the range 151–246 billion m^3/year (equivalent to 5 477-8 884 PJ/year). This estimate considers both the biomethane produced by anaerobic digestion and the syngas (bio-SNG) produced from biogenic feedstock through gasification. The wet biomass, directly derived from the food supply chain, could provide up to 26 billion m^3/year of methane.

2.5 Examples of relevant recent EU-funded projects

In this chapter, a non-exhaustive but representative list of relevant ongoing or recently completed EU-funded projects related to energy efficiency and renewable energies in the agriculture, fishery and aquaculture sectors is presented. In Chapter 3 similar projects targeting the rest of the food supply chain will be detailed. It should be noted that the majority of the projects described are ongoing. However, four recently finished projects are also included due to their contributions and relevance.

All the listed projects have been funded by one of the following EU instruments:

- The European Union's LIFE Programme (http://ec.europa.eu/environment/life/about/);
- The Seventh Framework Programme (http://ec.europa.eu/research/fp7/index_en.cfm) (all the projects falling either under the research theme 'Food, agriculture and fisheries, and biotechnology, KBBE' or 'Research for the benefit of SMEs, SME';
- The Intelligent Energy Europe (http://ec.europa.eu/energy/intelligent/projects/).

Although there is not a concrete example reported, DG AGRI is also committed to supporting research, innovation and knowledge sharing in the field of agri-environmental measures and organic farming by the new Common Agriculture Policy (CAP) (http://ec.europa.eu/agriculture/organic/eu-funding/eu-funding-and-the-new-cap/index_en.htm).

In line with the main objectives of this report, some of the projects included here have been selected not because the main goal was reducing the energy flow in the particular

([18]) Including biogas production from landfills.

sector but because the impacts on the issue are undeniable. This is the case with all the projects that deal with waste or contribute to the reduction of CO_2 emissions.

AGREE: Agriculture and energy efficiency

Administrative data:

Status:	Finished
Project reference:	289139, under FP7-KBBE
Duration:	1 October 2011 to 31 October 2013
Budget:	EUR 614 551.00 (81 % EU contribution)
Coordinated in:	Germany
Website:	http://www.agree.aua.gr/

Objectives:

AGREE ([19]) had the objective of showing the potential of short-term energy-efficiency gains and the promise of the long-term potential, considering both direct and indirect energy-use efficiency. AGREE addressed crosscutting energy-saving technologies as well as branch-specific technologies. The project differentiated between measures to optimise production systems as well as more long-term measures directed at changing agricultural systems and sub-systems. Besides awareness of the technologies involved, AGREE aimed at identifying drawbacks and pitfalls in dissemination and implementation trajectories. Regarding long-term transnational research and development (R & D) issues, the project unfolded a participatory approach to address stakeholders in different EU countries.

Results:

- An inventory of economic and feasible energy-saving measures.
- Based on the inventory, action-specific recommendations were drawn to promote energy efficiency in European agriculture by addressing dissemination pathways and pitfalls to innovation.
- Initiations of transnational sharing of knowledge on energy-efficiency measures for short-term introduction.
- Realisation of an agenda for transnational research collaboration using a participatory approach.
- Indication of the added value of transnational research collaboration.
- Indication of the added value of transnational R & D on energy efficiency in agriculture.
- Indication of the potential benefits of energy saving in European agriculture by providing evidence for the economic and ecological side effects of improved energy efficiency in agriculture.

The AGREE consortium compiled a good quantity of comprehensive reports on case studies and succeeded in the dissemination of the project outcomes. All these are publicly available from its website.

REWIND: Profitable small-scale renewable energy systems in agri-food industry and rural areas: Demonstration in the wine sector

Administrative data:

Status:	Ongoing
Project reference:	LIFE13 ENV/ES/000280
Duration:	1 July 2014 to 31 July 2017

([19]) http://cordis.europa.eu/project/rcn/100386_en.html

Budget: EUR 1 562 994.00 (43 % EU contribution)
Coordinated in: Spain
Website: -

Objectives:

The objective of the project REWIND ([20]) is to prove that the use of renewable energy in the farming sector and other rural industries (using the wine sector as an example) is viable from a technical, environmental and economic perspective.

The project will demonstrate three prototypes for renewable energy generation: a) adaptation of a conventional agricultural vehicle from diesel to hydrogen fuel consumption; b) construction and installation of a hybrid system (diesel-photovoltaic) to generate energy for drip irrigation and hydrogen production; and c) construction and installation of a hybrid system (photovoltaic-wind) to power a winery waste-water treatment plant.

Expected results:

- A manual for the application of renewable energy in the agricultural sector and rural industries.
- A software tool to assess the viability of renewables to power the wine industry and other agricultural activities.
- A software tool for the technical design of renewable energy generation systems in the wine industry and other similar sectors.
- It is expected that the photovoltaic-diesel hybrid system will reduce diesel consumption for irrigation activities by 2 519 litres/year, producing cuts in CO_2 emissions of about 7 028 kg/year.
- The hydrogen-fuelled vehicle is expected to reduce diesel consumption by 912 litres/year, with a corresponding reduction in CO_2 emissions of approximately 2 544 kg/year.
- The hybrid (wind-photovoltaic) system to power the winery waste-water treatment plant is expected to cut electricity consumption by around 23 000 kilowatt-hours per year, and to reduce CO_2 emissions by about 5 543 kg/year, nitrogen oxide (NO_x) emissions by 8.35 kg/year, and sulphur dioxide (SO_2) emissions by 11.82 kg/year.

LIFE+_Climate changE-R: Reduction of greenhouse gases from agricultural systems of Emilia-Romagna

Administrative data:

Status: Ongoing
Project reference: LIFE12 ENV/IT/000404
Duration: 1 July 2013 to 31 December 2016
Budget: EUR 1 853 900.00 (48 % EU contribution)
Coordinated in: Italy
Website: http://agricoltura.regione.emilia-romagna.it/climatechanger

([20]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4907&docType=pdf

Objectives:

The Climate changE-R ([21]) project aims to help reduce GHG emissions by 200 000 tonnes CO_{2e} over a three-year period in selected agricultural food chains (tomato, green bean, wheat, peaches and pears), and in the beef and milk production chains. Best practices will be tested and assessed through consultation with stakeholders and policy-makers. The analysis of best practices will also include an assessment of the impact of GHG reduction on agricultural productivity.

Expected results:

- A 3 % reduction in GHG emissions from agriculture compared to the current trend (equivalent to a reduction of 300 000 tonnes CO_{2e}/year, assessed for Emilia-Romagna from the 1990-2009 trend of the national inventory).
- Development of best practices for mitigating agricultural GHG emissions through techniques and means that are effective in reducing the release in the atmosphere of methane and natural gas (CH_4) of enteric origin and from manure; N_2O from soil and manure; and CO_2 from energy use, as well as in improving the soil's carbon sequestration.
- Mitigate climate change through the lessons learnt. Relevant governance practices will be applied in the forthcoming regional Rural Development Plan 2014-2020.
- Transition towards a low-carbon emissions economy in agriculture, thanks to dissemination of the project results among agriculture operators, citizens and consumers; and demonstration of the best practices to stakeholders and policy-makers at European, national and local levels.

LIFE AGROINTEGRA: Demonstration of sustainable alternatives to chemical products for European crop protection

Administrative data:

Status:	Ongoing
Project reference:	LIFE13 ENV/ES/000665
Duration:	1 July 2014 to 30 June 2017
Budget:	EUR 1 561 766.00 (50 % EU contribution)
Coordinated in:	Spain
Website:	http://www.agrointegra.eu/

Objectives:

The overall objective of LIFE AGROintegra ([22]) is to minimise the environmental risks in crop protection of cereals, vegetables, fruit trees and vineyards through the demonstration of the feasibility of more sustainable alternatives for pest, disease and weed controls, and support to the implementation of Directive 2009/128/EC of the European Parliament and of the Council, establishing a framework for Community action to achieve the sustainable use of pesticides by the targeted stakeholders.

The LIFE AGROintegra project aims to promote the most innovative tools available for integrated pest management (IPM) in the agricultural sector as a viable alternative to the use of chemical pesticides.

([21]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4564&docType=pdf

([22]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=5032

The project will demonstrate the environmental benefits of implementing alternative methods of crop protection, such as the biological and integrated control of plagues and the biological efficacy of low-risk phytosanitary products. It will design and implement IPM models in three different kinds of farm systems: fruit production, vineyards and extensive cultures — and on both irrigated and rain-fed lands.

In order to achieve this goal, LIFE AGROintegra has set the following specific objectives:

- Demonstrate the environmental benefits of implementing alternative methods of crop protection.
- Contribute to zero residue in food, thanks to IPM techniques.
- Bring innovative IPM techniques closer to farmers via practical demonstrations.
- Develop a specific Decision Support Tool (DST) for farmers, proposing methods for pest, disease and weed controls in each specific plot and situation.
- Raise awareness among farmers and advisors on the advantages of more sustainable crop protection methods, so that the transfer of knowledge, solutions and tools is comprehensive, effective and fast.
- Unify all knowledge generated in a working protocol that facilitates users in the change towards an integrated crop protection.

Expected results:

- Development of the HAD AGROINTEGRA web-based decision-making tool to help farmers identify the method of IPM that will be the most efficient in their particular situation.
- A protocol of training, advice, etc. to help farmers implement IPM.
- A reduction of at least 30 % in the volume of chemical protection used when compared to the current system.
- The avoidance of phytosanitary products that pose the greatest risk, thus delivering environmental benefits beyond that suggested by a simple measurement by volume.
- A contribution to achieving the targets set in the Spanish National Action Plan (NAP) on the sustainable use of pesticides.
- A contribution to the implementation of the European Directive (2009/128/CEE) on the sustainable use of pesticides.
- Dissemination of the project tools to more farms and situations — it is expected that by 2020, 80 % of European farmers will have integrated this model and be using IPM on their crops.
- A contribution towards the eventual objective of zero pesticide residues in the food chain.

LIFE.SU.SA.FRUIT — Low pesticide IPM in sustainable and safe fruit production

Administrative data:

Status:	Ongoing
Project reference:	LIFE13 ENV/HR/000580
Duration:	16 June 2014 to 16 December 2017
Budget:	EUR 1 839 378.00 (49 % EU contribution)
Coordinated in:	Croatia
Website:	http://www.life-susafruit.eu/

Objectives:

The project LIFE.SU.SA.FRUIT ([23]) aims to develop, apply and demonstrate an economically viable strategic plan to implement integrated pest management (IPM) by promoting the use of low chemical approaches in field and post-harvest fruit production in typical Croatian and Italian agro-ecosystems. The project intends to create an environmentally friendly management system for fruit production and storage, by making more efficient use of resources and ensuring that food safety is not compromised.

Expected results:

- Reduction of chemical pressure and of risks for growers (e.g. reduction of about 50 % of insecticides, and of about 25 % of chemicals used against diseases and pests).
- Reduction of agricultural costs and an increase in growers' profits, in terms of money and energy saved due to the use of exclusion netting systems (e.g. savings of about EUR 300-EUR 500/ha for the control of insects).
- Reduction of fruit losses (of at least 20 %) from pest and fungal diseases.
- Increase of fruit quality due to the effects of nets, on the basis of quality parameters such as firmness, colour, acidity and resistance to stem removal (RSR) (e.g. increase of sugar content of 1-1.5° Brix in apples).
- Reduction of pesticide residues (of at least 60 %, due to less insecticide and fungicide treatments, and to the hot water treatment to remove residue) and a consequent increase of food safety and decrease of risks for consumers and environmental health (e.g. lower pollution of water, soil and air).

LIFE-AGRICARE: Introducing innovative precision farming techniques in AGRIculture to decrease

Administrative data:

Status:	Ongoing
Project reference:	LIFE13 ENV/IT/000583
Duration:	1 June 2014 to 31 May 2017
Budget:	EUR 2 577 825.00 (38 % EU contribution)
Coordinated in:	Italy
Website:	-

Objectives:

The overall goal of the LIFE-AGRICARE ([24]) project is to demonstrate that the introduction of new integrated agriculture applications, incorporating precision farming technologies, have significant potential in terms of energy saving and GHG reductions.

The project will use four different crop systems to test and demonstrate the GHG mitigation potential of five types of new electronic and mechanical machines for minimum tillage and sustainable soil management. It will also work on benchmarking the effective potential for energy savings using equipment for precision farming and comparing it to traditional types.

Using modelling systems and GIS analysis, it will also evaluate the long-term effects of technology introductions upon the effects of climate change patterns in agriculture, as

([23]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4954&docType=pdf

([24]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4934

well as defining the Italian rural surfaces that are most suitable for introducing the tested technologies.

Expected results:

- Conducting 83 trials for low-carbon farming.
- Benchmarks for the mechanical operations, in terms of plant growth, yield, soil characteristics, energy and CO_2 consumption.
- Complete three comparative assessments, concerning plant production for each crop management technique, emissions and energy consumption, GHGs during the trials, and the economic benefits delivered.
- A model simulation of the long-term effects of new crop systems on carbon storage and GHG emission from soils, as well as the nitrogen balance.
- Report comparing the different technological solutions tested from the point of view of long-term soil carbon content.
- An evaluation analysis of the Italian arable land surfaces that could be suitable for the diffusion of new tillage and management techniques.
- Online tool for farmers for the self-assessment of the environmental impacts of innovative techniques in terms of GHG emissions.
- Evaluation of carbon market benefits showing the potential effects of tested technologies in providing meaningful carbon credits.
- Lifecycle assessment implemented for each of the four demonstration tests to assess the overall environmental impacts.

LIFE LIVE-WASTE: Sustainable management of livestock waste for the removal/recovery of nutrients

Administrative data:

Status:	Ongoing
Project reference:	LIFE12 ENV/CY/000544
Duration:	1 September 2013 to 31 August 2016
Budget:	EUR 2 147 182.00 (50 % EU contribution)
Coordinated in:	Cyprus
Website:	http://livewaste.org/

Objectives:

The main objective of LIVEWASTE ([25]) is to develop, demonstrate and evaluate an innovative decentralised approach for the sustainable management of livestock waste, so as to achieve environmental protection and climate change mitigation in line with the requirements of the EU and national legislation through actions complementary to those of the Competitiveness and Innovation Framework Programme.

The project activities introduce a high level of innovation concerning the development, operation and evaluation of a prototype system for livestock treatment and for the post-treatment of the by-products derived from the involved processes (combination of advanced biological and chemical treatment processes), resulting in the recovery of materials and energy, and developing a concrete market for the end products (i.e. energy, compost, reusable effluent and phosphorous). Furthermore, innovative assessment methodologies and tools will be developed and demonstrated for the evaluation of the applied livestock waste management scheme. The project provides

([25]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4501

insight on how the sustainable livestock waste scheme can be implemented on a larger scale in Cyprus, Italy, Greece, Spain and other EU countries.

Expected results:

- Identification of livestock waste production sources.
- An integrated methodology for effective livestock waste management.
- High-quality compost and the treatment of effluent phosphorus.
- Minimisation of the environmental disturbance resulting from the production, treatment and disposal of livestock waste.
- Reduction of greenhouse gas emissions.
- An assessment tool for the environmental and socioeconomic evaluation of the livestock waste management.
- A strategic plan for the integrated management of livestock waste in EU countries.
- Assessment of the environmental impact and the burden on climate change from current livestock waste management practices.

LIFE+Farms for the future: Farms for the future: Innovation for sustainable manure management from farm to soil

Administrative data:

Status:	Ongoing
Project reference:	LIFE12 ENV/ES/000647
Duration:	10 September 2013 to 9 September 2017
Budget:	EUR 2 367 610.00 (50 % EU contribution)
Coordinated in:	Spain
Website:	http://www.futuragrari.cat/

Objectives:

FUTUR AGRARI — Farms for the future ([26]) is a project that puts into practice manure management and treatment technologies in areas of Catalonia (Spain) that have a high concentration of livestock farming and are designated 'vulnerable zones'.

The project aims to minimise the extent of nutrient excesses in soils caused by the pig farming sector by acting in three main areas: on pig farms; where manure is applied to the land; and in soils affected by agricultural nutrient excess.

The project is for illustrative purposes and is aimed mainly at farms, service companies, their administration and the sector in general.

Expected results:

- A 20 % saving in water and nutrient output on pig farms.
- A 25 % reduction in the effective area of manure application.
- A 10 % reduction in management costs for manure application.
- Increased number of areas with catch crops, forest and riparian buffers.
- A 20 % increase in biogas production.

([26]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4663

GREENGASGRIDS: Boosting the European market for biogas production, upgrade and feed-in into the natural gas grid

Administrative data:

Status:	Finished
Project reference:	IEE/10/235
Duration:	1 June 2011 to 31 May 2014
Budget:	EUR 1 998 129.00 (75 % EU contribution)
Coordinated in:	Germany
Website:	http://www.greengasgrids.eu

Objectives:

The overall objective of the GREENGASGRIDS project ([27]) is to increase the production and use of bio methane for transport, heat and electricity by addressing the most hindering barriers to bio methane deployment in the EU by means of: a) hands-on know-how transfers from 'forerunner' to 'starter' countries, b) support the search for solutions to market barriers, c) bring together potential business partners, d) promote bio methane projects in countries with high potential but few activities.

Expected results:

- Provided know-how transfers from forerunner to starter countries with regard to bio methane market development.
- Passed hands-on experience and information to starter countries.
- Developed national roadmaps together with national stakeholders to address country-specific settings and barriers.
- Arranged business matchmaking.
- Developed business models for bio methane projects.
- Addressed EU-level legislative support by developing an EU roadmap for bio methane.

AQUASEF: Eco-efficient technologies development for environmental improvement of aquaculture

Administrative data:

Status:	Ongoing
Project reference:	LIFE13 ENV/ES/000420
Duration:	2 June 2014 to 30 June 2017
Budget:	EUR 1 899 318.00 (48.5 % EU contribution)
Coordinated in:	Spain
Website:	http://www.aquasef.com/

Objectives:

The main objective of this project ([28]) is to demonstrate, promote and spread across the EU, innovation-efficient and low-emission technologies and the best practices to be implemented in the aquaculture sector. This project proposes measures to reduce energy dependency on the installation, the oxygen dependence of the tanks and the environmental impact by using techniques of effluent treatment and fixation of CO2 emitted by the cultivation of microalgae. This action provides added value to the production in three ways: it adds nutrition to the diet of fish and molluscs by making the

([27]) http://ec.europa.eu/energy/intelligent/projects/en/projects/greengasgrids

([28]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4919&docType=pdf

contribution of chemical growing additives unnecessary, the CO2 fixation reduces the total GHG emissions balance, and it purifies the effects of effluents from the culture tanks.

In short, this project aims to reduce the carbon footprint and improve the water quality of the effluent through the implementation of innovative technologies that improve the environmental sustainability of fish and mollusc farming in a salt-water cycle on a global basis.

Specifically, the project will demonstrate the possibility of optimising energy consumption by implementing best management practices and using renewable energy. This project will consider three power generators (two photovoltaic and one wind turbine) in a test aquaculture facility and an electrolyser of 5 kW powered by renewable energy for the oxygen production. Moreover, high-efficiency aerators will be installed, the added value of microalgae will be used as feed for the fish and molluscs, and the purification of effluents will be demonstrated.

Expected results:

- Decrease fossil fuel consumption by not having the generator working 25 % of the time (thus saving 659 MWh/year of electricity) and avoiding 17.4 tonnes of CO_2/year.
- Increase the efficiency by producing *in situ* oxygen automatically via a renewable method, assuming that a route to achieving lower emissions is generated.

The project intends to publicise its findings to the final consumer and the public in general on how the technology can promote quality food cultivated in a sustainable and respectful manner using environmental resources.

INDUFOOD: Reducing GHG emissions in the food industry through alternative thermal systems based on induction technology

Administrative data:

Status:	Ongoing
Project reference:	LIFE11 ENV/ES/000530
Duration:	1 August 2012 to 31 October 2015
Budget:	EUR 1 097 199.00 (50 % EU contribution)
Coordinated in:	Spain
Website:	http://www.indufood.org/

Objectives:

The INDUFOOD project's ([29]) main objective is to reduce emissions of greenhouse gases from thermal processes in the seafood processing industry. It plans to design, develop and test a new induction system, which would provide an alternative source of heat and avoid the use of fossil fuels. The project ultimately hopes to contribute to the implementation of EU commitments under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC).

As well as building the pilot plant for the induction system, the project will develop a software application to calculate the carbon footprint of different functional units. It will calculate the CO_2 emissions generated by each system by multiplying fuel consumption with a corresponding emission factor.

([29]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4261

The project will analyse different thermal systems used in the cooking and sterilisation of seafood. It will compare the carbon footprint and financial costs of different functional units consuming fossil fuels with units using the new thermal processes based on induction technology. The project expects to demonstrate both the feasibility of the new technology and its benefits in terms of increased energy efficiency, reduced costs and lower GHG emissions.

Expected results:

- Validated thermal processes for the seafood processing industry based on induction technology.
- Significantly reduced CO_2 emissions compared to traditional processes.
- Improved energy efficiency, lower energy consumption and reduced costs, which will help to improve the competitiveness of the sector.

3. Energy-related challenges and solutions in food production — beyond the farm gate

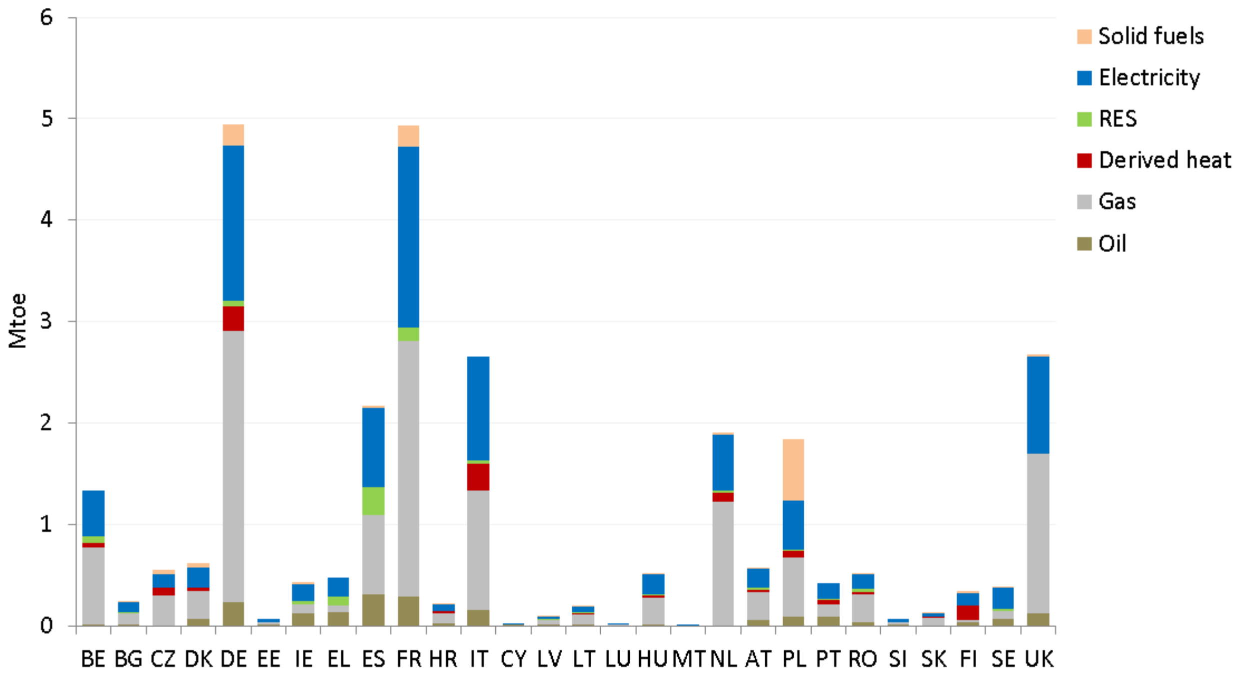
Accounting for the majority of energy embedded in the EU food consumption (66.6 % according to analyses in Chapter 0), the part of the food supply chain beyond the farm gate has been subdivided into food processing (with 28 % of energy embedded), logistics (9.4 %), packaging (10.7 %), use (13 %) and end of use (5.5 %).

This Chapter presents and discusses the main challenges and solutions for improving energy use in this segment of the supply chain. In the case of the food processing industry, the issue of increasing renewable energy sources will be also examined. Examples from EU research programmes will again complement the chapter.

3.1 Improving energy use in food transformation and the processing industry

3.1.1 Current situation and recent trends

According to Eurostat, the total direct energy consumed by the European food industry amounted to 28.4 Mtoe, accounting for about 2.6 % of the EU-28 average final energy consumption in 2013. In Member States this share broadly ranged between a few tenths of percentage points and 4 % of the national final energy consumption. Figure 3.1 shows the actual energy mix of the food sector industry in the EU-28 in absolute (top panel) and relative (bottom panel) terms in 2013. Gas (47.8 %), electricity (34 %) and oil (7 %) have dominated this sector's energy mix in 2013 with renewables accounting for 3 %.



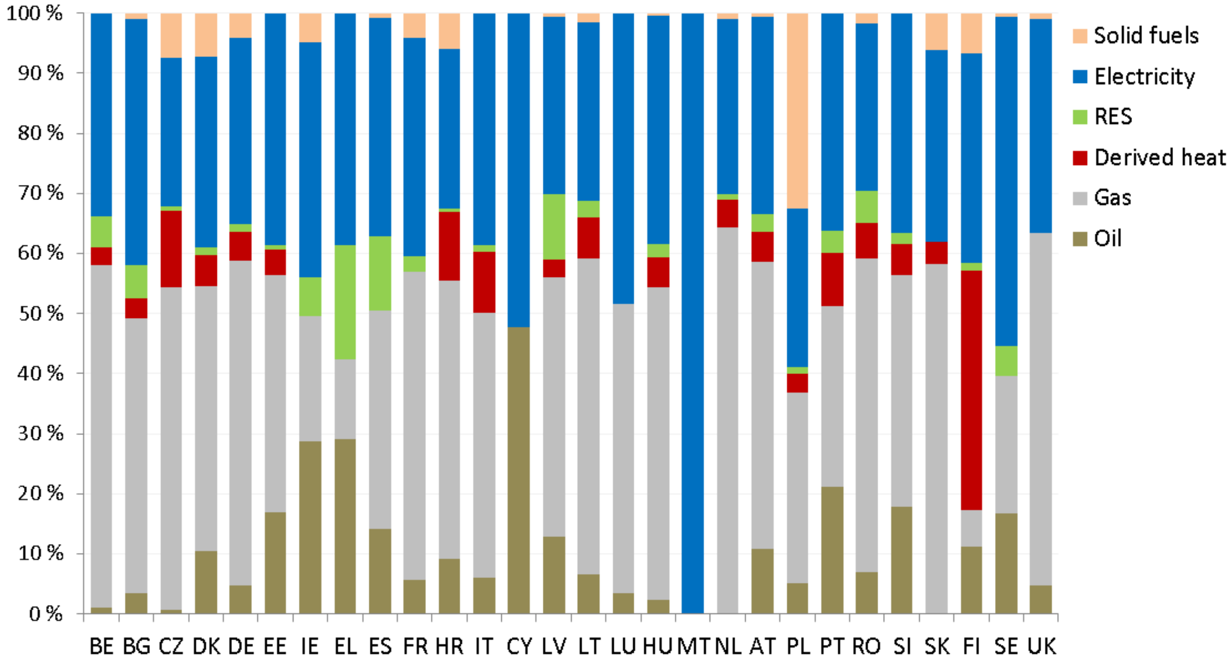


Figure 3.1 Direct energy consumption of the food sector in the EU-28 and its energy resources mix in absolute (top panel) and relative (bottom panel) terms for 2013. Source: Eurostat ([30]).

According to UNIDO (2007) as cited by FAO (2012, p. 29), the degree of industrial food processing depends on the economy of the country: in low-income countries, 30 % of food is industrially processed, while in high-income countries 98 % of food is processed more or less intensively. As for any other industrial product, the more processed the food, the higher the energy consumption required. The energy consumed per unit of processed foodstuff is very diverse among products (see also the JRC analysis described in Chapter 1) and event for the same product, it is very different depending on the country. Numerous studies have focused in energy needs for processing particular food products. Just citing the products analysed in the more recent studies: milk (Mancini, 2011; Ramirez, Patel. and Blok, 2006a), parmesan cheese (Mancini, 2011), meat (Fritzson and Berntsson, 2006; Mancini, 2011; Ramirez, Patel. and Blok, 2006b), pasta (Mancini, 2011), pastry (Kannan & Boie, 2003), rice (Mancini, 2011) or natural orange juice (Mancini, 2011).With such an ample diversity in energy needs, it is difficult to address actual energy improvements at the sectorial level. Production structure also has a role: a decrease in the industry energy consumption per product unit could be equally caused by an improvement in efficiency or a shift in production towards intrinsically less energy-intensive products.

Neverthless a positive trend is evident. Figure 3.2 shows how energy consumption in the food industry has steadily decreased in recent years, both in absolute terms and, even further, in terms of energy consumption per unit of production value. Such an observation provides an indication ([31]) of an ongoing pathway towards increasing energy

([30]) According to Eurostat's definition, derived heat covers the total commercialised heat produced in heating plants and in combined heat and power plants. It includes the heat used by the ancillary installations and losses in the installation/network heat exchanges. For auto producing entities (i.e. entities generating electricity and/or heat wholly or partially for their own use), the heat used by the operation for its own processes is not included.

([31]) The indicators shown in Figure 1.11 is just a partial indication of improved energy use, as a decrease of energy per production value could be also obtained in principle just by shifting production towards more remunerative productions, without acting on physical energy consumption.

efficiency. For the Dutch industry the detailed study by Ramírez, Blok *et al.* (2006) based on a much more complex pool of indicators, confirmed the trend. FoodDrink Europe (2012a) has also reported a decrease of GHG emissions per unit of production value, again suggesting an ongoing trend towards a more appropriate and optimised energy use in the sector.

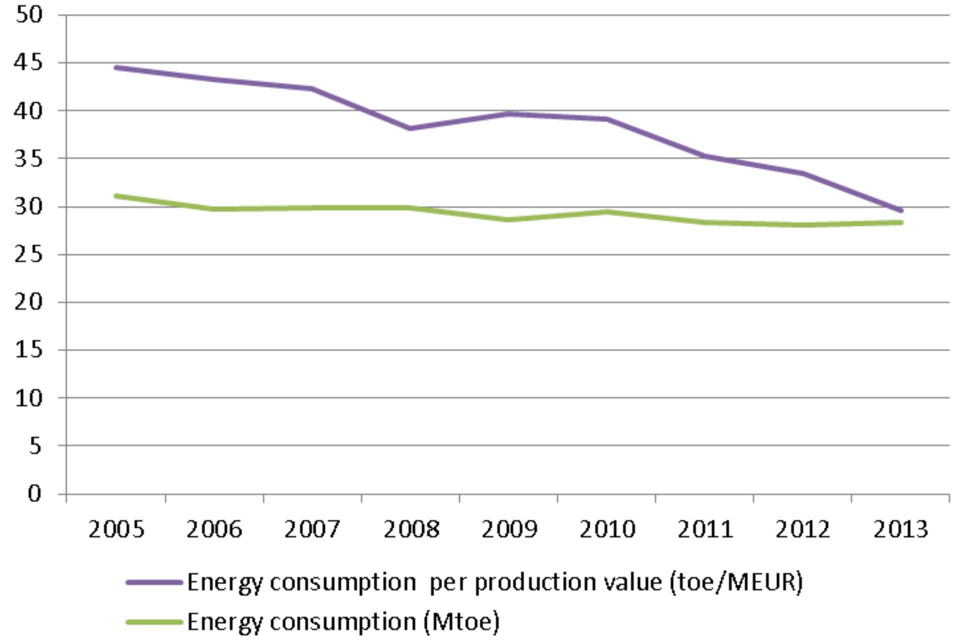


Figure 3.2 Energy consumption in the food sector in the EU-27 (EU-28 since 2011) in absolute terms (Mtoe) and per unit of production value (toe/EUR million) in 2005-2013. Source: own analysis of Eurostat data.

Such a success in producing more while using less energy.is especially relevant if one considers that food industry has some structural features that make energy efficiency difficult to be pursued.

Firstly, from the business-size perspective, the food industry in the EU-28 is largely dominated by small and medium-sized enterprises (SMEs). 99.1 % of around 287 000 companies operating in the sector have less than 250 employees (FoodDrinkEurope, 2012a, 2012b). Even if in terms of turnover (49 % in SMEs, the rest in large companies), value added (48 % in SMEs, the rest in large companies) and employment (64 % in SMEs, the rest in large companies) the SMEs share is less overwhelming, such a business fragmentation leads to a very large number of food processing sites of the most diverse kind. Among many others, Thollander and Palm (2013) have explained how applying effective energy-efficiency measures or promoting RE deployment in diversified and parcelled sectors is especially challenging.

Muller *et al.* (2007) classified the food industry as one of the less energy-intensive industries. According to these authors, on average, the direct energy cost was accounting (at the time of their analysis) for just 3 % of the total cost of production for the average company. For this reason, company managers generally look for cost optimisation in other areas, before addressing possible savings in energy consumption.

3.1.2 Technological and processes optimisation

Process optimisation can decrease energy use in industry. While certain energy ‘costs’ cannot be avoided, such as in chilling, freezing, or cooking, etc. the manner in which the process is carried out can lead to substantial savings.

According to Altmann *et al.* (2010), food production in Europe still has a notable energy savings potential. Figure 3.3 illustrates that the technical energy savings potential per value added can be estimated to be 15 % by 2020 (22 % by 2030) compared to 2004, according to the EU Database on Energy Saving Potentials (Altmann, Michalski, Brenninkmeijer and Tisserand, 2015).

Nevertheless, without policy or behavioural changes (i.e. in the situation represented by the 'autonomous' scenario in Figure 3.3) only 5-7 % specific energy reductions are likely to be achieved by 2020-2030. The economically feasible savings potential, between the autonomous and the technical potential, is represented by low policy intensity (LPI) and high policy intensity (HPI) scenarios in Figure 3.3, both leading to an intermediate result of 11-13 % energy savings in 2020 and 17 % in 2030.

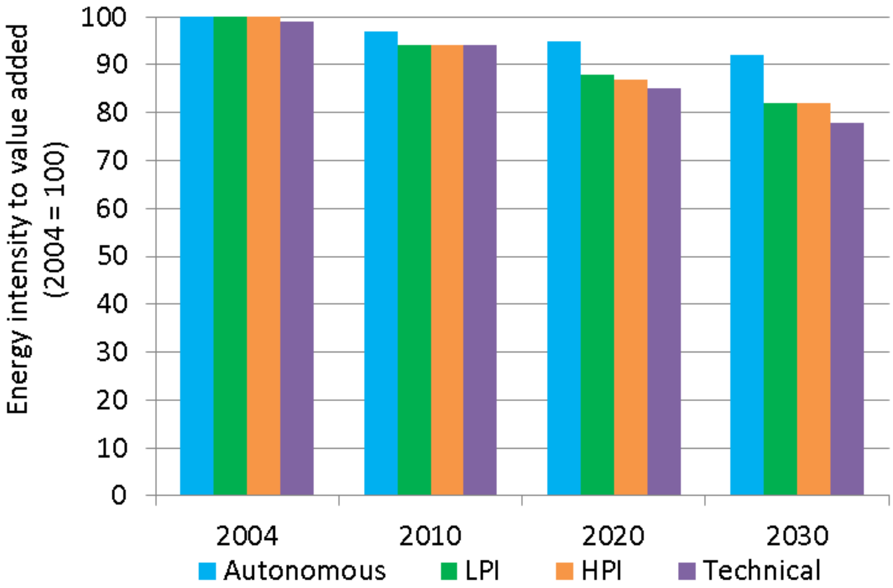


Figure 3.3 Energy intensity to value added in the food industry (EU-27) up to 2030 for the four EEPotential scenarios. Source: Authors´ own analysis based on the EEPotential database (Altmann et al., 2015).

It is also worth noticing that electricity consumption, even though it accounts accounting for one-third of the overall energy consumption in the sector, provides the larger saving potential: above 30 % in 2030 according to the EEPotential 'technical' scenario (see Figure 3.4).

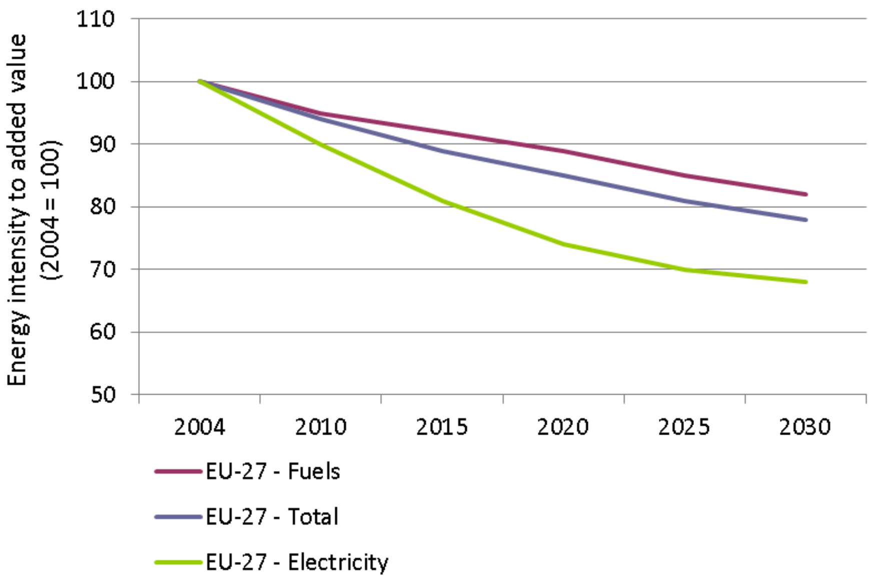


Figure 3.4 Total energy intensity to value added in the food industry (EU-27), and for electricity and other fuel consumption for the 'technical' EEPotential scenario. Source: Authors´ own analysis based on EEPotential (2015).

Moving to a process analysis, cooling and freezing account for about 30 % of electricity consumption in the food industry, a relatively high share if compared with other industrial sectors (see Figure 3.5 and Figure 3.6). According to Eichhammer *et al.* (2009), cooling and freezing has a 30 % long-term technical potential for energy savings and a cost-effective savings potential of 20-26 % by 2030. Other cross-cutting technologies have cost-effective savings potentials of 32-40 % by 2030 and represent an important savings potential in the whole food processing industry.

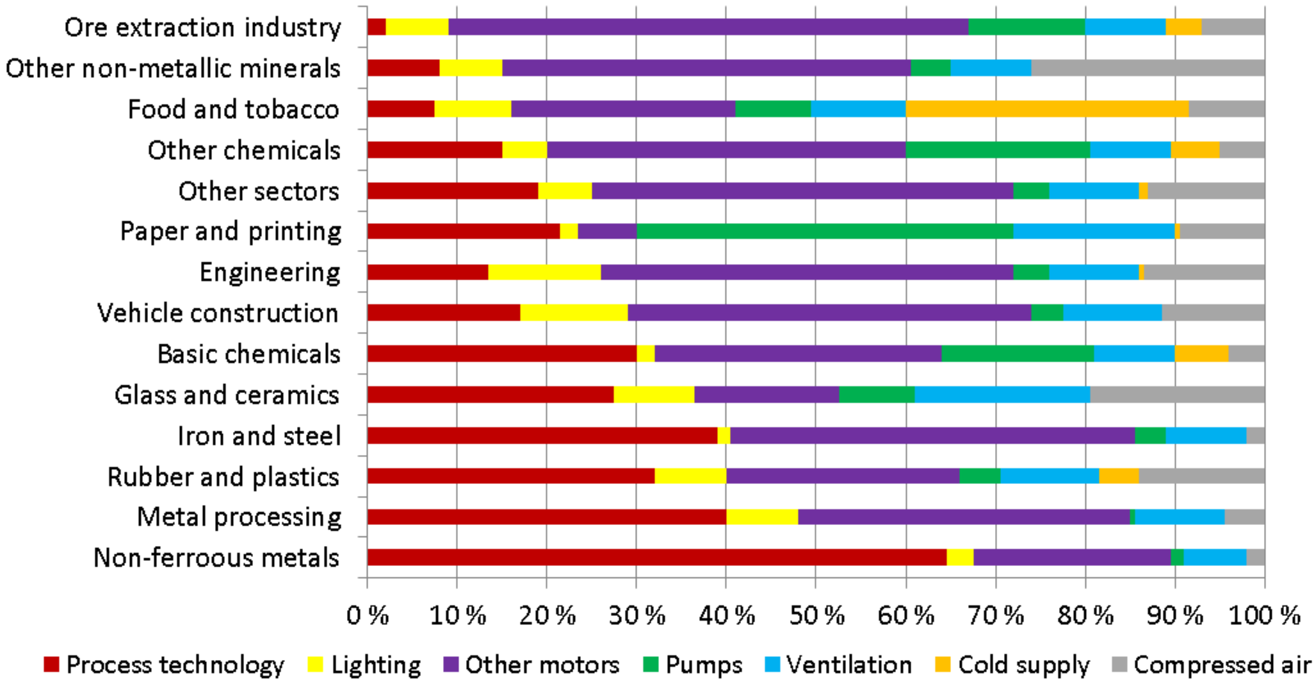


Figure 3.5 Share of electricity consumption of cross-cutting technologies by sector. Source: Authors' own analysis based on data included in (Altmann et al., 2010).

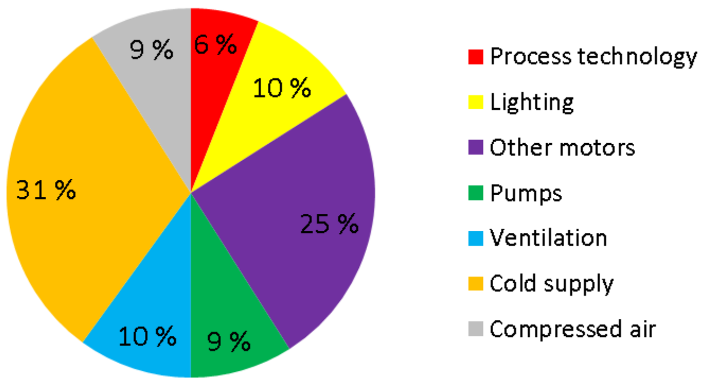


Figure 3.6 Share of electricity consumption of cross-cutting technologies in the food sector. Source: Authors´ own analysis based on EEPotential (2015).

Abdelaziz *et al.* (2011) have provided a general overview of industrial energy-saving opportunities, valid for each kind of industrial reality, promptly summarised by Siemens (2011) as 'the top 10 energy saving tips' in the industrial sector. Possible measures span from high-efficiency motors and increased use of combined heat and power (CHP) to intelligent and efficient lighting and appliances' voltage optimisation, all of which can be integrated in a comprehensive energy management system for the factory.

Thollander and Palm (2013) have focused their attention on individual processes especially important in the food sector. Eleven general production processes were identified in decomposition, mixing, cutting, joining, coating, forming, heating, melting, drying/concentration, cooling/freezing, and packing. Seven support processes were also defined, namely: lighting, compressed air, ventilation, pumping, space heating and cooling, hot tap water, and internal transport. A major result of the analysis is that in low energy-intensive SMEs, the largest share of energy is consumed in support processes (up to 70 %), while in larger energy-intensive factories, energy is mostly fed into production processes (up to 85 %). Such an energy consumption structure is an opprtunity for the low energy-intensive SMEs so common in the food industry: energy saving interventions on support processes are generally less expensive and more feasible than interventions on capital-intensive production processes.

Consistent with this picture, Kaminski and Leduc (2010) have identified the most important systems and processes where significant energy-efficiency improvements can be achieved in the EU's food industry: steam systems, motor and pump systems, compressed air systems, process cooling and refrigeration, and heating and lighting of buildings. The authors have also established a wide range of possible practical improvements for the named systems (e.g. leak maintenance, proper motor sizing, condensate return systems, etc.) and have ranked them based on payback time and energy saved, as illustrated in Figure 3.7.

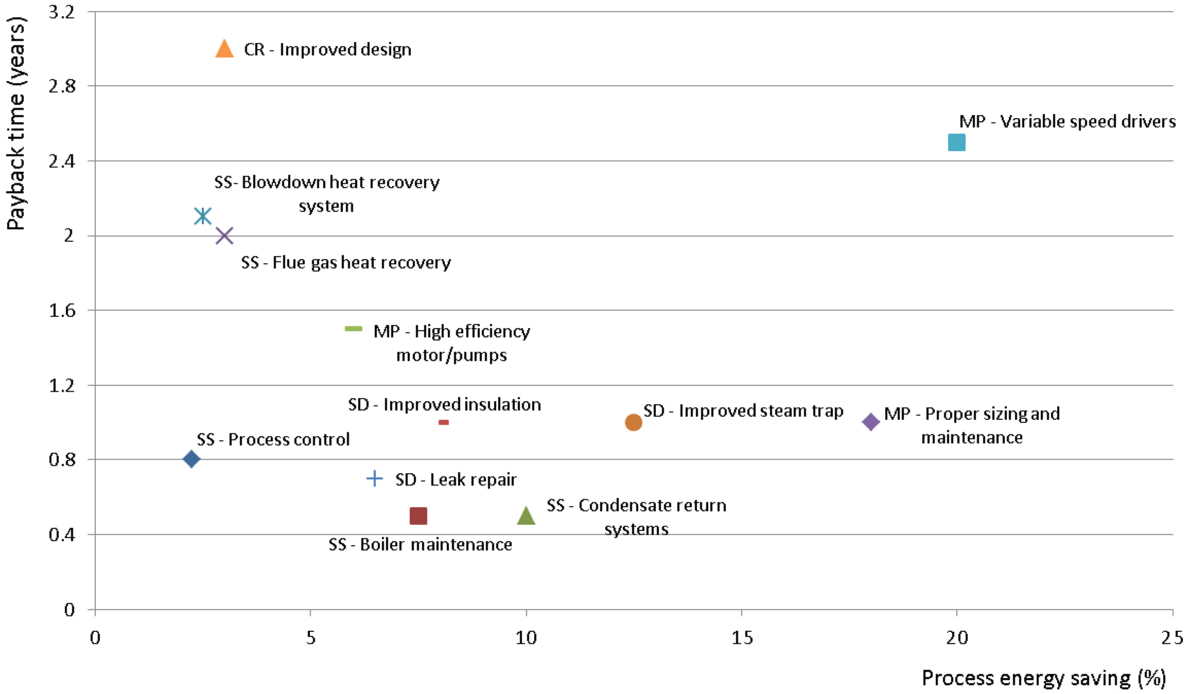


Figure 3.7 Payback time (years) versus process energy savings (%) for some improvements in the food industry, identified by Kaminski and Leduc (2010).
Key: SS: Steam systems; SD: Steam distribution; MP: Motors and pumps; CR: Cooling and refrigeration.

Other studies have targeted specific single unit processes. As an example, Burfoot *et al.* (2004) have assessed the energy savings arising from substituting ambient cooling with localised cold air delivery in chilled food production, while Damour *et al.* (2012) have shown the benefits of optimising defrosting systems. Opportunities provided by heat recovery optimisation in complex production lines have been investigated by Miah *et al.* (2014) for a multi-product confectionery factory. Krasulya *et al.* (2014) have reported tangible energy savings obtained from the introduction of ultrasound-based tools in some typical processes within the food industry, such as such as emulsification, filtration, tenderisation and functionality modification (Chandrapala, Oliver, Kentish and Ashokkumar, 2012).

3.1.3 Plant system improvement

Even when possible energy improvements are identified at process level, the actual savings achievable at plant level are not always straightforward to evaluate. Savings depend on the relative share of each process in the global factory budget, the actual plant design, its age and the maintenance status. Moreover, different improvements to the same process do not necessarily sum up their effects.

In order to guide plant managers towards the practical implementation of effective energy-efficiency measures, Muller *et al.* (2007) have developed a linear regression model aimed at tracking energy-saving opportunities specifically tailored to the food-processing industry. The method has to be fed with actual design data and plant operation data for a given period in order to identify the most effective possible interventions. The model was tested on an actual multi-product Swiss food factory, identifying, for the test case, possible improvements mostly related to air compression and vacuum production. A more direct approach to energy management, which targeted a small-size German bakery, was described by Kannan and Boie (2003). In this case, the combination of energy audit (see section 4.1.3) and the production of consistent energy balance sheets have enabled the production unit to permanently save about 7 % of energy at little or no cost.

Generally speaking, process analyses are difficult to be extended beyond the single plant test case since results strongly depend on the specific parameters of the plant itself. As an exception to this, Sokhna Seck *et al*. (2013) have developed a full bottom-up study for energy savings derived from heat recovery and heat pumps across the entire food and drink sector in France. The study was based on the application of the MARKAL-TIMES model of the French low-energy intensity industry sector, providing estimates of about 8 TWh of potential cumulated savings up to 2020.

3.1.4 In-the-plant energy re-use

Energy can be saved also thanks to in-the-plant re-use of production residues for self-energy generation (Hall and Howe, 2012), in particular through the anaerobic digestion (AD) of organic residues. Biodegradable residues are processed in AD plants by anaerobic microorganisms producing biogas (see paragraph 2.4.3) and solid and liquid substrates. Biogas is suitable for onsite uses such as local cogeneration of heat and power or oven and/or boiler fuelling. Within this topic, Jensen and Govindan (2014) have analysed the case of a Danish bakery company producing an average of 20 000 tonnes of residues per year and have evaluated the suitability of both local power and heat cogeneration alternatives from a business perspective. The business model is in this case feasible, with a return of investment generally favourable for both options. However, attention has to be given to boundary conditions deriving from national incentive policies, if existing.

3.1.5 Examples of relevant recent EU-funded projects([32])

ENTHALPY: Enabling the drying process to save energy and water, realising process efficiency in the dairy chain

Administrative data:

Status:	Ongoing
Project reference:	613732, under FP7-KBBE
Duration:	1 November 2013to 31 October 2016
Budget:	EUR 8 312 221.00 (72 % EU contribution)
Coordinated in:	Netherlands
Website:	http://www.enthalpy-fp7.eu/

Objectives:

The project ENTHALPY ([33]), funded by the Seventh Framework Programme (FP7), aims to significantly reduce energy and water consumption in the European dairy industry through a selected pool of technologies especially suitable for the SME sector framework. The proposal has significant SME participation in order to realise industrial and commercial relevance.

Energy savings are expected to reach 63 % and water savings 18 %. This will lead to increased competitiveness in the dairy sector.

The work packages address radio frequency heating, solar thermal energy, mono-disperse atomising, dryer modelling, online monitoring and cleaning with enzymes and membrane technology. Such a technology pool will allow energy and water loops to be closed instead of lost in the plant. These technologies will be demonstrated in pilot facilities.

Expected results:

([32]) Other real-world case studies and examples of best practice are also described in the Best Practice report developed by the Joint Research Centre for the Food and Drink Manufacturing sector; more information available at http://susproc.jrc.ec.europa.eu/activities/emas/fooddrink.html

([33]) http://cordis.europa.eu/project/rcn/110707_en.html

- Saving of energy in a dairy spray-drying plant: Improvements across the production process will lead to substantial energy savings.
- Water saving and recovery in a dairy spray-drying plant: Enhanced cleaning procedures combined with the recovery of water produced during the drying process will notably reduce the water consumption.
- Reducing environmental load: Due to the elimination of fines in the spray drying process and the recirculation of processing air, the output of atmospheric particulate matter will also be nullified.
- Optimised emerging and novel food production technologies: It will become possible to predict and tune the powder properties in order to obtain a desired product.
- Diagnosis of, for example, water and energy consumption within the food processing chain: The innovations introduced through this project will allow the implementation of inline monitoring in spray-drying towers. The information gained will enable a better diagnosis of the drying process.

Public deliverables: http://www.enthalpy-fp7.eu/public-deliverables/

LIFE ECO-DHYBAT: Demonstration of hygienic eco-design of food processing equipment as best available technique.

Administrative data:

Status:	Ongoing
Project reference:	LIFE12 ENV/ES/001070
Duration:	10 October 2013 to 30 September 2016
Budget:	EUR 874 089.00 (50 % EU contribution)
Coordinated in:	Spain
Website:	http://www.ecodhybat.com/

Objectives:

The general objective of the LIFE+ ECODHYBAT ([34]) project is to demonstrate that a proper eco-design criterion can reduce the consumption (and thus cost) of water, energy and chemical cleaning and disinfection agents of food processing companies, as well as the environmental cost of the sanitation processes.

Indeed, most of the equipment used by the food industry is sanitised (cleaned and disinfected) daily, in some cases several times per day, thus implying a respective consumption of water, energy and chemicals. The ECODHYBAT project aims to provide suitable experimental results at an industrial scale in two representative sectors: dairy and fish processing. The environmental impact (water, energy, cleaning products, waste water and air emissions) generated by the sanitation of hygienic eco-designed equipment and surfaces will be compared with standard ones. The results obtained here could be extrapolated to other food sectors.

Expected results:

- Sufficient data generated about the hygienic eco-design of food equipment to enable its assessment by the European Integrated Pollution Prevention and Control (IPPC) Bureau as an emerging technique for the next updating of the Food, Drink and Milk BAT Reference Documents (BREF).
- Reduced consumption of chemical cleaning agents.
- Reduced water consumption in the cleaning of food equipment by 10-30 % – partly dependent on the type of equipment.

([34]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4693&docType=pdf

- Reduced energy consumption by 10-20 %.
- Reduced total CO_2 emissions — direct and indirect — related to the cleaning of food equipment by 20-30 %.
- Reduced organic load and chemical contamination of waste water generated by cleaning activities in the food sector.

ENREMILK: Integrated engineering approach validating reduced water and energy consumption in milk processing for wider food supply chain replication

Administrative data:

Status:	Ongoing
Project reference:	613968, under FP7-KBBE
Duration:	1 January 2014 to 31 December 2017
Budget:	EUR 7 202 424.00 (74 % EU contribution)
Coordinated in:	Germany
Website:	http://www.enremilk.eu/

Objectives:

The FP7-funded EnReMilk ([35]) is a demonstration project aiming to achieve significant water and energy savings in representative dairy, mozzarella and milk powder production, across the whole supply chain. Savings will be validated against a consumption baseline of existing operations, both in model simulations and in physical trials involving emerging and novel engineering technologies. It will ensure a smooth transition into practical implementation, providing an innovation-driven increase in the competitiveness of the EU dairy sector. EnReMilk will ensure that engineering innovations are verified as environmentally sustainable, economically viable and socially responsible, and that food quality and safety is not compromised.

STEAMDRY: Superheated steam-based process for low energy and high quality drying of food and food residues

Administrative data:

Status:	Ongoing
Project reference:	605228, under FP7-SME
Duration:	1 November 2013 to 31 October 2015
Budget:	EUR 1 489 300.00 (74 % EU contribution)
Coordinated in:	Spain
Website:	http://www.steamdry.eu/

The SteamDry project ([36]) stems from the current trend in the EU market for processed foods. There is an increasing demand by consumers for foods that have undergone fewer changes during processing, and foods that look less processed and are closer to their original state whilst retaining high nutritive values, flavour and a 'natural' image.

SMEs manufacturing food processing machinery must not only improve the drying process so as to achieve the high quality demanded across the EU customer base, but they must also tackle the energy consumption and pollution issues that are typical of such equipment.

These SMEs have to respond to these demands and enable the dried food industries to tackle the following issues:

([35]) http://cordis.europa.eu/project/rcn/111424_en.html
([36]) http://cordis.europa.eu/project/rcn/110203_en.html

- low quality of the final dried products (50 % of the nutrients, vitamins and aroma are currently lost);
- high energy consumption required to dry the raw materials (conventional dryers have an efficiency level of 40-60 %);
- significant environmental pollution (via odour and CO_2 emissions).

Objectives:

The SteamDry project aims at offering European food producers and food processing industries an efficient and sustainable solution to dry their products and maintain the quality. In order to achieve this goal, the consortium partners will develop the following innovative components:

- A new dryer using superheated steam + low pressure technology: this ensures efficiency through better heat transfer and a better quality of product due to the lower temperature.
- Two-step cleaning system: this removes the dust/particles from the extra steam and allows its re-use in the upstream process, thus reducing the energy bill.
- Food quality multi-sensor and process control: this will be integrated in the process control to monitor the drying quality together with the energy balance of the system.

Expected results:

- Increase in final product quality: 80 % retention of nutrients, vitamins and aroma retention.
- Reduction in energy consumption: the new dryer with higher drying rates (1 500-2 000 kJ/kg H20) + the re-use of steam for evaporation + the re-use of the local available thermal energy will enable a reduction in total energy use of up to 60 %.
- Respecting the EU environmental policies and directives: low odour generation, CO_2 emissions below 60 kg/tonnes dried.

NANOBAK2: Innovative and energy-efficient proofing/cooling technology based on ultrasonic humidification for high quality bakery products

Administrative data:

Status:	Ongoing
Project reference:	FP7-KBBE 613622
Duration:	1 November 2013 to 31 October 2015
Budget:	EUR 2 297 140.00 (76 % EU contribution)
Coordinated in:	Netherlands
Website:	http://www.nanobak2.eu/

Objectives:

The project NanoBAK2 ([37]) aims to take up the successful research results from the earlier research project NanoBAK. It will scale up, demonstrate and disseminate the technical and economic innovation of a climate chamber for proofing and cooling with an innovative, energy-saving ultrasonic-based humidification system for the manufacture of high quality products in SME bakeries.

([37]) http://cordis.europa.eu/project/rcn/110706_es.html

- Uptake of NanoBAK results and development of two pre-commercial climatic chambers (for proofing and cooling) for direct market application in the SME bakery sector.
- Provision of an innovative, safe and energy-efficient solution for bread-making processes in SME bakeries.
- Increase in quality of all baked goods, especially with regard to avoidance of dehydration and of crust splattering by the realisation of permanent moistening.

Environmental objectives:

- Reduction of energy demand in current proofing/cooling processes by up to 60 %.
- Improvement of energy efficiency in bread-making processes.
- Apply the goals of the Environmental Technologies Action Plan (ETAP) (EC 2004), by helping decouple industrial development from environmental impacts.
- Evaluation of the economic and environmental aspects, as well as emissions and resource depletion, through life cycle assessment (LCA) and life cycle costing (LCC) methodologies.

This new technology is based on a climatic chamber for fermentation and cooling with an innovative energy-saving UltraBAK technology for the manufacturing of high quality bakery products.

The system can be used for three parts of the fermentation process (direct, retarding and interrupting fermentation) as a single fermentation chamber or as a single cooling unit (especially for the cooling of par-baked and fully baked goods), or as a multifunctional system covering both processes.

Compared to conventional humidifiers, where water is heated up, evaporated and cooled down to the required temperature, this new ultrasonic humidification system operates at a very low level of energy consumption. The technical and scientific results achieved so far have been excellent and very promising in terms of energy and cost efficiency.

LEO: Low energy ovens

Administrative data:

Status:	Ongoing
Project reference:	FP7-KBBE 613581
Duration:	1 January 2014 to 31 December 2015
Budget:	EUR 1 847 190.00 (76 % EU contribution)
Coordinated in:	Luxembourg
Website:	http://leo-fp7.eu/

The overall goal of the LEO project ([38]) is to develop three types of oven: i) batch-deck oven, ii) batch-rack oven and iii) conveyor oven. These ovens will be based on a similar technology to reduce energy consumption and save time during the baking process for a wide target group (craft bakery and bake-off actors). The LEO infrared technology will provide an overall reduction in energy of between 20 % and 40 %, and can be used in a two-step process (preheating and/or baking). The technology can be applied to partly baked bread (bake-off) and fully baked bread onsite (retail in-store and craft bakeries).

The LEO project aims to build prototypes for future commercialisation by SMEs involved in oven manufacturing (Ircon and Ramalhos), demonstrate their efficiency by the consortium SME bakeries (BPA and Die Havenbäcker), with the support of the research and technology development (RTD) partners (SIK and ONIRIS) and the SME service providers (LEMPA, Blonk and Intelligentsia).

([38]) http://cordis.europa.eu/project/rcn/110703_en.html

Objectives:

- Allow the exploitation of the FP6 EU-FRESHBAKE project results based on further R & D activities.
- Develop and demonstrate three infrared ovens ready for commercialisation on the market.
- Conduct an environmental, social and economic life cycle assessment in line with IRLCD to propose eco-designed ovens.
- Support the development of the baking industry, composed of a large pool of SMEs.
- Encourage the participation of SMEs in the project and offer them a competitive advantage: production of a new baking oven technology, use of an innovative oven to save costs and time, and participate in the business development of a new, innovative and promising technology.

The expected result will be an infrared technology for baking purposes.

One of the deliverables, a bakery and bake-off market study, is available, together with other comprehensive information, on the project website.

3.2 RE opportunities in food processing

As pointed in paragraph 3.1.1, the food transformation industry is a moderately energy-intensive industrial sector and is mostly composed of SMEs. In these conditions, energy is not necessarily the first option when looking for practical cost savings. On the contrary, the entrepreneur could be interested in 'greening' an energy source, in exchange of an added value, either directly or through appropriate incentives.

Mekhilef *et al.* (2011) have reviewed the possible uses of *solar energy* in industry, showing its special suitability when a constant flow of moderate heat (80-120 °C) is needed. Washing, cleaning, sterilising, pasteurising, cooking, hydrolysing, distillation, evaporation, extraction and polymerisation in food processing have these features. Solar heat, if available, could be a relevant and cheap alternative to fossil fuels: Pirasteh *et al.* (2014) have specifically noticed that around 12 % of energy consumption in the food and agriculture industry goes into the single drying process and have discussed a possible increase of solar-based drying, independent of geographical location and available technology. It is worth noticing that, although less popular, even solar cooling can be used in the food industry and Best *et al.*(2013) have shown how this solution led to 19 % savings in electricity in a meat-processing unit in Mexico.

Muller *et al.* (2014) studied the brewing subsector in Germany and found a potential for solar energy to provide about 30 % of the thermal energy needed for drying. Muster-Slawitsch *et al.* (2011) have suggested how to integrate solar heat and energy recovered from waste to build a 'green brewery' pilot study. In the test cases analysed, a brewery with optimised heat recovery could supply its thermal energy demand (about 37 MJ/hl of produced beer — excluding space heating) from its own resources. Energy was produced from biogas derived from biogenic residues of the brewery and its waste water. The payback time of the overall intervention was estimated to be 18 months.

More generally, on-site energy recovery from food waste, either through the energy use of residues or biogas production, is a potentially major source of RE use in the food industry (Hall & Howe, 2012).For instance, Jensen and Govindan (2014) have assessed a the case study large bakery company (turnover of EUR 130 million and approximately 550 employees) in Denmark. The authors investigated the financial feasibility of inserting biomass energy recovery into the production cycle and, despite a generally good overlook, they found evidence of business uncertainties originating from market and incentive policy instabilities. On a European scale, the FABbiogas project (FABbiogas, 2014) reports examples of biogas production from organic waste in the European food and beverage sector. The energy potential of food and beverage waste could result in an increased renewable energy production of 35 000 toe/y and hence 183 000 t CO_2/y could be saved.

Beyond the food sector, the International Renewable Energy Agency has recently published an analysis (IRENA, 2014) of opportunities for RE in the overall manufacturing sector, with chapters devoted to SMEs, biomass re-use and solar heating.

With regard to SMEs*,* IRENA estimated that for several industries, including the food sector, more than 50 % of energy could be provided through a portfolio of renewable energy technologies, including biomass, solar thermal systems, geothermal and heat pumps. However, due to the limited size of each single SME business, companies often do not have the resources and the weight needed to negotiate preferential energy prices, especially in case sectorial associations are not active.

As far as *biomass* is concerned, the major renewable energy source currently employed in industry (8 EJ worldwide in 2010), IRENA analysis suggests that its potential is even larger and that approximately three-quarters of the renewable energy potential in industry could come from biomass (22 EJ worldwide), still ensuring a full sustainability of biomass uses. About 30 % of this potential biomass could be used in high-temperature applications, 60 % as a fuel and 10 % as a feedstock.

In the case of solar thermal heating in the manufacturing industry, IRENA analysis suggests that an economic realisable potential of 1.3 EJ could be reached globally in 2030, accounting for 2 % of the total process heating demand. IRENA concludes that, although high capital costs are currently restricting the deployment of solar thermal systems in industrial applications, technological improvements are expected to reduce these costs substantially in the 2030 time horizon.

As an example of actual applications, Schweiger *et al.* (2011) evaluated the solar thermal potential in the Spanish industrial sector. Based on a detailed study of energy consumption, industrial processes and available surface data, a standard industry representative of each of the 32 industrial sectors and subsectors was defined. According to authors' results, low and medium heat demand (up to 250 °C) in the industrial sector accounts for 40.9 % of the total heat demand; the theoretical techno-economic potential equals 68.2 GW (up to 2020) with the biggest share of the total solar thermal energy potential being precisely allocated to the food industry (almost 40 %).

3.2.1 Examples of relevant recent EU-funded projects

FABBIOGAS: BIOGAS production from organic waste in the European Food And Beverage industry

Administrative data:

Status:	Ongoing
Project reference:	IEE/12/768
Duration:	1 April 2013 to 30 September 2015
Budget:	EUR 1 105 045.00 (75 % EU contribution)
Coordinated in:	Austria
Website:	http://www.fabbiogas.eu/

Objectives:

The FABbiogas project ([39]) addresses all the stakeholders in the waste-to-energy chain who are trying to promote residues from the food and beverage (FaB) industry as a new and renewable energy source for biogas. Project outputs will support the diversification of energy sources within FaB companies, leading to widespread valorisation and efficient integration of FaB residues into energy systems, and boosting the realisation of a

([39]) http://ec.europa.eu/energy/intelligent/projects/en/projects/fabbiogas growing number of biogas projects in Austria, Czech Republic, France, Germany, Italy and Poland.

Expected results:

- Awareness raising events (national/international seminars, national info-days + study tours, national workshops) targeting all the involved stakeholders along the waste-to-energy chain.
- Maps depicting existing waste biogas plants and FaB waste streams; including 12-18 best practice examples and recommendations.
- Preliminary feasibility studies (12-18) will prepare the ground for future projects on implementing the use of FaB waste for sustainable bio-energy production.
- The establishment of national advisory services on using FaB waste for biogas production will implement extensive biogas expertise in FaB associations, which can become sustainable contact points for industry requests.
- Information compendium — handbook, DVD, information technology (IT)-tool) for a future standard on the efficient use of FaB waste as a renewable bio-energy resource. FABbiogas results will comprise the set of tools and guidelines needed for creating a European reference standard on industrial FaB waste usage for bio-energy generation. Thus, the FABbiogas project significantly supports the preparation and application of legislative measures.

SUSMILK: Re-design of the dairy industry for sustainable milk processing

Administrative data:

Status:	Ongoing
Project reference:	FP7-KBBE 613589
Duration:	1 November 2013 to 31 October 2016
Budget:	EUR 7 641 675.20 (71 % EU contribution)
Coordinated in:	Germany
Website:	http://www.susmilk.com/

Abstract:

Industrial food production serves to satisfy basic human needs; the dairy industry's turnover accounts for 13 % of the total food and drink industry in Europe. The aim of the project SUSMILK ([40]) is to initialise a system change within the whole process chain for milk and milk products so as to minimise energy and water consumption and establish renewable energy resources. Milk processing is characterised by a large variety of heating and cooling processes. The main R & D activities are intended to substitute steam as the heat transfer medium for hot water, produced by means of renewable resources. The supply of heat and electricity should be fulfilled completely by combined heat and power generation, heat pumps, solar heat and, where appropriate, biogas produced onsite or other renewable fuels produced from waste utilisation. As process machines and equipment are often used over periods of up to 30 years in the food industry, such innovations will have an impact on energy consumption and CO2 emissions for the next decades. The system change is overdue in order to ensure a sustainable supply of energy and raw materials over such a long period.

To maintain hygiene standards, water-consuming clean-in-place (CIP) processes are necessary, which produce waste water with a high organic load. Closing water circuits, recycling CIP solutions and recovering the inherent heat is a second challenging part of the project. As a further means of saving water and energy, the pre-concentration of milk on the dairy farm will be investigated. This measure has the potential to reduce transport energy, to reduce the sizes of tanks and machines in the dairy, and increase the efficiency of production processes for cheese, yoghurt and other such products.

([40]) http://cordis.europa.eu/project/rcn/110705_en.html

The whole project includes the development of technical components, their installation and testing at partner dairies of all sizes, as well as a process simulation of a 'green dairy' and the life cycle assessment of such a facility.

Objectives:

- Application of new technologies for heat generation (solar heat, heat pumps) and distribution (hot water instead of steam) in dairies.
- Adaptation of new chilling technologies.
- Application of membrane filtration techniques for an innovative pre-concentration of milk on the farm.
- Development of new concepts for low-temperature drying of milk.
- Optimising/classifying of waste-stream treatments for water savings and/or energy production.
- Testing of all technologies and concepts in pilot applications under real life conditions.
- LCA of the entire dairy food chain and development of a decision-making tool for more competitive and 'green dairy' plants.
- Energy-based analysis to show the full potential of energy and water savings within the dairy industry.

Expected results:

- The evaluation of the feasibility, efficiency and economy of the technology developments to reduce the water and energy demand in the dairy in order to establish a resource-efficient food-processing unit.
- Concepts based on research results in order to highlight the potential for recycling energy and mass flows by transforming waste flows into valuable products.
- A 'green dairy' simulation tool based on all the data generated within the different pilot and demonstration plants, which will help engineers and the dairy industry to design new or adapt existing facilities.

VALORLACT: Full use of the whey produced by the dairy industry

Administrative data:

Status:	Ongoing
Project reference:	LIFE11 ENV/ES/000639
Duration:	1 July 2012 to 31 December 2015
Budget:	EUR 1 727 071.00 (45 % EU contribution)
Coordinated in:	Spain
Website:	http://valorlact.eu/

Objectives:

The main aim of the VALORLACT ([41]) project is to demonstrate and validate a method of processing whey into added value or energy products, contributing towards minimising the environmental impact from cheese factories while improving the competition in that sector.

Among the detailed goals, the project plans to develop a methodology to collect and/or process whey to make it profitable and implement systems, equipment or plants to use it

([41]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4256

as a raw material in animal feed and human food or to generate biogas. The project will also contribute towards enabling further legislation to restrict the dumping of whey in water bodies and/or sewage, and further enhancing the overall environment.

Expected results:

- Operation of a pilot whey treatment plant with a capacity of 250 litres/hour.
- Operation of a pilot plant to extract biogas from lactose with a capacity of 1 500 litres/day.
- Collection and valorisation of more than 80 % of whey generated in the area — equivalent to more than 18 million litres/year (18 000 tonnes/year) of whey.
- Production and validation of 5 tonnes of animal feed and at least 100 kg (350 units) of food products.
- Generation of 6 400 m^3 of biogas — offering a reduction of 56 000 kg of CO_{2e} emissions.
- Definition and agreement of a system for ongoing revalorisation of whey in the Basque Country.
- Definition of the conditions and technology necessary for implementing the system in other regions.

Food prototypes are already in the study phase and the biogas pilot plan has been commissioned.

GREENFOODS: Towards zero fossil CO2 emissions in the European food and beverage industry

Administrative data:

Status:	Ongoing
Project reference:	IEE/12/72
Duration:	1 April 2013 to 31 July 2015
Budget:	EUR 1 993 804.00 (75 % EU contribution)
Coordinated in:	Austria
Website:	http://www.green-foods.eu

Objectives:

The overall objective of the GREENFOODS project is to lead the European food and beverage industry to high-energy efficiency and a reduction in fossil carbon emissions in order to ensure and foster worldwide competitiveness, improve the security of energy supply and guarantee sustainable production in Europe.

Expected results:

- Usage of the GREENFOODS branch concept in 204 SMEs in the food and beverage industry, including a calculation tool for energy balance, heat integration and process optimisation, a calculation tool for efficient heat and cold supplies, integrating renewable energy (biomass and biogas boilers and burners, solar process heat, high-temperature industrial heat pumps, absorption cooling and CHP), economic and environmental considerations, country-specific funding and guidelines. A benchmark database based on the audits performed will be developed.
- A GREENFOODS training course developed as a standalone training programme and implemented within the European Energy Manager (EUREM or equivalent) for at least 150 energy auditors, industrial technicians and other relevant actors in the field of industrial energy efficiency. Sixty trainers will be educated in special GREENFOODS train-the-trainer courses.
- Development and presentation of sector-specific funding schemes for energy audits and investment funding schemes for energy efficiency measures and renewable energy in the industry in each of the participating countries (AT, DE,

ES, PL, UK, FR) in order to implement at least five best practice case studies during the action.
- Implementation of six virtual energy competence centres in each participating country plus France as one-stop-shops for knowledge exchange, training, renting equipment, etc. that will be connected to a European network with approximately 240 members in the first year. See national contact points at http://www.green-foods.eu/contact-points/
- Dissemination activities for raising awareness and for widespread dissemination of the project results at EU level. Creation of an interactive compendium (database) based on a GREENFOODS WikiWeb. At least 2 000 companies in the food and beverage industry are expected to get in contact with the GREENFOODS branch concept during this action.

3.3 Energy use in food transport, storage and distribution

Another important element of energy usage in the food transformation industry is transport and logistics, accounting to 9.4% of energy embedded in food consumed in EU-27 in 2013 (see Chapter 1) Food transport depends on the food type and origin and covers a wide range of distances. It is worth highlighting that the amount of transportation needed for a given product is not related to the mobilisation of the final product only, but also includes the transport of raw and semi-finite materials. Pasta production in Italy provides a clear example: while pasta is generally produced in the country, part of wheat is nationally transported for the relatively short average distance of 183 km, while another part is imported from global markets with an average transportation distance of 5 558 km (Mancini, 2011).

For this reason, Mancini (2011) suggests the decomposition of the food-related transport chain into six main phases as depicted in Figure 3.8:

- agricultural inputs (transport of fertilisers, pesticides and herbicides to the field);
- agricultural phase (transport of agricultural products from storage to final production or animal breeding);
- cattle breeding (transport of milk and meat products from farms to food processing industry);
- food processing (transport of processed food to distributors);
- distribution (transport of food products to retailers);
- purchasing (transport from retailers to final consumers).

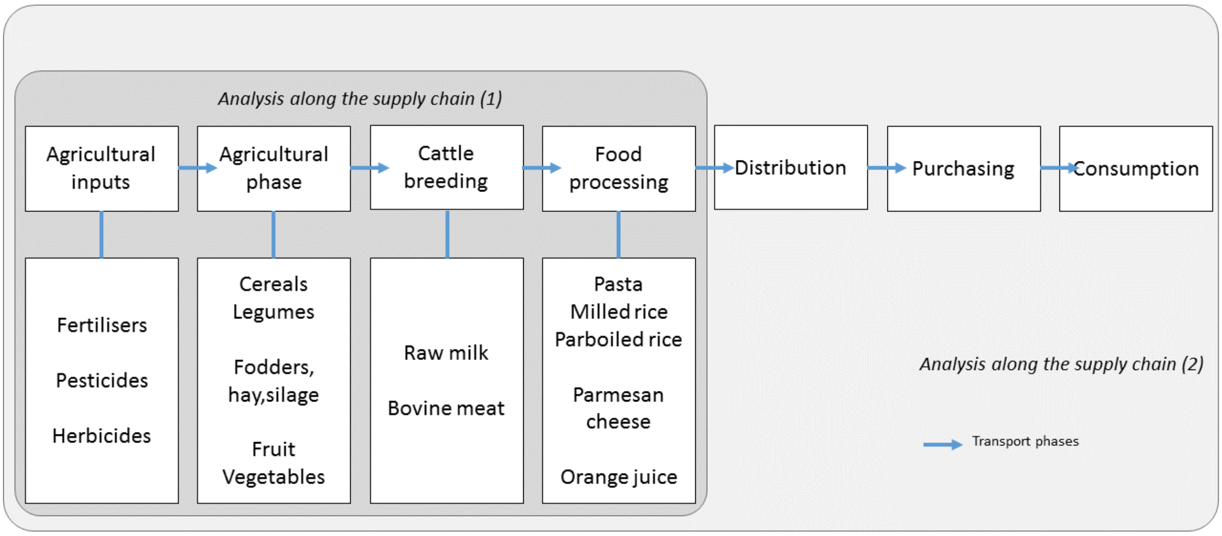


Figure 3.8 Transport phases in the food chain. Source: (Mancini, 2011).

Food and food precursors can travel very long distances before reaching the table and it was estimated (James, James and Evans, 2006) that in 2002 over 1 million refrigerated road vehicles, 400 000 refrigerated containers and many thousands of other forms of refrigerated transport systems were used to distribute chilled and frozen foods throughout the world.

3.3.1 Current situation and recent trends

Table 3.1 shows the import flows of food and food-related goods between 2010 and 2013 from outside the EU-28 to within the EU-28, according to ComExt Eurostat statistics in units of 1 000 kg [last extraction May 2015].

Table 3.1 EU-28 imports of food and beverage products during the period 2010-2013 (units of 1 000 kg). Source: (Eurostat — ComExt, 2015).

Product	Year			
	2010	2011	2012	2013
Meat and meat preparations	1 431 396	1 388 682	1,347,163	1,306,290
Dairy products and birds' eggs	260 590	249 513	266,230	249,860
Fish, crustaceans, molluscs and aquatic invertebrates, and preparations	4 998 802	5 013 802	4,919 248	4,941,458
Cereals and cereal preparations	10,214,702	16,278,953	17,084,278	17,506,387
Vegetables and fruit	21,050,760	20,837,665	19,781,752	20,987,210
Sugars, sugar preparations and honey	4,679,187	6,704,990	6,147,368	6,643,616
Coffee, tea, cocoa, and spices	5,316,637	5,587,833	5,537,116	5,548,651
Feeding stuff for animals	30,795,759	31,586,767	31,250,101	28,539,803
Miscellaneous edible products and preparations	808,814	866,931	904,956	969,516
Beverages	3,413,171	3,072,628	3,150,380	3,273,788
Total	**82,969,818**	**91,587,763**	**90,388,590**	**89,966,578**

Table 3.2 Top 30 non EU-28 food and beverage providers to the EU-28 in 2013 in terms of total goods provided (units of 1 000 kg). Source: Eurostat — ComExt, 2015.

Partner	Product										
	Meat	Dairy	Fish	Cereals	Vegetables and fruit	Sugars	Coffee, tea, cocoa, spices	Animal feed	Misc.	Beverages	Total
Brazil	578 041	48	6 185	2 805 275	2 048 140	1 048 133	838 726	8 370 129	14 181	9 158	15 718 015
Argentina	55 618	1 241	156 220	382 558	581 850	52 652	10 457	8 550 492	918	73 675	9 865 680
Ukraine	231	0	805	7 134 897	164 437	157 309	7 334	1 691 718	29 794	24 406	9 210 932
United States	24 095	10 795	226 840	1 289 375	1 023 120	141 903	21 926	2 844 683	93 861	345 651	6 022 248
Russian Federation	704	737	129 883	808 798	113 868	139 662	9 055	1 688 577	24 455	49 046	2 964 785
Indonesia	3 538	13	67 078	9 175	92 004	45 886	259 603	1 877 852	15 250	909	2 371 308
China	31 363	110	530 681	63 129	1 071 069	99 851	204 590	185 437	133 890	36 636	2 356 755
Canada	6 540	1 888	59 030	1 713 923	310 999	8 431	1 311	200 372	8 811	11 544	2 322 849
Turkey	1 385	182	60 988	299 232	1 403 388	80 103	23 746	4 365	63 393	199 934	2 136 715
India	3	1 112	155 326	442 625	341 398	443 266	219 294	497 444	12 852	2 698	2 116 017
Costa Rica	0	0	727	221	1 815 979	92 753	20 211	1 020	441	466	1 931 818
South Africa	724	8	47 439	60 411	1 319 066	3 183	4 931	4 546	5 855	370 582	1 816 744
Ecuador	0	0	210 190	717	1 469 771	1 440	60 052	31 725	516	35	1 774 446
Norway	2 765	14 056	1 104 586	6 813	4 195	723	6 774	232 557	8 850	126 564	1 507 883
Colombia	0	0	16 077	7 120	1 210 180	46 290	140 227	1 630	712	6 494	1 428 731
Chile	33 170	0	111 509	19 865	720 767	7 677	761	38 839	437	406 174	1 339 198
Serbia	897	5 524	44	492 457	284 868	265 719	4 063	190 451	29 711	56 189	1 329 922
Morocco	12 413	12	201 435	1 224	1 061 317	1 048	3 618	26 056	11 023	7 676	1 325 822
Vietnam	710	1	273 184	90 311	77 335	24 036	713 020	80 128	36 948	3 230	1 298 904
Cote D'Ivoire	0	0	37 598	154	313 680	9 900	857 744	62 320	1 971	1	1 283 367
Switzerland	23 388	130 059	142	103 086	38 553	18 470	172 558	94 836	163 377	530 797	1 275 265
Thailand	246 117	111	156 970	233 350	328 701	71 969	10 769	35 107	137 288	24 901	1 245 283
Egypt	0	23	1 386	95 948	631 325	259 310	4 808	158 213	699	7 804	1 159 515
Peru	11	0	96 009	8 978	566 695	2 844	190 366	116 747	816	1 537	984 004
Mexico	5 481	27	17 959	61 211	285 645	254 227	39 448	22 990	5 065	129 829	821 881
Malaysia	0	81	3 193	4 510	7 066	177	27 742	705 814	24 952	5 169	778 704
Israel	5 863	1 548	646	6 037	623 464	35 610	3 805	1 566	28 135	4 872	711 547
Australia	37 913	7 310	624	238 500	76 737	32 431	411	14 193	2 775	279 040	689 934
New Zealand	169 237	51 044	33 760	6 485	351 343	3 721	181	8 562	406	56 737	681 476
Ghana	29	1	27 169	645	107 741	15	437 644	10 572	1 665	509	585 990

Table 3.3 Top 10 non EU-28 food and beverage providers to the EU-28 in 2013 for each food category in terms of total goods (units of 1 000 kg) and percentage of imported goods. Source: Eurostat — ComExt, 2015.

Meat			Dairy			Fish			Cereals			Vegetables and fruit		
Country	Imports	%	Country	Imports	%	Country	Imports	%	Country	Imports	%	Country	Imports	%
Brazil	578 041	44.3	Switzerland	130 059	51.4	Norway	1 104 586	22.3	Ukraine	7 134 897	40.8	Brazil	2 048 140	9.7
Thailand	246 117	18.8	New Zealand	51 044	20.2	China	530 681	10.7	Brazil	2 805 275	16.0	Costa Rica	1 815 979	8.6
New Zealand	169 237	13.0	Bosnia and Herzegovina	20 414	8.1	Vietnam	273 184	5.5	Canada	1 713 923	9.8	Ecuador	1 469 771	7.0
Argentina	55 618	4.3	Norway	14 056	5.6	United States	226 840	4.6	United States	1 289 375	7.4	Turkey	1 403 388	6.7
Uruguay	43 580	3.3	United States	10 795	4.3	Iceland	212 341	4.3	Russia	808 798	4.6	South Africa	1 319 066	6.3
Australia	37 913	2.9	Australia	7 310	2.9	Ecuador	210 190	4.2	Serbia	492 457	2.8	Colombia	1 210 180	5.8
Chile	33 170	2.5	Serbia	5 524	2.2	Morocco	201 435	4.1	India	442 625	2.5	China	1 071 069	5.1
China	31 363	2.4	N.A.	3 191	1.3	Thailand	156 970	3.2	Argentina	382 558	2.2	Morocco	1 061 317	5.0
United States	24 095	1.8	Canada	1 888	0.7	Argentina	156 220	3.2	Turkey	299 232	1.7	United States	1 023 120	4.9
Switzerland	23 388	1.8	Israel	1 548	0.6	India	155 326	3.1	Australia	238 500	1.4	Chile	720 767	3.4

Sugars			Coffee, tea, cocoa, spices			Animals feeding			Miscellaneous			Beverages		
Country	Imports	%	Country	Imports	%	Country	Imports	%	Country	Imports	%	Country	Imports	%
Brazil	1 048 133	15.67	Cote D'Ivoire	857 744	15.4	Argentina	8 550 492	30.0	Switzerland	163 377	15.9	Switzerland	530 797	16.1
Mauritius	446 188	6.67	Brazil	838 726	15.0	Brazil	8 370 129	29.3	Thailand	137 288	13.4	Chile	406 174	12.3
India	443 266	6.626	Vietnam	713 020	12.8	United States	2 844 683	10.0	China	133 890	13.0	South Africa	370 582	11.3
Cuba	321 025	4.799	Ghana	437 644	7.8	Indonesia	1 877 852	6.6	United States	93 861	9.1	United States	345 651	10.5
Pakistan	315 989	4.724	Indonesia	259 603	4.7	Ukraine	1 691 718	5.9	Turkey	63 393	6.2	Australia	279 040	8.48
Swaziland	303 240	4.533	India	219 294	3.9	Russia	1 688 577	5.9	N.A.	58 636	5.7	Turkey	199 934	6.07
Serbia	265 719	3.972	China	204 590	3.7	Malaysia	705 814	2.5	Vietnam	36 948	3.6	Mexico	129 829	3.94
Egypt	259 310	3.876	Peru	190 366	3.4	India	497 444	1.7	Ukraine	29 794	2.9	Norway	126 564	3.84
Mexico	254 227	3.8	Cameroon	188 135	3.4	Norway	232 557	0.8	Serbia	29 711	2.9	N. A.	85 311	2.59
Mozambique	180 718	2.702	Honduras	170 992	3.1	Paraguay	209 127	0.7	Israel	28 135	2.7	Argentina	73 675	2.24

Table 3.2 reports the top 30 non EU-28 food and beverage providers to the EU-28 in 2013 in terms of total goods provided (units of 1 000 kg), while Table 3.3 lists the top ten providers for each category in terms of share of imports for each category. The importance of long distance /transcontinental places of origin is evident in both tables. Imported food brings its embedded energy with it to European tables and this fact is particularly relevant for the flows analysis developed in Chapter 0.

Similarly, food and food precursors are exported from EU countries all over the world, with the balance being positive or negative according to the food or feed category (see Table 3.4).

Table 3.4. Extra EU-28 traded fluxes for food and food precursors in 2013. Data in units of 1 000 kg.

Product	Import	Export	Balance
Meat and meat preparations	1 306 153	4 525 648	3 219 495
Dairy products and birds' eggs	249 887	3 485 954	3 236 067
Fish, crustaceans, molluscs and aquatic invertebrates, and preparations	4 943 127	1 601 998	-3 341 129
Cereals and cereal preparations	17 503 003	42 013 410	24 510 407
Vegetables and fruit	21 035 409	11 871 633	-9 163 776
Sugars, sugar preparations and honey	6 688 733	2 261 589	-4 427 144
Coffee, tea, cocoa, spices, and manufactures	5 577 793	1 448 411	-4 129 382
Feedstuff for animals (not including unmilled cereals)	28 540 409	6 720 099	-21 820 309
Miscellaneous edible products and preparations	969 340	3 242 960	2 273 620
Beverages	3 288 481	10 580 118	7 291 638
Total	**90 102 332**	**87 751 819**	**-2 350 513**

As far as the mean of transportation is concerned, 83 % of the food and food precursors imported into the EU in 2013 had travelled by sea, 10 % by road, 2 % by rail and 1 % or less by air and inland water (see Figure 3.9).

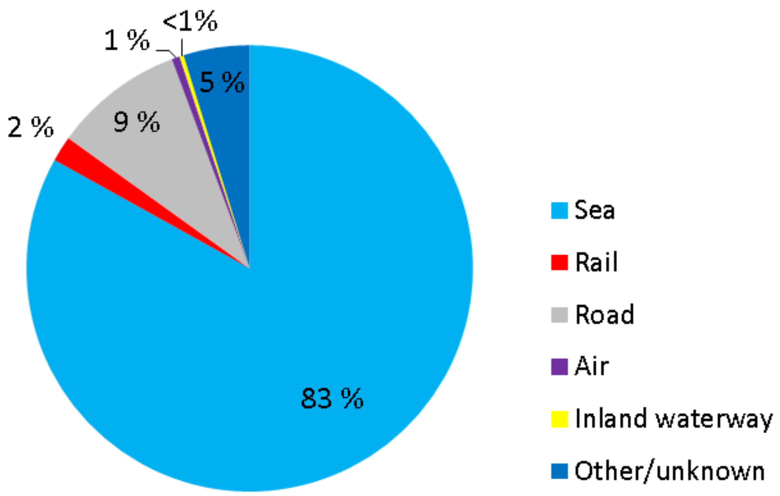


Figure 3.9 Means of transport for food imported into the EU-28 in 2013 (shares). Source: Eurostat — ComExt, 2015.

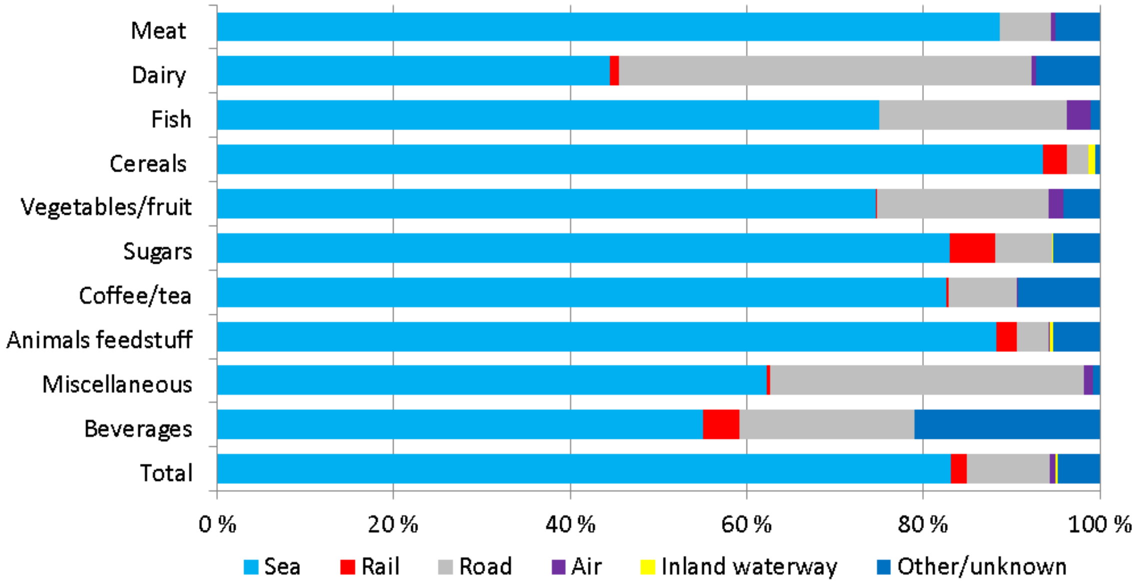


Figure 3.10 Means of transport for food imported into the EU-28 in 2013 (shares for each food category). Source: Eurostat — ComExt, 2015.

The sea is by large the predominating means of transport for all food categories imported into the EU (see Figure 3.10) with the exception of imported dairy products, mostly produced in closer non-EU countries, such as Switzerland and Bosnia, and transported to EU borders by road (see Table 3.3).

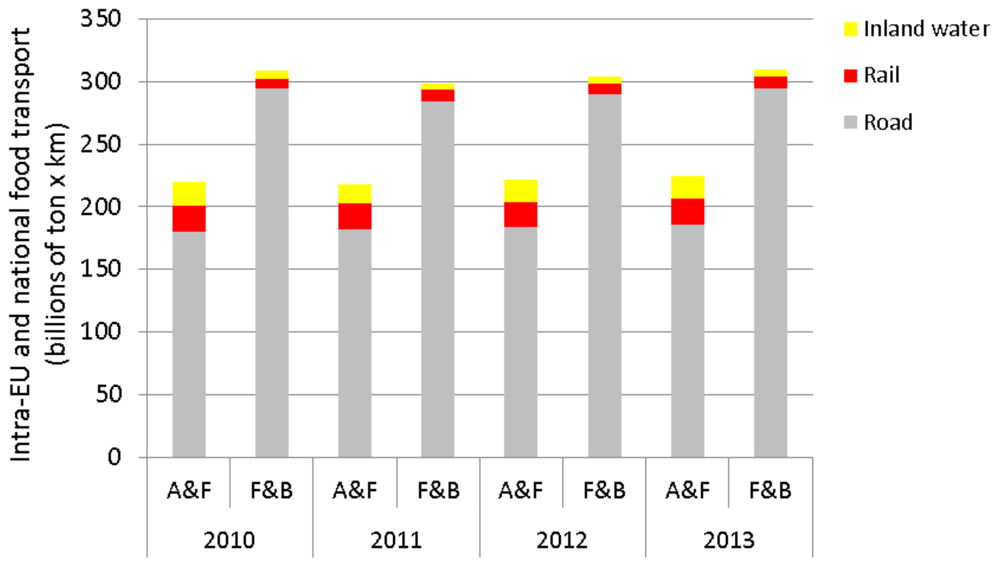


Figure 3.11 Transport of food-related products inside the EU-28 (excluding Malta) in the period 2010-2013. Data from Eurostat ([42])
Key: A&F: Agriculture and fishery products; F&B: Food and beverage products.

Food also travels between the EU countries and inside each of the Member States. Figure 3.11 shows the means of transport used in intra-EU and national food transportation in

([42]) Due to partial incompleteness of rail transport data, the following assumptions were needed. Belgium and Denmark: 2012 and 2013 data was assumed equal to 2011 data; Germany: 2013 data was assumed equal to 2012; Italy: F&B data for 2010 was assumed equal to 2009; Netherlands provided incomplete data for rail transport and is not considered in the totals.

the 2010-2013 period. The total amount of food transport has slightly increased by 1.2 % from 528 billion tonnes per km in 2010 to 534 billion tonnes per km in 2013. Growth has not been constant as 2011 showed a slight decrease to 516 billion tonnes per km, probably following the overall shrink of EU consumption for that year. The modal shares of the intra-EU and national food have remained constant all along the analysed period: road transport accounted for 90 % of all food journeys, rail for 5.5 % and inland water for 4.5 %. In terms of food categories, 82.5 % of agriculture and fishery products are mobilised by road, 9.5 % by rail and 7 % by inland water. On the other hand, 95.5 % of food and beverage products travel by road, 2 % by rail and 2.5 % by inland water.

3.3.2 Pathways to energy efficiency in EU food transport

Given the long traveling distance of large amounts of several products and the general need for refrigeration, transport is an important element in the food energy balance (see Chapter 1 for details). Energy efficiency in food transport is pursued through two possible pathways: improving the energy performance of the transportation systems and decreasing or optimising the amount of transportation itself. Thanks to EU legislation and emission standards on vehicles (see Chapter 4), more and more energy-efficient vehicles are introduced at EU level. Neverhtless, in the case of food transport, energy is consumed not only for moving the vehicles: one-third of food transported by road needs refrigeration or chilling (Tassou, De-Lille and Ge, 2009).

3.3.3 Improving refrigeration

Analysing the case for road transport (the largely predominant intra-EU and national transportation means) Tassou *et al.* (2009; 2010) have reviewed the main available technologies for the in-vehicle refrigeration systems and their possible improvements. Authors found that systems based on the vapour compression refrigeration cycle, the most common ones, tend to be oversized to provide abundant operational margin. Also auxiliary diesel engines are almost always installed, although rarely used in practice. Large portions of the thermal energy in the Diesel exhaust also provide could also be recovered and can be used to operate a thermally-driven refrigeration system (e.g., absorption cooling systems, ejector systems, thermo-acoustic refrigerators) and/or for power generation using thermo-electrics or turbo-generators. According to Tassou *et al.* (2009), heat by-product from the engine of articulated vehicles should be sufficient to drive sorption refrigeration systems at normal out-of-town driving conditions while additional energy would be needed only during in-town driving.

Table 3.3 also shows that considerable amounts of vegetables and fruit are transported very long distances before reaching European tables, mostly by sea. Ships are normally equipped with refrigeration systems: to prevent degradation without causing chilling hold temperature is usually set around 12-15 °C. Wills *et al*. (2014) have suggested and tested the case of Australian bananas imported to Europe with limited or in some cases even absent refrigeration: such a result was obtained introducing a controlled concentration of ethylene in the stove atmosphere, avoiding fruits to go rotten.

Refrigeration is also a key point for food awaiting its last trip from the shop to the consumer tables; food retailing is also *per se* an energy consuming service. More detailed calculations based on the JRC food basket (see Chapter 1) show that about 12% of the energy consumed in the logistics step is related to retail. Tassou *et al.* (2011) have studied 2 570 retail food stores of diverse sizes, from convenience stores to hypermarkets in the United Kingdom. According to their analysis, energy consumption linked to food chilling and refrigeration largely dominates (up to 60 %) in small shops (below 1 400 m^2), while in larger shops and hypermarkets lighting, heating and other appliances absorb most of the energy. For this reason, the choice of appropriate refrigeration technologies (Tassou et al., 2010) and the especially adequate design of food display cabinets are among the most promising and feasible energy-saving interventions in food shops.

3.3.4 Decreasing transportation needs

Decreasing the overall distance travelled by food and food precursors is another way of minimising the amount of energy embedded in food products by transportation.

Research is currently focusing on two aspects: optimising transport supply and decreasing transport demand. From the supply point of view, food transport, like the whole transportation sector, is benefiting from the introduction of integrated telematics, communication, control and automation technologies usually known as Intelligent Transport Systems (ITS) (see for example Gattuso and Pellicanò, 2014). ITS include the latest technologies, infrastructure and services as well as the operations, planning and control methods that are used for the transportation of passengers and freight and applied to every transport mode (road, rail, air and water). More details on ITS and its implementation in the EU are discussed in Chapter 4.

From the point of view of transportation demand, decreasing the overall impact and energy content of food products by using local origins of food has been also well studied in the literature. While it is generally true that food travelling long distances embeds more energy than locally originated food, several studies reveal that the issue needs to be carefully assessed on a case-by-case approach.

For instance, Blanke and Burdik (2005) have actually demonstrated that locally produced German apples need less energy than the equivalent product imported from New Zealand. On the contrary, Coley *et al.* (2009) have compared the fuel use and transport-related carbon emissions of two food production chains. They have confronted large-scale cultivation, bulk cold storage, mass distribution and home delivery by a nation-wide organic food production with the same product provided by a hypothetical local organic farm shop in the United Kingdom. Their findings showed that if customers have to drive more than 7.4 km in order to reach te local shop to purchase organic vegetables, the large-scale distribution system results preferable in terms of fuel and carbon emissions per unit of product.

Along the same lines, Schlich and Fleissner (2005) compared the energy budget of fruit juices and lamb meat of European origin with equivalent products imported from South America and Australia, respectively, following an LCA approach. While transport partially counts, a much stronger relation between energy content and the business size was found, regardless of the origin of the product. This leads to the idea that the economy of scales, or 'ecology of scales', as defined by the authors, should also be at the core of energy efficiency analysis in food production.

Similarly, Mundler and Rumpus (2012) studied 'short' and 'long' food supply chains in Southern France, focusing on the transport from farm gate to consumers' tables. Indeed, according to Mancini (2011, p. 96) on the case of shopping by car, the length of the round trip between consumers' houses and the shops is currently averaged at 30 km in Europe. The industrialisation of the food sector has reinforced this habit by increasing the number of out-of-town shopping centres, which have replaced small local shops. The frequency of shopping trips and the distance travelled to purchase foodstuffs has increased in the last decades, thus imposing further energy consumption.

3.4 Food packaging

In the EU, the food contact materials for packaging are subject to severe regulations, ensuring safety for consumers. Materials such as plastics, metals, ceramics, paper and paperboard are commonly used for the manufacturing of food packaging, but also for kitchenware, cutlery and food processing equipment. The safety of such materials relies on insuring that during contact there is no migration of unsafe levels of chemical substances from the material to the food (JRC EURL-FCM, 2014). Even if packaging is responsible for 10.7 % of the embodied energy in the EU food consumption (see also Figure 1.9), according to Russel (2014), improved packaging sustainability does not need to be achieved at the expense of quality. Moreover, good and long lasting packaging is an essential tool in minimising food waste and improving food durability, thus decreasing the overall energy consumption.

3.4.1 Designing optimal packaging

Consumers are aware of material use and energy consumption related to packaging and food packaging is an important part of the customer perception of a product. For instance, Ipsos MORI (2008) reported the results of a UK survey where the excessive amount of packaging was considered the most relevant environmental and ethical issue by 51 % of responders, overcoming other issues such as fair trade (37 %), animal welfare (33 %), food miles (24 %) or the overall product's 'carbon footprint' (16 %).

Barlow and Morgan (2013) have studied the trade-offs present in the design of food packaging. They focused in particular on the pros and cons of single-layer packaging versus multi-layered polymers: the first provide better recycling opportunities while the second allow less material to be used but almost always have to be disposed in landfills.

Optimisation and energy reduction can be also pursued through acting on secondary (trays, boxes, etc.) and tertiary packaging (pallets and film that are used to facilitate transport in trucks) in the frame of a proper industrial and logistic policy (Barlow and Morgan, 2013).

3.4.2 New materials and food packaging

Bioplastics derived from biological materials, in some cases from the food production residues themselves, are being investigated even if still suffering from some serious limitations (see Peelman et al., 2013 for a review). The brittleness, thermal instability, low melt strength, difficult heat insulation and high water vapour and oxygen permeability currently limit their use for packaging short-life products (like fresh fruit and vegetables), or long shelf-life products (like pasta and chips), which do not need very high oxygen and/or water barrier properties. On the other hand, these films show a wide variety of properties, which could make them suitable as a packaging material for other food products. Relevant research projects are ongoing in order to make the great potential offered by these materials available to the packaging industry.

Another relatively new field of research involves the so-called intelligent food packaging technology (Puligundla, Jung and Ko, 2012); packaging that is able to monitor and communicate information about the quality state of the packed food. This would allow optimal food consumption and minimise food waste and its related energy waste.

3.4.3 Examples of relevant recent EU-funded projects

RPET-FC: Environmentally friendly food packaging tray with lower carbon footprint

Administrative data:

Status:	Finished
Project reference:	232055, under FP7-SME
Duration:	1 October 2009 to 30 September 2011
Budget:	EUR 1 462 480.00 (74 % EU contribution)
Coordinated in:	Ireland
Website:	http://www.rpet-fc.eu/

Objectives:

The FP7-funded RPET-FC project ([43]) aimed at providing SME food-processing companies with a new food-packaging tray, lighter than the marker leader, using 25 % less material and made from 100 % recycled Polyethylene Terephthalate (rPET).

Results:

This project succeeded in facilitating cooperation between SMEs of different nations, research institutes and other enterprises, thus improving the SMEs' strategic partnerships and networking for innovation. The RPET-FC project has achieved a saving of 1.8 tonnes of oil for every tonne of tray material switched to rPET. Two valid dossiers have been submitted to the European Food Security Agency (EFSA) as required under Regulation (EC) No 282/2008 and have been included on the 'Register of valid applications for authorisation of recycling processes to produce recycled plastic materials and articles intended to come into contact with foods'

ECOBIOCAP: Eco-efficient Biodegradable Composite Advanced Packaging

Administrative data:

Status:	Ongoing
Project reference:	265669, under FP7-KBBE
Duration:	1 March 2011 to 28 February 2015
Budget:	EUR 4 235 859.00 (71 % EU contribution)
Coordinated in:	France
Website:	http://www.ecobiocap.eu/

Objectives:

The main goal of the EcoBioCAP FP7 project ([44]) is to develop a new generation of customisable, eco-efficient, biodegradable packaging solutions with direct benefits for both the environment and EU consumers in terms of food quality and safety.

Results:

The project has already achieved important results. In particular, three main packaging constituents were developed by upgrading food industry by-products:

- microbial polyesters (PHAs) were obtained from liquid effluents;
- fibre-based fractions from solid by-products were obtained from wheat straw;
- brewing grains and olive oil.

Several tailored additives and adhesives were obtained, such as pure keratin from chicken feathers. Anti-oxidant nano-clays were derived from olive waste water and oil as well as bio-adhesives from zein and pullulan. Finalised packaging materials were also formulated and structured and assessed for physical-chemical stability and chemical safety. Finally, the productions of PHA, wheat-straw fibre fractions, cellulose, lignin-rich fractions and zein-based adhesives were up-scaled to a small pilot plant.

SUCCIPACK: Development of active, intelligent and sustainable food PACKaging using PolybutyleneSUCCInate

Administrative data:

Status:	Finished
Project reference:	289196, under FP7-KBBE
Duration:	1 January 2012 to 31 December
Budget:	EUR 4 037 593.00 (74 % EU contribution)

([43]) http://cordis.europa.eu/project/rcn/91991_en.html
([44]) http://cordis.europa.eu/project/rcn/97870_en.html

Coordinated in: France
Website: http://www.succipack.eu/

Objectives:

SUCCIPACK ([45]) aimed to support European industry efforts to introduce bio-based polybutylene succinate (PBS) as a new material on the food packaging market.

Its main advantage is that it has complementary properties compared to other bio-based polymers like polylactic acid. PBS is synthesised by polycondensation of succinic acid and butanediol, both identified as key 'building blocks' from renewable resources which will be produced on a large scale in the coming years.

The aim of SUCCIPACK was to develop sustainable, active and intelligent food packaging materials based on green PBS that can be flexibly used by packaging and food industries. A first aspect was the optimisation of the synthesis and compounding the polymer and copolymer grades for industrial plastic transformation processes to obtain films, trays and pouches. Tailored packaging functionalities can be obtained by flexible in-line surface treatments to control gas barrier properties and to introduce antimicrobial activity.

3.5 Cooking and domestic conservation

Food domestic conservation, preparation andcooking entail fuel, electricity and water consumption. According to FAO (2014), 40 % of the world's population still depend on bioenergy sources for cooking and heating. Inefficient and poorly designed cooking stoves are leading to major energy wasting and serious public health issues. Even if generally managed in a safer way, food cooking and domestic conservation accounts for 13% of the energy embodied in the average EU food consumption in 2013 (see Chapter 1), although generally less impacting population health.

3.5.1 Appliances improvement

Refrigerators, freezers and combined fridge-freezers have been getting larger and more sophisticated in recent years: internal volume grew of 32 % on average over the last decade in the EU. Larger models mean a greater energy consumption, and this trend towards large appliances is threatening to cancel out any savings achieved through greater efficiency (this is called the 'rebound effect', see also Introduction). The most recent available data from the European Commission estimates an annual European electricity consumption by these products of 122 TWh in 2005, corresponding to 56 million tonnes of CO_2e, which is comparable to the emissions produced annualy by 24 million cars.

In the EU, some policies have been put in place to reduce the energy consumption of products, including domestic appliances. The Ecodesign Directive 2009/125/EC sets minimum requirements for energy and environmental performance, which manufacturers must meet in order to legally bring their product to the market. Energy labelling requirements through the EU Energy Label Directive 2010/30/EU aim at providing consumers with information on performance. Nevertheless, concerns remain as the appliances' energy profile tends to worsen with cheaper products. More details on Ecodesign legislation will be provided in section 4.1.4.

3.5.2 Energy-conscious cooking habits

Hager and Morawicki (2013) have assessed energy-efficient measures and appliances in domestic cooking in the United Kingdom and have evaluated the energy savings that could be obtained through some 'common sense' cooking "tips" involving cooking

([45]) http://cordis.europa.eu/project/rcn/101826_en.html

methods (e.g. simmering or steaming rather than boiling, using the residual heat in electric appliances, etc.) and proper use of kitchen tools (using properly sized and insulated pans). "Tips" were found to be extremely effective in decreasing energy consumption, in some cases by up to 50 %.

3.5.3 Examples of relevant recent EU-funded projects

LIFE Fresh Box: a sustainable transport solution conserving quality of fresh produce, reducing waste and fuel consumption

Administrative data:

Status:	Ongoing
Project reference:	LIFE13 ENV/ES/001362
Duration:	1 July 2014 to 30 June 2017
Budget:	EUR 1 851 396.00 (50 % EU contribution)
Coordinated in:	Spain
Website:	http://fresh-box.info/

The LIFE Fresh Box project ([46]) aims to enhance the sustainability of the distribution of fresh products in order to improve the sector's ability to offer better products to the end consumer. This will help to boost the sector's overall competitiveness.

Such aims will be achieved by developing and demonstrating an innovative, and more environmentally friendly, container called the Fresh Box. This container will improve the sustainability of the full value chain of fresh product distribution (from farm to consumer). The Fresh Box container will reduce food waste, extend fresh product shelf life and reduce fuel/energy consumption.

Fresh Box container characteristics:

- Active/smart container that stores/transports each type of fresh produce in ideal conditions of respiration rate.
- Monitored with an innovative integrated sensor kit to check the main environmental features in the container and allow traceability.
- Lightweight, manufactured with a technology that saves energy and made of innovative recyclable material.
- Transports fresh produce harvested at to a higher stage of maturity; consumers will be able to enjoy fruit and vegetables with better features.

This project will not only develop a new container, but also improve the sustainability of the whole value chain (see image above) of fresh produce distribution up to the final consumer. In this way, the innovative Fresh Box will demonstrate its ability to reduce food waste due to an extended shelf-life, save CO_2 emissions due to lighter and more sustainable materials which lead to the reduction of energy/fuel consumption, and improve the quality of fresh produce offered to the final consumer.

Expected results:

- 30 % increase in the shelf life of fresh produce compared to fresh produce transported in conventional containers.
- 20 % reduction of food waste compared to fresh produce transported in conventional containers.
- Better physical, chemical and organoleptic features, compared to fresh produce transported in conventional containers.

([46]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=5007&docType=pdf

- Fresh Box containers will be produced using less energy and material consumption (expected minimum of 20 %), compared to conventional ones.

FRISBEE: Food Refrigeration Innovations for Safety, consumer Benefit, Environmental impact and Energy optimisation along cold chain in Europe

Administrative data:

Status:	Finished
Project reference:	245288, under FP7-KBBE
Duration:	1 September 2010 to 31 August 2014
Budget:	EUR 8 165 746.00 (73 % EU contribution)
Coordinated in:	France
Website:	http://www.frisbee-project.eu/

Objectives:

The objective of the FP7 project FRISBEE ([47]) was to provide new tools, concepts and solutions for improving refrigeration technologies along the European cold food chain.

The existing technologies targeted included the design of thermal energy storage devices and predictive controllers in the case of using intermittent (possibly non-conventional) energy sources.

Emerging technologies to be developed at the laboratory scale will include four system-based technologies (air cycle refrigeration, magneto-caloric refrigeration, nanoparticles and vacuum-insulated panels) and three food-based technologies (super chilling, super-cooling and smart packaging).

Results:

The project developed tools for evaluating quality, energy consumption and the environmental impact of refrigeration technologies, including sensors, equipment, software, protocols and methodologies to assess and improve existing and emerging refrigeration technologies. Several versions of the FRISBEE QEEAT (Quality and Energy/Environment Assessment Tools) were released user setting of cold chain block technologies).

The FRISBEE project also developed a database of the cold chain in Europe in order to identify refrigeration needs and the currently available technologies in the food industry, and investigated consumer needs and expectations with respect to the food cold chain (available at: http://frisbee-wp2.chemeng.ntua.gr/coldchaindb/).

3.6 Food waste

Material losses of food along the successive steps of the food chain imply losses of embedded energy. Apart from structural production residues, by the time food reaches the table the overall edible material losses may account for between 17 % (dairy products) and 47 % (roots and tubers) of the original material, depending on the food category (FAO, 2013b, p. 15).

According to FAO (2011b), one-third of the food produced for human consumption, i.e. 1.3 billion tonnes annually, is lost or wasted globally. The FAO (2012) identifies the need to increase food availability by 60 % by 2050, while currently the food produced but not eaten corresponds to almost 1.4 billion hectares of land, representing close to 30 % of the world's total agricultural land area (FAO, 2013a).

([47]) http://cordis.europa.eu/project/rcn/94794_en.html and http://ec.europa.eu/research/bioeconomy/food/projects/food_processing/frisbee_en.htm

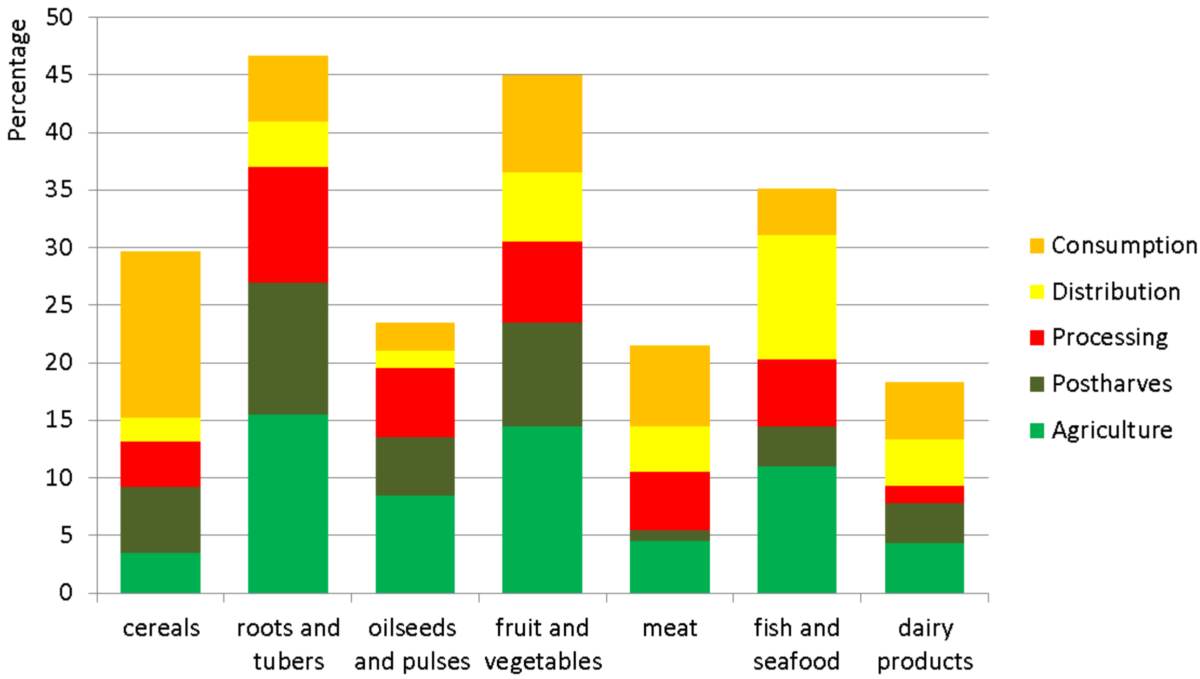


Figure 3.12 Material losses in steps of the food chain worldwide. Source: (FAO, 2013b, p. 15).

Additionally, reducing food waste by half by 2050 would provide one-quarter of the gap in food needs (Lipinski *et al*., 2013). More specifically, global agricultural losses could be reduced by 47 % and global consumption waste by 86 % (Kummu *et al.*, 2012). The food loss implies financial, environmental and social issues. Worldwide, food produced but not consumed was estimated at having an annual bulk-trade value of USD 936 billion (Lipinski *et al.*, 2013). In the Chinese economy, food waste is estimated at USD 32 billion while USD 48.3 billion of food is wasted every year in the United States of America (UNEP, 2014).

In the EU, BIO Intelligence Service, (2010) estimated food waste to 89 million tonnes in in 2006, expected to increase to 126 million tonnes in 2020 (EC, 2015) provides a value of 100 million tonnes of food wasted in the EU in 2014. The sectorial analysis addressed in BIO Intelligence Service (2010) showed that households produce the largest proportion of food waste and generate predominantly avoidable food waste. The manufacturing sector is responsible for the next largest proportion of food waste but in this case, predominantly composded by inedible food waste. Cuellar and Webber (2010) have estimated that in 2007 the energy embedded in the 27 % share of edible food lost in the USA was equivalent to 2 % of the annual energy consumption in the USA in the same year. An estimate of what this means for EU food dispersion in terms of loss of energy has been provided in Chapter 0.

3.6.1 Food waste minimisation

A considerable support to food waste minimisation could be derived from households' behavioural changes since 35 % of household food waste has been determined as avoidable (Bernstad and Andersson, 2015). For education purposes, the European Commission (EC, 2014) has summarised simple tips in order to avoid food waste including, for example, correctly planning shopping, checking expiry dates and storing food properly. More details on EU policies on food waste prevention will be discussed in section 4.1.7.

3.6.2 Energy recovery from wasted food

Due to its organic- and nutrient-rich composition, food waste can, theoretically, be utilised as a useful resource for the production of biofuel through various fermentation processes providing biogas, hydrogen, ethanol and biodiesel as final products. Not surprisingly, the energy valorisation of food waste has attracted increasing interest. A recent review has presented the state of the art of food waste fermentation technologies for renewable energy generation (Kiran *et al.,* 2014): instead of going to land fill or being incinerated, food waste is, in principle, suitable and economically viable for a more efficient energy recovery.

In order to identify the optimal solution in terms of energy and resource recovery, different food waste treatments can be compared using life cycle assessment (e.g. Kim and Kim, 2010). For instance, the anaerobic digestion applied to the organic waste (Nasir et al, 2012), as well as the co-digestion with sewage sludge, deliver benefits to food waste management, energy recovery and waste-water treatment (Iacovidu et al 2012).

The energy recovery option should also be compared with other choices, in connection with the actual mix of available raw material on a case-by-case basis. Following such an approach, Vandermeersch *et al.* (2014) have contrasted pathways in which the whole food waste was valorised in anaerobic digestion against pathways in which wasted bread was used to produce animal feed and only the non-bread fraction of waste food was digested. The study has shown that the use of bread waste as animal feed can be preferable to its valorisation in the digestate from the energy budget point of view, although the result remains very sensitive to local (Belgium) boundary conditions and uncertainties. Other examples of energy uses of food chain waste and residues in relation to energy recovery have been also discussed in sections 2.4 and 3.2.

3.6.3 Examples of relevant recent EU-funded projects

FUSIONS: Food Use for Social Innovation by Optimising waste prevention Strategies

Administrative data:

Status:	Ongoing
Project reference:	311972, under FP7-KBBE
Duration:	1 August 2012 to 31 July 2016
Budget:	EUR 5 033 160.00 (80 % EU contribution)
Coordinated in:	Netherlands
Website:	http://www.eu-fusions.org/

Objectives:

The FP7-funded project FUSIONS ([48]) is working towards significantly reducing food waste. The project will establish a European Multi-Stakeholder Platform to generate a shared vision and strategy to prevent food loss and waste across the whole supply chain using social innovation. The project will contribute towards the harmonisation of food waste monitoring, improved understanding of the extent to which social innovation can reduce food waste and the development of guidelines for a common food waste policy for the EU-28

FUSIONS seeks to identify the relationship between food waste and prices, health and nutrition, and how to monitor these impacts.

([48]) http://cordis.europa.eu/project/rcn/104335_en.html

LIFE+ GISWASTE: GIS-based decision-making tool for food by product valorisation alternatives in the Basque Country

Administrative data:

Status:	Ongoing
Project reference:	LIFE12 ENV/ES/000406
Duration:	15 July 2013 to 30 June 2017
Budget:	EUR 1 419 832.00 (49 % EU contribution)
Coordinated in:	Spain
Website:	http://www.lifegiswaste.eu/

Objectives:

The LIFE+ GISWASTE ([49]) project aims at developing a GIS-based tool for simulating the technical, economic and environmental feasibility of biogas and animal feed valorisation alternatives for vegetable, meat and dairy by-products. The project will gather relevant data that could be used to expand the tool's usefulness to encompass EU regions and other valorisation options.

Expected results:

1) Key factors (at least five for each recovery option), both economic and technical/environmental, which determine the viability of the chief recovery alternatives for agri-food by-products: animal feed and biogas.
2) An index which weights the key viability factors for each recovery option (one for each option), to establish which factors are the greatest determinants of the viability of each of the options.
3) Ensuring that the information pertaining to the generation of by-products in the Basque Autonomous Community is unified and up to date, so that it is available and accessible both for the firms that generate the by-products and the Basque Administration.
4) At least three maps in GIS format, which will include quantified information for each viability factor associated with each recovery option, as well as the geographical component associated with each by-product. A map will be produced for each type of by-product (vegetables, meat and dairy products).
5) Validated software will be developed for analysing viability and proposing the location of plants.

LIFE Zero Residues: Towards a sustainable production and supply chain for stone fruit

Administrative data:

Status:	Ongoing
Project reference:	LIFE12 ENV/ES/000902
Duration:	1 July 2013 to 30 June 2017
Budget:	EUR 3 445 458.00 (47 % EU contribution)
Coordinated in:	Spain
Website:	http://www.zeroresidues.eu/

Objectives:

The project Zero Residues ([50]) aims to improve the sustainability and quality of the production of stone fruit in order to create a more competitive and healthy sector.

([49]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4799&docType=pdf

([50]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4656&docType=pdf

In the course of the project a zero-residue (ZR) methodology will be developed. This will demonstrate that this new approach to produce, store, process and market stone fruit without residues creates a new trend in fruit production, with a higher quality that is more attractive and healthier at a competitive price. At the same time, the ZR methodology helps to improve various generated environmental problems; for example, integrated pest management will dramatically reduce pesticide doses and instead prevent degradation of soil and groundwater contamination.

Furthermore, the implementation of new technologies will increase the shelf life of the fruit after harvest by the use of innovative micro perforated packaging and atmospheric controls. As for fruit waste generated by imperfections of quality, this will be transformed into a suitable product for baby food factories, thus leading to new sales channels.

Finally, a certification system will be developed, which can only be obtained if production meets the requirements of zero residues. All knowledge is made available to other producers in order to disseminate the information as much as possible.

Expected results:

- Achievement of external certification for a zero-residue production process for stone fruit.
- 75 % of the harvest realised in the project will comply with the objective of zero residues (< 0.01 mg/kg of any detectable residue).
- Decrease of residual chemicals in the soil by 20 % at end of the project, compared to the situation at the beginning of the project.
- A 20 % increase in the shelf life of the resultant fruit, compared with conventionally produced and packaged fruit.
- The ZR products to be sold at a 10 % premium compared to the conventionally produced products.
- Successful pascalisation of 80 % of discarded fruit and proven interest from baby-food manufacturers.

BIFFIO: Cooperation between the aquaculture and agriculture sectors with the intent to use animal manure and fish faeces for sustainable production and utilisation of renewable energy and recovered nutrients

Administrative data:

Status:	Ongoing
Project reference:	605815, under FP7-SME
Duration:	1 November 2013 to 31 October 2016
Budget:	EUR 2 339 316.00 (75 % EU contribution)
Coordinated in:	Norway
Website:	http://www.biffio.com/

Description:

The BiFFiO project ([51]) is an example of industrial symbiosis, initiated from aquaculture, agriculture and renewable energy industries to enable a sustainable waste management by producing renewable energy from mixed aquaculture and agriculture waste, in addition to producing fertiliser, which will be used in the agriculture sector. The partners will develop energy-efficient, cost-effective, easy-to-implement and easy-to-operate biogas reactor technology.

Objectives:

([51]) http://cordis.europa.eu/project/rcn/110696_en.html

- Development of a new best practice and novel technology for handling mixed waste from aquaculture and agriculture for the production of energy, and further use of the digested waste.
- Development from current large-scale state-of-the art technologies for treating animal waste, to an economical, efficient and scalable three-stage system of pre-treatment, biogas reactor and fertiliser recuperation, which can be located at or in the vicinity of most near-shore and onshore fish farm operations.
- Application of new technology in the agriculture industry alone or together with the fish farming industry, on both remote and central locations to save costs for waste transport and deposition.
- Impact on socioeconomic conditions through the benefits of improved hygienic and environmental standards of closed fish farming, and by reduced greenhouse gas emissions and other pollution burdens from the agriculture sector.

NOSHAN: Sustainable production of functional and safe feed from food waste

Administrative data:

Status:	Ongoing
Project reference:	312140, under FP7-KBBE
Duration:	1 August 2012 to 31 January 2016
Budget:	EUR 4 075 842.00 (74 % EU contribution)
Coordinated in:	Spain
Website:	http://noshan.eu/index.php/en/

Objectives:

The main focus of NOSHAN ([52]) is to investigate the process and technologies needed to use food waste for feed production at low cost, low energy consumption and with maximal valorisation of starter waste materials. Nutritional value and functionality according to animal needs as well as safety and quality issues will be investigated and addressed as the leading factors for feed production using food derivatives (fruit/vegetable/plant and dairy).

Food wastes are characterised by their nutritional potential, but also suitable technologies to stabilise and convert them into suitable raw materials for bulk feed will be investigated. Obtaining functional feed ingredients (additives) from these wastes will also be targeted as it is an important factor in determining final feed costs and functionality in animals.

Two different groups of activities will be thus addressed:

- Replacement of bulk feed ingredients (constituting up to 90-95 % of feed weight) with starter waste materials to cope with part of the huge amounts of food waste generated in Europe.
- Valorisation of active ingredients as well as the upgrade of waste into more valuable feed additives will be studied. The latter constitutes approximately half of the feed cost.

Expected results:

The main expected result of NOSHAN is the creation of a broad portfolio of valorised waste for feed production. During the first phase of the project, a selection of waste materials will be graded according to their potential nutritional properties, quantities produced, seasonality, possibility of stabilisation, safety and regulatory issues, cost and logistics. In order to improve nutritional content of feed and be able to fulfil animal needs, waste will be treated alone or mixed with other types of waste to look for

([52]) http://cordis.europa.eu/project/rcn/104299_en.html

complementation and synergistic effects. The characterisation at molecular level of the different waste streams will allow provision of the most suitable technology for the different materials in order to obtain the desired nutritional/functional properties.

3.7 Behavioural and customer-centred analyses

If the whole life cycle energy-content impacts are considered, eating is one of the most energy-consuming everyday activities of the EU citizen (see Chapter 1 results). The amount of energy embedded in food products vary between a few and a few hundred MJ per kg consumed.

For this reason the total daily energy inputs for different kind of diets can be highly variable (Carlsson-Kanyama, Ekström and Shanahan, 2003). For this reason, personal habits in food consumption can strongly impact on the overall societal energy consumption, and research has also focused on the behaviour of private citizens as a tool to reduce the overall energy impact from the sector.

Consumers can substantially reduce the environmental and energy impact of their food habits by taking several kinds of decisions, ranging from simple decisions such as the choice of packaging for a product, preferences for certain labels, choices on ingredients for a meal, etc. up to more fundamental choices such as switching to vegetarian or other diets (Jungbluth, Tietje and Scholz, 2000).

Generally speaking, there are some simple 'rules of thumb' for consumers willing to reduce their energy 'food print' by changing their diet habits. The main measures that can be taken are:

- reducing meat consumption, especially red meat, or adopting a vegetarian/vegan diet;
- buying locally (locally grown food purchasing, especially avoiding air-transported food) and seasonally (i.e. avoiding fruits and vegetables from heated greenhouses);
- reducing food waste in households (post-purchase food wastes);
- opting for organic food.

According to Jungbluth *et al.* (2013), the most promising single change in behaviour impacting on food-related energy consumption is to opt for a vegetarian diet instead of a meat-based diet. As an order of magnitude, within the meat category, beef has energy inputs of up to 75 MJ per kg, chicken 35 MJ per kg, pork and lamb 40 and 43 MJ per kg, respectively. Legumes have a high protein content, ranging from 20-34 % for dried products, comparable with meat and fish, but with a lower energy input, which ranges for cooked legumes from 5-20 MJ per kg; also some dairy products have a high energy input, similar to certain types of meat. For instance, 10 litres of milk are used for 1 kg of cheese, and almost all energy during cheese production is allocated to the main product (see again the JRC elaborations in Chapter 1 for Europe-tailored data) ([53]).

The energy content is not the only indicator associated with different dietary preferences: Pimentel and Pimentel. (2003) have investigated several environmental indicators, focusing on the higher impact of meat-based diets with respect to the vegetarian ones. Many other studies in the scientific literature have claimed the high ecological cost of meat in terms of climate-change potential (Carlsson-Kanyama and González, 2009; Eshel and Martin, 2006; McMichael, Powles, Butler and Uauy, 2007) and water footprint and energy consumption (Pimentel and Pimentel, 2003; Pimentel, 2006).

Buying seasonally and locally produced food can also reduce total food energy inputs. Globalised food systems rest upon wide transport infrastructures and foodstuffs cover

([53]) It is indeed well known that, in metabolic terms, animal production is less efficient than crops; 1 kg of meat requires, on average, 3 kg of grain and 16 000 litres of virtual water (Hoekstra et al., 2011; Nellemann et al., 2009).

thousands of kilometres before reaching the table (see section 3.3). The availability of fresh fruit and vegetables has been extended to exotic products that are imported in large quantities from tropical areas, often transported by plane from overseas (Mancini, 2011). Fruit and vegetables are available out of season nowadays, thanks to an energy-intensive greenhouse production. In addition, the modern food industry provides highly processed food that must be cooked, refrigerated, packed, stored and transported. Yet, consumers need to be properly and fully informed about available alternatives because counter-intuitive situations and hidden trade-offs are often found in daily practice.

As for consumer choices on food waste, it is well known (see also section 3.6) that households account for a consistent share of food wasted before it can be consumed (Hoolohan, Berners-Lee, McKinstry-West and Hewitt, 2013). In order to quantify the impact of consumer choices around waste, it is necessary to distinguish between post-purchase waste and waste resulting elsewhere in the supply chain. As an example, post-purchase waste in the United Kingdom is estimated to be around 19 % of all food, of which 12 % of all food is considered avoidable (Quested & Parry, 2011).

3.7.1 Examples of relevant recent EU-funded projects

LiveWell for LIFE: LiveWell plate for low impact food in Europe

Administrative data:

Status:	Ongoing
Project reference:	LIFE12 ENV/ES/000406
Duration:	1 October 2011 to 30 March 2015
Budget:	EUR 2 078 844.00 (50 % EU contribution)
Coordinated in:	United Kingdom
Website:	http://livewellforlife.eu/

Objectives:

The LIFE+ funded project LiveWell ([54]) aims at demonstrating what sustainable diets look like for EU Member States, facilitating a conducive policy environment, developing tangible pathways for implementation of sustainable diets and disseminating this widely across Europe. LiveWell for LIFE works with members of the Network of European Food Stakeholders to reduce the impact food consumption has on the environment. The project also looks at health, nutrition, carbon and affordability. The project demonstrates how low-carbon, healthy diets can help us achieve a reduction in greenhouse gas emissions and energy content from the EU food supply chain.

Expected results:

- Map what sustainable diets could look like for each pilot country.
- Investigate the barriers and opportunities for sustainable diets.
- Build policy recommendations and practical pathways to implement sustainable diets.

([54]) http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3936&docType=pdf

4. Un-tapping the potential for energy savings and renewable energy in the European food chain

Analyses discussed in the previous chapters have shown that the amount of energy involved in food production and consumption in Europe is very relevant. Several feasible strategies and practical measures aiming at either decreasing food-related energy consumption or increasing the share of renewable energy employed have been presented and discussed on the basis of the current scientific literature. In this final chapter, the relevant policy tools and initiatives, currently in place in the European Union, will be presented and discussed together with examples of R & D projects and actual practical implementations of the measures listed.

4.1 The role of European institutions

Regardless of the complexity and the extension of the overall food supply chain, the European institutions have put in place several key legislative tools and initiatives that impact the energy content of food and it has promoted several initiatives through its different departments for guiding their practical application.

Several measures, programmes and initiatives have been implemented in the numerous economic sectors involved in food production and will be reviewed in the next paragraphs. Measures directly targeting energy efficiency and renewable energy will be considered, together with additional legislative approaches and initiatives not directly targeting energy issues, but inducing a positive impact on them. A summary is presented in Table 4.1 to Table 4.8 where the sectorial energy flow analysis developed in Chapter 1 and the technical measures presented in Chapters 2 and 3 are linked with the policy framework and the case studies discussed in this chapter.

4.1.1 The big drivers: the Energy Efficiency Directive and the Renewable Energy Directive

Current EU policies in energy efficiency and renewable energy are driven by two scene-setting Directives: the Renewable Energy Directive (RED — 2009/28/EU) and the Energy Efficiency Directive (EED — 2012/27/EU), both parts of the 2020 Energy Strategy, aiming to reduce EU greenhouse gas emissions by 20 %, increase the share of renewable energy to at least 20 % of consumption, and achieve energy savings of 20 % or more. Greenhouse gas emissions, renewable energy and energy efficiency targets for 2030 were endorsed in October 2014 by the European Council: the EU should collectively reduce its emissions by at least 40 % compared to 1990 levels, and achieve at least 27 % renewable energy in the EU's final energy consumption and a 27 % or greater improvement in energy efficiency by 2030. Both the Directives play their role on the large economic scale, do not directly target the food production process in itself but build a framework to which the several sectors and processes involved in food production can refer. Member States had to detail their plans in order to reach the set targets in the form of National Renewable Energy Action Plans (NREAPs) and National Energy Efficiency Action Plans (NEEAPS), and the presentation of progress reports constantly monitoring the achieved progresses is periodically requested: every second year in the case of the RED and on a yearly basis for the EED.

Table 4.1 Sectorial and framework EU policies in the area of **agriculture**, which according to JRC estimates, is responsible for 33.4 % of share of embedded energy in the food basket.

Energy-relevant framework policies and EU-led initiatives	Main energy consumption areas	Suitable actions	Relevant sectorial EU policies and EU-led initiatives
Common Agricultural Policy – mostly second pillar European Innovation Partnership for Agricultural productivity and sustainability (EIP-AGRI)	Fertilisers and pesticides	Apply best available technologies in fertiliser production	Reference document on BAT in large volume inorganic chemicals – ammonia, acids and fertilisers
		Adopt farm practices minimising fertiliser and pesticide applications (notillage, precision agriculture, organic)	Council Regulation 834/2007 on organic production and labelling of organic products Action Plan for the future of organic production in the European Union – COM(2014) 179
		Wind to ammonia production chain	European Industrial Initiative on Wind Energy
	Machinery use	Precision agriculture	
		Local use of biofuels	
	Water supply	Upgrade irrigation systems	Regulation1305/2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) – mainly Article 46
		Diversification of water sources	Communication from the Commission addressing the challenge of water scarcity and droughts in the European Union – SEC(2007) 993
	Livestock feeding and husbandry	Improved feed crop production Energy recovery of residues High efficiency appliances in stables	Reference document on best available techniques for intensive rearing of poultry and pigs
	Greenhouse heating	Geothermal greenhouses Solar greenhouses	Renewable Energy Directive European Industrial Initiatives
	Cultivation practices	Privilege less energy intensive cultivation (e.g. notillage, organic)	Council Regulation 834/2007 on organic production and labelling of organic products Action Plan for the future of organic production in the European Union – COM(2014) 179
		Privilege seasonal products Privilege products appropriate to the climate conditions	Regulation 1151/2012 on quality schemes for agricultural products and foodstuffs
		Apply advanced cultivation systems	
	Farm energy self consumption	Install PV panels and small scale wind turbines for auto production Stand-alone PV powered appliances (irrigation pumps, fertilisers, tractors, etc.) Energy use of farm residues (biogas, thermal) Selfgeneration of warm water through sun heaters	Renewable Energy Directive European Strategic Energy Technology Plan (SET-Plan) European Industrial Initiatives on solar energy and bioenergy Report from the Commission on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling – SEC(2010) 65

Table 4.2 Sectorial and framework EU policies in the area of **fishery and aquaculture** (included in agriculture when estimating the embedded energy in the food basket; see previous table caption).

Energy-relevant framework policies and EU-led initiatives	Main energy consumption areas	Suitable actions	Relevant sectorial EU policies and EU-led initiatives
Common Fisheries Policy (CFP)	Fleet movement	Remote detection of stocks	European Maritime and Fisheries Fund (EMFF) – Articles 41, 43, 44, 51, 53 and 69
	Onboard food pre-processing	Apply energy-efficient onboard machinery	

Table 4.3 Sectorial and framework EU policies in the area of **food processing**, which according to JRC estimates, is responsible for 28 % of share of embedded energy in the food basket.

Energy-relevant framework policies and EU-led initiatives	Main energy consumption areas	Suitable actions	Relevant sectorial EU policies and EU-led initiatives
EED Articles 7, 8 and 14 Industrial Emissions Directive and reference and related BREFS: Document on best available techniques in the food, drink and milk industries Reference document on best available techniques in the slaughterhouses and animal by-products industries (JRC, 2005) Green Action Plan for SMEs Horizon 2020 – SME instrument	Individual industrial processes (decomposition, mixing, cutting, joining, coating, forming, heating, melting, drying/concentration, cooling/freezing)	Install high-efficiency/low-consumption components (coolers, pumps, motors, valves, lights, boilers, etc.)	Reference document on the application of best available techniques to industrial cooling systems
		Advanced metering	EED, Articles 9-11
		Optimised power control	Ecodesign (electric motors, ventilation fans, lighting regulations)
	Heat production	Combined heat and power	EED, Article 14 Commission Staff Working Document: Guidance note on Directive 2012/27/EU on energy efficiency; Article 14 – SWD(2013) 449
		Solar production for moderate temperature water Solar drying and solar cooling (where possible)	European Industrial Initiative on Solar Energy
	Structural inefficiencies	Group energy buying Energy service company (ESCO) consultancy Energy auditing	EED, Article 14 Commission Staff Working Document: Guidance note on Directive 2012/27/EU on energy efficiency; Article 14 SWD(2013) 449

Table 4.4 Sectorial and framework EU policies in the area of **logistics**, which according to JRC estimates, is responsible for 9.4 % of share of embedded energy in the food basket.

Energy-relevant framework policies and EU-led initiatives	Main energy consumption areas	Suitable actions	Relevant sectorial EU policies and EU-led initiatives
Directive 2009/33/EC on the promotion of clean and energy efficient road transport vehicles (Clean Vehicles Directive) Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport	Imported/'*long distance*' food	Privilege local productions and short supply chains	Report from the Commission to the European Parliament and the Council on the case for a local farming and direct sales labelling scheme – COM(2013) 866
		Improve energy saving in refrigerated transport	
		Optimise transport logistic	Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport
	Retailing	Improved and appropriate refrigeration technologies	Ecodesign regulations (draft regulation for professional refrigerated storage cabinets, blast cabinets, condensing units and process chillers) and Energy Labelling (draft regulation for professional refrigerated storage cabinets)

Table 4.5 Sectorial and framework EU policies in the area of **packaging**, which according to JRC estimates, is responsible of 10.7 % for share of embedded energy in the food basket.

Energy-relevant framework policies and EU-led initiatives	Main energy consumption areas	Suitable actions	Relevant sectorial EU policies and EU-led initiatives
Packaging and Waste Packaging Directive (PWPD) Green Paper on a European strategy on plastic waste in the environment – COM(2013) 123	Packaging production	Intelligent food packaging technology	Commission regulation 450/2009 on active and intelligent materials and articles intended to come into contact with food
	Packaging use	Use the most appropriate packaging to diminish food waste	
	Secondary packaging	Optimised food logistics	

Table 4.6 Sectorial and framework EU policies in the area of **food use as in cooking and domestic conservation**, which according to JRC estimates, is responsible for 13 % of share of embedded energy in the food basket.

Energy-relevant framework policies and EU-led initiatives	Main energy consumption areas	Suitable actions	Relevant sectorial EU policies and EU-led initiatives
Ecodesign and Energy Labelling Directives	Domestic cooking and conservation	Costumer education on energy-saving cooking and conservation practices	
		Promote efficient appliances	Ecodesign and labelling requirements for domestic refrigerators and freezers and kitchen appliances (domestic ovens, hobs and range hobs)

Table 4.7 Sectorial and framework EU policies in the area of **end of life**, which according to JRC estimates, is responsible for 5.5 % of share of embedded energy in the food basket.

Energy-relevant framework policies and EU-led initiatives	Main energy consumption areas	Suitable actions	Relevant sectorial EU policies and EU-led initiatives
Waste Framework Directive Green Paper on the management of bio-waste in the European Union – COM(2008) 811 Green Paper on a European strategy on plastic waste in the environment – COM(2013) 123 Landfill Directive (1999/31/EC)	Managing end-of-life food residues (including packaging residues)	Differentiated collecting	Waste Framework Directive, Article 22
		Energy recovery	Waste Incineration Directive, Articles 4 and 23
		Prevention of food residues	Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Towards a circular economy: A zero waste programme for Europe – COM(2014)398

Table 4.8 Sectorial and framework EU policies in the area of **food waste**, which according to EU estimates, represents 100 million tonnes per year.

Energy-relevant framework policies and EU-led initiatives	Main energy consumption areas	Suitable actions	Relevant sectorial EU policies and EU-led initiatives
Waste Framework Directive Green Paper on the management of bio-waste in the European Union – COM(2008) 811 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Towards a circular economy: A zero waste programme for Europe – COM(2014)398	Managing food waste	Preventing food waste	Commission Implementing Decision establishing a format for notifying the information on the adoption and substantial revisions of the waste management plans and the waste prevention programmes – 2013/727/EU Advisory Group on the Food Chain and Animal and Plant Health – working group on food waste
		Exploiting food waste	Waste Framework Directive, Article 22 Waste Incineration Directive Landfill Directive – 1999/31/EC

4.1.2 Energy in the framework of the Common Agriculture and Fishery policies

The Common Agriculture Policy (CAP) has paid attention to the energy component of farming and in its latest 2014 version a special emphasis is reserved for sustainable agriculture.

Following the 2014 reform of the direct payments system (first pillar) ([55]), in order to receive their full entitlement of income support payments, farmers have to adopt environmentally sustainable farming methods and they may also receive additional support if they adopt more strict agri-environmental farming practices.

The second CAP pillar ([56]), devoted to rural development, has among its explicit objectives the 'increasing efficiency in energy use in agriculture and food processing'. Pursuing such a scope, tailored incentives for farm restructuring, investment and modernisation are foreseen. Moreover, a set of agri-environment/climate payments is available to preserve and promote necessary changes to agricultural practices that make a positive contribution to the environment and climate, while a single separate measure is introduced to support organic farming practices, which, as shown in Chapter 2, are generally less energy intensive.

Opportunities are offered by CAP through financial support that could be provided for setting up producer organisations to jointly place goods on the market and centralise

([55]) Regulation (EU) No 1307/2013 of the European Parliament and of the Council.
([56]) Regulation (EU) No 1305/2013 of the European Parliament and of the Council.

sales. Such a scheme is limited to SMEs, i.e. the sector that is expected to bring, amongst other benefits, the logistic-related energy savings described in section 3.1.

It is also worth remembering that rural development policies do not stop at the farm gate and the European Agricultural Fund for Rural Development can be involved in rural village renewal, such as investments in energy-saving technologies and renewable energy generation.

Sustainable agriculture also needs new technologies, new farming models and more applied research. For this reason, the European Innovation Partnership for Agricultural productivity and sustainability (EIP-AGRI http://ec.europa.eu/eip/agriculture) was launched by the European Commission in 2012. It aims to foster a competitive and sustainable agriculture and forestry sector that 'achieves more from less'. It contributes to ensuring a steady supply of food, feed and biomaterials, and to the sustainable management of the essential natural resources on which farming and forestry depend, working in harmony with the environment. To achieve this aim, the EIP-AGRI brings together innovation actors (farmers, advisors, researchers, businesses, non-governmental organisations — NGOs, etc.) and helps to build bridges between research and practice.

EIP-AGRI focus groups on energy-related matters such as fertiliser efficiency, organic farming, precision farming and short food supply chains are currently active in proposing new practical solutions to be tested and research directions to be explored. The farm is also seen as a potential energy producer by the CAP and a further objective of the rural development pillar consists of 'facilitating the supply and use of renewable sources of energy, of by-products, wastes and residues and of other non-food raw material, for the purposes of the bio-economy'. Section 2.4 refers to several ways in which this objective can be pursued in the farmer's daily reality.

The Common Fisheries Policy (CFP) is a set of rules for managing European fishing fleets and for conserving fish stocks. The CFP aims to ensure that fishing and aquaculture are environmentally, economically and socially sustainable and that they provide a source of healthy food for EU citizens. Its goal is to foster a dynamic fishing and energy efficiency at the core of several measures foreseen in the new (2014-2020) European Maritime and Fisheries Fund (EMFF) regulations ([57]). Moreover, investments aimed at increasing the energy efficiency of fishing vessels, energy efficiency audits, and schemes and studies to assess the contribution of alternative propulsion systems and hull designs to the energy efficiency of fishing vessels (Reg. 508/2014, Article 41) are eligible for funding under the EMFF, together with energy-efficiency-focused investments improving the infrastructure of fishing ports, auction halls, landing sites and shelters (Reg. 508/2014, Article 43) for both sea and inland fishing (Reg. 508/2014, Article 44). Energy-efficiency measures are also eligible for funding under the EMFF in the aquaculture (Reg. 508/2014, Articles 48, 51 and 53) and early fish product processing (Reg. 508/2014, Article 69), while investments promoting the conversion of aquaculture enterprises to renewable sources of energy are eligible again under Article 53 of Reg. 508/2014.

([57]) Regulation (EU) No 508/2014 of the European Parliament and of the Council on the European Maritime and Fisheries Fund.

4.1.3 Energy efficiency and renewable energy in industry

The EED promotes energy auditing ([58]) in industries, through specific programmes in the case of SMEs and by legal obligations for large enterprises. More specifically, Article 8(2) of the Directive establishes that Member States must develop programmes to encourage SMEs to undergo energy audits and the subsequent implementation of the recommendations from these audits, while under Article 8(4) Member States must ensure that large enterprises ('that are not SMEs') carry out regular energy audits — no sectors excluded. Article 8 also requires Member States to actively promote the availability and use of energy audits, and allows the setting up of support schemes for SMEs to carry out and implement energy audits. Likewise, Member States are explicitly allowed to set up incentives and support schemes for enterprises, including non-SME enterprises, to implement the recommendations of energy audits.

Moreover, Article 14 of the EED extends the scope and replaces the substantive provisions of Directive 2004/8/EC2 on the promotion of cogeneration and utilisation of waste heat (the so-called 'CHP Directive'), which also involves the industrial sector. It requires Member States to comply with several obligations, including the adoption of authorisation or permit criteria and procedures for industrial installations, ensuring that they carry out an installation-level cost-benefit analysis on the use of high-efficiency cogeneration and/or the utilisation of waste heat and/or connection to a district heating and cooling network when they plan to build or refurbish capacities above 20 MW thermal input.

Energy-use optimisation in industry is also a goal of the Industrial Emissions Directive 2010/75/EU (IED). Indeed, Chapter II of IED (and its preceding Directives) requires the integrated control of the consumption of energy, water and raw materials from approximately 50 000 industrial installations across Europe. This control is implemented in each EU Member State through a system of permits that include conditions requiring the use of the best available techniques (BAT). The European Integrated Pollution Prevention and Control Bureau (EIPPCB), managed by JRC, develops, maintains and updates the Best Available Techniques Reference Documents (BREFs). BREFs are generated following the exchange of technical information between experts from industry, EU Member States, research institutes, environmental NGOs and the European Commission, and are the main reference documents used by the competent authorities in EU Member States when issuing operating permits for industrial installations. A BREF is the vehicle through which BAT and emerging techniques are determined in a transparent manner, based on sound techno-economic information. It gives predictability to the process of determining conclusions on BATs and provides confidence in the quality of the end result. Its key elements, BAT conclusions, are adopted through committee procedures and are the reference for setting permit conditions to installations covered by the IED.

Several BREFs are related to industries or processes involved in food production, namely:

([58]) According to the EED, 'energy audit' means a systematic procedure with the purpose of obtaining adequate knowledge of the existing energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation, or a private or public service, identifying and quantifying cost-effective energy savings opportunities, and reporting the findings.

- Reference document on best available techniques for energy efficiency;
- Reference document on best available techniques in the food, drink and milk industries;
- Reference document on the application of best available techniques to industrial cooling systems;
- Reference document on best available techniques for intensive rearing of poultry and pigs;
- Draft of the best available techniques (BAT) reference document for the intensive rearing of poultry and pigs;
- Reference document on best available techniques in the slaughterhouses and animal by-products industries (JRC, 2005);
- Reference document on best available techniques in large volume inorganic chemicals — ammonia, acids and fertilisers.

All BREF documents are available for download http://eippcb.jrc.ec.europa.eu/reference/

The recent Green Action Plan for SMEs ([59]) has set up the facilitation to access finance for resource-related improvements and energy efficiency in SMEs as an objective to be pursued through several funding channels. For instance, the European Investment Bank (EIB) will provide financing through financial intermediaries for resource-efficiency improvements linked to ecosystem services and climate change adaptation with the Natural Capital Financing Facility (NCFF). The Private Finance for Energy Efficiency instruments (PF4EE) can support SMEs and larger mid-cap companies, among others, undertaking small energy-efficiency investments, and which are capable of using energy savings to repay up-front borrowing.

Moreover, some sectorial funds such as the European Regional Development Fund (ERDF), the European Agricultural Fund for Rural Development (EAFRD) and the European Maritime and Fisheries Fund (EMFF) for the period 2014-2020 will support SMEs' competitiveness, targeting energy efficiency and the use of renewable energy sources. These are identified as investment priories to be pursued by Member States and regions through their operational programmes.

4.1.4 Ecodesign and energy labelling regulations

Ecodesign regulations require manufacturers to decrease the energy consumption of their products by establishing minimum energy-efficiency standards. Requirements for individual product groups are created under the EU's Ecodesign Directive (2009/125/EC) or, as an alternative, industry sectors may also sign voluntary agreements to reduce the energy consumption of their products. The Commission formally recognises such agreements and monitors their implementation.

Ecodesign regulations involve both domestic and industrial appliances and are complemented by energy labelling, a system that helps consumers choose energy-efficient products. The labelling requirements for individual product groups are created under the EU's Energy Labelling Directive (2010/30/EU).

([59]) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Green Action Plan for SMEs: Enabling SMEs to turn environmental challenges into business opportunities. COM(2014) 440 final.

Several Ecodesign regulations focus on industrial components largely employed in the food sector, such as ventilation units (Reg. 1253/2014), power transformers (Reg. 548/2014), heaters and water heaters (Reg. 813/2013), hot water storage tanks (Reg. 814/2013), water pumps (Reg. 547/2012), industrial fans (Reg. 327/2011) and electric motors (Reg. 4/2014). Actual energy savings realised through these regulations involve any industrial sector and business size could be very important. As an example, electric motors are estimated to consume about 40 % of all electricity in the EU and the related Ecodesign measures are estimated to lead to annual use-phase electricity consumption saving in the EU of about 139 TWh by 2020.

As far as food retail and domestic consumptions are concerned, Ecodesign regulations for domestic cold appliances entered into force in August 2009; an energy label first appeared on these products from December 2010. The expected energy savings from the combined effect of both regulations is expected to be 4 TWh annually from 2020, which is roughly equal to the residential electricity consumption of Slovakia.

Ecodesign requirements for domestic kitchen appliances were adopted in February 2014, with a range of additional improvements scheduled to come into force gradually over the next five years. An energy labelling regulation (No 65/2014) was issued on domestic ovens and range hoods, with a staged implementation. The regulation established an A to G scale for 2015, followed by scales of A+ to F in 2016, A++ to E in 2018, and A+++ to D in 2020. For domestic ovens, the A+++ to D scale will be displayed on these products from 2015 onwards. The expected energy savings from the combined effect of these regulations is expected to amount to 27 PJ annually by 2020, roughly equivalent to the residential electricity consumption needs of 2 million EU citizens.

A revision of these regulations was initiated in 2014 and is expected to be finalised by 2016. In particular, the currently applicable correction factors will be reassessed, as well as the possibility of setting resource efficiency requirements (material recovery, durability, etc.). An assessment of possible Ecodesign requirements for wine storage appliances will also be undertaken.

4.1.5 Packaging

The Packaging and Waste Packaging Directive (PWPD) was first adopted in 1994 (94/62/EC) with the overall aims of providing a high level of environmental protection. PWPD sets targets for the recovery and recycling of packaging waste that were increased following the Directive revision in 2004 and 2005. Alongside a number of other waste stream Directives, the Packaging and Packaging Waste Directive was subject to a review of waste policy and legislation in 2014, covering a further review of key targets and including the same waste packaging management hierarchy defined by the Waste Framework Directive (see section 3.1.7)

On 2 July 2014, in the framework of the 'circular economy package', the European Commission adopted a legislative proposal ([60]) to review recycling and other waste-related legislation, including the PWPD. The aim of the proposal is to help turn Europe

([60]) Proposal for a Directive of the European Parliament and of the Council amending Directives 2008/98/EC on waste, 94/62/EC on packaging and packaging waste, 1999/31/EC on the landfill of waste, 2000/53/EC on end-of-life vehicles, 2006/66/EC on batteries and accumulators and waste batteries and accumulators, and 2012/19/EU on waste electrical and electronic equipment, COM(2014) 397.

into a circular economy with packaging playing a major role: recycling and preparing for the re-use of packaging waste is expected to be increased to 80 % by 2030, with material-specific targets set to gradually increase between 2020 and 2030 and to reach 90 % for paper by 2025 and 60 % for plastics, 80 % for wood, and 90 % for ferrous metal, aluminium and glass by the end of 2030.

In 2013, the European Commission adopted a proposal ([61]) that requires Member States to reduce the use of lightweight plastic carrier bags. This proposal has been subject to discussion with the European Parliament and the Council, and these institutions found a compromise in November 2014. Formal adoption of the Directive is expected in Spring 2015.

Standards also play a major role in ensuring packaging complies with the essential requirements of PWPD. Relevant standards adopted by the EU ([62]) include CEN EN 13428:2004 (Prevention by source reduction), CEN EN 13429:2004 (Re-use), CEN EN 13430:2004 (packaging recoverable by material recycling), CEN EN 13431:2004 (packaging recoverable in the form of energy recovery), and CEN EN 13432:2000 (packaging recoverable through composting and biodegradation).

4.1.6 Logistics

The Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles (Clean Vehicles Directive or CVD) requires that energy and environmental impacts linked to the operation of vehicles over their whole lifetime are taken into account in all purchases of road transport vehicles, as covered by the Public Procurement Directives and the Public Service Regulation. This Directive is expected to result, in the longer term, in a wider deployment of clean and energy-efficient vehicles. Increased sales will help reduce costs through economies of scale, resulting in progressive improvements to the energy and environmental performance of the whole vehicle fleet.

A legal framework for Intelligent Transport Systems (ITS Directive — 2010/40/EU) was adopted on 7 July 2010 to accelerate the deployment of these innovative transport technologies across Europe. It aims to establish interoperable and seamless ITS services while leaving Member States with the freedom to decide which systems to invest in. Under this Directive, the European Commission has to adopt within the next seven years specifications (i.e. functional, technical, organisational or service provisions) to address the compatibility, interoperability and continuity of ITS solutions across the EU. According to Annex 2, the adoption of specifications, the issuing of mandates for standards and the selection and deployment of ITS applications and services shall be effective and make a tangible contribution towards solving the key challenges affecting road transportation in Europe, including improving energy efficiency.

4.1.7 End of life and food wastage

Directive 2008/98/EC (the Waste Framework Directive — WFD) sets the basic concepts and definitions related to waste management and in Article 4(1) defines the waste

([61]) Proposal for a Directive of the European Parliament and of the Council amending Directive 94/62/EC on packaging and packaging waste to reduce the consumption of lightweight plastic carrier bags, COM(2013) 761.

([62]) Commission communication in the framework of the implementation of the European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste, 2005/C 44/13.

hierarchy indicating the waste management strategies in order of priority: (a) prevention, (b) re-use, (c) recycling, (d) other recovery, e.g. energy recovery, and (e) disposal. According to Article 23(4), it shall be a condition of any permit covering incineration or co-incineration with energy recovery that the recovery of energy takes place with a high level of energy efficiency.

Bio-waste, including food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants (but not including forestry or agricultural residues, manure or sewage sludge) has been discussed in the Green Paper on the management of bio-waste in the European Union (COM(2008) 811) and is the subject of Article 22 of the WFD encouraging, among other measures, the separate collection of bio-waste with a view to its composting and digestion. The Landfill Directive (1999/31/EC) obliges Member States to reduce the amount of biodegradable municipal waste (in which food residues and wastes play a major role) that they landfill to 35 % of 1995 levels by 2016 (for some countries by 2020). Finally, the incineration of bio-waste is regulated in the Waste Incineration Directive, while the health rules for composting and biogas plants which treat animal by-products are laid down in the Animal By-products Regulation.

Again under the umbrella of the WFD, a guidance document has been prepared to support Member States when developing Waste Prevention Programmes. Specific guidelines have been prepared to address food waste ([63]), which are aimed primarily at national policy-makers developing National Waste Prevention Programmes. They can also support policy-makers in developing national strategies for biodegradable municipal waste required under the Landfill Directive, and can be a useful tool for waste management organisations, businesses, institutions, local authorities and environmental protection agencies and other actors dealing with food waste. Key sectors addressed in the guidelines include local authorities, households, the hospitality industry, the retail supply chain, businesses and institutions (such as schools and hospitals).

Finally, the already cited 'circular economy package' (see section 4.1.5) includes a specific target for reducing food waste generation by 30 % by 2025.

4.1.8 Eco-Management and Audit Scheme (EMAS)

EMAS is the European Union's environmental management system, a management tool for companies and other organisations to evaluate, report and improve their environmental performance. The latest revision of the EMAS Regulation (EC No. 1221/2009) introduced a particular focus on promoting best environmental management practices. To support this aim, the European Commission is producing sectoral reference documents (SRDs) to provide information and guidance on best-practice in eleven priority sectors, including in particular three sectors along the value chain of food production and distribution: agriculture (crop and animal production); food and drink manufacturing; and retail trade.

The documents are intended to support environmental improvement efforts of all actors in each sector, not only those who have adopted EMAS. In particular the reference

([63]) Guidelines on the preparation of food waste prevention programmes: http://ec.europa.eu/environment/waste/prevention/pdf/prevention_guidelines.pdf documents are based on extensive Best Practice Reports ([64]) produced by the Joint Research Centre in collaboration with industry experts and stakeholders. These Reports include examples of best practice from existing adopters, as well as indicators and benchmarks to monitor progress, to encourage and support widespread adoption.

Since energy consumption is a major environmental impact in the three sectors relevant to the food supply chain, numerous examples are available on how to improve energy efficiency and implement renewable energy solutions in these sectors.

4.1.9 Other relevant legislation and initiatives at EU level

Other sectorial initiatives that are expected to impact the energy profile of European food are referenced in Table 4.1. Among them, it is worth citing the European Strategic Energy Technology Plan (SET-Plan) ([65]), which aims to accelerate the development and deployment of low-carbon technologies, including several renewable energy technologies. The SET-Plan includes the European Industrial Initiatives (EIIs), bringing together EU countries, industry and researchers in key areas, and promoting the market uptake of key energy technologies by pooling funding, skills and research facilities. EIIs currently include, among others, the European Wind Initiative, the Solar Europe Initiative and the European Industrial Bioenergy Initiative.

Funding initiatives generally targeting energy efficiency in different sectors include several instruments. The Project Development Assistance (PDA) helps public and private project promoters develop sustainable energy investment projects ranging from EUR 6 million to EUR 50 million, while ELENA, managed by the European Investment Bank, provides grants to help local and regional authorities develop and launch large-scale sustainable energy investments covering up to 90 % of the technical support costs. The Private Financing for Energy Efficiency instrument (PF4EE) is a new financial instrument under the EU's LIFE programme, which co-funds energy-efficiency programmes in several EU countries. Finally, under the European Structural and Investment Funds (ESIF), more than EUR 27 billion is ring-fenced to support the shift towards a low-carbon economy, including renewable energy and energy efficiency.

Support schemes for renewable energy are designed to push the markets towards the desired level of renewables in the EU, overcoming market failure and spurring increased investment in renewable energy. Support schemes are designed by Member States; nevertheless, if these public interventions are not carefully designed, they could distort the functioning of the energy market and lead to higher costs for European households and businesses. In order to assist Member States when designing and reforming appropriate renewable energy support schemes, the EU has adopted a guidance document ([66]).

4.1.10 Summary of relevant national initiatives

Austria: The klimaaktiv energy-efficient enterprises programme aims to achieve a significant increase in energy efficiency in Austrian companies. The development of

([64]) Information on the documents, which are currently being developed, is available at http://susproc.jrc.ec.europa.eu/activities/emas/index.html

([65]) A European Strategic Energy Technology Plan (SET-Plan) — Towards a low carbon future, COM(2007) 723.

([66]) Commission Staff Working document on European Commission guidance for the design of renewables support schemes, SWD(2013) 439.

guidelines for technologies and industries and the dissemination of know-how throughout Austria in the form of standardised training make an important contribution to the implementing quality of efficiency measures and thus to the full exploitation of efficiency potential.

See more at: http://www.klimaaktiv.at/english.html

Ireland: The Large Industry Energy Network (LIEN) is a voluntary grouping of companies, facilitated by the Sustainable Energy Authority of Ireland (SEAI), that work together to develop and maintain robust energy management. One hundred and sixty of Ireland's largest energy users are members of the LIEN. Over 80 of these companies are also members of the Energy Agreement Programme and are now working towards the new international standard ISO 50001. Many companies in the food industry are part of this group. The Energy Agreements Programme (EAP), launched in May 2006, is a subset of the LIEN. Companies commit to managing their energy use in a strategic and systematic way, and the EAP will support implementing an energy-management system through the ISO 50001 standard.

http://www.seai.ie/Your_Business/Large_Energy_Users/LIEN

http://www.seai.ie/Your_Business/Large_Energy_Users/Energy_Agreements_Programme

France: Stimulating awareness of SMEs in the agri-food sector for the installation of specific measuring systems finalised for the reduction and managing of their energy consumption.

http://www.entreprises.gouv.fr/politique-et-enjeux/sensibilisation-des-pme-lindustrie-agro-alimentaire-a-la-mise-place-systemes-mes (in French)

Portugal: The objective of the Intensive Energy Consumption Management System (SGCIE) is to promote the increase of energy efficiency through the modification of production processes, the introduction of new technologies and behavioural change.

The SGCIE is relevant for all companies and facilities that have an annual consumption of more than 500 toe/year, imposing binding energy audits, with a six-year periodicity, in energy-intensive facilities with a consumption above 1 000 toe/year, and an eight-year periodicity for energy audits to facilities with an energy consumption of between 500 and 1 000 toe/year. Intensive energy users are obliged to elaborate and execute Energy Consumption Rationalisation Plans (PREn), establishing targets for energy and carbon intensity and specific energy consumption, which also outlines energy rationalisation measures.

Finland: There is a comprehensive energy-efficiency agreement scheme for businesses and energy audits.

https://www.tem.fi/en/energy/energy_efficiency/energy_efficiency_agreements_and_audits

Sweden: Sweden offers aid for energy audits at SMEs. This aid may be granted to enterprises with energy consumptions in excess of 500 MWh per annum or for farms with at least 100 animal units. A voluntary agreement on energy efficiency for energy-intensive industries also exists.

Denmark: There are agreements on the implementation of energy-efficiency measures with large, energy-intensive companies, including some food and drink companies. http://www.ens.dk/sites/ens.dk/files/info/aftaleordningen-eng.pdf

United Kingdom: Climate Change Agreements:

https://www.gov.uk/climate-change-agreements--2#sector-associations-with-ccas

Netherlands: Long-term agreements (energy audit, energy plan, plus obligation to carry out all the cost-effective energy-efficiency measures identified):

http://www.rvo.nl/sites/default/files/bijlagen/2MJAA1002%20LTA%20results%202009_0.pdf

4.2 Actual examples of innovative energy management in the European food supply chain ([67]).

The European Food Sustainable Consumption and Production (SCP) Round Table (www.food-scp.eu) is an initiative that is co-chaired by the European Commission and food supply chain partners, and supported by the United Nations Environment Programme (UNEP) and the European Environment Agency.

There are 16 member organisations representing the European food supply chain that participate in the European Food SCP Round Table. It is also open to consumer representative organisations and environmental/nature conservation NGOs.

In the context of preparing the present study, the European Food SCP Round Table was requested by JRC to provide successful examples of energy management taking place in the EU. The contributions received are shown on the following pages.

Contributions have been kindly provided to SCP by Cogeca, Pepsi Co., Kellogg's, Mars, Nestlé and the Danish Agriculture & Food Council, and also through FoodDrink Europe, and are reported as received[68].

4.2.1 Cogeca

Cooperativa Fattoria Della Piana

Sector: Multi-purpose
Member State: Italy
Brief description of the innovation: Fattoria della Piana is an environmentally friendly development and totally autonomous in terms of heat and energy production. Fattoria della Piana recycles not only its own by-products but also by-products coming from neighbouring farms. In addition to the cogeneration of heat and power from biogas (998 kW), Fattoria della Piana installed solar panels so as to be able to generate an additional 400 kW.

In the near future, part of the bio-methane, which is now being used for heat and power generation, will be directly used as automotive fuel for vehicles. Fattoria della Piana is ready to start as soon as the required authorisation (to be approved at national level) arrives.

General website: http://www.fattoriadellapiana.it/
Project link:
http://www.fattoriadellapiana.it/index.php?option=com_content&view=article&id=101&Itemid=93&lang=en

Profile:

Turnover (million euros): 10
Number of members: 13
Number of employees: 87

Union Services Coop de France

Sector: Services

([67]) Other real-world case studies and examples of best practice are also described in the reports on Best environmental management practice for the Agriculture (crop and animal production) sector, available at http://susproc.jrc.ec.europa.eu/activities/emas/agri.html, and Food and Beverage manufacturing sector (http://susproc.jrc.ec.europa.eu/activities/emas/fooddrink.html)

([68]) The inclusion of a specific case study in the following paragraph should not be regarded as an endorsement of companies' policies from JRC or the EC.

Member State: France
Brief description of the innovation: The energy observatory aims to further develop the energy-efficiency efforts of grain businesses by using energy indicators to monitor their energy performance. This can also identify potential areas for making significant savings. The results are available on the website. The objective of the observatory is to set up a permanent platform for information and exchange between energy experts and grain professionals. Already, at national level, more than 300 sites and ten energy performance indicators have been established for the sector. Action plans have been drafted, with the aim of providing operational advice. Self-diagnosis guides are also available to support cooperatives in their decision-making.
All information is available on the website:
http://observatoiredelenergie.coopdefrance.coop/
General website: http://www.servicescoopdefrance.coop/

Profile:

Turnover (million euros): 2
Number of members: 294
Number of employees: 20

Ingredia

Sector: Dairy
Member State: France
Brief description of the innovation: In 2006, Ingredia carried out its first feasibility study for a biomass boiler, which was put into operation in 2008 by Next Energie. This boiler provides 48 % of the cooperative's energy needs thanks to the use of class A wood biomass/wood chips from areas located within a 150 km radius of the cooperative. In addition to the savings made (EUR 1 million per year compared to the previous gas-powered installation), there are significant ecological advantages for a cooperative that must respect CO_2 quotas, with more than 20 000 tonnes of CO_2 emissions avoided every year.

The cooperative works with several local suppliers and involves its own employees in this innovative approach, which significantly cuts costs and improves both internal structures and the cooperative's energy independence.

Despite some points that were flagged up, feedback from the project has been entirely positive on all financial, environmental and energy issues.

General website: http://www.ingredia.fr/
Link project: http://www.nextenergies.com/references-et-projets/laiterie-ingredia.html

Profile:

Turnover (million euros): 400
Number of members: 1 800
Number of employees: 447

Boortmalt

Sector: Malting
Member State: France
Brief description of the innovation: With the aim of making savings and improving its efficient use of resources, BOORMALT set up a project to use biomass and energy provided by natural gas on its Issoudun site. The 4 MW VYNCKE wood-fuelled boiler was adapted so that it could run on the agricultural co-products (silo residue, etc.) found on the cooperative's land. Almost 17 000 MWh of agricultural co-products are used every year. This project, with an estimated four-year return on the investment period, has made it possible to make energy savings of EUR 500 000/year and 18 000 toe.
General website: http://www.boortmalt.com/fr/

Link project: http://www.agrodistribution.fr/actualites-cooperatives-negoces/centre-axereal-se-dote-d-une-chaudiere-biomasse-73904.html#.VNSgto05B9A

Profile:

Turnover (million euros): 554 for Boortmalt, EUR 12 million for the Franco-Swiss malting facilities
Number of members: 13 000 (Axereal)
Number of employees: 30 for the Franco-Swiss malting facilities

Carbery

Sector: Dairy
Member State: Ireland
Brief description of the innovation: This project is the first dedicated green initiative of its kind in Ireland. Its overall aim is to improve the sustainability of dairy suppliers to Carbery, both environmentally and financially. The project entails the voluntary participation of 14 suppliers who have participated in this project since 2012. (This had increased to 20 suppliers as of January 2014). These participants were provided with specialist advice relating to all areas of their farming practice and encouraged to incorporate this advice wherever possible. The advice ranged from employing new technologies to making simple changes around their farm. All advice given to the participants was recorded and all changes made by any participants is being measured and disseminated to all Carbery suppliers through a variety of media, in association with the four West Cork Co-ops (Drinagh, Lisavaird, Barryroe and Bandon).
General website: http://www.carbery.com/
Link project: http://www.teagasc.ie/news/2014/201406-10a.asp

Profile:

Turnover (million euros): 318
Number of members: 1 405
Number of employees: 220

Aurivo

Sector: Dairy
Member State: Ireland
Brief description of the innovation: The strategic plan at Aurivo Dairy involves embedding sustainable principles throughout the supply chain by initially ensuring that the facility performance is optimised through improved energy-efficiency, which ensures the minimum use of energy within the facility, thus minimising conversion costs for the products. This is then coupled with the development of a local sustainable fuel source, which drives revenue back into the local economy rather than through the importation of oil. This strengthens a winning approach for the business and ensures the long-term viability of the local rural economy, which is the foundation of the principals of the cooperative society as founded back in 1897.
General website: http://www.aurivo.ie/
Link project:
http://www.aurivo.ie/about-us/news-media/taoiseach-opens-aurivo-biomass-plant-2/
http://www.aurivo.ie/about-us/news-media/aurivos-biomass-project/

Profile:

Turnover (million euros): 454
Number of members: 1 000, milk suppliers
Number of employees: 750

Tesla

Member State: Spain
Brief description of the innovation: Tesla aims at energy-cost reductions in European cooperatives in the agro-food sector, by promoting good practices on energy efficiency through an alliance among Spanish, French, Portuguese and Italian cooperatives, universities, and technological and research centres.

The main objective of the project is to extend the best available practices for the evaluation of the energy situation and for the adoption of improving measures amongst European SMEs in the agro-food sector.

Within this sector, TESLA will focus on the agro-industry cooperatives of wineries, olive oil mills, animal feed factories, and fruit and vegetable processing plants. It will use several instruments to manage reductions in energy consumption.

General website: http://teslaproject.org/

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4.2.2 PepsiCo Case Study — Energy efficiency projects

PepsiCo is a multinational food and beverage corporation, which generated more than USD 66 billion in net global revenue in 2014, driven by a complementary food and beverage portfolio that includes Frito-Lay, Gatorade, Pepsi-Cola, Quaker and Tropicana. The company employs approximately 274 000 associates around the world.

In Europe, it is one of the leading food and beverage companies. Encompassing over 50 000 employees, almost 900 million consumers, 11 time zones and more than 45 countries, the business spans from Russia westwards to Portugal, and from Turkey northwards to Norway.

PepsiCo's global commitments on energy

PepsiCo's Performance with Purpose ([69]) goals have guided its strategy and operations every step along the way, and are integral to how it strives to 'future-proof' PepsiCo for long-term success.

One of the goals is environmental sustainability. Here the company aims to find innovative ways to minimise its impact on the environment and lower the costs through energy and water conservation, as well as through optimising packaging materials. It seeks to reduce energy use in the manufacturing operations, explore renewable alternatives to fossil fuel, improve the efficiency of the fleet, and work with suppliers to help them manage and reduce their energy use and GHG emissions. PepsiCo is working to achieve an absolute reduction in GHG emissions across the business. To that end, there are programmes and initiatives to reduce energy use and emissions in the operations, to move towards lower-carbon energy sources and to work with the company's supply chain, particularly farmers, to help them achieve reductions.

Moreover, PepsiCo is using alternative energy sources that are helping to reduce the reliance on traditional energy sources. With this, it is lowering its environmental impact,

([69]) http://www.pepsico.com/docs/album/performance-with-purpose/pep_2013_sustainability_report.pdf?sfvrsn=2 saving money and creating best practices to share across PepsiCo. For instance, the total energy consumption in 2013 for PepsiCo's legacy operations (operations as they existed in 2006, i.e. not including any major acquisitions since the baseline year, and adjusting for divestitures) was 15.2 million megawatt hours (MWh). In 2013, the energy efficiency has improved by nearly 14 % when compared with the 2006 baseline, as progress is made towards the goal of reducing energy intensity by 20 % per unit of production by 2015. Based on projections of performance, PepsiCo anticipates achieving the 2015 targets, driven by its resource conservation initiatives that improve the energy efficiency of the operations, as well as by converting to renewable forms of energy. The company's progress in 2013 delivered estimated energy cost savings of USD 75 million.

Case studies

EU CoolSave Project — reducing the energy consumption of PepsiCo's cooling installations in Seville, Spain

In Seville, PepsiCo have partnered with the Instituto Tecnológico de Castilla y León under the framework of the EU-funded CoolSave project to identify ways of reducing the energy consumption of their cooling installations. The project is co-funded through the Intelligent Energy Europe Programme of the European Union and aims to develop and disseminate cost-effective strategies to improve energy efficiency by up to 15 % in cooling systems in the food and drink sector.

The project collected data about the energy consumption of 25 food and drink cooling systems, including PepsiCo's cooling installation in Seville. Energy-saving strategies were derived from energy simulations. An energy audit report was produced for each site and the energy-efficiency saving strategies with the best return on investment were identified and implemented. PepsiCo's site achieved 18 % energy savings from implementing CoolSave's recommendations.

CoolSave will collect the outcomes from this project in a best practice document, which is to be shared with food and drink companies across Europe. PepsiCo is also reviewing the findings to potentially include key outcomes in our Resource Conservation Programme (ReCon), which enables the company to identify and implement new ways to advance its environmental sustainability goals.

Green buildings in Veurne, Belgium

PepsiCo is committed to saving energy through green buildings and design worldwide. Since the takeover by PepsiCo of the **Veurne** snack factory in 1998, the energy and water consumption to produce each unit of product has been dramatically reduced: electricity consumption by 53 %, gas consumption by 31 % and water consumption by 71 %.

These reductions have been achieved through an ongoing focus on waste minimisation, utility efficiencies, raising employee awareness and behavioural practices. In addition there have been two milestone projects to support the journey. It has installed a state-of-the-art reverse osmosis water-recycling plant that has reduced the site's water consumption by more than 50 %. The site also produces electricity from organic waste which has enabled it to generate 25 % of its electricity needs. Anaerobic digestion plants are now being considered for other PepsiCo sites in Europe.

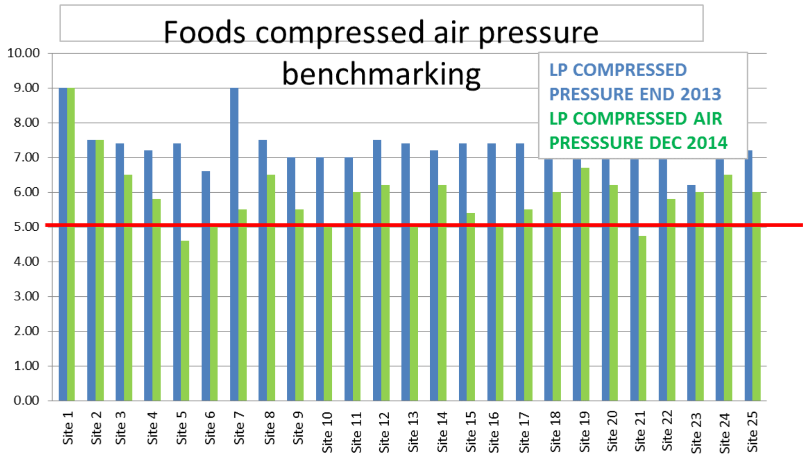
Compressed air efficiency helps reduce energy consumption across Europe

Within PepsiCo's European food manufacturing sites, approximately 10 % of the electricity consumption is used to generate compressed air for use within the manufacturing process. Generating compressed air is an inefficient process, as most of the energy used by the compressors is wasted as heat and only approximately 13 % is converted into the compressed air; also there are often leaks within the pipework.

PepsiCo's European ReCon network of specialists defined a project to reduce the pressure at which the compressors generated the air. A review was carried out and it was found that the range of operating pressures varied considerably, from 4.75 to 9 bar.

A machine catalogue was established to capture the operating flows and pressures for the equipment which can run at 5 bar or lower, and the sites have been targeted to reduce their operating pressure down to 5 bar. This has reduced their consumption of electricity and also the number of air leaks within the system.

The lowest site pressure now being generated is in Grodzisk Poland which operates at 4.6 bar.



Due to other ongoing initiatives to reduce energy consumption at these sites, the exact amount of energy savings achieved by increasing compressed air efficiency is not known. However, this initiative has contributed toward the total energy reductions of the relevant sites.

A similar project is now underway for PepsiCo's beverage sites following the same principles, with a target of 6 bar, due to technological feasibility.

Together, these initiatives are helping the company to improve the energy efficiency of its operations and deliver energy cost savings.

Future challenges

A challenge that PepsiCo and many other companies face with the roll-out of large-scale initiatives is the uncertainty about incentives and an unstable energy market. Long-term stability in the energy market, support for decentralised energy generation and long-term support for incentives would help businesses plan and invest for the long term.

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4.2.3 Kellogg's

Supply chain stage — manufacturing

Having achieved significant reductions in water and waste, the focus for the Kellogg UK business is in reducing energy use and greenhouse gas emissions.

The engineering teams at the Kellogg factories in Manchester and Wrexham have identified innovative applications for the capture and use of heat as an energy source, which has helped reduce gas consumption.

Its Manchester factory operates a wastewater treatment plant where heat energy would have traditionally escaped to the atmosphere from the treatment process. The site is now putting this heat to good use, using an advanced heat pump system that cools the waste-water treatment tank and also uses the energy recovered to heat water for cleaning and staff use on site. The Wrexham factory has initiated a project to recover previously wasted energy from the exhaust systems on the cookers, and this is used to preheat boiler feed water.

Both projects have recognised energy reductions of over 3 700 MWh with a payback of less than four years. The Manchester factory has reduced its greenhouse gas emissions by 24 % since 2009 and is now seen as a global front-runner within Kellogg for meeting reduction targets.

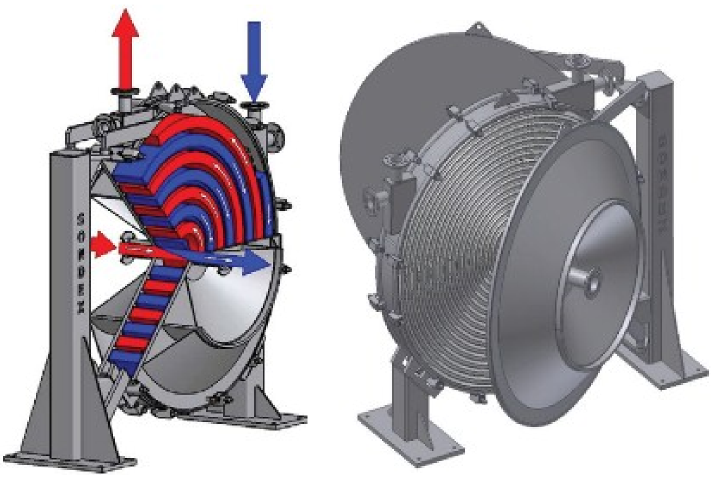
'As a company, and as individuals, we are passionate about enriching and delighting the world through foods and brands that matter. We understand that people care about how the foods they eat are grown and produced. That's why environmentally sustainable practices are such a crucial part of ensuring our brands remain relevant with consumers.' Diane Holdorf, Chief Sustainability Officer, Kellogg Company.

Food manufacturing. Heat pump: Performance and efficiency (location: Manchester, UK)

The challenge: The Engineering and Environment team at Kellogg's Manchester plant identified an innovative application for the use of heat pump technology. Kellogg's Manchester plant is now in its 76th year at Trafford Park. In 1938, Kellogg started production of ready-to-eat breakfast cereals in Manchester with the production of corn and corn-based, rice and biscuit products totalling 120 000 tonnes per annum.

Although the Manchester plant is Kellogg's second longest running plant, the site sits at the forefront of innovation in energy, water and waste reductions in Kellogg's globally.

The challenge faced by this plant was with the aerobic effluent system. The system had a history of overheating due to its natural exothermic reactions and to waste heat from the factory accumulating in the system. The site therefore incurred significant costs in having to attempt to cool down treated effluent; operational problems caused by the overheating also incurred extra costs, such as an increased use of water to aid the cooling of the aerobic tank.



The solution: At the point where this heat energy would traditionally be rejected to the atmosphere, the Manchester plant looked to put the heat to good use and proposed an advanced heat pump system that would not only cool the aerobic tank down to the required temperature but also provide heated water to the domestic hot water and CIP systems on site.

In order to utilise the heat energy taken from the biology tank most effectively, the Engineering and Environment team proposed the use of a semi-hermetic screw compressor heat pump. The heat pump performs to an excellent coefficient of performance of 5.5 and is capable of producing 25 % of the site's hot water demand.

To fully optimise the supply of heat, a new specialised spiral heat exchanger replaced the existing shell and tube unit, significantly reducing the maintenance requirements of the cooling system by minimising blockages. The spiral heat exchanger is designed specifically for high solid rates, such as pulp and sludge, and an automated backwash system maximises the availability of heat recovery to the site.

The results and benefits: The expected annual savings of 2 100 MWh equating to 338 tCO_2 will provide a financial return within three years.

Capital expenditure:	GBP 246 565
Savings:	GBP 78 727 per year
Payback:	3.13 years
Carbon saving:	338 tCO_2/year

Lessons learnt, advice for those considering the same options. The success of the project has resulted in a phase two project now being investigated to release more potential from the waste heat at the waste-water treatment plant. Long-term possibilities include increased cooling potential to the effluent system and increased recovery of heat in order to heat a greater percentage of the hot water needed for the operations.

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4.2.4 Mars

Mars' renewable energy from waste using new anaerobic technology and 'green steam'

Background

Mars Inc. is a global company, entirely owned by the Mars family, with net sales of more than USD 33 billion. There are six business segments, including Petcare, Chocolate, Wrigley, Food, Drinks and Symbioscience, and more than 75 000 associates worldwide that are putting its principles into action to make a difference for people and the planet through its performance. In Europe, Mars has more than 18 400 employees and 34 factories, with its global headquarters for Petcare and Food segments in Brussels, Belgium.

Mars is a member of FoodDrinkEurope, the confederation that represents the European food and drink industry.

Principles in action

Mars' approach to business is based on five principles — quality, freedom, mutuality, efficiency and responsibility. These five principles are at the heart of everything the company does. The objective as a business is to put the principles in action every day (see the annual Principles in Action Summary ([70]).

To reduce its impacts, Mars is pursuing absolute reductions, even as production volumes increase. The *'Sustainable in a Generation'* targets are influencing the ways the company designs, builds and manages its operations. The goal for factories and offices includes eliminating fossil fuel energy use and greenhouse gas emissions, minimising the company's impact on water quality and mitigating the impacts of waste by 2040.

Mars is exploring four main strategies to meet its targets: operational efficiency, capital efficiency, new technology and renewable energy. While there are many examples on how it reduces the use of fossil fuels and mitigates the impact on the environment, the company wishes to highlight two examples: the implementation of an outstanding waste-water treatment and recovery facility at the Veghel plant in the Netherlands, which is the first of its kind in Europe; and the Green Steam project, which uses steam generated by using energy recovered from waste at the Haguenau plant in France.

Case studies

Renewable energy from waste using new anaerobic technology — Veghel plant, the Netherlands ([71]).

The Mars factory in Veghel is the world's largest chocolate factory, producing Mars, Snickers, Milky Way, Bounty and Twix chocolate bars for the European market. The construction of a new waste-water treatment plant for the purification of waste-water from the factory started in August 2013 and opened at the end of October 2014.

The new treatment plant purifies the waste water to a level of 99 % purity, reducing the chemical oxygen demand (COD) concentration from 10 000 to 50 mg/l in one single step, without pre-treatment. The anaerobic membrane bioreactor ferments the sugars, oils and fats, which are extracted from the waste water into biogas that is used for steam production. The amount of produced biogas covers 5 % of the overall energy need of the Veghel plant.

The project received support from a Dutch Stimulation of Sustainable Energy Production grant and was carried out in cooperation with Veolia Water Technologies, utilising anaerobic Memthane® technology. Memthane® is an anaerobic membrane bioreactor that combines two proven technologies: Veoilia Biothane's anaerobic biological waste-water treatment and Pentair's X-Flow ultrafiltration membrane separation process. The most important challenges for Mars are to adjust and balance the waste-water effluent

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([70]) Available at http://mars.com/global/assets/doc/pia_exec_2013/Mars_PIA_Highlights_2013_EN_report.pdf

([71]) Press release (in Dutch) available at http://www.mars.com/netherlands/nl/press-center/press-list.aspx from the factory to avoid fluctuations in the cleaning process, and to run with as low as possible pressure on the membranes to reduce electrical pump energy.

There are also financial benefits from no longer needing to pay a cleaning fee to the municipal waste-water treatment facility. In addition, the value of the biogas offsets the operating costs of running the facility.

'Green steam' at Mars Chocolat France in Haguenau

The Haguenau plant — Mars' largest plant in France — is the first to benefit from 'green steam' generated using energy recovered from waste. By outsourcing its steam generation, which was previously reliant on fossil fuels, the Mars Chocolat France plant in Haguenau now benefits from steam generated locally using energy recovered from waste. The incineration factory is burning household waste from 225 000 inhabitants and this heat is used to generate steam. The steam is transferred to the Mars factory via 1.2 km of underground pipes; this method has been in operation since January 2014. It is fed into a heat exchanger, which enables Mars to generate its own steam for food safety reasons. The green steam is used mainly for melting the chocolate used in the production of M&Ms, but also to heat the buildings.

The green steam system now meets 90 % of the steam requirement of Mars Chocolat France, and 50 % of the demand from its neighbour, Sonocco. To achieve Mars' target of zero carbon emissions by 2040, the next step will be to achieve 100 % of plant demand with locally generated green steam. To ensure that this happens, a biomass heating plant will be installed close to the Energy Recovery Unit to provide total coverage of this plant's energy needs.

This project has been performed in partnership between Mars Chocolat France, GDF SUEZ Group subsidiary Cofely Services, SITA France and SMITOM Haguenau-Saverne (the household waste treatment provider serving local communities).

Conclusion

By using green steam that is generated using energy recovered from waste, and also by using third-generation anaerobic waste-water treatment techniques, both projects contribute to Mars' Sustainable in a Generation (SIG) programme, which aims for a fully sustainable production by 2040.

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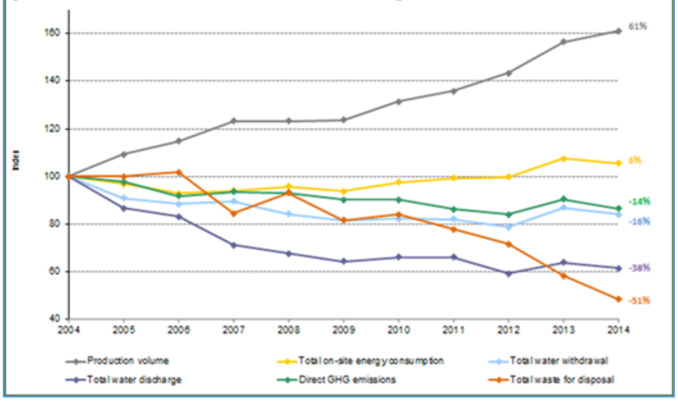
4.2.5 Nestlé

Nestlé: Committed to improve resource efficiency

Nestlé has long sought to improve resource efficiency. This focus has shaped both its beliefs as a company and its practices, along the entire supply chain.

For Nestlé CEO Paul Bulcke, respect is at the heart of Nestlé: respect for the society in which the company operates, respect for the environment and respect for future generations. In practical terms, Nestlé is continuously making efforts to improve the environmental performance of its operations. Today, it uses a third less energy per kilo of product than it used ten years ago and emits almost half the greenhouse gases per kilo of product it emitted ten years ago. And, by 2015, it aims to further reduce direct emissions of greenhouse gases by 35 % and reduce energy consumption, per tonne of product, in every product category to achieve an overall reduction of 25 % compared to 2005 levels.

Continuous improvement of Nestlé environmental performance over the last 10 years



The Nestlé Environmental Target Setting programme aims to improve the environmental performance of its factories based on a thorough assessment of baseline energy and water consumption. The savings delivered by projects implemented in 2014 amounted to 1.8 million GJ of energy, 1.2 million m^3 of water and 149 000 tonnes of CO2e. Examples include: the installation of energy recovery systems and energy-reduction improvements at the freeze-dried coffee plant in Orbe, Switzerland, which cut the factory energy use by 8 %; the replacement of ageing air heaters at the Dalston plant in the UK with a modern heating system, which delivered a 30 % reduction in gas consumption and a 2 % reduction in the plant's overall energy use; the achievement of a 55 % reduction in production-line energy use during changeovers between products at its cereal bar factory at Lubicz, Poland, which is equivalent to 19 % of the total site's energy consumption.

At the UN Climate Summit in 2014, Nestlé announced its endorsement of the Carbon Disclosure Project's six climate action initiatives, committing to a strategy to procure 100 % of electricity from renewable sources within the shortest practical timescale. The company's renewable energy utilisation accounts for 15 % of the total consumption across its sites. Of that, spent coffee grounds represent 24 %, wood accounts for an additional 27 % and an estimated 49 % can be attributed to the purchase of electricity generated from renewable sources. In 22 Nescafé factories, the spent coffee grounds, resulting from the manufacturing process, are used as a source of renewable energy and 16 Nestlé factories use wood as a source of renewable energy.

Some examples of renewable energy use:

- Following a power purchase agreement with a Mexican wind-turbine company, 85 % of the total electricity consumed by Nestlé's factories in Mexico is now supplied by wind power; this reduces air emissions, including greenhouse gases, by more than 125 000 tonnes of CO_2e annually.
- Nestlé France's Challerange factory, which produces milk powder for Dolce Gusto capsules, now operates a wood-fired boiler using woodchips sourced from forests certified by the Programme for the Endorsement of Forest Certification, meeting 96 % of the plant's fuel needs. This initiative generates approximately 8 000 tonnes of CO_2 savings per year and helps to minimise the impact of energy price increases. Two other wood-fired boilers came online at the Rosières (mashed potatoes) and Herta St Pol (sausages and hams) factories in 2013. These three wood boilers make estimated CO_2 savings of 25 % for Nestlé France.
- In a project launched in Switzerland in 2013, the natural heat created by the source of the mineral water brand Cristalp, which emerges from the ground at 25 °C, is used to provide heat to the bottled water factory and local municipal

buildings. The Cristalp factory has been running on 100 % renewable energy since October 2014, a first for Nestlé Waters.

Nestlé also looks at the beginning of its supply chain on environmental issues, helping farmers improve their practices through, for example, the NESCAFÉ Plan, the Nestlé Cocoa Plan and Nespresso Ecolaboration. These plans seek to make the farming of key commodities for Nestlé, like coffee and cocoa, more sustainable — from an economic, social and environmental perspective. Nestlé has also facilitated a three-year partnership with the Humanist Institute for Development Cooperation, which helps dairy cooperatives in the East Java milk district of Indonesia to use biogas units to convert methane from cattle manure into useable energy.

At the other end of the supply chain, when it comes to keeping products like ice-cream and yoghurts cool and safe to eat, every new horizontal chest freezer bought by Nestlé from 2015 uses natural refrigerants, rather than synthetic refrigerants, and has far more efficient running costs. Nestlé has managed to half the energy consumption of horizontal ice cream freezers compared to 2005 levels. The company also continues to shift from road to rail and sea transport in Europe, which helped to save around 1 400 tonnes of CO_{2e} in 2014.

The company is determined to combat food wastage, itself a major source of greenhouse gas emissions, and is co-steering, on behalf of The Consumer Goods Forum, the development of the World Resources Institute Food Loss and Waste Protocol.

These actions contribute towards making Nestlé products not only tastier and healthier but also better for the environment along the entire value chain.

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4.2.6 The Danish Agriculture and Food Council

State-of-the-art energy-conscious slaughterhouse, Denmark

Danish Crown opened a new, modern pork slaughterhouse in Horsens in 2005. In the process of building the slaughterhouse, resource and energy efficiency were optimised in cooperation with COWI consultancy, while at the same time taking due consideration of both the working environment and the surroundings.

This state-of-the-art facility has set new standards for energy efficiency and environmental responsibility in food production. It has since developed and expanded considerably, now handling 103 000 pigs per week.

In the abattoir, 41 % of the heat demand is covered by heat recovery and 2 000 electricity-saving motors reduce the emission of CO_2 by 570 tonnes annually. Also, the cooling system that keeps the produce at -20 °C has been optimised. The facility uses ammonia as a refrigerant instead of freon, together with with an optimised operation of the system.

It uses the least amount of energy, saving 4 100 MWh annually — equal to the power consumption of 820 families.

(Courtesy: Danish Crown and COWI)

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5. Recommendations and conclusions

Food production is a very composite industrial sector presenting very diverse challenges as far as energy efficiency and the use of renewable energies is concerned. Europe already offers a wide portfolio of policies that lead to tangible improvements in the field of energy and food.

Moreover, the scientific community is very actively investigating both new solutions and the optimal implementation of existing solutions. Industry has shown real commitment in translating measures into practical improvements regarding the use of energy in the food sector.

In a nutshell, a great deal has been done and is being done in Europe for improving the energy profile of daily food consumption and for decoupling the EU food system from fuel (especially fossil fuel) consumption and CO_2 emissions, both in consequence of direct policies and indirectly through actions targeting other issues but impacting on the food sector.

Summarising the main findings from scientific, policy and industrial experiences, some main lines of intervention that have been shown or are expected to be especially promising can be listed, such as:

- greener, more efficient agriculture and low-carbon agriculture;
- organic farming;
- R & D innovating farming techniques (e.g. improved irrigation, precision agriculture);
- local production and consumption of agriculture products, including in the framework of decreasing food-related transport needs;
- sustainable packaging, including a higher use of renewable materials;
- increasing the recovery share of food packaging along the entire supply chain for recycling purposes;
- decreasing the amount of avoidable food waste and improving the recovery (including energy recovery) of both industrial and domestic food residues and waste;
- increasing the use of renewable energies (e.g. PV, biogas, bio heat, wind) throughout the production chain, especially at farming and industrial levels, including retailing;
- more efficient appliances, processes and buildings across the entire food supply chain.

Most of these pathways to a better energy use in the food sector are composed of several 'atomic' measures that have been discussed in the report. Taken singularly, these measures have been proven to be useful every time they have been properly applied. Nevertheless, while the overall picture and directions to be taken are relatively clear and rather consensual in the scientific and policy communities, their practical applications must consider the huge diversity of foods, production systems and consumption habits in Europe. Research and implementation has then to continue to take into consideration national and even more local peculiarities in order to properly combine the traditional approach to food preparation with the most updated energy-smart techniques.

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APPENDICES

A. Bibliometric study on food and energy: is EU research moving towards 'smart energy food'?

This appendix aims to map the intersection between energy and food within the scientific literature as an indirect measure to assess the EU-28 ([72]) research landscape. By using descriptive bibliometrics, which are measures of scholarly outputs, we have tried to address the following aspects: a) to examine the EU-28's contribution to world literature; b) to investigate the pattern of publication; and c) identify the active institutions in the EU-28 in that field of research. The data for the analysis has been sourced from SciVerse Scopus, one of the most used abstract and citation databases of peer-reviewed literature.

The path towards decreasing the amount of energy or 'greening' the energy embedded in every food product does not fall into a particular field of research but is located at the intersection of many fields; finding the particular area of research where these two relevant topics overlap is not straightforward. A simple search of papers published by the EU-28 Member States in the last five years containing the word 'food' in the title, the abstract or keywords produces more than 85 000 results belonging to various disciplines (from agricultural sciences to medicine, including biochemistry, environmental sciences, engineering, microbiology and many more). The same exercise, but focusing on energy instead of food, reveals more than 250 000 documents; 30 000 is the limit when searching for the subject 'Energy' ([73]), even though, numerous disciplines are involved (engineering, environmental sciences, material sciences, chemistry, economics, etc.)

Bearing in mind that both fields are broad and multi-disciplinary in nature, the definition of search terms that allow delineating their interception is challenging. For this reason, and as the best approach based on the output of various attempts, the following steps were followed: a) use the keywords contained in the papers/documents already identified during the literature research; b) select the combination of terms to be used, for both energy and food and; c) check the retrieved results (the most cited ones were checked manually, together with some descriptors such as subject areas, journals, keywords, etc.).

This procedure is conservative and seeks to avoid the use of concepts that are too general, which lead to non-desirable gaps in the fields of energy and/or food (e.g. those that would not favour the intersection). This said, it should be noted that there is a chance that not all the publications contributing to the analysed field were successfully accounted for, but the restrictions imposed ensure the incorporation of those that are the most relevant.

The literature research was conducted based on key terms in the fields of document title, abstract and keywords. Key terms were used in logical combinations to find the appropriate filtering effect ([74]):

i) FOOD FIELD SPACE PRONE TO OVERLAP WITH ENERGY FIELD *('Food production' OR 'Crop production' OR 'Livestock production' OR 'Fish production' OR 'Food supply' OR 'Food system' OR 'Agri-food sector' OR 'Food industry' OR 'Food processing' OR 'Food storage' OR 'Food distribution' OR 'Food retail*' OR 'Food preparation' OR 'Food waste' OR 'Food packaging' OR 'Food transport' OR 'Food miles' OR 'Food chain*')*

([72]) EU28: AT, BE, BG, HR, CY, CZ, DE, EE, FI, FR, DE, EL, HU, IE, IT, LV, LT, LU, MT, NL, PL, PT, RO, SK, SI, ES, SE and UK.

([73]) Journal titles in Scopus are classified under four broad subject clusters (Life Sciences, Physical Sciences, Health Sciences and Social Sciences & Humanities), which are further divided into 27 major subject areas and 300+ minor subject areas. Titles may belong to more than one subject area. In Scopus, there are 294 journal titles listed under 'energy'.

([74]) The asterisk is a wildcard used to search for variant ending. Therefore, a filter which includes 'food chain*' will retrieve results with food chain, food chains, etc.

ii) ENERGY FIELD SPACE PRONE TO OVERLAP WITH FOOD FIELD *('Energy consumption' OR 'Energy saving*' OR 'Energy efficiency' OR 'Energy use' OR 'Energy management' OR 'Renewable energy*')*

In the following paragraphs, documents, records and publications will be used indistinctively to refer to the output results from SciVerse Scopus. The food/energy field refers to the documents obtained when filtering using the key terms included in i)/ii), while the energy and food intersection refers to the output resulting from combining both i) and ii).

Energy and food intersection: abundance and dynamics

A total of 137 892 records were retrieved from Scopus when filtered with the period 1960-2014 and food field (Table A.1). Out of those, 44 615 have at least one author with affiliation in an EU-28 Member State. Worldwide, the number doubles when talking about the energy field, while for the EU-28 the number increases by 30 %. A total of 2 545 and 831 for the EU-28 records were selected according to the food and energy methodological criterion (explained in previous paragraphs). If these last numbers are compared to the total number of records found in each field, it shows that the percentage of energy studies in the EU-28 that relate to food issues is above the total (world) average.

Table A.1 Publications in food, energy and intersection fields, 1960-2014.

	Food field	Energy field	Intersection	E&F/F [%]	E&F/E [%]
World	137 892	264 559	2 545	1.846	0.962
EU-28	44 615	57 465	831	1.863	1.446

The distribution by year is illustrated in Figure A.1 (left). The reason for the fall-off in both plots for 2014 is not known, but may reflect incomplete data for this year. Trends in Europe follow global trends. In the energy field, the European contribution varies between 20 % and 30 %, while in the food field the contribution increases.

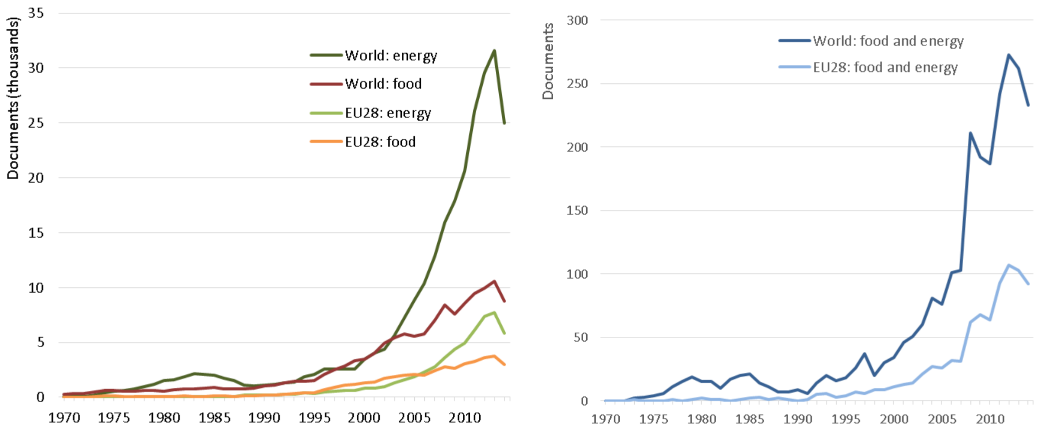

Figure A.1 Distribution of published records by year, worldwide and in the EU-28, 1970-2014, in food and energy (left) and in the food and energy intersection (right).

There is a clear growth in the number of papers published on energy and food (Figure A.2, right), both globally and on the European scale.

A closer look at the records retrieved for the food and energy intersection on the European scale shows that:

- by subject areas: 38.8 % in environmental science, 35.1 % in agricultural and biological sciences, 22.6 % in energy and 15.9 % in engineering;
- Countries with the greatest number of publications (in order): United Kingdom, Germany, Italy, Netherlands, Spain, France, Sweden, Denmark and Austria.
- Affiliations: Wageningen University and Research Centre (NL), Swedish Institute for Food and Biotechnology (SE), Cranfield University (UK), Sveriges lantbruksuniversitet (SE), Universidad de Santiago de Compostela (ES), Imperial College London (UK), Universidad Autonoma de Barcelona (ES), International Institute for Applied Systems Analysis, Laxenburg (AT), Technische Universitat Munchen (DE), Lunds Universitet (SE), Newcastle University (UK).

The distribution of records by EU Member States in the food and energy intersection is depicted in Figure A.2.

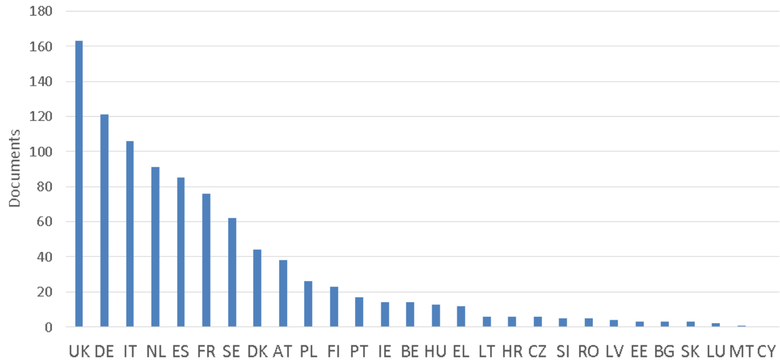

Figure A.2 Distribution of published records by country in food and energy intersection.

As previously stated, United Kingdom, Germany, Italy, Netherlands, Spain, France, Sweden, Denmark and Austria are the countries with the most publications in the field under research.

Figure A.3 Clustering of publications on food and energy publications, 2010 to 2014.

Figure A.3 and Figure A.4 show the geographical distribution of publications. The author locations are shown as red circles, with the size of the circle reflecting the number of papers. The red lines indicate the links between the co-authors.

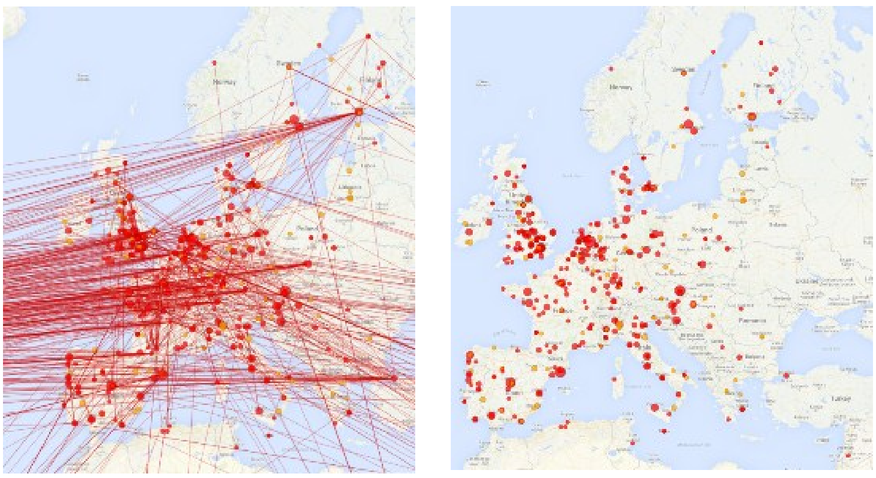

Figure A.4 Geographical distribution of food and energy publications, 2010 to 2014: collaborations within Europe (left) and 'hot spots' (right).

Sectorial analysis, 1960-2014

Expressing the results by sector allows depicting specialisation trends and localisation among the different authors. In Figure A.5, the number of publications annually for the EU-28 by sector is presented, while Table A.2 and Table A.3 show the top ranked countries and affiliations per sector.

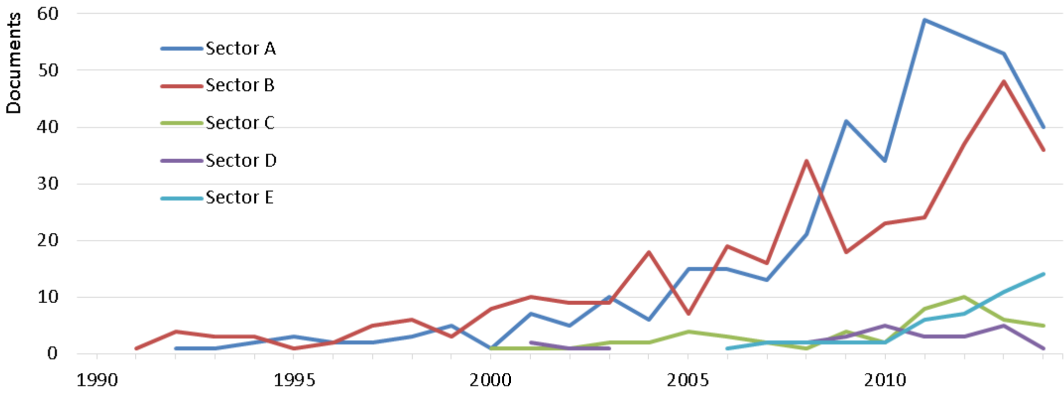

Figure A.5 Distribution of publications by year and sector in the EU-28, 1970-2014. Sector A being agricultural and livestock; sector B: food transformation and processing industry; sector C: transport, storage and distribution; sector D: packaging; and sector E: food waste.

Table A.2 Countries with most publications in the field FOOD and ENERGY in the EU-28 per sector as defined in previous paragraphs.

SECTOR A			SECTOR B			SECTOR C			SECTOR D			SECTOR E		
COUNTRY	Doc.	Rank	COUNTRY	Doc.	Rank	COUNTRY	Doc.	Rank	COUNTRY	Doc.	Rank	COUNTRY	Doc.	Rank
UK	71	1	UK	56	1	UK	20	1	Italy	8	1	United Kingdom	17	1
Germany	63	2	Italy	48	2	Spain	11	2	UK	8	2	Italy	9	2
Netherlands	58	3	Germany	47	3	Germany	7	3	Germany	5	3	Sweden	7	3
Italy	50	4	Spain	41	4	Sweden	7	4	Spain	3	4	Denmark	3	4
Spain	42	5	France	34	5	Netherlands	6	5	US	3	5	Spain	3	5
France	34	6	Netherlands	28	6	Portugal	4	6	Denmark	2	6	Australia	2	6
Sweden	30	7	Sweden	24	7	France	3	7	Sweden	2	7	Austria	2	7
Denmark	26	8	Austria	14	8	Austria	2	8	Argentina	1	8	Finland	2	8
US	21	9	Denmark	12	9	Italy	2	9	Canada	1	9	France	2	9
Austria	20	10	Ireland	12	10	New Zealand	2	10	France	1	10	Germany	2	10
Poland	16	11	US	11	11	US	2	11	India	1	11	Belgium	1	11
Finland	14	12	Poland	11	12	Algeria	1	12	Lithuania	1	12	China	1	12
Belgium	8	13	Finland	9	13	Argentina	1	13	Netherlands	1	13	Ireland	1	13
China	8	14	Portugal	8	14	Australia	1	14	New Zealand	1	14	Latvia	1	14
Australia	7	15	Hungary	8	15	Belgium	1	15	Portugal	1	15	Netherlands	1	15
Brazil	6	16	Canada	7	16	Bulgaria	1	16				New Zealand	1	16
Kenya	6	17	Greece	7	17	Canada	1	17				United States	1	17
Portugal	6	18	India	5	18	Finland	1	18						
Greece	5	19	Belgium	4	19	Ireland	1	19						
Hungary	5	20	Lithuania	4	20	Mexico	1	20						
Switzerland	5	21	Bulgaria	3	21	Norway	1	21						
India	4	22	China	3	22	UAE	1	22						
Iran	4	23	Czech Republic	3	23									
Norway	4	24	Algeria	3	24									
Slovenia	4	25	Romania	3	25									
Canada	3	26	Colombia	2	26									
Nigeria	3	27	Japan	2	27									
Croatia	3	28	Switzerland	2	28									
Czech Republic	3	29	Latvia	1	29									
Mexico	3	30	Israel	1	30									

Table A.3 Affiliations with most publications (first 15) in the field FOOD and ENERGY in the EU-28 per sector as defined in previous paragraphs.

SECTOR A

AFFILIATION	Doc.
Wageningen University and Research Centre	37
Sveriges lantbruksuniversitet	11
Cranfield University	10
INRA Centre de Rennes	7
Imperial College London	6
University of Aberdeen	6
Universidad Autonoma de Barcelona	6
Universitat fur Bodenkultur Wien	6
Rothamsted Research	5
Helsingin Yliopisto	5
Danmarks Tekniske Universitet	5
MTT Agrifood Research Finland	5
Universita degli Studi di Palermo	5
Universitat Hohenheim	5
International Institute for Applied Systems Analysis, Laxenburg	5

SECTOR B

AFFILIATION	Doc.
Swedish Institute for Food and Biotechnology	13
Wageningen University and Research Centre	10
Universidad de Santiago de Compostela	6
Universidad Politecnica de Valencia	5
Universita degli Studi di Palermo	5
Technische Universitat Munchen	5
Lunds Universitet	5
Unilever	5
University College Dublin	4
CNRS Centre National de la Recherche Scientifique	4
University of Limerick	4
Pannon Egyetem	4
Universita degli Studi di Udine	4
Kaunas University of Technology	4
Universita degli Studi di Padova	3

SECTOR C

AFFILIATION	Doc.
The Royal Institute of Technology KTH	4
Brunel University	4
University of Surrey	4
Wageningen University and Research Centre	3
Universidad Autonoma de Barcelona	3
Universidad de Santiago de Compostela	3
London South Bank University	3
Totalforsvarets forskningsinstitut	2
Rijksuniversiteit Groningen	2
ISARA Lyon	2
Manaaki Whenua – Landcare Research	2
International Institute for Applied Systems Analysis, Laxenburg	2
Unilever	2
Institut de Recerca I Technologia Agroalimentaries	2
East Malling Research	1

SECTOR D

AFFILIATION	Doc.
Universidad de Santiago de Compostela	2
Novamont S.p.A.	1
Landesgesundheitsamt BW	1
Europe	1
Praxis für Ernährungsberatung	1
Nordmeccanica Group	1
CIS MADEIRA	1
FINSA	1
Sonnergy Limited	1
IFEU-Institut für Energie- und Umweltforschung Heidelberg GmbH	1
soci Srl	1
Swedish Institute for Food and Biotechnology	1
USDA ARS Beltsville Agricultural Research Center	1
Universite Pierre et Marie Curie	1
USDA Agricultural Research Service, Washington DC	1

SECTOR E

AFFILIATION	Doc.
Politecnico di Milano	3
Lunds Universitet	3
Waste & Resources Action Programme	3
Newcastle University (UK)	2
Politecnico di Torino	2
University of Surrey	2
University of Southampton	2
University of Oxford	2
University of Cambridge	2
London South Bank University	2
Ita-Suomen yliopisto	2
East Malling Research	1
Swedish Institute of Agricultural and Environmental Engineering	1
Novamont SpA	1
ENSGTI	1

B. Fossil fuel prices and food prices — A concise literature review

The most commonly used fossil fuels are oil, natural gas and coal and, as can be seen in Figure 1.9, fossil fuels make up more than 80 % of the energy embedded in the average food consumed in Europe in 2010. Figure 2.1 also shows that in the case of the agriculture sector in the EU-28, oil consumption is dominant, while in the food processing industry, gas is the most used fossil fuel (see also Figure 3.1) and in both cases the consumption of coal is not as relevant as the consumption of oil and gas. Crude oil prices in the 1986-2013 period are shown in Figure B.1 for Brent Oil.

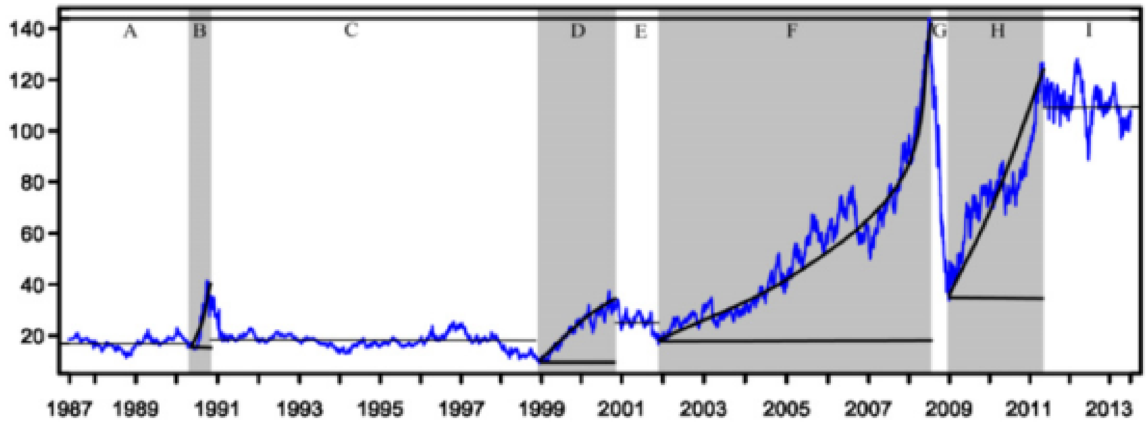

Figure B.1 Crude oil prices, 1986-2013. The price increasing periods are evidenced. Source: Balcilar, Ozdemir and Yetkiner, 2014. © *Elsevier*

Analysing the oil price in that period, Balcilar et al. (2014) came to the conclusions that during the observed period there have been both bubbles and crashes in crude oil prices that have been triggered by different kinds of information, whether political, military, financial or related to the economy. During the same period, according to the FAO (2015), the nominal food price index followed the evolution depicted in Figure B.2, showing an increasing trend since the 60s.

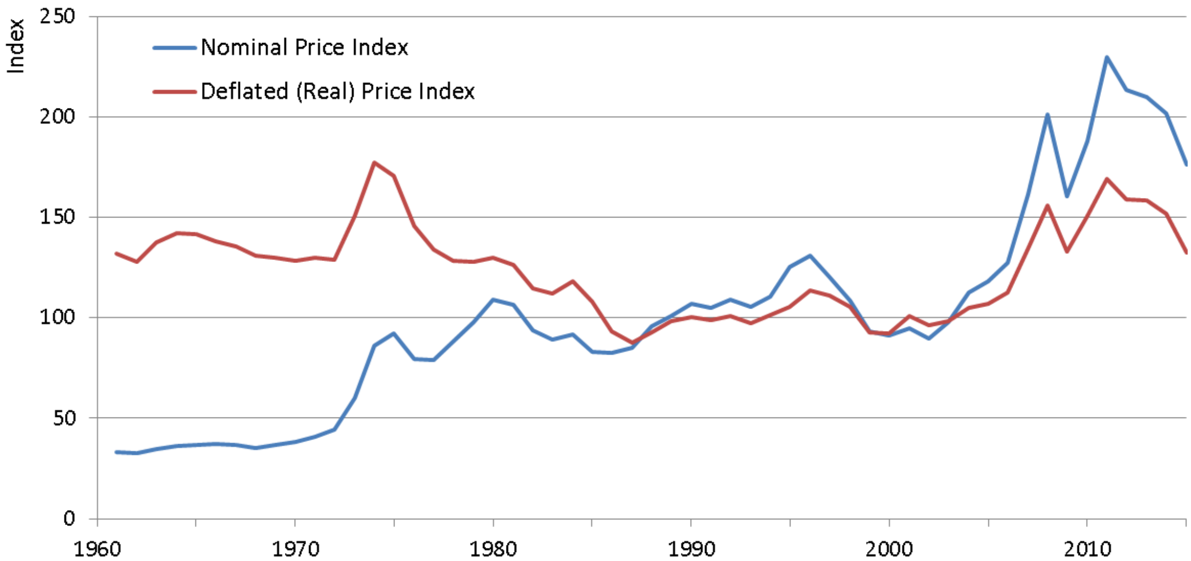

Figure B.2 FAO Food Price Index, 1961-2015 in nominal and real terms. Source: (FAO, 2015).

Food prices are known to depend on many factors, starting from the type of food, the weather, season, supply or demand, but Tadesse et al. (2014) consider that besides demand and supply shocks, speculation is also an important factor in explaining and triggering extreme price spikes in the case of the food sector.

Nazlioglu and Soytas (2012) found strong evidence of the impact of oil prices on agricultural commodity prices, but Esmaeili and Shokoohi (2011) did not find any direct long-run relation between the oil price and the agricultural commodity prices. Cartwright and Riabko (2015) agree with Saghaian (2010) on finding a correlation between wheat futures prices and the spot oil prices, but at the same time warn on the stability of that correlation.

Jebabli et al. (2014) stated that there are some general similarities between different food commodities, but at the same time each of them have their particularities that create differences on the market. They point their attention to the presence of low volatility spillovers from crude oil to most food returns, which makes it possible to forecast food prices and volatilities through information on the crude oil price, but also note that the impact of the crude oil price shocks has an immediate and short-term influence on food prices. In addition, they mention that after mid-2008, crops in particular (more than other food categories) are inducing crude oil volatility.

Chen et al. (2010) have analysed the relation between oil prices and grain prices in the 1983-2010 period and have identified four main sub-periods in which the relation underwent a sudden change: before the 48^{th} week of 1985, before the 3^{rd} week of 2005, before the 20^{th} week of 2008 and afterwards.

More generally, many authors have witnessed changes in the behaviour of the correlation between prices of crude oil and food, but some authors relate this phenomenon to the global financial crisis while others consider the influence of a higher policy support to biofuels in the USA.

For instance, Wang et al. (2014) consider that during the period before the global financial crisis in 2008, synchronous changes between agricultural and oil prices, if they appeared, were just a 'fiction driven by global economic activity', while after the crisis the correlation of agricultural commodity prices and oil-specific demand shocks have become highly significant.

Ciaian and Kancs (2011) have also observed the relation between the fuel price and agricultural prices and found that the impact of crude oil prices on agricultural prices is stronger with than without biofuel production. Nazlioglu (2011) has affirmed that the link between energy and agricultural markets becomes stronger as the demand for biofuel production increases due to rising oil prices; this link is even stronger if the prices of corn and soybeans are considered.

Gardebroek and Hernandez (2013) have examined the transmission of volatility between US oil, ethanol and corn markets and have concluded that there is no evidence of volatility spill-overs from oil (or ethanol) to corn, but, on the contrary, a shock in corn price volatility leads to a short-run shock in ethanol price volatility. Also it is important to mention that the correlation observed, starting from 2007 with increased bioethanol production, has been shown to be much stronger than before when the main relation between the two markets consisted of crude oil being an input to corn production.

Avalos (2014) has followed a similar line and has stated that, after 2006, corn prices are related to oil prices in the long run and in the short run both are more affected by oil price shocks. Reboredo (2012) has mentioned that fluctuations in agricultural commodity prices were not driven by oil price movements in the period before a structural break was detected, but starting from 2008 the relation between the energy and agricultural markets became stronger because of the demand for biofuels, which was related to environmental concerns and higher oil prices. Abdelradi and Serra (2015) have also observed that European biodiesel markets have not been able to generate long-lasting impacts on agricultural feedstock prices, and the biofuel industry was not capable of causing long-run increases in food prices, but biodiesel prices strongly depend on rapeseed prices.

It is important to note that all of the referenced research was performed during the period of expected increases in crude oil prices when all the major international institutions were agreeing in expecting a further increase in energy prices (EC, 2014; IEA-WEO, 2013; EIA, 2013). But in autumn 2014 crude oil prices started to decrease, which had a significant influence on the price of oil products (see Figure B.3 where the price decrease of all oil and oil products in the period from October 2014 to January 2015 is well evident)

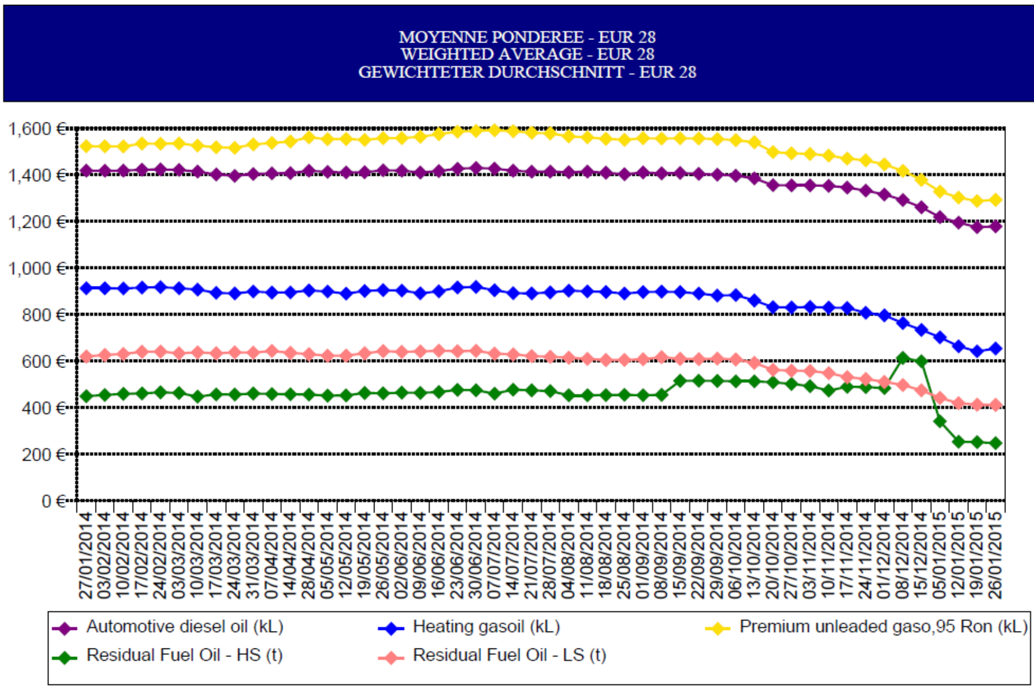

Figure B.3 EU-28's average oil product prices. Source: EC — DG ENER, 2015.

Figure B.4 presents Standard and Poor's index ([75]) (Standard and Poor, 2014) for crude oil (dark green and shaded), agriculture (green) and food and beverage industries (purple) for the February 2014-February 2015 period (left) and for the 2005-2014 period (right (Standard and Poor, 2015).

The effects and causes of the impact the decrease in the price of crude oil in the second half of 2014 had on food prices have still not been thoroughly analysed.

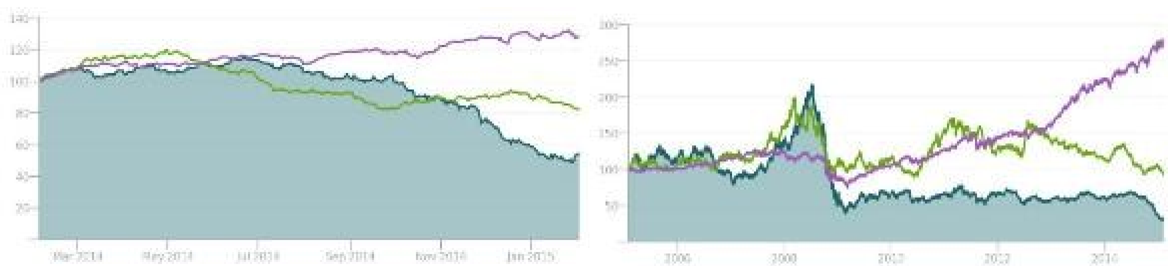

Figure B.4 S&P GSCI indices for crude oil (dark green and shaded, agriculture (green) and food and beverage (purple) industries. Source: Standard and Poor (2015). ([76])

([75]) S&P GSCI is designed as a benchmark for investment in the commodity markets and as a measure of commodity market performance over time.
([76]) The S&P GSCI Crude Oil, S&P GSCI Natural Gas, S&P GSCI Agriculture and S&P Food & Beverage Select

The short literature review discussed above has shown that the relation between the price of crude oil and food prices was the subject of many studies rooted in the high share of usage of oil products in agriculture. Nevertheless, although Figure 3.1 shows that in the food processing industry the share of natural gas is much higher than the share of oil, no significant research was found on the relation between the price of natural gas and food prices. Figure B.5 presents the S&P GSCI indices for natural gas (dark green and shaded), agriculture (green) and food and beverage industries (purple) for the February 2014-February 2015 period (left) and for the 2005-2014 period (right) (Standard and Poor, 2015)

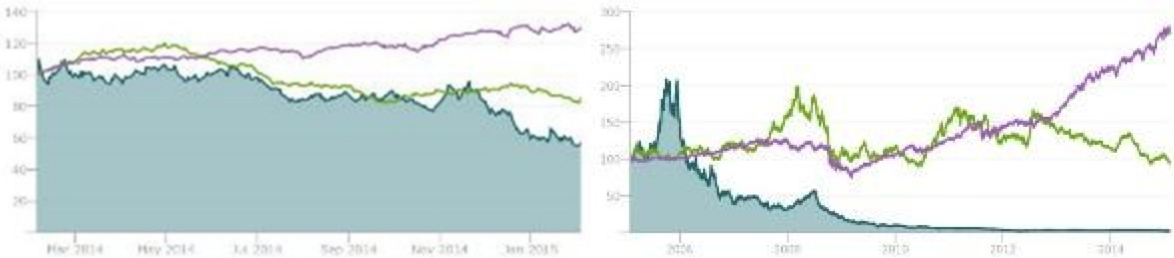

Figure B.5 S&P GSCI indices for natural gas, agriculture and food and beverage industries. Source: Standard and Poor, 2015. © 2015 S&P Dow Jones Indices LLC, its affiliates and/or its licensors. All rights reserved

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C. Food consumption patterns in Europe

Despite an underlying set of common features and main ingredients, food consumption patterns are quite diverse through the EU-28 Member States, making the task of defining a consistent and representative 'food basket' for EU citizens quite challenging. In order to provide a general vision of food consumption habits and trends in Europe, two main data sources are analysed in more detail: the European Food Safety Authority (EFSA) surveys and the food sector of the households' consumption basket on which the Harmonised Index of Consumer Prices (HICP) is based. The two databases emphasise complementary aspects, with EFSA focusing on actual quantity consumptions, its variability per age class and individuals, and HICP accounting for the economic value of food and beverage consumption and its evolution.

The European Food Safety Authority food consumption surveys

In 2011, EFSA launched a Comprehensive Food Consumption Database (EFSA, 2011) for Europe that contains, at the moment, data from a total of 32 different dietary surveys from 22 Member States where the daily consumption of several food categories are provided, in some cases differentiated per age group. EFSA surveys are not exhaustive but they are especially useful to provide an initial idea of the food consumption pattern in most of Europe, patterns that are to be represented and properly simplified in defining a suitable food basket, as discussed in the next paragraphs.

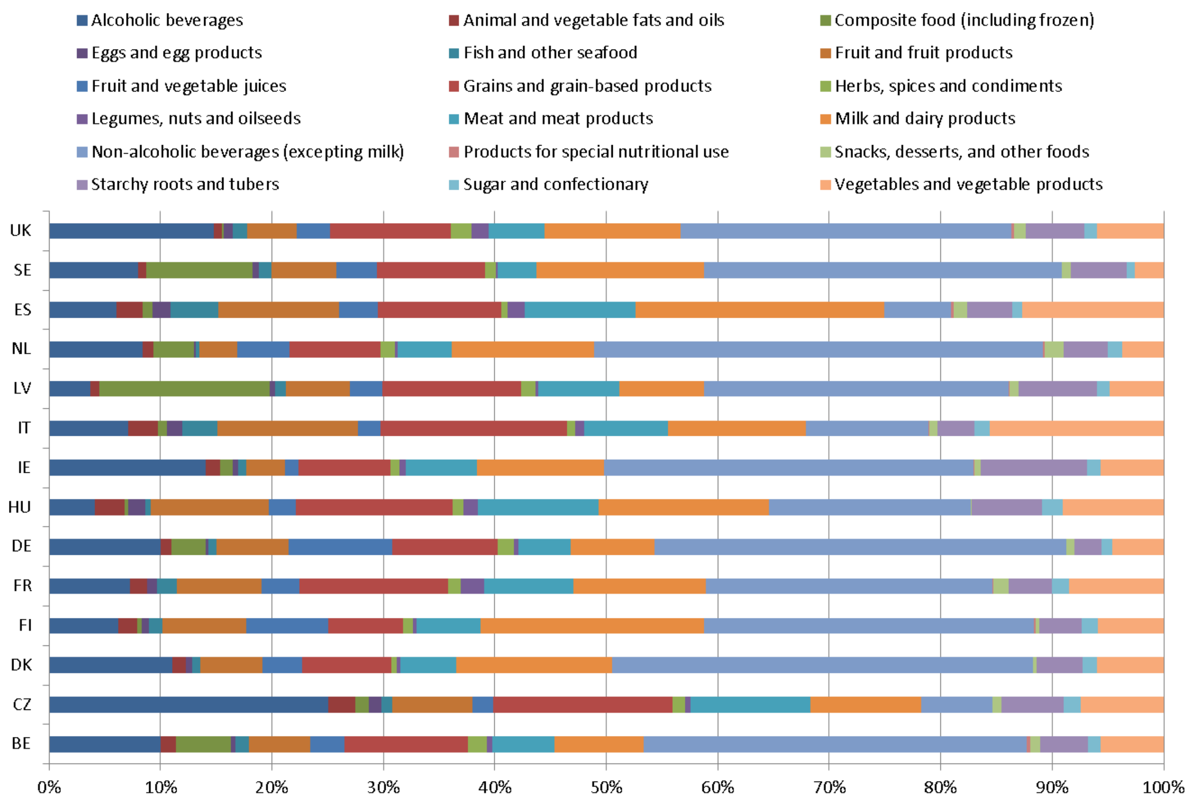

Figure C.1 Mean daily consumption in weight shares of 18 food categories for an adult consumer in 14 EU Member States (EFSA, 2011).

Figure C.1 shows the consumption patterns of adults for 18 food categories defined in the EFSA survey in the 14 Member States for which data has been made available. National differences are quite evident and a first variability in food consumption linked to national habits appears quite evident.

Differences in food consumption related to age groups are shown in Figure C.2 in the case of Belgium, a country for which a detailed survey covering several age groups was available.

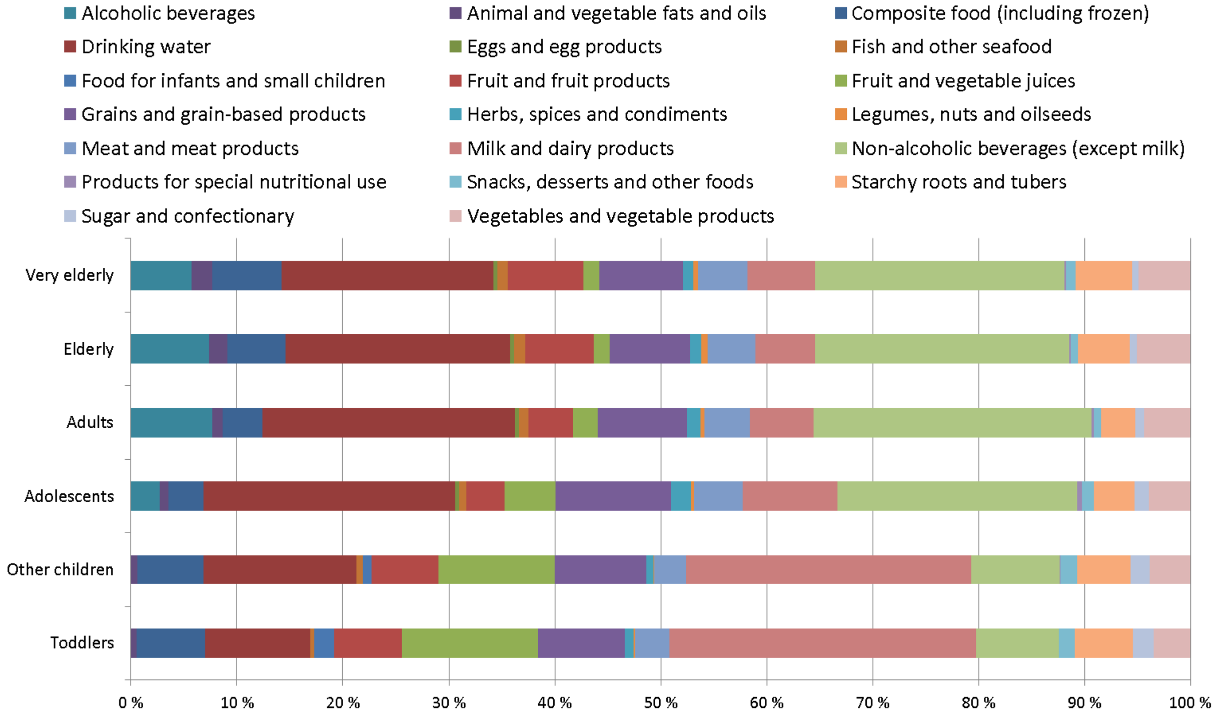

Figure C.2 Mean daily consumption in weight shares of 20 food categories for consumers in different age groups in Belgium (EFSA, 2011)

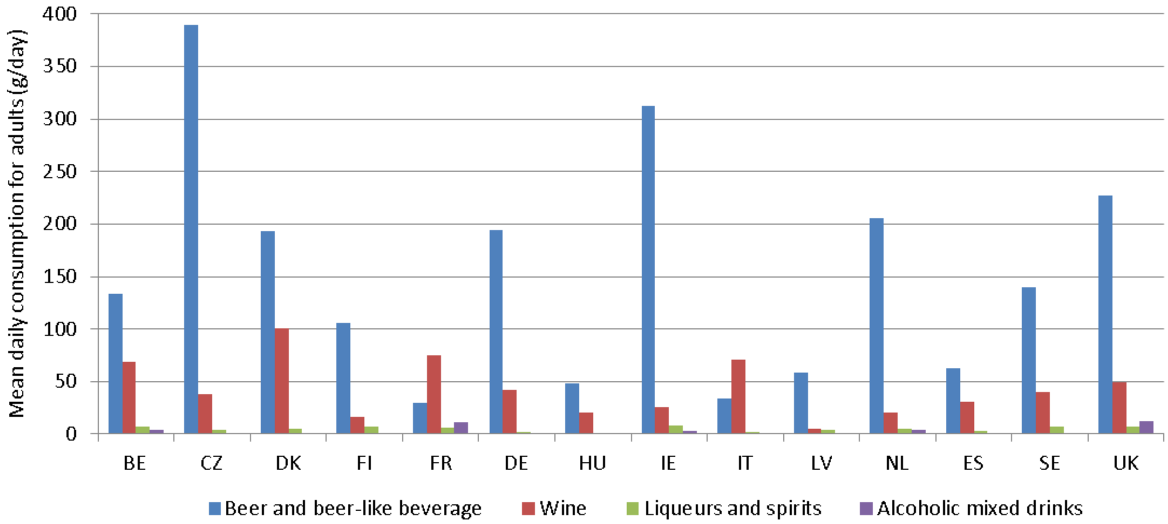

Figure C.3 Mean daily consumption of consumption of alcoholic beverages for adults in 14 EU Member States (EFSA, 2011).

It is worth noticing that national nutritional habits also differ considerably in terms of specific product consumption whenever food consumption categories are investigated in more detail. Again as an example, Figures C.3 to C.7 show the adult daily mean consumption of some categories of food in the 14 European Member States for which the EFSA database provides information.

As can be seen from Figure C.3, in most of the countries where the survey has been conducted, beer is the most preferred alcoholic beverage. The only two countries where the level of wine consumed is higher than that for beer are France and Italy. However, the type of typical beer consumed is different from country to country, with some beer types having 4-5 % of alcohol and others being between 8 % and 12 %. For instance, according to Vignali and Vrontis (2000), in the United Kingdom, the share of alcohol by volume in beer ranges from 3.4 % to 4.2 % for draught lagers, 4 % to 4.2 % for packed lagers, with the maximum being over 7.6 % in the case of super-strength lagers.

Figure C.4 represents the habits of adult consumers of drinking water, evidencing that in some countries the amount of bottled water consumed is significantly higher than the amount of tap water consumed.

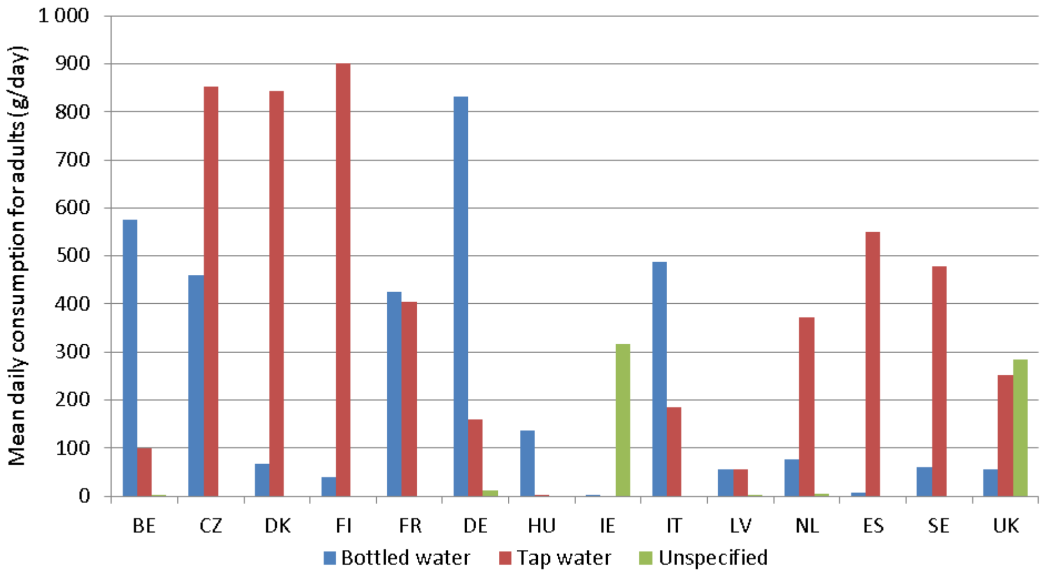

Figure C.4 Mean daily consumption of drinking water for adults in 14 EU Member States (EFSA, 2011).

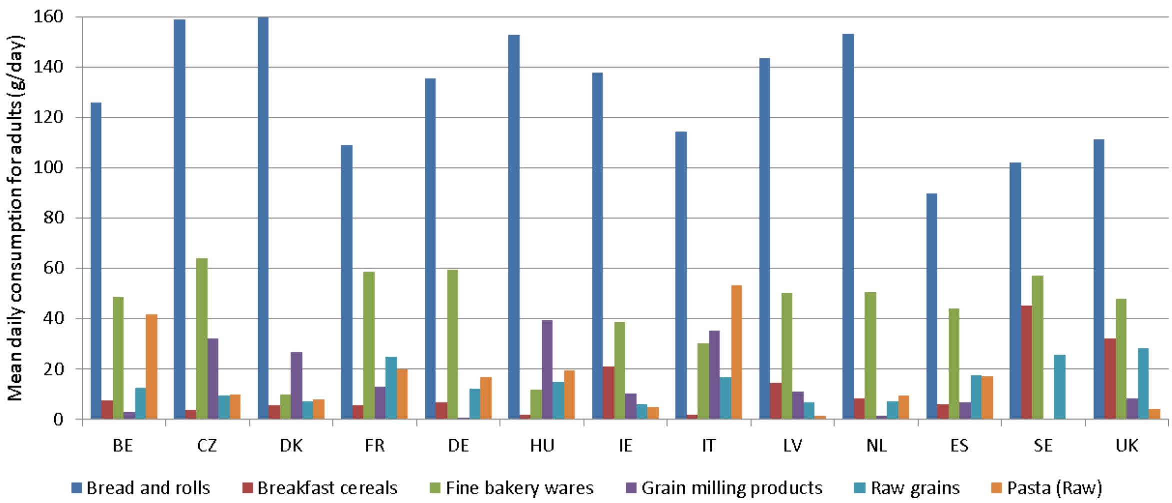

Figure C.5 Mean daily consumption of consumption of grains and grain-based products for adults in 14 EU Member States (EFSA, 2011).

Figure C.5 shows that bread and rolls are the most commonly consumed grain-based products, usually followed by fine bakery products. But some cultural differences are also evident, as in the case of breakfast cereals, which are mostly consumed in Sweden, United Kingdom, Ireland and Latvia, and in the case of pasta, which is most popular in Italy and Belgium.

As can be seen in Figure C.6, most consumers prefer livestock meat (this includes both beef and pork in the EFSA aggregation) and poultry, while in some countries, significant amounts of sausages or preserved meat are consumed.

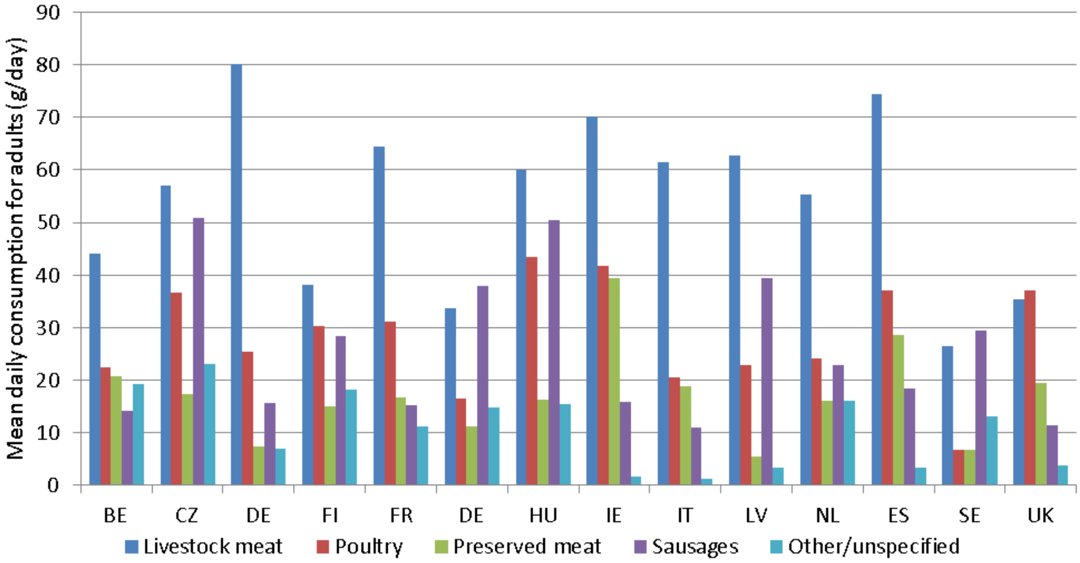

Figure C.6 Mean daily consumption of meat and meat products for adults in 14 EU Member States (EFSA, 2011)

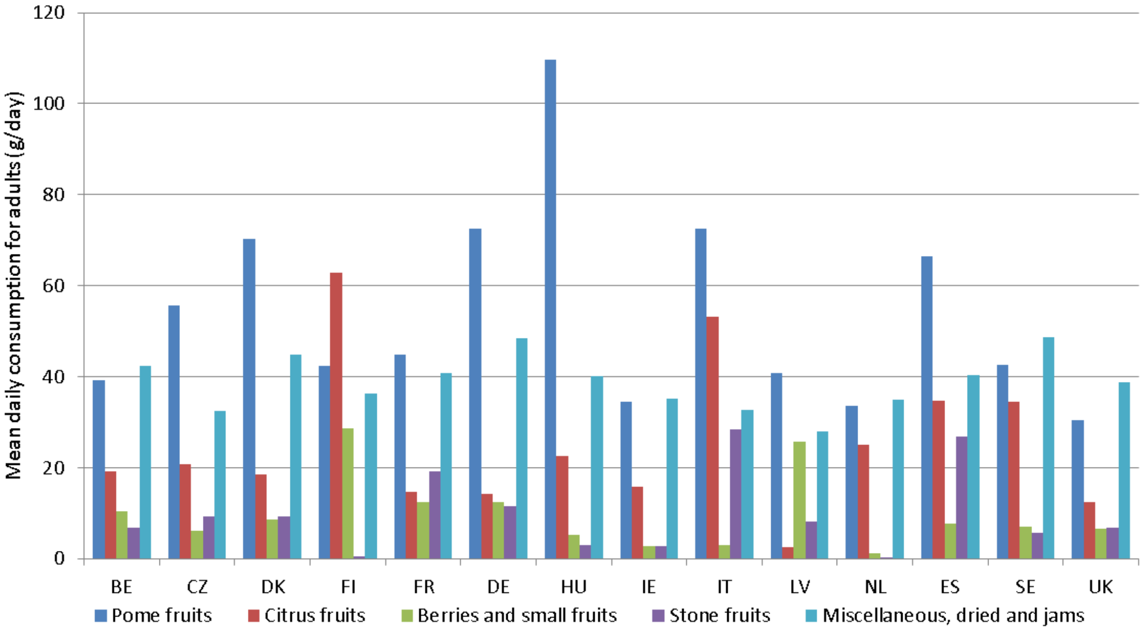

Figure C.7 Mean daily consumption of fruit and fruit products for adults in 14 EU Member States (EFSA, 2011)

Figure C.7 represents the mean daily consumption of fruit and fruit products for adults, demonstrating that pome fruits and citrus fruits are the ones mostly eaten in European Member States.

The EFSA database also offers the opportunity to evaluate the statistical variability of consumption data collected, analysing the huge diversity of consumer preferences, both across the European Union and inside single Member States. Figure C.8 illustrates such a diversity, showing the median consumption of bread, cheese and livestock meat (beef and pork) for adults together with its 5th and 95th percentiles in the 14 EU Member

States for which data is available. Apart from the national differences already discussed, huge differences reaching factors of 10 can be found in the preferences of different consumers living in the same country.

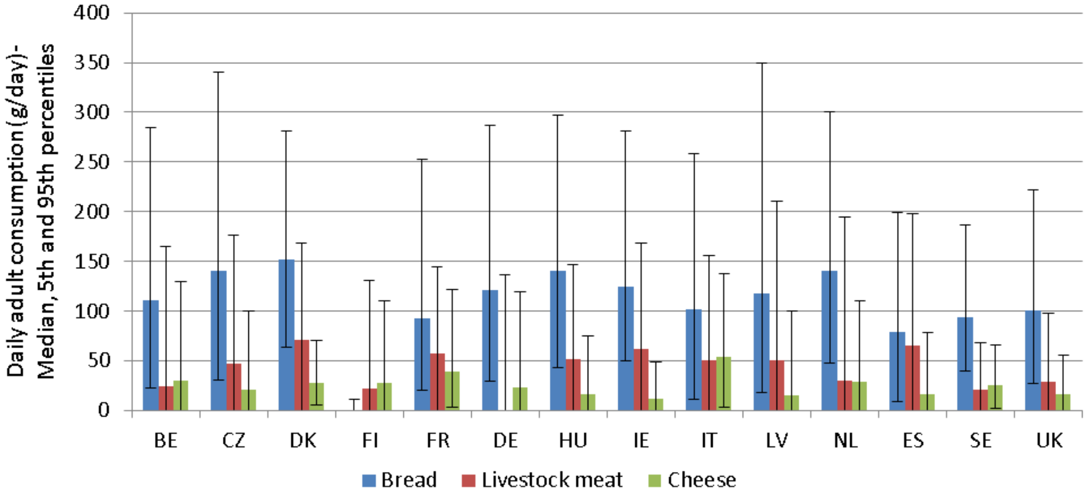

Figure C.8 Median, 5th percentile and 95th percentile consumption of bread, cheese and livestock meat (beef and pork) for adults in 14 EU Member States (EFSA, 2011).

Food expenditure in the HCIP index

The Harmonised Index of Consumer Prices, (HICP) is the consumer price index as it is calculated in the European Union (EU), according to a harmonised approach and a single set of definitions. It is mainly used to measure inflation; the actual calculation of the index is performed on a monthly basis by Eurostat.

The core information for HCIP development is the Household Final Monetary Consumption Expenditure (HFMCE), i.e. that part of the final consumption expenditure which is made by households, irrespective of their nationality or residence status on the economic territory of the EU Member States. Expenditure on goods and services that are used for the direct satisfaction of individual needs or wants taking the form of monetary transactions are considered. See EuroStat-HCIP (2015) for further details.

The share of income spent by the average EU citizen on food and beverage goods has shown some fluctuations (see Figure C.9) in the 2008-2014 period but has generally remained inside the interval between 17 % and 18 %, being of the same order of magnitude of expenditure in other sectors such as housing and transport. On the contrary, the share of food expenditure is quite diverse in the EU-28 Member States, both in absolute terms (see Figure C.10 showing food expenditure in the EU-28 Member States in 2010 ([77]) and also as far as its subdivision into different item groups (see Figure C.11).

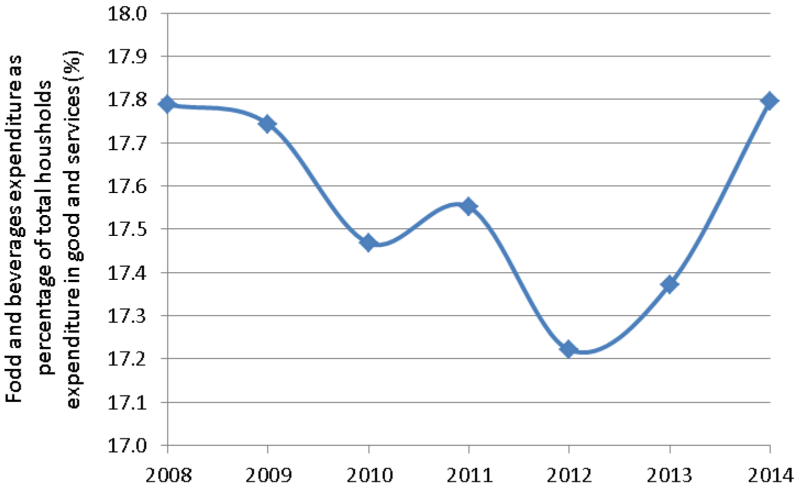

Figure C.9 Percentage of overall household expenditure devoted to food and beverage items in the EU-28 in the 2008-2014 period. Source: EuroStat-HCIP (2015).

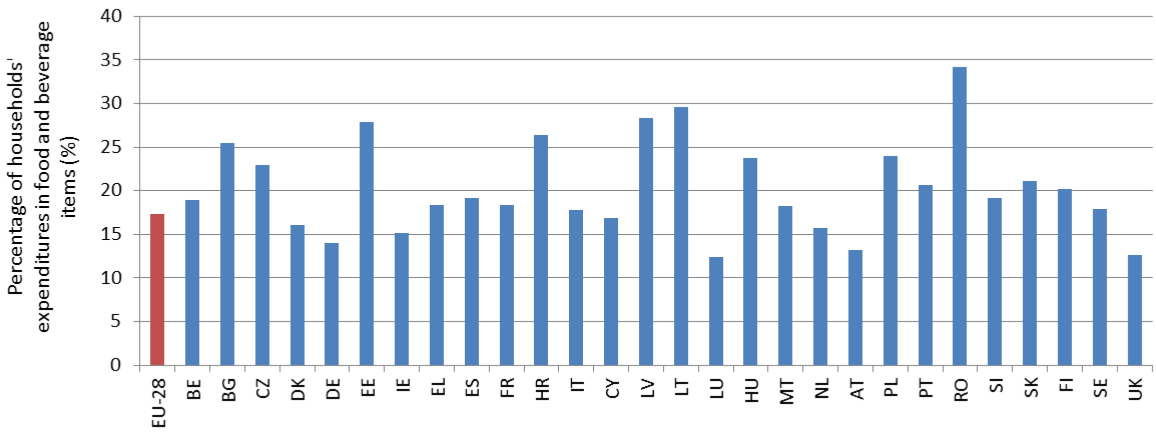

Figure C.10 Share of the overall households' expenditure devoted to food and beverage items in the EU-28 Member States in 2013. Source: EuroStat-HCIP (2015).

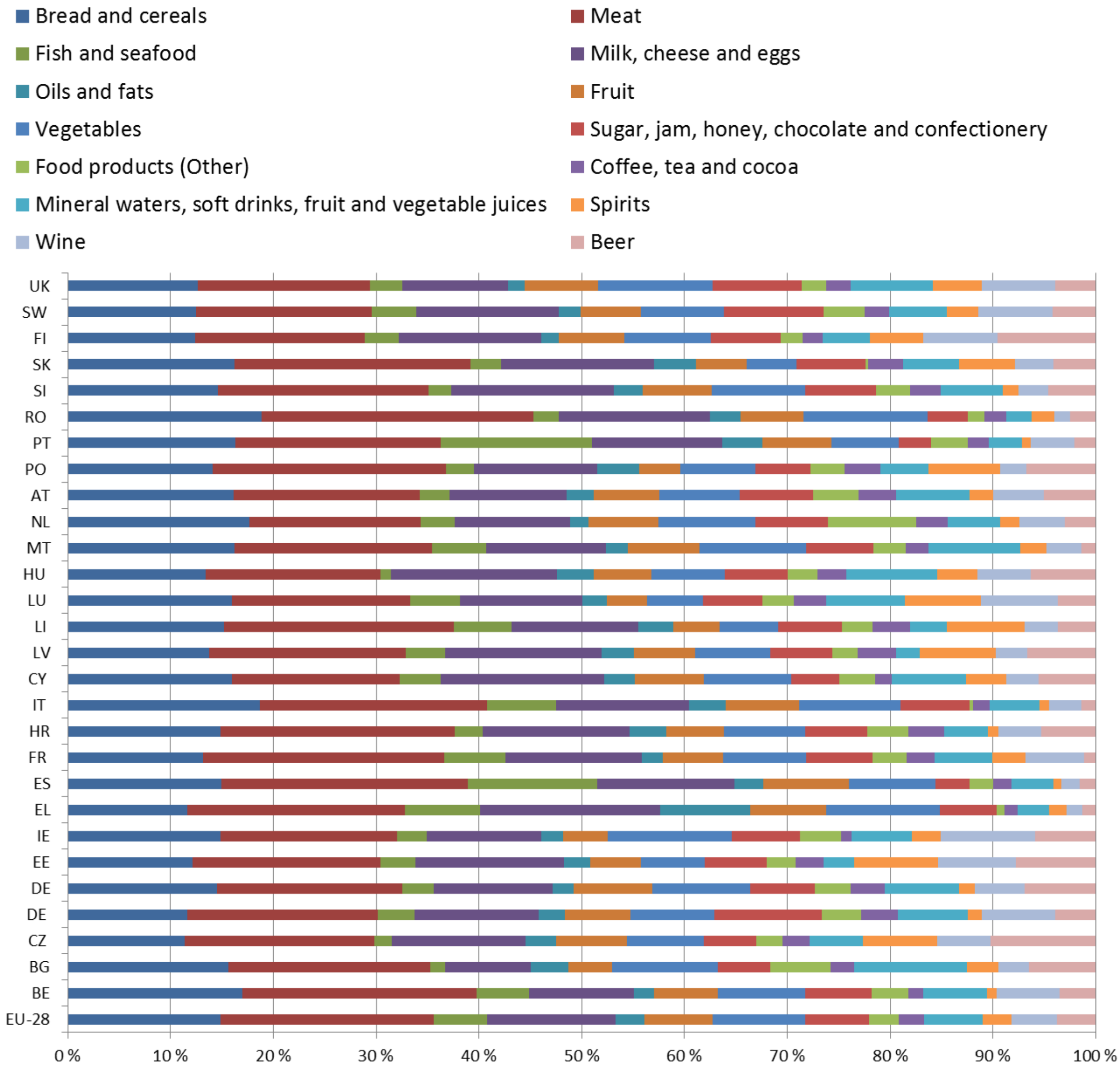

Figure C.11 Subdivision of household food and beverage expenditure into 14 groups in the EU-28 Member States in 2013. Source: EuroStat-HCIP (2015).

D. Energy flows and greenhouse gas emissions from a set of traditional European breads

The basket of products study summarised in Chapter 1 has allowed the estimation of energy flows and GHG emissions associated with the average food products consumed in the European Union. Nevertheless, as already highlighted, food consumption is very diverse across Europe: not only consumption patterns differ (see e.g. Appendix 0), but also equally named products are very different in different cultures and countries.

Bread is an example of a largely consumed food product that is often prepared following diverse traditional receipts. Different recipes including different ingredients and different preparation patterns are obviously expected to result into different amounts of embedded energy and of equivalent GHG emissions.

In the framework of their participation in EXPO 2015, 19 Member States of the European Union have identified a traditional bread recipe and made it available to visitors to the EU Pavilion to its website ([78]).

These 19 traditional bread recipes, together with other two recipes from two EU countries not present at EXPO (Bulgaria and Latvia), provided JRC the basis for estimating the energy flows and the green-house gas (GHG) emissions associated with their preparation following an LCA approach similar to the methodology used for assessing the 'basket of products' impacts described in Chapter 1 of this report.

It is worth noticing that these types of breads are not necessarily the most consumed ones in each country while, on the contrary, some of them are quite peculiar 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, as already discussed in Chapter 1, results can help to provide a further estimate of the overall variability and uncertainties associated with the evaluation of energy implications in food consumption.

Types of bread

Table D.1 shows the names and the originating countries of the types of bread selected for this study, while in Table D.2 the main ingredients of each recipe are listed. Figure D.4 to Figure D.24 include a picture of the breads under study.

Table D.1 The different EU breads

	Type of bread
1	Kaisersemmel - Austrian wheat buns
2	Cramique/Kramiek - Belgian sweet bread
3	Pogacha - Bulgarian ceremonies round bread
4	Houska - Czech braided rolls
5	Vaukhoore Leivakreem - Estonian grated bread
6	Baguette - French sourdough bread
7	Breitzel - German crossed-shaped bread
8	Pita - Greek flat bread
9	Pogácsa - Hungarian salty buns
10	Soda bread - Irish wholemeal and baking soda bread
11	Focaccia - Italian flat bread

	Type of bread
12	Salinata Rudzu Rupjmaize - Latvian parboiled rye bread
13	Rugine Duona - Lithuanian sourdough dark rye bread
14	Hobż Malti - Maltese sourdough bread
15	Krentenbollen - Dutch raisins buns
16	Chleb Žytni Razowy na Zakwasie - Polish sourdough rye bread
17	Pasca - Romanian Easter cheese bread
18	Bratizlawsky Rożok - Slovak walnut horseshoes
19	Pleteno Srce - Slovenian braided heart loaf
20	Pan con Tomate - Spanish snack
21	British Devon scones- Traditional British quick-bread

The production model employed refers to the artisanal production of the bread, with the reference business model of a family owned bakery operating on the local market.

([78]) http://europa.eu/expo2015/participating-eu-member-states

Table D.2 Ingredients considered for the calculations ([79]) — For Flour: R-Rye; W-Wheat

Ingredients	Country																				
	AT	BE	BG	CZ	EE	FR	DE	EL	HU	IE	IT	LV	LT	MT	NL	PL	RO	SK	SI	ES	UK
Flour	W	W	W	W	R	W	W	W	W	W	W	R	R	W	W	R	W	W	W	W	W
Butter		X	X		X		X		X						X		X		X		X
Cheese									X								X				
Cream					X				X								X				X
Egg	X	X	X	X						X					X		X	X			X
Egg yolk									X												
Fat																		X			
Honey										X			X				X				
Jam					X																X
Boiled potato									X												
Milk		X	X	X			X			X					X		X		X		
Milk powder																		X			
Olive oil								X			X									X	
Raisins		X													X		X	X			
Salt	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sugar	X	X	X		X		X				X	X	X		X		X	X	X	X	X
Tomato																				X	
Sunflower oil	X			X													X				
Water	X		X	X	X	X	X	X			X	X	X	X		X		X		X	
Yeast	X	X	X	X	X	X	X	X	X		X	X		X	X		X	X	X	X	X

Methodology

The energy and GHG emission calculations were carried out using, whenever possible, data originating from the country of each type of bread. Whenever necessary, justified assumptions were made when the provided bread recipe was lacking specific information. For example the Bulgarian recipe mentions the use of an unspecified mixture of water and milk: for the calculations it was assumed that such a mixture is made half by water and half by milk.

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

The methodology already developed in the previous JRC studies and summarised in Chapter 1 of this report was followed as closely as possible. A common framework with respect to the assumptions and models in order to achieve consistent LCAs and to obtain comparable results has been first developed, following the development of the process-based life cycle inventory models for the products and of the corresponding process-based life cycle inventories.

The production system is composed by seven stages covering the agricultural stage, the storage of cereals, wheat/rye milling, the production of other ingredients different from flour, the logistics including international trade and internal distribution, the packaging production (whenever possible) and the bread production. Food losses throughout the life cycle have also been accounted for.

([79]) The ingredients representing 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.

The impact categories chosen are Cumulative Energy Demand v 1.08 and Global Warming. The category Cumulative Energy Demand (here referred also as 'embedded energy' — see Chapter 1) reports the consumption of primary energy in terms of MJ. For Global warming, the characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterisation factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP hereafter), in kg carbon dioxide equivalent/kg emission (IPCC, 2007).

Data sources

Foreground data were obtained from the literature and from direct industry sources.

As regards wheat production, the environmental datasets for each (producing and exporting) country was built using different data sources.

- IFA database provides data on the fertiliser consumption per country (IFA 2012).
- FERTISTAT database provides data on the specific consumption of fertilisers in the cultivation of wheat for different countries (FertiStat 2004).
- FAOSTAT database was used to obtain the yields of grain per hectare in the various countries (FAOSTAT 2013).
- The consumption of pesticides for each country was estimated using the Eurostat Statistical Book 'The use of plant protection products in the European Union', (EC 2007).
- For some countries, energy consumption in the cultivation of wheat was obtained from the database Agrifootprint; for the remaining countries it was estimated using data from Golaszewski et al. (2014) which divides the various countries into climatic zones.
- Data on the production of rye were obtained predominantly from the Agrifootprint database that shows the production process of rye referred to Poland and Germany. For the other countries employing rye flour, these datasets have been changed in the part relating to the production and consumption of pesticides that was also derived from the Eurostat Statistical Book.
- The milling data were obtained from the Agrifootprint database and modified in the part relating to the electricity mix of the producing country
- The electricity mixes of some producing countries that were not present in the databases (Weidema et al. 2013, EC 2010), were reconstructed from data on the electric mix contained in the IEA database
- The yields of rye per hectare, related to each country, have been obtained from the FAOSTAT database (FAOSTAT 2013)

Some of the bread recipes include milk and some dairy products (butter, cream, cheese) as ingredients. The inventory of milk production was built for each country from the data of the process 'Raw milk, at dairy farm' contained in the Agrifootprint database. In order to tailor the dairy inventory data of each country, this process was modified in the section on production yields, with data from the FAOSTAT database, electricity mix and production losses.

Data on other ingredients were obtained from the study relative to the basket of products of the JRC (Notarnicola et al. 2014).

For those ingredients not included in the basket-of-products reports, the following data sources were used:

- Honey: Kendall et al. (2013)
- Jam: Agricultural cultivation of strawberry: Ribaudo (2011). Production of jam: International Food Safety Consultancy — Guide to jam production unit (IFSC 2015)
- Raisins: Agricultural cultivation of grape: Ribaudo (2011). Production of raisins: Thompson (2000)

- Salt: Process 'Sodium chloride, production mix, at plant, dissolved RER' taken from ELCD database
- Yeast: Dunn et al. (2012); COFALEC (2015).

Background data are mainly taken from the Agrifootprint and Ecoinvent v.3 databases.

Country specific import data for wheat and rye are taken from Eurostat international trade database.

Main assumptions

Assumptions are fully detailed in Notarnicola *et al*. (2015), while only the most relevant ones are briefly summarised here.

- Lifetime of food products, utilised as ingredients for bread, are considered to be less than 1 year.
- Infrastructure is included with a life time of 50 years and a construction time of 2 years
- Waste management is included.
- Electricity consumed in the food chain always refers to low voltage electricity (LV) (However this assumption is referred to the foreground of the product systems and not to all the other background processes which could make use of medium voltage electricity).
- 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.
- The loss of matter that takes place in the various life cycles of bread ingredients has been accounted for on the basis of the FAO report 'Global food losses and food waste — Extent, causes and prevention' (FAO 2011) and the end of life of the waste generated from losses was also considered.
- Since the import of flour for each EU country, according to the Eurostat data, was on average around 3.3 % of the total mass of cereal, the flour used for each bread was assumed to have been produced in the country of bread production from nationally available cereal (cereal produced + imported cereal).
- For the various products, whenever possible, the primary packaging was considered, including the end of life of the packaging itself.
- The final weight of the different types of breads has been estimated taking into consideration humidity loss during baking.
- For the baking process, energy consumption of the oven was related to the mass of bread and to cooking time.
- Logistics deserved a specific attention and was divided into international trade, domestic transport and distribution applying the following specific assumptions.

International trade. For wheat, rye and all ingredients included in the basket of products study, the international trade was considered; in particular for imports, the relevant amount in relation to domestic production and the countries of origin were considered. As regards to wheat and rye imports, those countries that represent the source of at least 95 % of the total imports of each country were considered.

For wheat and rye, logistics referred to international trade, has been considered for each country in which bread is produced. International transports have been assumed to occur in the following way:

- from the capital of the exporting country to the capital of the importing country;
- means of transport:
    - in general, by lorry
    - for those countries not connected by land routes — by lorry between the capital of the exporting country and the country's main port; by ship from the port of the exporting country to the main European ports and finally, by lorry between the port of destination and capital city of

the importing EU country. The distances between ports in kilometres were taken from http://www.sea-distances.org/.

Domestic transport has been considered both for domestic wheat and for foreign wheat. For each (importing and exporting) country the maximum length of that country has been estimated.

The transports considered are as follows:

For domestic cereals. Transport by lorry from the production site to the milling site; the length of this transport is considered as an eighth of the maximum length of the country.

For foreign cereals. Transport by lorry from the agricultural production site to the internal distribution platform (located in the capital of the exporting country); the length of this transport is considered as a quarter of the maximum length of the exporting country.

Transport by lorry from the domestic distribution platform (located in the capital of the importing country) to the milling site; the length of this transport is considered as a quarter of the maximum length of the importing country.

Distribution. For wheat and rye flour, distribution is considered as the flour transport from the milling site to the retailer. This transport is considered by lorry for a distance that is a quarter of the maximum length of the country.

For the other ingredients, distribution consists of transport by lorry from the manufacturer/farm to a regional distribution centre and further transport by lorry from the regional distribution centre to the retailer. The total distance travelled was assumed to be 500 km for all products. In the case in which the product required refrigerated transport, a 20 % increase in fuel consumption was assumed (Lalonde *et al*. 2013).

Results and interpretation

Figure D.1 shows the main results of the calculation for both total Cumulative Energy Demand indicator (left panel), derived from the calculation of the energy flows and the Global Warming Potential indicator (right panel) which are derived from the calculation of the Greenhouse Gas Emissions (GHGs) of each of the twenty one types of bread.

Differences reach up a factor of three for both the indicators with embedded energy ranging from 9 MJ/kg to 37 MJ/kg. In comparison the 'average' European bread included in the JRC food basket has an embedded energy of 16.1 MJ/kg.

Breads which have simple recipes, characterised by the presence of flour, water and yeast have the best energy and global warming results. On the contrary, the breads which have more complex recipes, characterised by the presence of animal-based products such as cheese, butter, milk, cream and eggs, are the most burdening.

For both the indicators the French Baguette, Greek Pita and the Italian Focaccia, result as the most energy and carbon friendly, mostly due to the simplicity of their recipes, made up of wheat flour, water and yeast (plus some extra-virgin olive oil in the Focaccia and in the Pita), without any animal-derived ingredient. Hungaria Pogácsa and Romania Pascã breads have very high burdens in both the indicators due to the animal-derived ingredients, especially cheese (but also butter and cream), and due to the high energy consumption and respective GWP in the manufacturing phase in addition to those of CH_4 and N_2O respectively occurring during the animal breeding and manure management.

In all cases, the energy consumption in the bread production (baking process) represents a hot spot (See Figure D.2).

Referring to the other breads, it is possible to state that higher burdens are due to the:

1. Presence of animal-derived ingredients characterised by CH_4 emissions during livestock breeding (enteric fermentation) and to N_2O emissions due to manure management.

2. National electricity mix based on fossil fuels, in particular coal.
3. Import of the main ingredient — wheat/rye — which in some countries amounts to 50 % of its available domestic wheat supply.
4. High ratio between intensive use of fertilisers and yields of the cultivations.

Referring to the two indicators, it is possible to see that, in general, they broadly show the same tendency with differences due to particular national conditions such as higher contribution of nuclear power in the electricity mix or higher presence of animal-derived ingredients in the recipe.

Moreover, by classifying the most burdening ingredient in the different breads (see Figure D.3) it is possible to note that flour is the most contributing ingredient in the breads of 8 countries, namely Austria, France, Greece, Italy, Latvia, Lithuania, Malta and Poland with a range between about 30 % to 80 % of the embedded energy in case of Greek Pita. On the contrary, animal-derived products are the most contributing ingredients to the overall embedded energy in the case of the types of breads proposed by Belgium (25), Bulgaria (41), Estonia (52), Germany (26), Hungary (75), Ireland (48), Netherlands (26), Romania (75), Slovenia (31) and UK (47), with a share ranging from 25 % up to 75 % in the case of breads containing significant quantities of cheese or butter.

Fat is the most contributing ingredient to the embedded energy in the bread proposed by Slovakia (37 %), sunflower oil in that of the Czech Republic (42 %) and tomato in that of Spain (38 %).

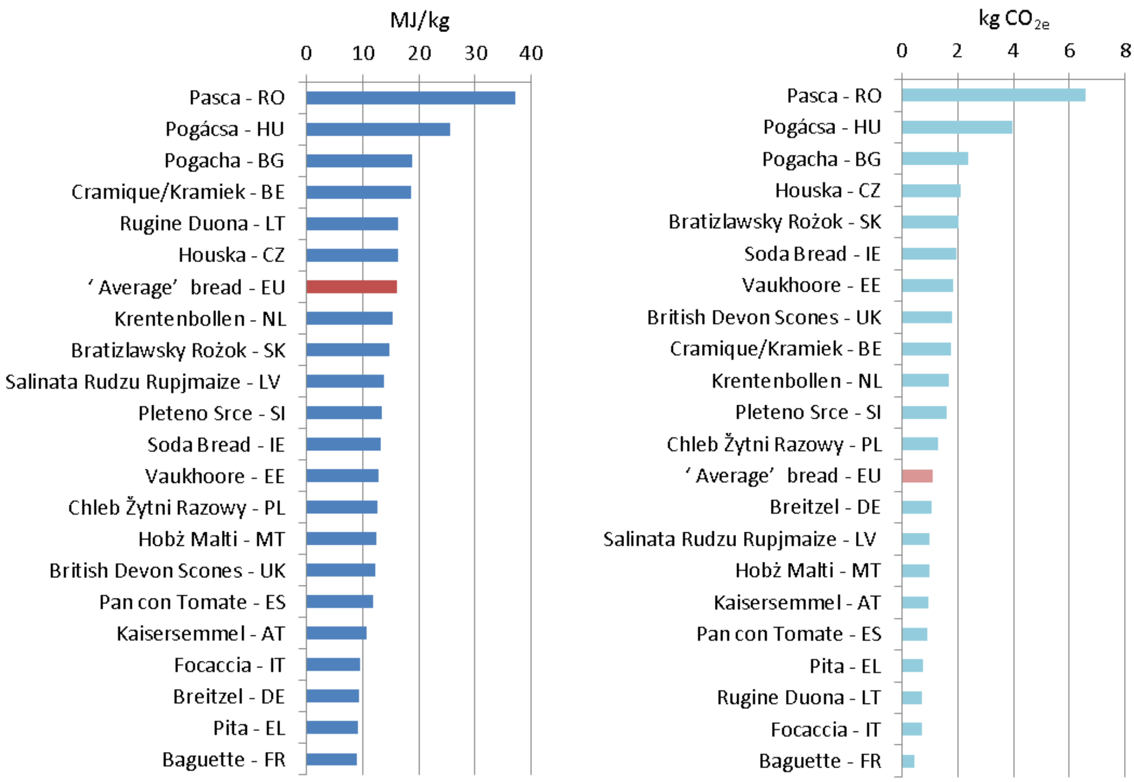

Figure D.1 Embedded energy (left) and equivalent GHG emissions (right) for the production of 1 kg of the 21 types of traditional breads studied.

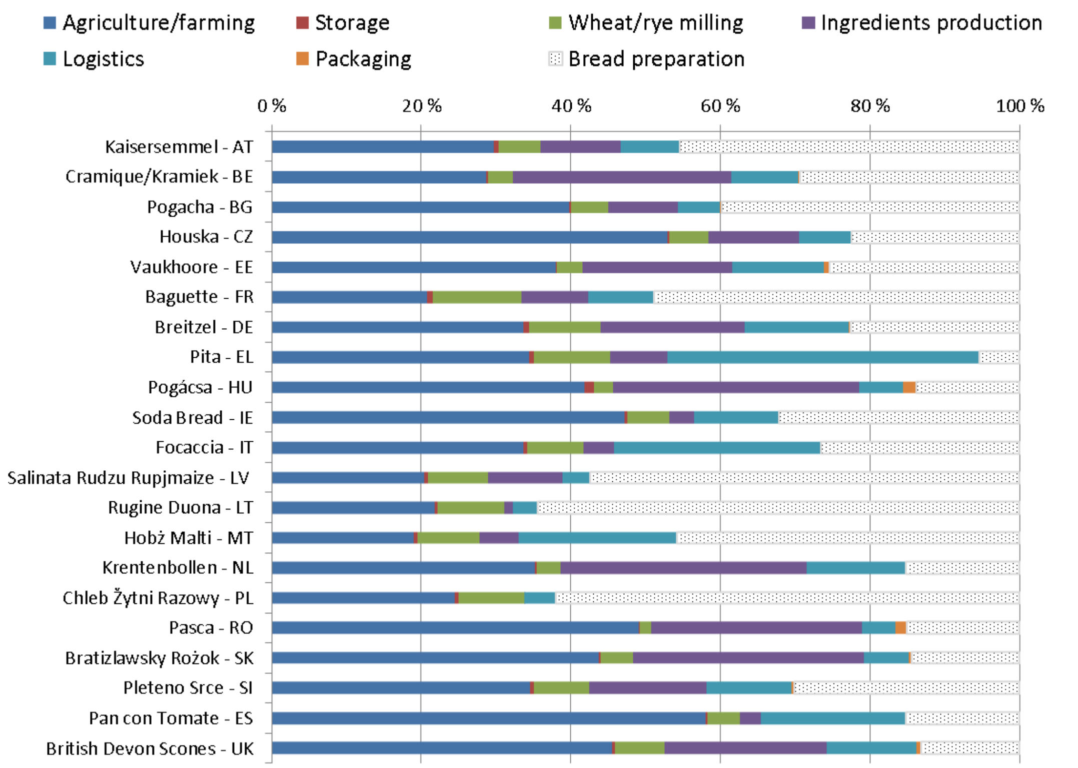

Figure D.2 Share of embedded energy in the 21 types of traditional breads in each production step.

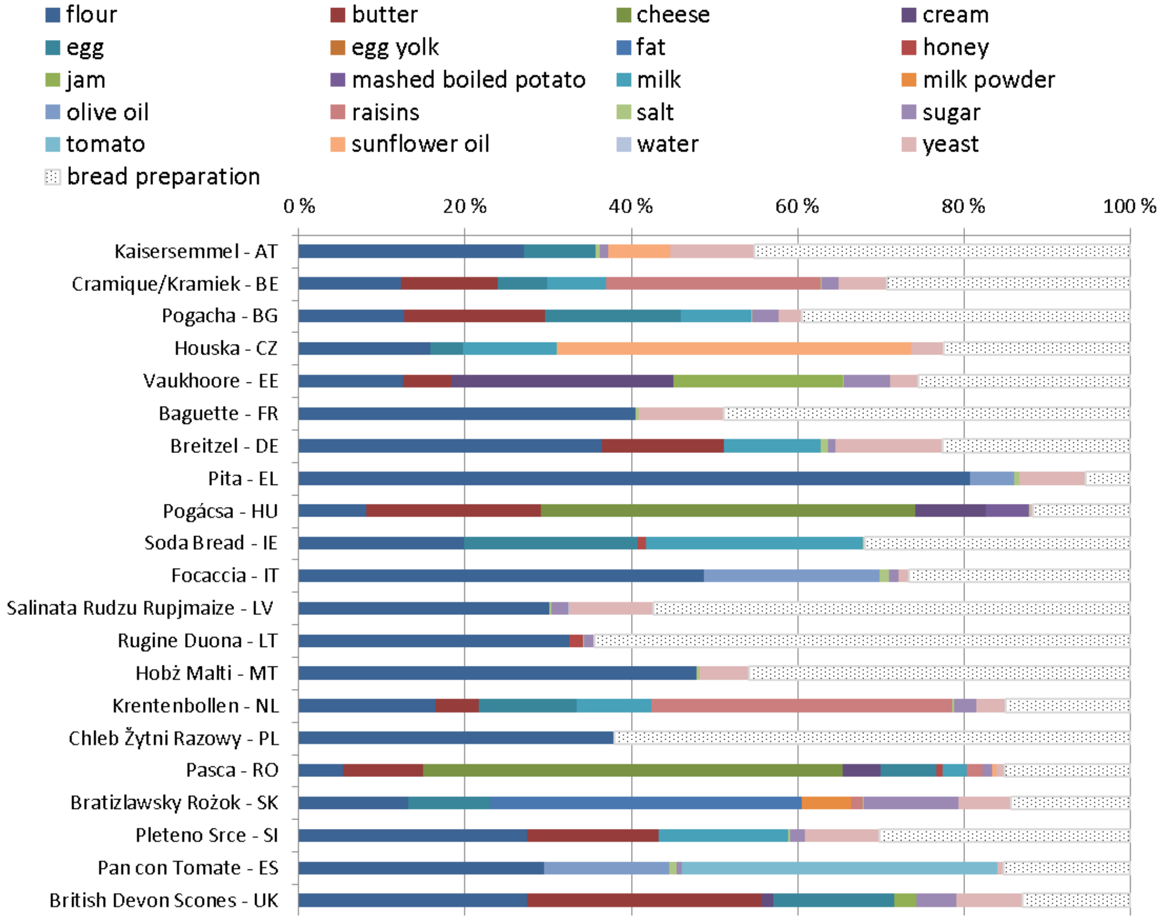

Figure D.3 Share of embedded energy in the 21 types of traditional breads related to ingredients (colours) and final bread preparation (dotted).

Figure D.4 Kaisersemmel — Austrian wheat buns

Figure D.5 Cramique/Kramiek — Belgian sweet bread

Figure D.6 Pogacha — Bulgarian ceremonial round bread

Figure D.7 Houska — Czech braided rolls

Figure D.8 Vaukhoore Leivakreem — Estonian grated bread

Figure D.9 Baguette — French sourdough bread

Figure D.10 Breitzel — German crossed-shaped bread

Figure D.11 Pita — Greek flat bread

Figure D.12 Pogácsa — Hungarian salty buns

Figure D.13 Soda bread — Irish wholemeal and baking soda bread

Figure D.14 Focaccia — Italian flat bread

Figure D.15 Salinata Rudzu Rupjmaize — Latvian parboiled rye bread

Figure D.16 Rugine Duona — Lithuanian sourdough dark rye bread

Figure D.17 Hobż Malti — Maltese sourdough bread

Figure D.18 Krentenbollen — Dutch raisins buns

Figure D.19 Chleb Żytni Razowy na Zakwasie — Polish sourdough rye bread

Figure D.20 Pasca — Romanian Easter cheese bread

Figure D.21 Bratizlawsky Rożok — Slovak walnut horseshoes

Figure D.22 Pleteno Srce — Slovenian braided heart loaf

Figure D.23 Pan con Tomate — Spanish snack

Figure D.24 British Devon scones-
Traditional British quick-bread

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List of abbreviations and definitions

A&F	Agriculture and Fishing
AD	Anaerobic Digestion
BAT	Best Available Techniques
BREFs	Best Available Techniques Reference Document
CA	Conservation Agriculture
CAP	Common Agriculture Policy
CFP	Common Fisheries Policy
CH_4	Methane and natural gas
CHP	Combined Heat and Power
CIP	Clean-In-Place
CO2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
COD	Chemical Oxygen Demand
CVD	Clean Vehicles Directive
DEFRA	Department for Environment, Food & Rural Affairs (UK)
de-N_2O	Nitrous oxide decomposition
EAFRD	European Agricultural Fund for Rural Development
EAP	Energy Agreements Programme (IE)
EE	Energy Efficiency
EED	Energy Efficiency Directive
EFSA	European Food Safety Authority
EIB	European Investment Bank
EII	European Industrial Initiatives
EIP-AGRI	European Innovation Partnership for Agricultural productivity and sustainability
EIPPCB	European Integrated Pollution Prevention and Control Bureau
EMFF	European Maritime and Fisheries Fund
EPLCA	European Platform on Life Cycle Analysis
ERDF	European Regional Development Fund
ESCO	Energy Services COmpany
ESF	Energy-smart Food for People and Climate programme
ESIF	European Structural and Investment Funds
ETAP	Environmental Technologies Action Plan
EU	European Union
F&B	Food and Beverages
FAO	Food and Agriculture Organization of the United Nations
FP7	Seventh Framework Programme
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HFMCE	Household Final Monetary Consumption Expenditure
HICP	Harmonised Index of Consumer Prices
HPI	High Policy Intensity
IAFS	Integrated Arable Farming Systems
IED	Industrial Emissions Directive
IO	Input-Output analysis
IRENA	International Renewable Energy Agency
IT	Information Technology
ITS	Intelligent Transport Systems
JRC	Joint Research Centre
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
LI	Low Input
LIEN	Large Industry Energy Network (IE)
LPI	Low Policy Intensity
MIT	Massachusetts Institute of Technology

NO_x	Nitrogen oxide
N_2O	Nitrous oxide
NCFF	Natural Capital Financing Facility
NGO	Non-Governmental Organisation
NEEAPS	National Energy Efficiency Action Plans
NREAPs	National Renewable Energy Action Plans
NUTS	Nomenclatures des Units Territoriales Statistiques
PDA	Project Development Assistance
PF4EE	Private Financing for Energy Efficiency instruments
PREn	Energy Consumption Rationalisation Plans (PT)
PV	Photovoltaic
PWPD	Packaging and Waste Packaging Directive
R & D	Research and Development
RE	Renewable Energy
RED	Renewable Energy Directive
RES	Renewable Energy Sources
RTD	Research and Technology Development
SCP	Sustainable Consumption and Production
SEAI	Sustainable Energy Authority of Ireland
SET-Plan	European Strategic Energy Technology Plan
SGCIE	Intensive Energy Consumption Management System (PT)
SH	Solar Heating
SMEs	Small and Medium-sized Enterprises
SO_2	Sulphur dioxide
UAA	utilised agricultural area
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
WFD	Waste Framework Directive

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