BIOREFINE

Recycling inorganic chemicals from agro- and bio-industrial waste streams

Project/Contract number: 320J - Biorefine

Document number: BIOREFINE – WP2 – A4 – P2 – D

Inventory of wastes produced in Belgium, Germany, France, The Netherlands and The United Kingdom

Date: 16/11/2015

Start date of project: 1 May 2011 Duration: 56 months

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Project funded by the European Regional Development Fund through INTERREG IV B		
Dissemination Level		
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PP	Restricted to other programme participants (including the Commission Services)	
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Table of contents

1 Glossary

AFF: Agriculture, Fishing and Forestry

AG: Agriculture

As: Arsenic

AU: Agricultural Use

AVW: Animal and Vegetal wastes

C/N ratio: Carbon-to-Nitrogen ratio

C (%): Carbon content

CaO (%): Calcium content expressed in calcium oxide

Cd: Cadmium

CD: Composting/Anaerobic Digestion

CMW: Chemical and Medical Wastes

Co: Cobalt

COA: Compost and Other Applications

Cr: Chromium

CS: Common Sludges

Cu: Copper

DL: Deposit onto or into Land

DM (%): Dry Matter content

EEG: Renewable Energy Act

EQ: Equipment

EU: European Union

EU-28: European Union counting 28 countries

H: Households

Hg: Mercury

I: Incineration

ID: Incineration/Disposal

IER: Incineration/Energy Recovery

IES: Industrial Effluent Sludges

K: Potassium

K_2O (%): Potassium content expressed in potassium oxide

L: Landfilling

LA: Landfill

LD: Landfill/Disposal

LSU: Livestock Unit

LTRW: Land Treatment and Release into Water bodies

MFBT: Manufacture of Food products, Beverages and Tobacco products

MgO (%): Magnesium content expressed in magnesium oxide

Mha: Million hectares

MLSU: Million Livestock Units

Mo: Molybdenum

MOW: Mixed Ordinary Wastes

MP: Manufacture of Paper and paper products; printing and reproduction of recorded media

MR: Material Recycling

MSW: Mineral and Solidified Wastes

MT: Million Tonnes

MWCS: Manufacture of Wood and of products of wood and Cork, except furniture; manufacture of articles of Straw and plaiting materials

N: Nitrogen

Ni: Nickel

N_{NH4} (%): Ammoniacal Nitrogen content

N_{NO3} (%): Nitrate Nitrogen content

N_{tot} (%): Total Nitrogen content

O: Others, Other techniques

P: Phosphorus

P_2O_5 (%): Phosphorus content expressed in phosphorus pentoxide

Pb: Lead

PCB: Poly-Chlorinated Biphenyls

PKH: Production in kg per capita

PT: Production in Tonnes

R\ER: Recovery other than Energy Recovery

R\ER-B: Backfilling

R\ERB: Recovery other than Energy Recovery, excluding Backfilling

RW: Recyclable Wastes

S: Services

SE: Sewage

SLW: Sludges and Liquid Wastes from waste treatment

TNH: Total Number of agricultural Holdings

TNHF: Total Number of agricultural Holdings possessing storage Facilities

UAA: Utilized Agricultural Area

UWWT: Urban Wastewater Treatment

WCTD: Waste Collection, Treatment and Disposal activities, materials recovery

WRW: Water collection, treatment and supply, sewerage, Remediation activities and other Waste management services

WWT: Wastewater Treatment

WWTP: Wastewater Treatment Plant

Zn: Zinc

2 General introduction

Nutrients are essential for ensuring sufficient food production. Due to the World's increasing food demand, the need for fertilisers is increasing. In addition, minerals are required in other sectors, such as in the chemical sector. At the same time there are regions in North- West Europe (NWE) that suffer from a surplus of nutrients present in waste streams. This surplus can have adverse effects on the environment. In this context, considering wastes as new nutrient resources could help solving the problems of waste surpluses and nutrients' demand.

The waste flows are significant and some of them contain substantial concentrations in nitrogen, phosphorus and potassium, well known as key elements in agriculture. Manure, slurry, digestate, sewage sludge, household wastes, ashes and industrial wastes contain these nutrients but also pollutants, such as heavy metals. The use of such materials as nutrients' sources also requires the extraction of nutrients in a suitable form, usable by plants.

The presence of pollutants in wastes causes legal problems. The extraction of nutrients from wastes and the production of fertilisers from them require a purification step of pollutants during the process. These pollutants must respect the legal constraints applied to fertilisers in each member of EU. The legal status of waste in another constraint, because a material coming from wastes will be considered as waste as well unless it can be proven that it qualifies for the use as a fertiliser. Transnational transport of wastes is also problematic between regions and countries.

The present report will not consider the legal aspects of waste valorization as fertilisers but focuses on the opportunities relating to wastes, on the basis of their composition and production. The majority of data presented in this report were taken from Eurostat®.

3 Global waste production in Europe

It has been established that European people generate about four billion tonnes of solid waste each year, while about two billion tonnes are produced in the European Union (Hillstrom and Collier Hillstrom, 2003; Morselli et al., 2009). The mean waste generation is not identical in the countries of the EU15 (France, Germany, Italy, The Netherlands, Belgium, Luxemburg, Ireland, United Kingdom, Denmark, Greece, Spain, Portugal, Finland, Sweden, Austria) and in the other countries that joined EU after 1995 (Estonia, Latvia, Lithuania, Poland, Czech Republic, Slovakia, Hungary, Slovenia, Cyprus, Malta, Bulgaria, Romania, Croatia). A general trend of recycling and valorization has been observed in all countries, and the use of landfills has been decreasing from 1995. The basic principles which are now applied in the field of wastes were included in the Sixth Environmental Action Programme of the EU "Environment 2010: Our future, Our choice". This programme is based on major observations:

- Pollution caused by transport, agricultural activities, industrial processes, municipal and industrial waste management is the cause of a poor environmental quality, contributing to a negative impact on human health.

- Our planet has a limited capacity to ensure resource demand and wastes deriving from their use. Negative effects have been identified and are bound to metal, mineral and hydrocarbon consumption.
- The European Union produces a growing volume of wastes, coupled with a loss of land and resources and a pollution increase.
- A significant part of waste must be considered as hazardous (Morselli et al., 2009).

Consequently, it has become necessary to apply environment-friendly techniques and processes to wastes. EU waste management policies are now aiming to reduce the environmental and health impacts of wastes. The final objectives are to reduce the amount of waste generated and the promotion of recycling methods.

In 2008, the total amount of waste generated in the EU-27 reached a value of 2.62 billion tonnes, which means 5.2 tonnes of waste per capita. The variation of waste production across the European countries is considerable, with a minimal value of 660 kg/cap in Latvia and a maximal value of 37,528 kg/cap in Bulgaria. Those differences can be explained by the economic and urban structure and the environmental practices which are specific to each member state. **Figure 1** shows the total waste production in European countries in 2012.

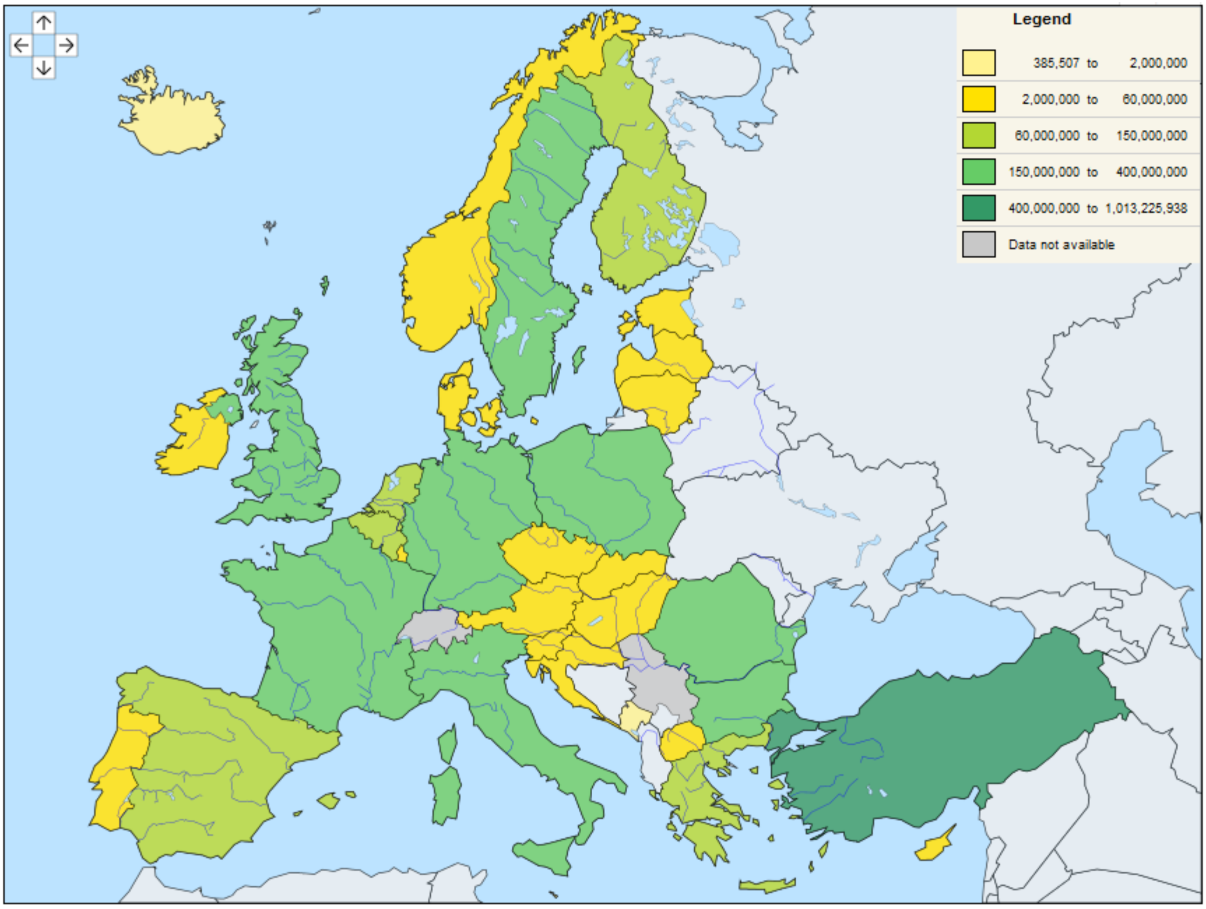

Figure 1: Total waste production (2012) in European countries in tonnes. The following categories are considered: chemical and medical wastes, recyclable wastes (metallic, glass, paper, cardboard, rubber, plastic, wood and textile wastes excluding wastes containing PCB), equipment (waste containing PCB and discarded equipment), vegetal and animal wastes (animal and mixed food waste, vegetal wastes, animal faeces, urine and manure), mixed ordinary wastes (household and similar wastes, mixed and undifferentiated materials, sorting residues), common sludges, mineral and solidified wastes.

Source: EUROSTAT®

The minimal waste production corresponds to Montenegro, while the maximal production relates to Turkey. In 2012, Belgium, France, Germany, The Netherlands and The United Kingdom generated 68, 345, 368, 124 and 241 MT of wastes, respectively. The BioRefine project involved these five countries, and this report will focus on them.

The different amounts of wastes produced all over EU-28 are shown in **Figures 2**, **3, 4** and **5** with detailed information about Belgium, Germany, the United Kingdom, the Netherlands and France. Here, we focus on the categories which may have a key role in the field of nutrient recovery, and considered as non-hazardous. **Figures 2** and **3** relate to the generation of waste by economic activity and highlight the most relevant activities as regards nutrient recovery, while **Figures 4** and **5** focus on some specific wastes which can be considered as nutrient sources.

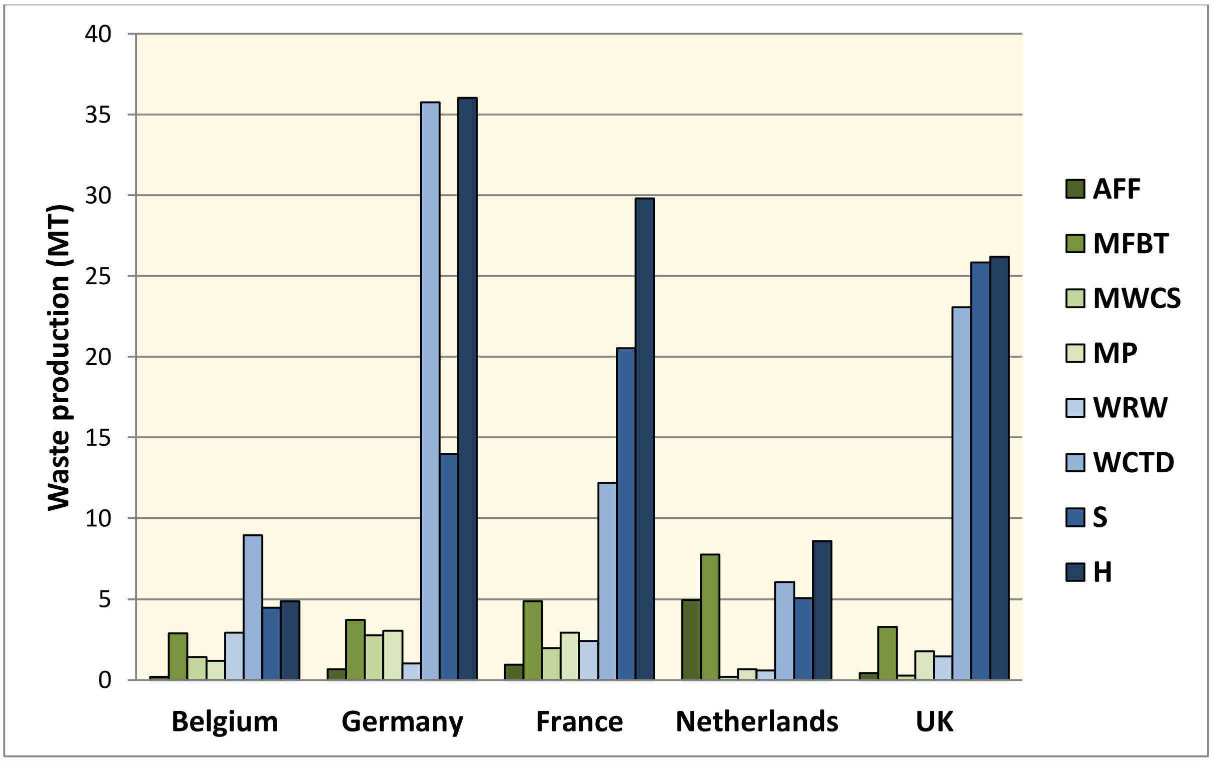

Figure 2: Waste production in Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 according to economic activities expressed in million tonnes. The following activities are considered: Agriculture, Fishing and Forestry (AFF); Manufacture of Food products, Beverages and Tobacco products (MFBT); Manufacture of Wood and of products of wood and Cork, except furniture; manufacture of articles of Straw and plaiting materials (MWCS); Manufacture of Paper and paper products; printing and reproduction of recorded media (MP); Water collection, treatment and supply, sewerage, Remediation activities and other Waste management services (WRW); Waste Collection, Treatment and Disposal activities, materials recovery (WCTD); Services (S); Households (H).

Source: data collected from EUROSTAT®

Belgium generates the lowest quantities of wastes in the specific categories which are highlighted here, but it has also the smallest population (about 11 million people in 2015). Household wastes are predominant in the five countries and it must be noted that WCTD activities are quite developed in the five countries. The Netherlands show important opportunities with the highest production of wastes coming from agriculture, fishing and forestry, with a population of about 17 million people in 2015. Germany, France and The UK generate the highest amounts of wastes with respective populations of about 81, 67 and 65 million people. Considering the categories that have been chosen because of their nutrient contents, these three countries mainly generate household wastes and wastes coming from services, but considerable amounts of wastes are collected, treated and recycled (WCTD category). "Services" consist of wastes generated by many types of activities: wholesale and retail trade, repair of motor vehicles, motor cycles, transportation and storage, accommodation and food service activities, information and communication, financial and insurance activities, real estate activities, professional, scientific and technical activities, administrative and support service activities, public administration and defence, compulsory social security, education, human health and social work activities, arts, entertainment and recreation, activities of households and employers, undifferentiated goods, services producing activities of households for own use, activities of extraterritorial organisations and bodies, and some other services (Eurostat, 2010). Consequently, the complexity of the figures which relate to this category must be taken into account. In **Figure 2**, the figures are expressed in absolute values (tonnes of materials), but they can be expressed according to the populations (see **Figure 3**).

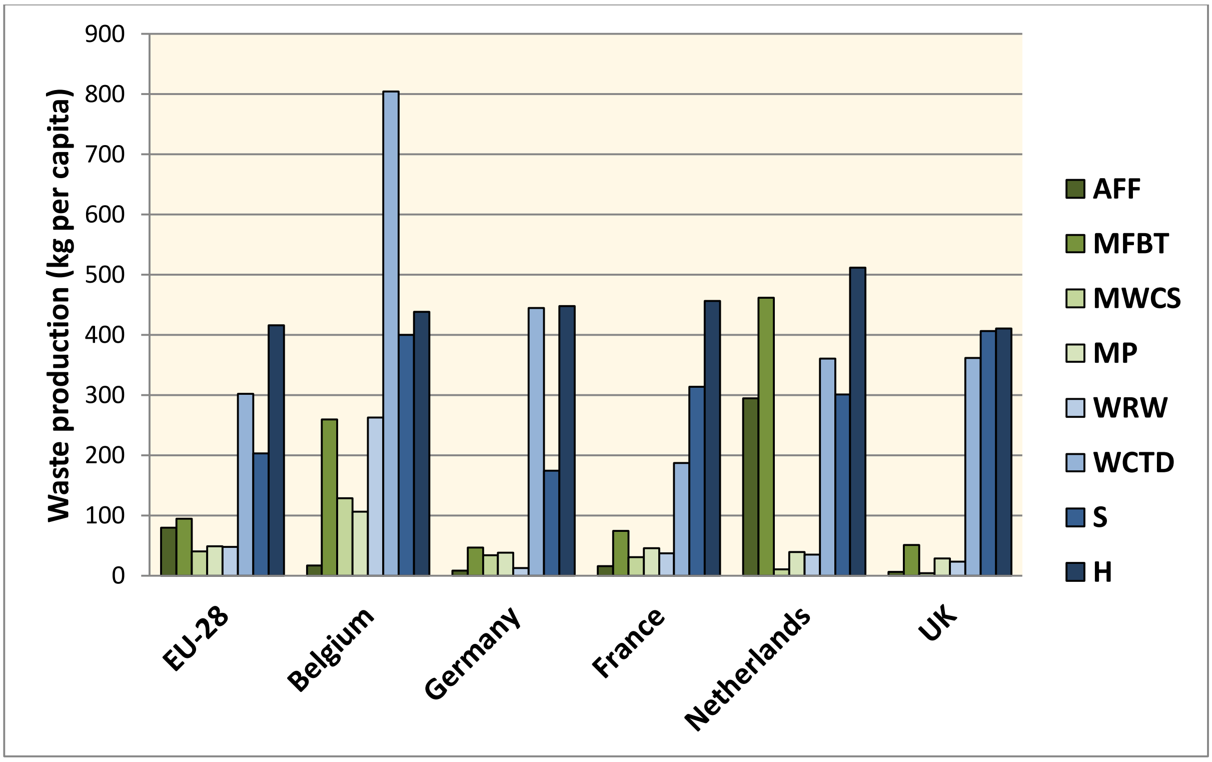

Figure 3: Waste production in EU-28, Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 according to economic activities, expressed in kg per capita. The following activities are considered: Agriculture, Fishing and Forestry (AFF); Manufacture of Food products, Beverages and Tobacco products (MFBT); Manufacture of Wood and of products of wood and Cork, except furniture; manufacture of articles of Straw and plaiting materials (MWCS); Manufacture of Paper and paper products; printing and reproduction of recorded media (MP); Water collection, treatment and supply, sewerage, Remediation activities and other Waste management services (WRW); Waste Collection, Treatment and Disposal activities, materials recovery (WCTD); Services (S); Households (H).

Source: data collected from EUROSTAT®

Figure 3 shows a stability of production of household wastes in the 28 European countries. However, **Figure 3** also confirms a relatively important production of wastes coming from agriculture, forestry and fishing in The Netherlands, in comparison with the other countries and the European mean value. The high value relating to the wastes generated by the industries which relate to food products, beverages and tobacco products in The Netherlands should also be highlighted. In Germany, France, The Netherlands and The United Kingdom, the amounts of wastes produced by paper industry (MP) and water collection and treatment (WRW) are lower than the European mean value. In Belgium, the waste productions relating to the MFBT, MWCS, MP, WRW and S activities tend to exceed the European mean values, which means that this country shows the highest waste productions expressed in kg per capita for these categories compared to Germany, France, The Netherlands and The UK.

It must be noted that two main activities generate high levels of waste in EU-28: construction and mining/quarrying. The majority of wastes generated by those activities are excavated earth, road construction waste, demolition waste, dredging spoil, waste rocks, tailings, etc. These wastes are mainly composed of mineral materials but do not offer opportunities in respect of nutrient recovery. Consequently, these wastes were not considered in the figures.

The production of wastes can also be considered according to the type of waste. Here, we will focus on some non-hazardous wastes containing nutrients (nitrogen, N; phosphorus, P; potassium, K): industrial effluent sludges (IES), sludges and liquid wastes from waste treatment (SLW), animal and vegetal wastes (AVW), mixed ordinary wastes (MOW) and common sludges (CS). IES are sludges and solid residues from industrial wastewater treatment, including external and/or physical treatment, solid and liquid wastes from soil and groundwater remediation, sludges from boiler cleaning, wastes from cooling water preparation and cooling columns and drilling mud. SLW include wastes from the physico/chemical treatment of hazardous wastes, liquids and sludges from the anaerobic treatment of waste (digestate), landfill leachate and effluent treatment sludges from oil regeneration. AVW corresponds to animal and mixed food waste, vegetal wastes, animal faeces, manure and urine. MOW is composed of household and similar wastes, mixed and undifferentiated materials and sorting residues. CS is composed of wastewater treatment sludges from municipal sewerage water and organic sludges from food preparation and processing. They mainly originate from households and industrial branches with organic wastewater (mainly pulp and paper as well as food preparation and processing). They can also occur in wastewater treatment plants or in the anaerobic treatment of waste. All common sludges are considered as non-hazardous (Eurostat, 2010).

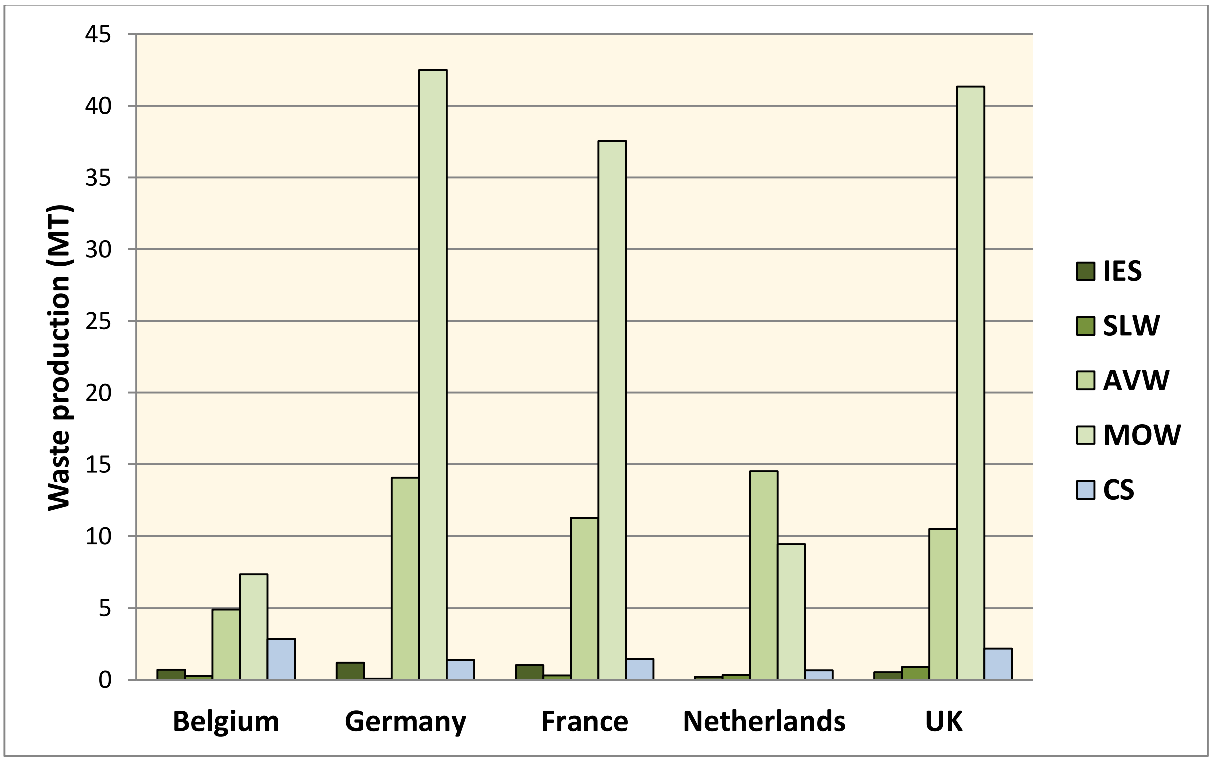

Figure 4: Waste production in Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 according to the type of waste expressed in million tonnes (MT). The following wastes are considered: Industrial Effluent Sludges (IES), Sludges and Liquid Wastes from waste treatment (SLW), Animal and Vegetal wastes (AVW), Mixed Ordinary Wastes (MOW) and Common Sludges (CS).

Source: data collected from EUROSTAT®

Household wastes are predominant in most countries, but animal and vegetal wastes are also produced in relatively important amounts. The other wastes which correspond to the categories IES, SLW and CS are of less importance in terms of quantities. Indeed, the five countries produced about 140 MT of mixed ordinary wastes, 55 MT of animal and vegetal wastes, while the last three categories (including industrial effluent sludges, sludges and liquid wastes from waste treatment and common sludges) corresponded to a total amount of 14 MT of wastes. These data highlight the importance of opportunities which relate to household wastes and animal/vegetal wastes. These data can also be expressed according the respective populations of each country (**Figure 5**).

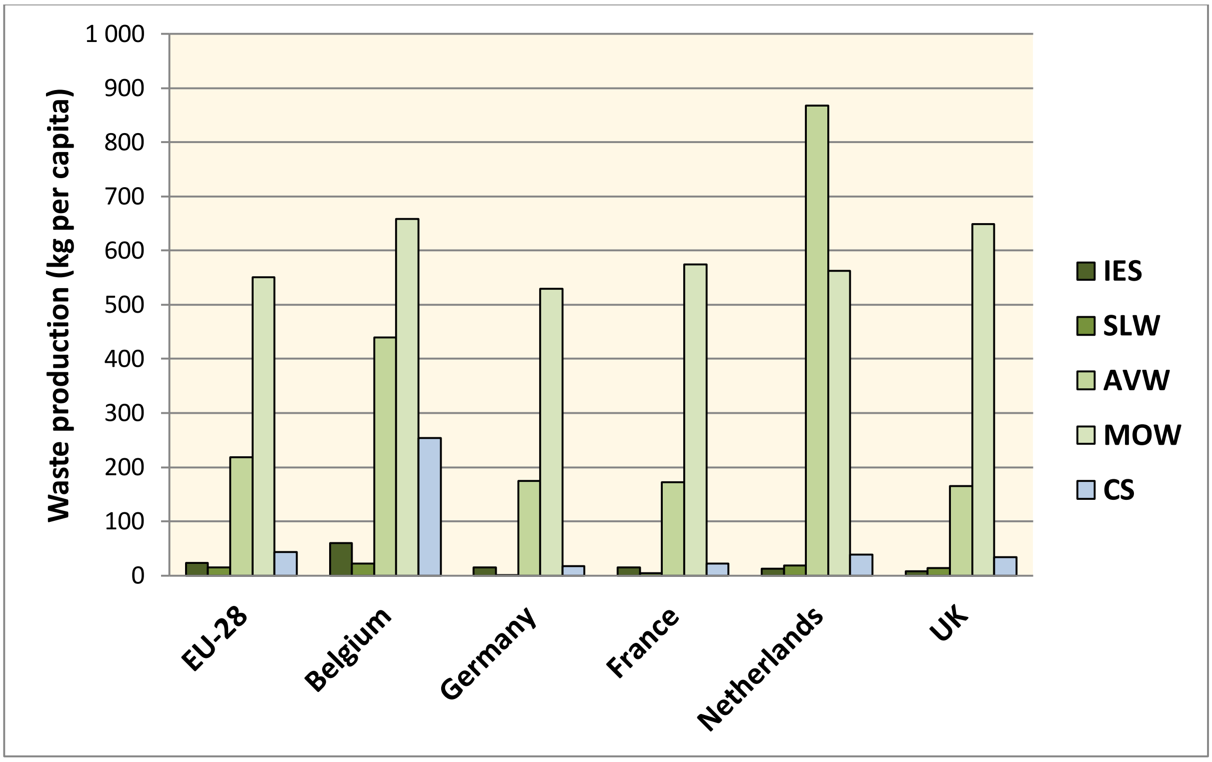

Figure 5: Waste production in Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 according to the type of waste expressed in kg per capita. The following wastes are considered: Industrial Effluent Sludges (IES), Sludges and Liquid Wastes from waste treatment (SLW), Animal and Vegetal wastes (AVW), Mixed Ordinary Wastes (MOW) and Common Sludges (CS).

Source: data collected from EUROSTAT®

Figure 5 shows a higher waste/population ratio for industrial effluents in Belgium, while it remains quite stable for the other countries (from 8 to 15 kg waste per capita). It is also higher than the mean European value. Once again, the production of household wastes is found to be stable and close to the mean value in EU-28. Belgium and The Netherlands show a high waste/population ratio for animal and vegetal wastes, but animal wastes, especially manure and slurry, will be further discussed in the next sections. Belgium also shows the highest waste/population ratio for the production of common sludges (254 kg per capita), much higher than the mean value in EU-28 (43 kg of common sludges per capita).

Waste treatment is also dependent on the country considered. **Figure 6** shows the treatments applied to non-hazardous wastes (all classes considered) in Belgium, Germany, France, The Netherlands and The United Kingdom.

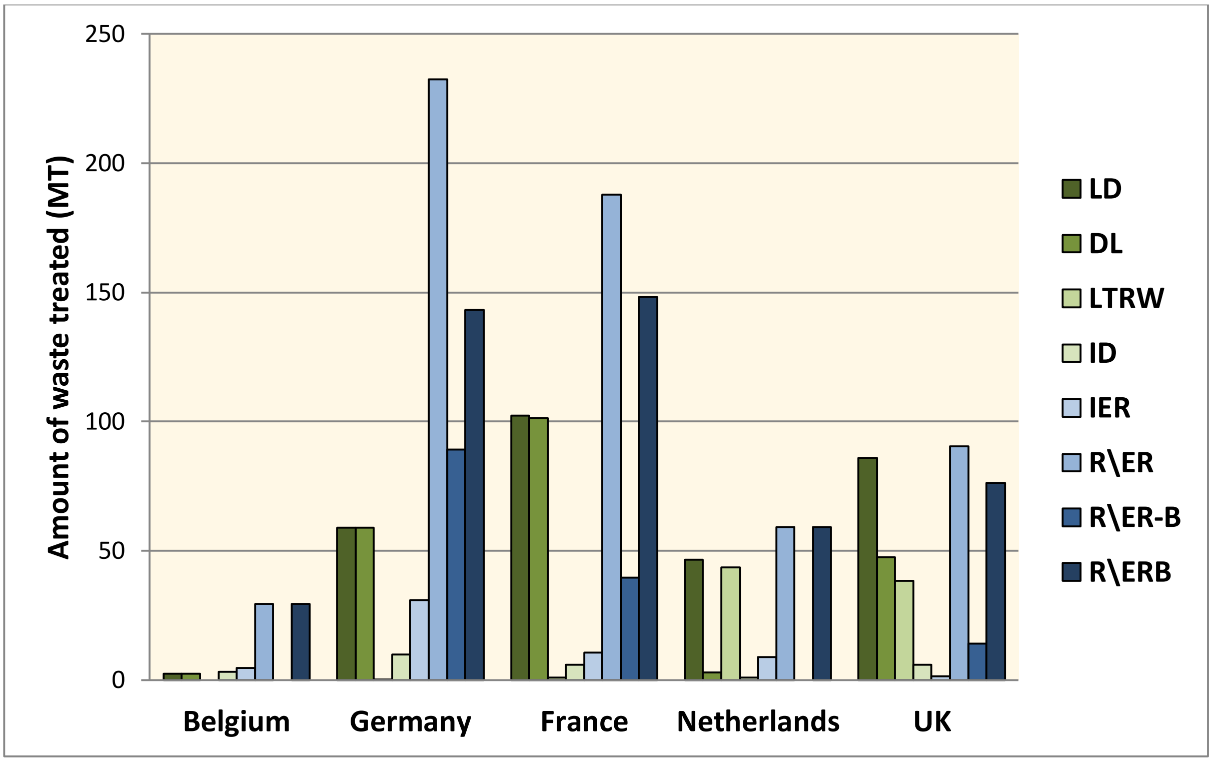

Figure 6: Waste treatment in Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 expressed in million tonnes of waste. All types of non-hazardous wastes are considered. LD = Landfill/Disposal; DL = Deposit onto or into Land; LTRW = Land Treatment and Release into Water bodies; ID = Incineration/Disposal; IER = Incineration/Energy Recovery; R\ER = Recovery other than Energy Recovery; R\ER-B = Backfilling; R\ERB = Recovery other than Energy Recovery, excluding Backfilling.

Source: data collected from EUROSTAT®

LD, or Landfill and disposal correspond to different operations and include DL (Deposit into or onto Land). LD also includes land treatment (e.g. biodegradation of liquid or sludgy discards in soils, etc.), deep injection (e.g. injection of pumpable discards into wells, salt domes or naturally occurring repositories, etc.), surface impoundment (e.g. placement of liquid or sludgy discards into pits, ponds or lagoons, etc.), specially engineered landfill (e.g. placement into lined discrete cells which are capped and isolated from one another and the environment, etc.), release into a water body (including seas/oceans and sea-bed insertion), and permanent storage (e.g. emplacement of containers in a mine, etc.). ID is waste incineration on lands. IER is incineration with energy recovery, which means that wastes are used as fuels or other means to produce energy. R\ER corresponds to the other types of recovery, which include: solvent reclamation and regeneration, recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes), recycling/reclamation of metals and metal compounds, recycling/reclamation of other inorganic materials, regeneration of acids or bases, recovery of components used for pollution abatement, recovery of components from catalysts, oil re-refining or other reuses of oil, land treatment resulting in benefit to agriculture or ecological improvement, use of wastes obtained from energy recovery processes and backfilling. R\ER-B relates to backfilling only. Finally, R\ERB relates to all types of recovery (as in R\ER), excluding backfilling (Eurostat, 2010).

Techniques for recovery (energy and materials) from wastes are widely used in Belgium, Germany, France, The Netherlands and The UK. The importance of backfilling in Germany (89 MT) and in France (40 MT) should be highlighted. Backfilling is a recovery operation where waste is used in excavated areas (such as underground mines, gravel pits) for the purpose of slope reclamation or safety or for engineering purposes in landscaping and where the waste is substituting other non-waste materials which would have had to be used for the purpose. Unfortunately, landfilling and similar activities which do not valorize wastes are still widely used in all countries (2, 59, 102, 46 and 86 MT in Belgium, Germany, France, The Netherlands and The UK, respectively). It is also important to notice the wide use of incineration (with and without energy recovery) in each country, which generates ashes, usually sent to landfills or further valorized.

In this global context, the BioRefine project the objectives of which are the valorization and the recovery of useful nutrients from organic wastes is justified. Some countries produce high amounts of wastes which contain recoverable nutrients for agriculture. The BioRefine project focuses on specific wastes which are known to contain notable concentrations in nitrogen, phosphorus and potassium: manure and slurry, sewage sludge, ashes, digestate, household and some industrial wastes. These materials will be further discussed in the next sections.

4 Animal wastes

4.1 Composition

Animal wastes, such as manure, slurry and spoiled straw are common residues generated by livestock production. Animal wastes have been commonly used as fertilisers in agriculture for a long time. However, raw animal residues may require specific treatments before their use as fertilisers for the following reasons:

- The farm operation can get more efficient,
- The pollution risks from manure and slurry can be reduced,
- Nuisance factors can be reduced as well, such as offensive odours,
- Hygienic concerns can be solved,
- The value of solid and liquid animal wastes in the farm can be increased (Burton, 2007).

Table 1 shows the composition of some samples of manure and slurry coming from different types of livestock. These data are only informative and were obtained from a small number of samples.

Table 1: Composition of bovine manure, bovine slurry, pig slurry and poultry manure (non-exhaustive data).

Source: Bureau d'études environnement et analyses (BEAGx)

Bovine manure			*Bovine slurry*		
Parameter	**Raw matter**	**Dry matter**	**Parameter**	**Raw matter**	**Dry matter**
DM (%)	20.7-43.1		DM (%)	4.54-8.04	
N_{tot} (%)	0.53-1.43	2.19-4.12	N_{tot} (%)	0.25-0.36	4.1-5.6
N_{NH4} (%)	0.1-0.30	0.36-1.13	N_{NH4} (%)	0.17-0.23	2.4-3.8
P_2O_5 (%)	0.22-0.65	1.08-2.15	P_2O_5 (%)	0.082-0.13	1.6-1.8
K_2O_t (%)	0.69-1.56	2.88-5.24	K_2O_t (%)	0.30-0.36	3.8-7
C (%)	6.80-15.1	24.7-39.8	C (%)	1.7-3.1	38.2-39.5
C/N ratio	8.3-15.6		C/N ratio	7-9.6	
Pig slurry			*Poultry manure*		
Parameter	**Raw matter**	**Dry matter**	**Parameter**	**Raw matter**	**Dry matter**
DM (%)	9.9-16.2		DM (%)	42.8	
N_{tot} (%)	0.64-0.83	4.1-7.2	N_{tot} (%)	1.49	3.5
N_{NH4} (%)	0.42-0.60	2.6-5.2	N_{NH4} (%)	0.45	1.1
P_2O_5 (%)	0.38-0.53	2.6-4.6	P_2O_5 (%)	2.72	6.4
K_2O_t (%)	0.40-0.59	2.5-5.1	K_2O_t (%)	1.76	4.1
C (%)	3.5-5.9	30.8-36.6	C (%)	12.2	28.6
C/N ratio	4.6-9.3		C/N ratio	8.2	

4.2 Production and treatment

Key parameters necessary for the assessment of animal wastes' production (including animal faeces, urine and manure) are the Utilized Agricultural Areas (UAAs), the number of holdings, the livestock and the number of holdings with storage facilities for solid dung. These key data are shown in **Figures 7** and **8**. In these figures, animal faeces, urine and manure include slurry, manure and spoiled straw stemming from agriculture. These wastes are considered as non-hazardous (Eurostat, 2010).

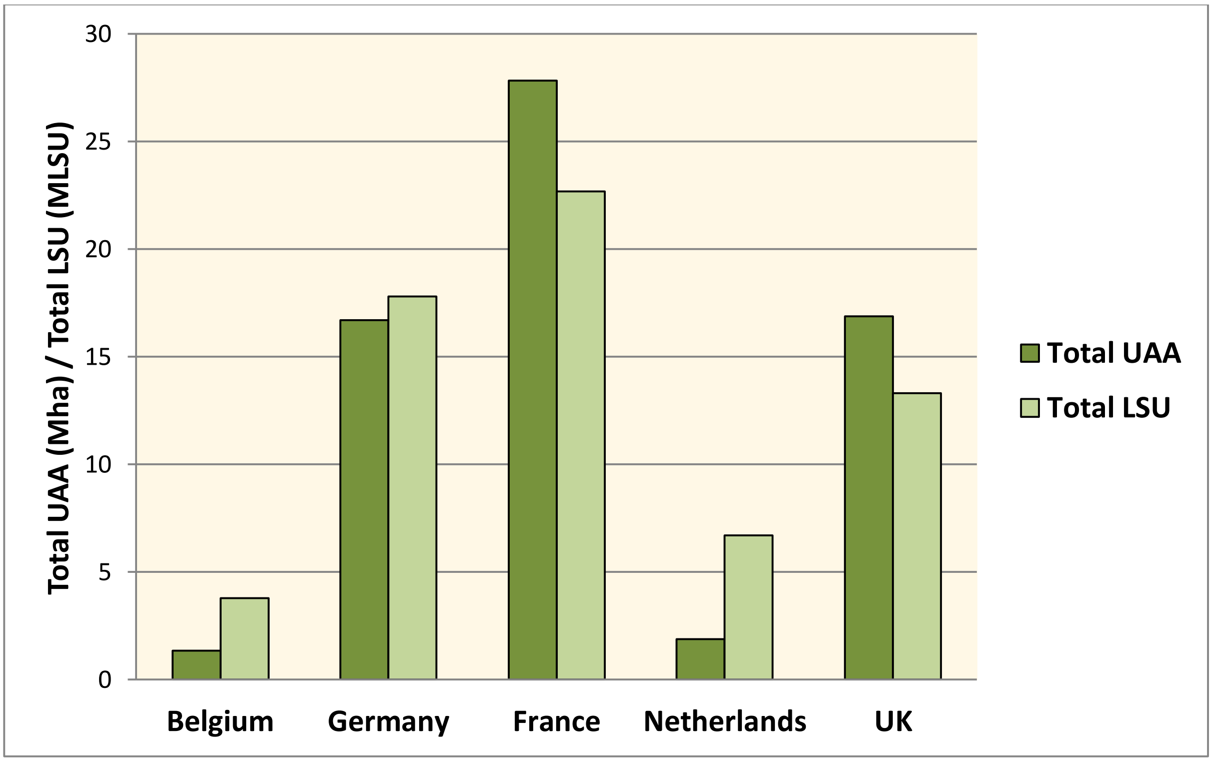

Figure 7: Total utilized agricultural areas (UAAs) and livestock units (LSUs) in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in million hectares (Mha) and million livestock units (MLSU), respectively.

Source: data collected from EUROSTAT®

Germany, France and The UK showed the highest utilized agricultural areas, with respective UAA/LSU ratios of 0.94, 1.23 and 1.27 in 2010. Belgium and The Netherlands showed lower ratios (0.36 and 0.28, respectively). These differences are explained by intensive farming in these two countries, while Germany, France and The UK are more focused on cultivation. Consequently, Belgium and The Netherlands are more concerned in nutrient recovery from animal wastes and potential nutrient surpluses relating to these materials.

Figure 8 shows the total numbers of agricultural holdings and holdings with storage facilities for animal dung mapped out in 2010.

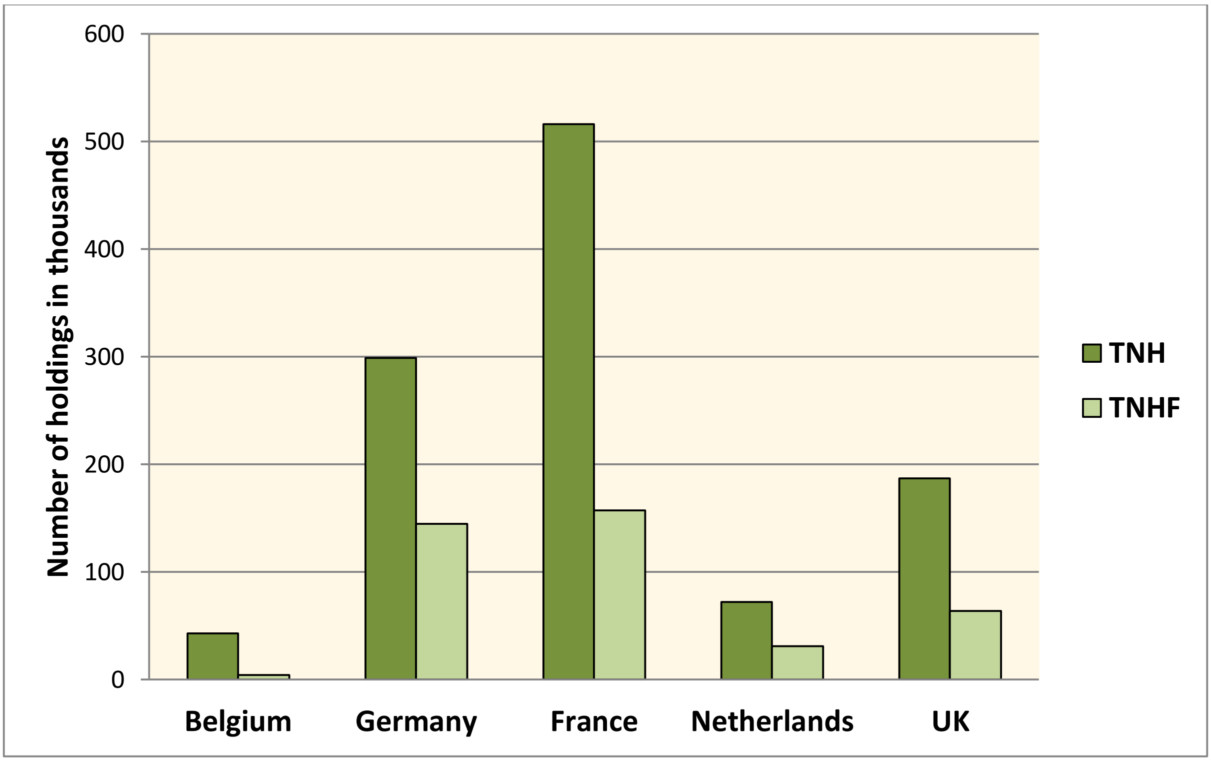

Figure 8: Total number of agricultural holdings (TNH) and of agricultural holdings possessing storage facilities (TNHF) for animal dung in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in thousands.

Source: data collected from EUROSTAT®

France possessed the highest number of agricultural holdings in 2010, with and without taking storage facilities into account. Germany showed approximately the same number of holdings with storage facilities than France, while it also included many less agricultural holdings (about 300,000 compared to about 500,000 holdings), all categories considered. Germany, France and The United Kingdom counted a total of about 1 million agricultural holdings, while this number was estimated at 115,000 for Belgium and The Netherlands. These two countries include the lowest numbers of farms, but produce relative high amounts of animal wastes in comparison to Germany, France and The UK.

The amounts of animal wastes including manure, slurry and spoiled straw produced in Belgium, Germany, France, The Netherlands and The United Kingdom are shown in **Figure 9**.

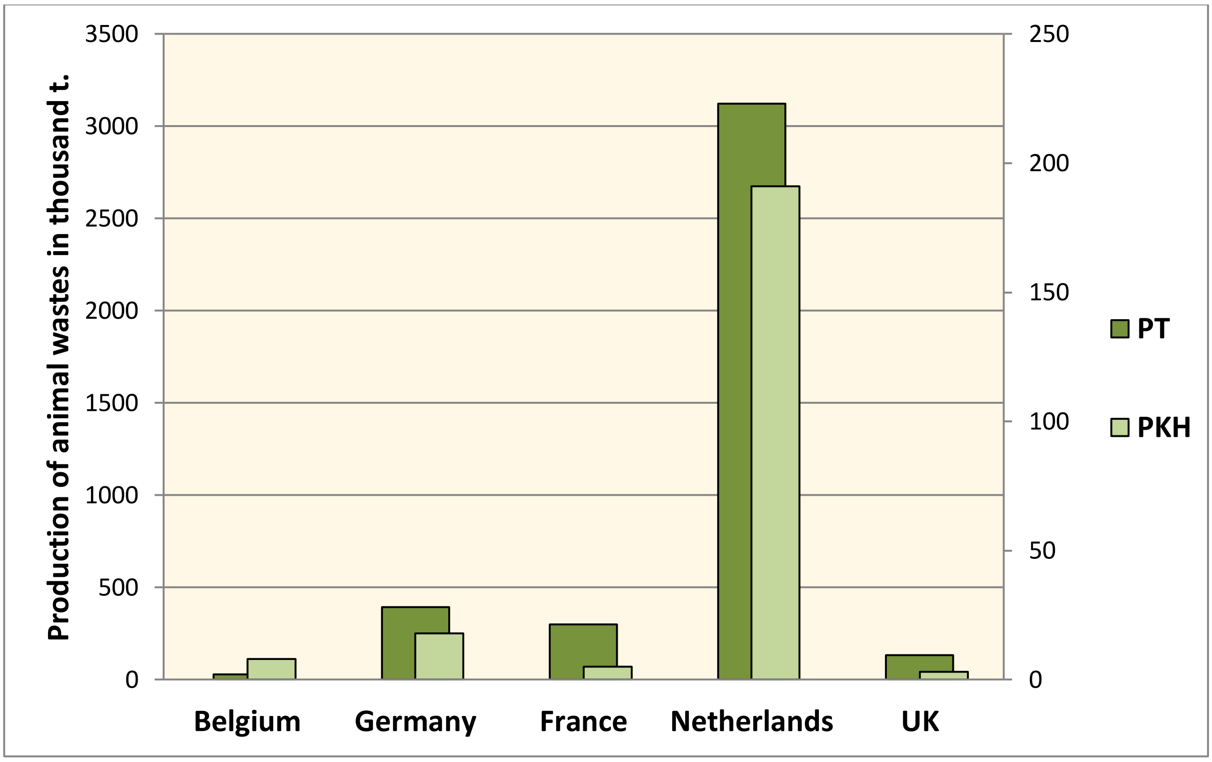

Figure 9: Total production of animal wastes (manure, slurry and spoiled straw) in Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 expressed in tonnes (noted PT, in dark green, left scale) and in kg per capita (noted PKH, in clear green, right scale).

Source: data collected from EUROSTAT®

The highest amounts of manure and slurry are produced by The Netherlands, with a total production close to 3,000,000 tonnes in 2012. The Netherlands also showed the highest production expressed in kg per capita (191 kg per capita). Germany showed an intermediate production (18 kg per capita) while Belgium, France and The UK generated 8, 5 and 3 kg per capita, respectively. Germany and France produced 393,000 and 300,000 tonnes of animal wastes in 2012, while Belgium and The UK produced 30,000 and 134,000 tonnes. **Figure 10** shows the different treatments applied to animal wastes in 2012 in Belgium, Germany, France, The Netherlands and The UK.

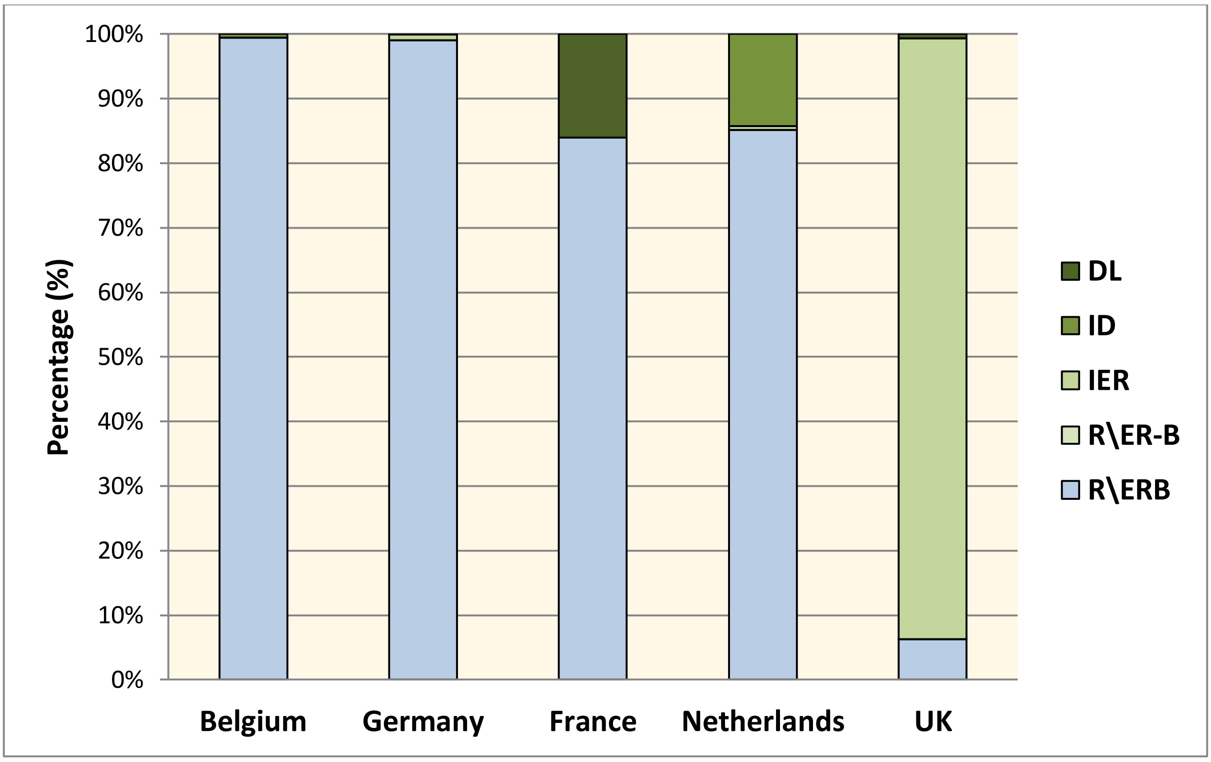

Figure 10: Treatment applied to animal wastes (manure, slurry and spoiled straw) in Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 expressed in percentage. DL = Deposit onto or into Land; ID = Incineration/Disposal; IER = Incineration/Energy Recovery; R\ER-B = Backfilling; R\ERB = Recovery other than Energy Recovery, excluding Backfilling.

Source: data collected from EUROSTAT®

In Belgium and Germany, animal wastes are mainly valorized through the pathways included in the category R\ERB. This category includes the direct valorization in agriculture but also the recovery techniques applicable to specific components, such as N, P and K. In France, about 16 % of animal wastes are simply deposited into or onto land, and the remaining part is valorized through the category R\ERB. In The Netherlands, the majority of animal wastes are also valorized through agriculture (or through the valorization of specific components as described previously), and about 14 % are incinerated. The UK shows a completely different profile and mainly uses incineration coupled with energy recovery to treat animal wastes. About 93 % of animal wastes are incinerated to produce energy, while about 6 % are used in agriculture or components' recycling.

Figure 11 shows the global production of animal and vegetal wastes (considered as non-hazardous) in 2012 in the European countries. Here are considered three categories:

- Animal and mixed food wastes from food preparation and products, sludges from washing and cleaning, separately collected biodegradable kitchen and canteen wastes, edible oils and fats. They are produced by food preparation and production, and also originate from separate collection.

- Vegetal wastes which are produced by food preparation, sludges from washing and cleaning, materials unsuitable for consumption and green wastes. They are generated by food and beverage production, agriculture, horticulture and forestry.
- Animal faeces, urine and manure, as described before (Eurostat, 2010).

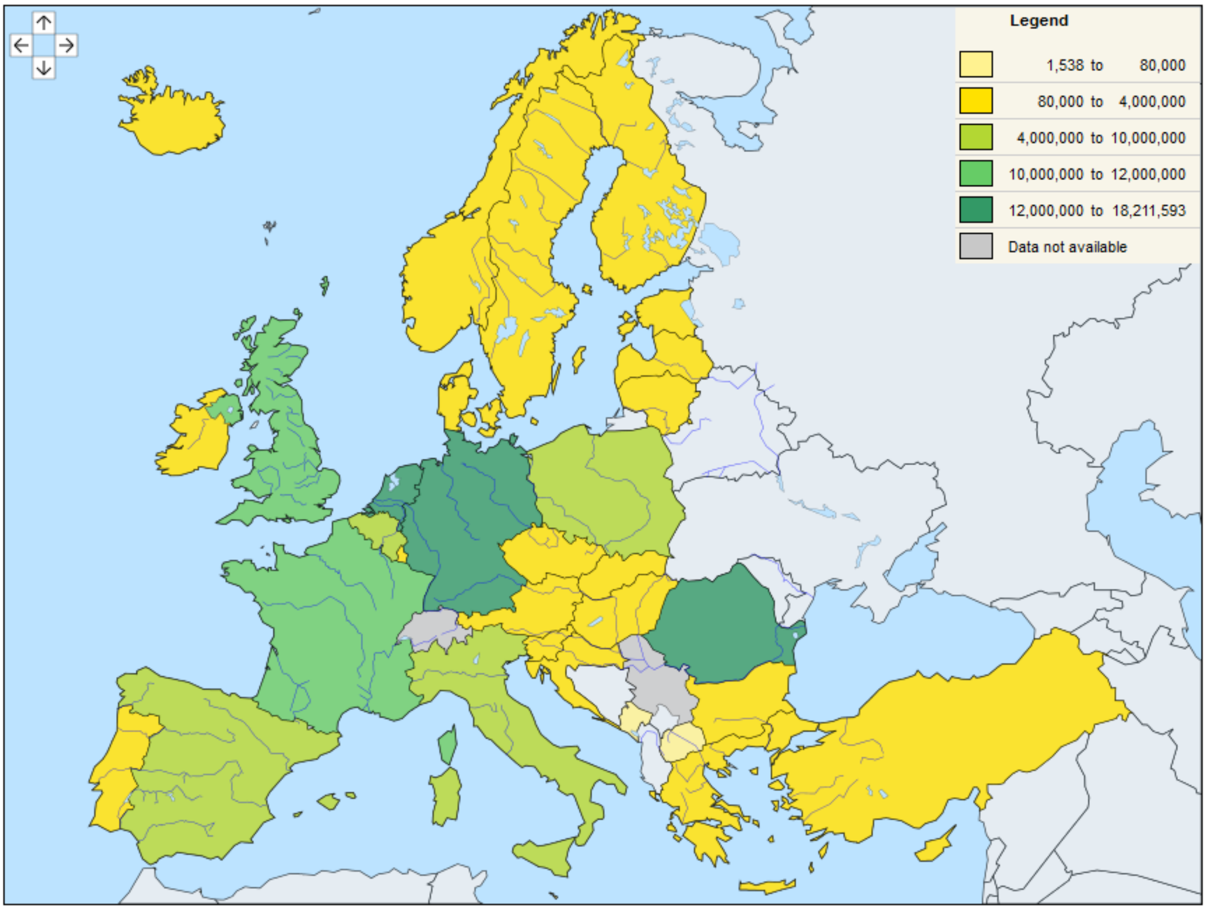

Figure 11: Total production of animal and vegetal wastes (2012) in European countries in tonnes.

Source: EUROSTAT®

5 Digestate

5.1 Composition

Digestate comes from the anaerobic biodegradation of organic wastes. Biodegradation is a microbiological process applicable to organic materials in which microorganisms degrade the matter under aerobic or anaerobic conditions (Merlin Christy et al., 2014).

Aerobic degradation of organic wastes, or composting, transforms the organic matter into carbon dioxide, water, nitrates and sulphates. In nature, this transformation is common in forests, where droppings from trees and animals are turned into stable organic materials (Merlin Christy et al., 2014). Composting is widely applied to various types of wastes, such as green wastes or animal wastes, leading to a solid residue called compost.

Table 2 shows the composition of some samples of green waste compost. These data are only informative and were obtained from a small number of samples.

Table 2: Composition of compost obtained from green waste composting (non-exhaustive data).

Source: Bureau d'études environnement et analyses (BEAGx)

Parameter	Raw matter	Dry matter
DM (%)	45.9-77.3	
pH	6.9-8.4	
N_{tot} (%)	0.59-1.41	0.92-2
N_{NO_3} (mg N/kg)	<10-32.9	<19-42.6
N_{NH_4} (mg N/kg)	<10-113	<19-220
P_2O_5 (%)	0.20-0.44	0.32-0.84
K_2O_t (%)	0.41-1.13	0.62-2.08
MgO (%)	0.31-0.92	0.58-1.38
CaO (%)	1.34-2.82	2.92-5.06
As (mg/kg)	1.06-2.4	2.3-3.3
Cd (mg/kg)	0.24-0.43	0.45-0.66
Cu (mg/kg)	11.9-36.7	24-71
Ni (mg/kg)	5.0-13.1	9.5-17
Pb (mg/kg)	18.4-54.1	40-94
Zn (mg/kg)	75.7-151.5	145-240
Hg (mg/kg)	0.028-0.07	0.06-0.11
Cr (mg/kg)	6.5-11.9	14-20
Co (mg/kg)	0.62-2.60	0.8-4.9
C (%)	8.9-14.9	12.6-27.9
C/N ratio	6.9-24.3	

Anaerobic digestion is also applicable to organic wastes. By this process, a complex mixture of microorganisms transforms organic materials into biogas. The remaining solid part, called digestate, is composed of nutrients, additional cell matter, salts and refractory organic matter. This microbiological process occurs under oxygen-free conditions. Biogas is typically composed of methane (60%), carbon dioxide (40%), water vapour and hydrogen sulfide.

Anaerobic digestion is considered as one of the most energy-efficient and environmentally beneficial technology for bioenergy production. Anaerobic treatment is widely used in diversified topics and devices: septic tanks, sludge digesters, industrial and municipal wastewater treatment, hazardous waste management and agricultural waste management (Merlin Christy et al., 2014).

Different types of input materials can be valorized through anaerobic digestion: food wastes, sewage sludge, animal wastes, green wastes, etc. Consequently, the quality of digestate is variable and depends on the composition of these materials. These residues may contain pollutants, such as heavy metals. Anaerobic digestion leads to the valorization of carbon under the form of methane and carbon dioxide, reducing the total volume of the solid input flow recovered in digestate. It also causes a concentration effect of the other components, such as nutrients (N and K) but also pollutants (heavy metals).

Table 3 shows the composition of some samples of digestate obtained through the anaerobic digestion of different types of organic materials, mixed or not. These data are only informative and were obtained from a small number of samples.

Table 3: Example of composition of digestate (non-exhaustive data).

Source: Bureau d'études environnement et analyses (BEAGx)

Parameter	Raw matter	Dry matter
DM (%)	3.5-5.8	
pH	8.3-9.9	
N_{tot} (%)	0.5-0.64	6.5-11.9
N_{NH4} (%)	0.19-0.39	2.3-10.9
N_{NO3} (%)	<0.001	<0.012
P_2O_5 (%)	0.044-0.26	1.24-3.0
K_2O_t (%)	0.37-0.39	4.5-4.8
As (mg/kg)	0.051-0.26	0.98-3.3
Cd (mg/kg)	0.015-0.15	0.26-1.87
Cu (mg/kg)	4.7-10.1	55-188
Ni (mg/kg)	0.42-0.93	11-13
Pb (mg/kg)	0.89-6.6	25-83
Zn (mg/kg)	21.8-27	258-771
Hg (mg/kg)	0.0015-0.0021	0.03-0.04
Cr (mg/kg)	0.7-1.3	13-23
Co (mg/kg)	0.16-0.18	3-4.4
C (%)	1.9-3.11	32-36.6
C/N ratio	3.1-3.5	

5.2 Production

Biogas plants accept different types of organic wastes as input materials. Biogas production is not developed at the same level inside the European countries. **Figure 12** shows the total number of biogas plants in 2012 and 2013 in Belgium, Germany, France, The Netherlands and The UK.

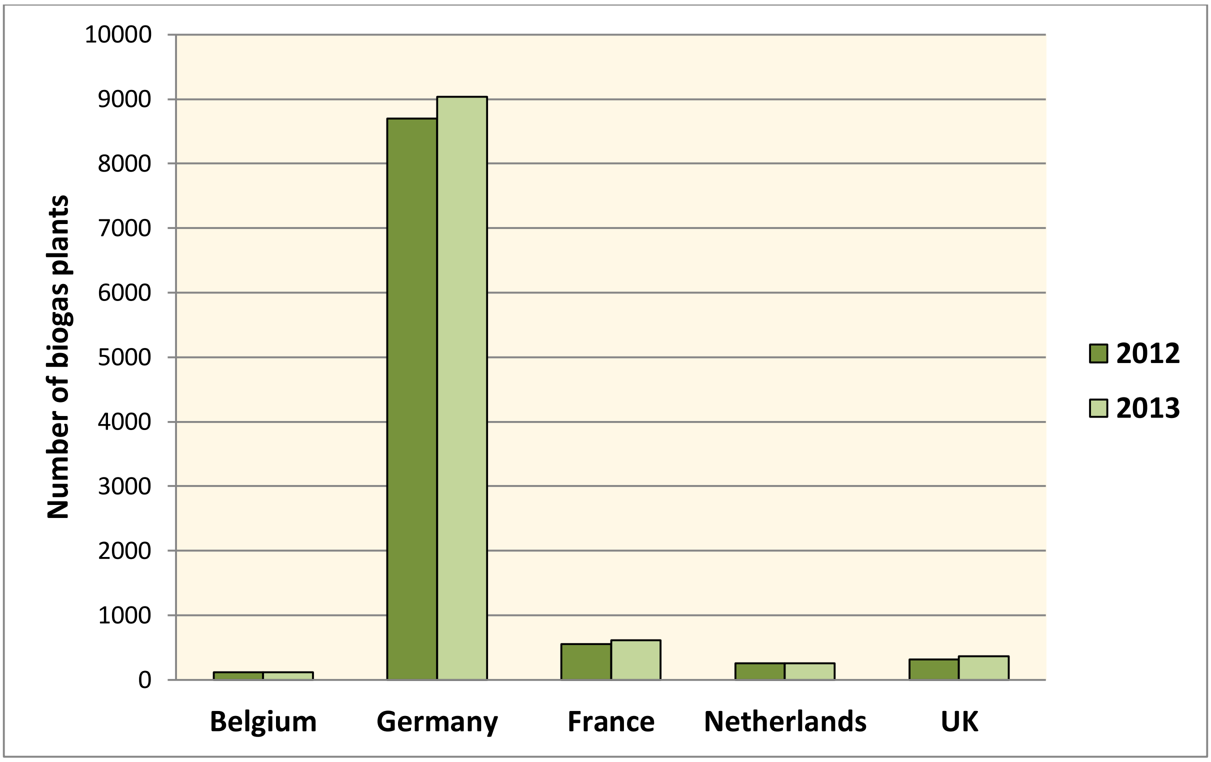

Figure 12: Total number of biogas plants in Belgium, Germany, France, The Netherlands and The UK in 2012 and 2013.

Source: European Biogas Association, (2014)

The most important biogas producer is Germany, with a total number of biogas plants of 9,035 in 2013. The other countries counted much less biogas plants in 2013 (118, 610, 252 and 360 plants in Belgium, France, The Netherlands and The UK, respectively). Germany is consequently the most important producer of biogas, but also produces the major part of digestate among the European countries. The countries included in EU-28, excluding Malta but including Switzerland, counted 14,572 biogas plants in 2013, which means that Germany possesses 62 % of total biogas plants. The two other top countries in biogas production are Italy and Switzerland, with 1,391 and 620 biogas plants in 2013, respectively. However, it must be kept in mind that Germany and Italy had to adapt to the new Renewable Energy Act (EEA) and to slow down the development of biogas plants (European Biogas Association, 2014).

Figure 13 shows the distribution of biogas plants according to the sectors: agriculture, sewage, landfill and others.

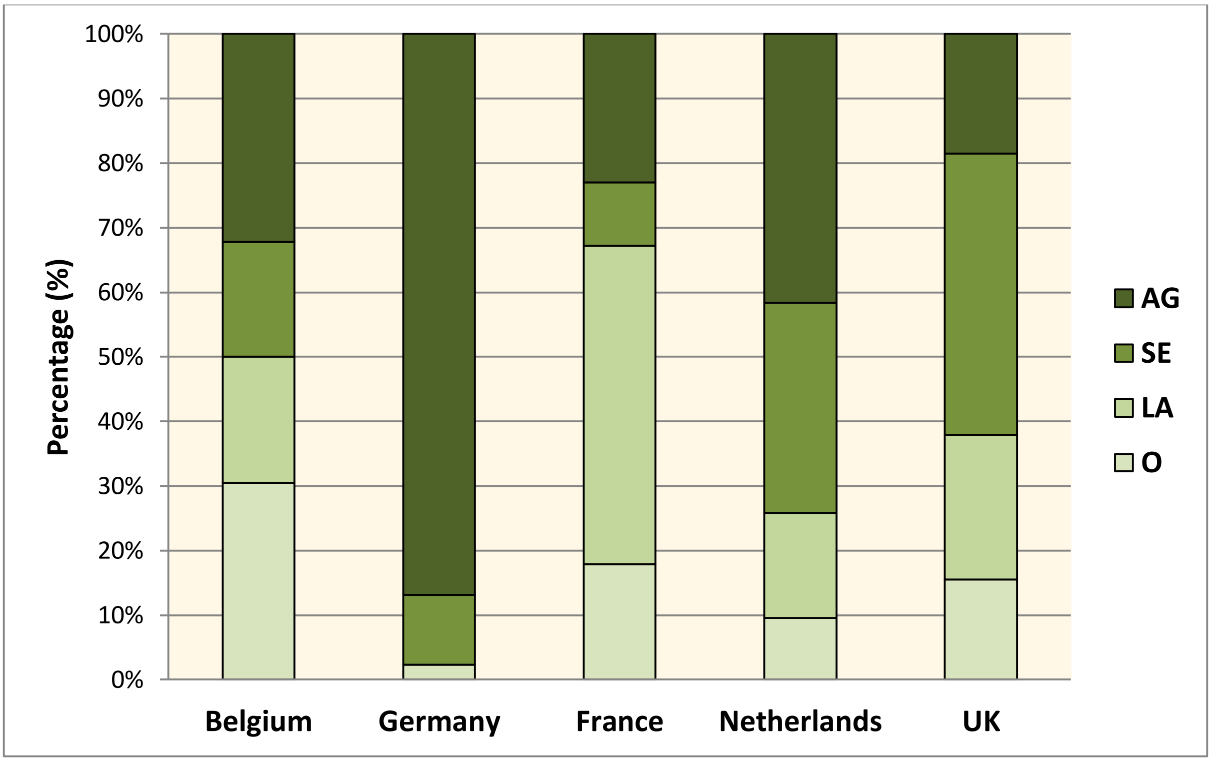

Figure 13: Distribution of biogas plants according to the sectors in Belgium, Germany, France, The Netherlands and The UK in 2013. AG = Agriculture; SE = Sewage; LA = Landfill; O = Others.

Source: European Biogas Association, (2014)

The distribution of biogas plants according to the different sectors (agriculture, sewage, landfill and others) is quite balanced in the case of Belgium. Germany mostly considers agricultural wastes as an input flow for anaerobic digestion. Sewage sludge is also considered but to a lower extent (about 11 %). In France, landfill is the predominant sector (49 % of total French biogas plants), while agricultural wastes, sewage sludge and other wastes are digested in 18, 10 and 23 biogas plants. The anaerobic digestion of agricultural wastes is also much developed in The Netherlands (42 % of total plants), but this trend can be correlated to the high production of manure, slurry and spoiled straw (see **section 4.2.**). In The UK, sewage sludge is predominant, with 44 % of total biogas plants used to treat this type of waste. This can be correlated to the high production of sewage sludge in this country (see **section 6.2.**).

An important parameter which can be considered to estimate the production of digestate in European countries is their specific biogas productions. **Figure 14** shows the production of biogas in the European countries.

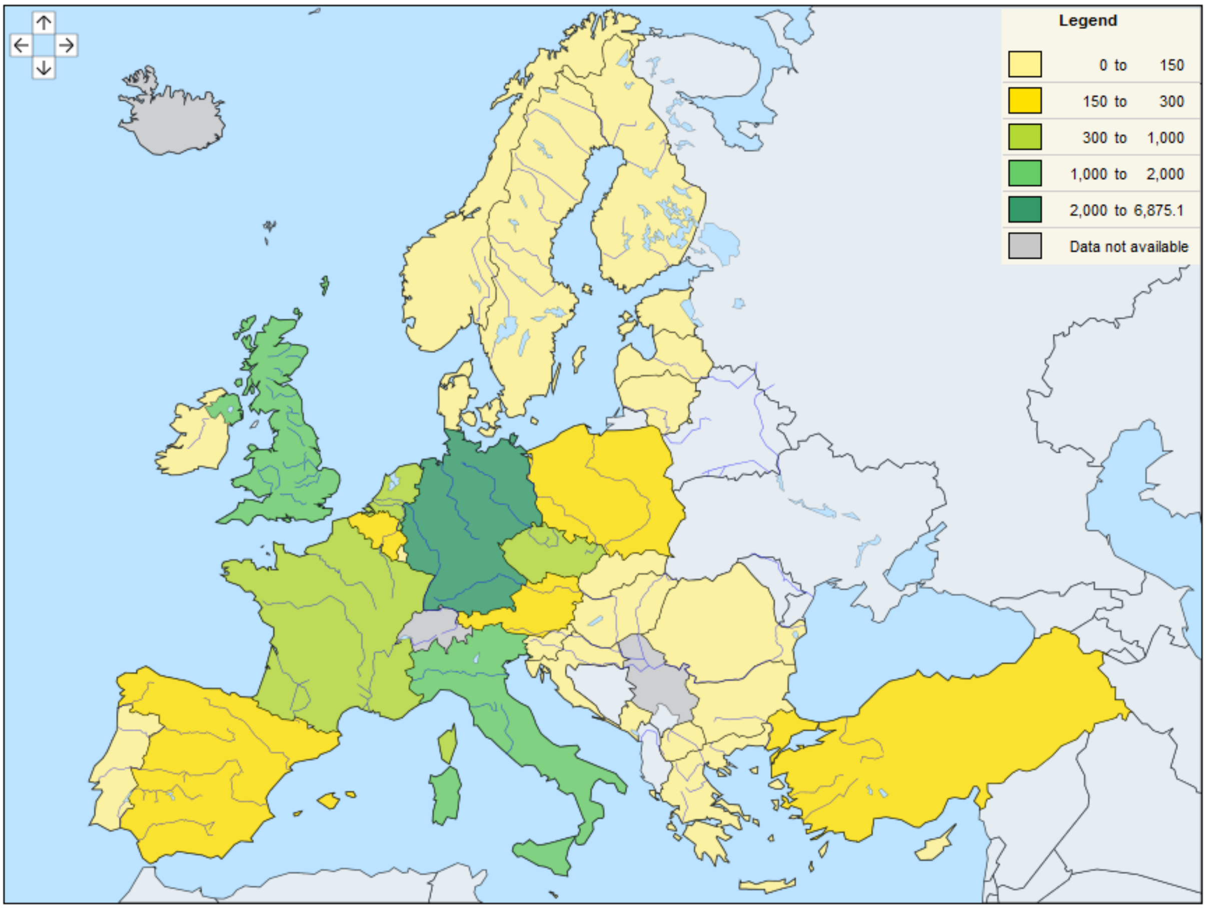

Figure 14: Total production of biogas (2013) in European countries in thousand tonnes oil equivalent.

Source: EUROSTAT®

This map highlights the highest biogas productions in Germany and Italy (data were not available for Switzerland). This observation correlates with the numbers of biogas plants, estimated at 9,035 and 1,391 in Germany and Italy, respectively (European Biogas Association, 2014). However, the high production of biogas in The UK in 2013 must be noted, with a total production of 1.824 million tonnes oil equivalent. Germany produced 6.875 million tonnes oil equivalent of biogas in 2013, and is the predominant biogas producer in Europe.

Anaerobic digestion of animal wastes (manure, slurry and spoiled straw) has been discussed in section **4.2** and is included in the treatment category “Recovery other than Energy Recovery, excluding Backfilling”. The treatments of sewage sludge are further discussed in section **6.2**. Here, we will focus on composting and anaerobic digestion of household wastes, as landfills are the third major sector to be considered in the field of biogas (and digestate) production. **Figure 15** shows the amounts of household wastes treated by composting or anaerobic digestion in Belgium, Germany, France, The Netherlands and The United Kingdom.

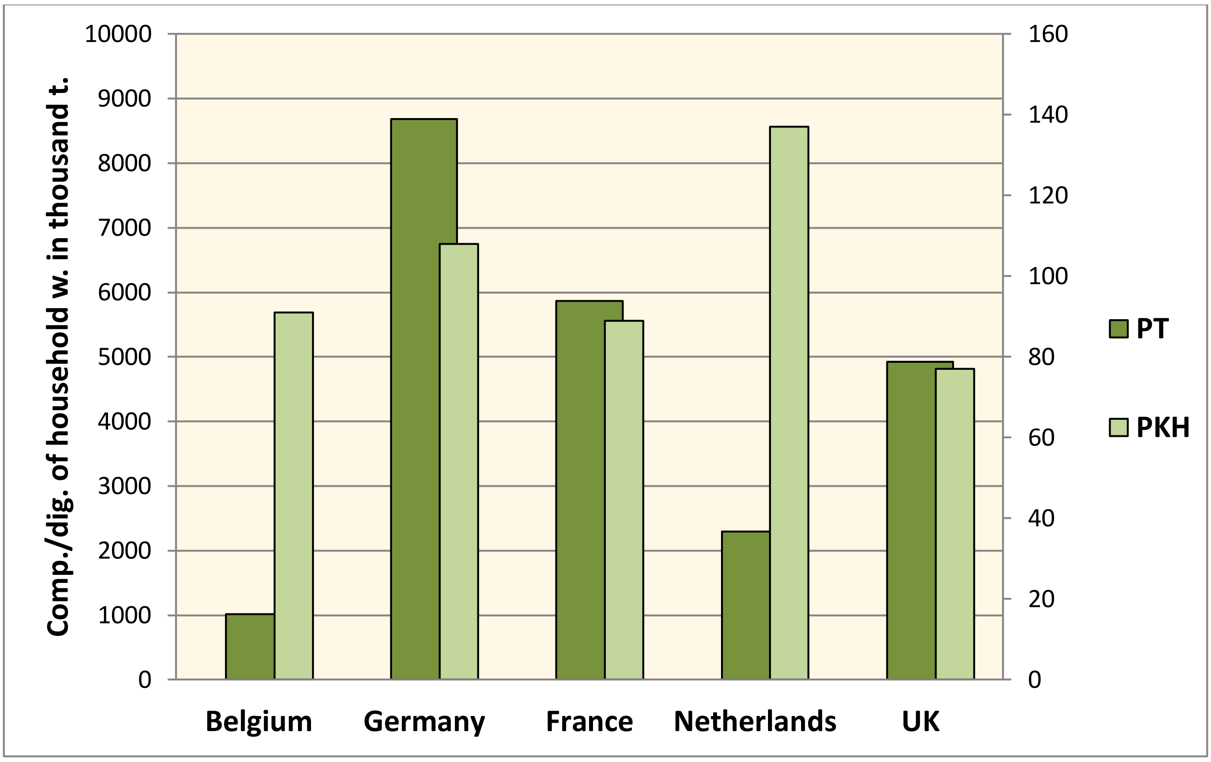

Figure 15: Amounts of household wastes treated by composting and anaerobic digestion in Belgium, Germany, France, The Netherlands and The United Kingdom in 2013 expressed in thousand tonnes (noted PT, in dark green, left scale) and in kg per capita (noted PKH, in clear green, right scale).

Source: EUROSTAT®

Composting and anaerobic digestion are widely used in the five countries. In comparison with the local populations, the Netherlands are the most important users of these processes. Considering the same unit, Germany is the second user of composting and anaerobic digestion behind The Netherlands. However, this country is the biggest user of these techniques in terms of total quantities of household wastes. France, The UK, The Netherlands and Belgium used these processes on about 6, 5, 2 and 1 million tonnes of household wastes in 2013, respectively.

6 Sewage sludge

6.1 Composition

Sewage sludge is a semi-solid residue obtained from wastewater treatment. More specifically, the treatment of municipal wastewater leads to the production of huge amounts of sewage sludge. In recent years, the World quantity produced increased dramatically, and it has been determined that this trend will increase many folds in the years to come. Land application is the most common valorization of sewage sludge because this material contains easily available nutrients. N, P, K and micro-nutrients are particularly beneficial to forestry, vegetal production and landscaping. Applying sewage sludge onto agricultural lands improves physical, chemical and biological properties of soils (Pathak et al., 2009). However, sewage sludge also contains notable concentrations in heavy metals. The repeated application of sewage sludge onto agricultural land can therefore lead to the release and accumulation of heavy metals in soil, due to the decomposition of sludge organic matter. These metallic elements can contaminate soils up to 20 years after the application of sewage sludge. Another topic relates to the contamination of groundwater and surface water by these heavy metals. Leaching to the groundwater can also concern the nutrients themselves if they are not consumed by plants. Finally, toxic organic pollutants and pathogenic bacteria can also cause serious environmental problems (Pathak et al., 2009). The use of treatment techniques is consequently suitable to avoid these problems.

Table 4 shows the composition of some samples of raw activated sludge, thickened sewage sludge and dehydrated sewage sludge. These data are only informative and were obtained from a small number of samples.

Table 4: Composition of different types of sewage sludge (non-exhaustive data).

Source: Bureau d'études environnement et analyses (BEAGx)

	Activated sludge		*Thickened sewage sludge*		*Dehydrated sewage sludge*	
Parameter	**Raw matter**	**Dry matter**	**Raw matter**	**Dry matter**	**Raw matter**	**Dry matter**
DM (%)	0.4-1.05		3.5-8.8		21.5-24.9	
pH	6.7-7.6		5.8-6.4		11.9-12.3	
N_{tot} (%)	0.031-0.073	7.5-7.75	0.21-0.41	4.7-6	0.77-1.01	3.09-4.08
N_{NO3} (%)	0-0.002	0-0.5	0	0	0	0
N_{NH4} (%)	0.003-0.005	0.48-0.75	0.029-0.041	0.33-1.17	0.09-0.024	0.11-0.38
P_2O_5 (%)	0.014-0.024	2.4-3.5	0.11-0.2	2.3-3.1	0.52-0.76	2.42-3.08
K_2O_t (%)	0.005-0.008	0.67-1.25	0.03-0.08	0.86-0.91	0.08-0.15	0.32-0.61
As (mg/kg)	0.0079-0.034	1.98-3.27	0.175-0.67	5-7.63	<1.25	<5
Cd (mg/kg)	0.0034-0.0057	0.54-0.85	0.05-0.24	1.02-2.77	0.19-0.36	0.904-1.44
Cu (mg/kg)	0.58-1.09	104-145	6.01-14	128-160	21.7-23.7	95.2-101
Ni (mg/kg)	0.068-0.231	17-22	0.67-2.7	14.2-30.9	3.2-5.5	14.9-22.1
Pb (mg/kg)	0.128-0.273	26-32	1.59-7.3	34-83	10.5-38	42.3-177
Zn (mg/kg)	3.44-6.09	580-860	27.9-86.4	798-982	101-178	407-721
Hg (mg/kg)	0.00084-0.0019	0.18-0.21	0,019	0.22-0.54	0.125-0.27	0.5-1.24
Cr (mg/kg)	0.072-0.41	18-39	0.79-4.6	16.9-52.2	4.62-6.52	21.5-26.2
C (%)	0.16-0.35	33.3-38.9	0.16-0.35	33.3-38.9	4.7-7.3	19-34
C/N ratio	6.2-7.1		6.2-7.1		6.2-7.1	

6.2 Production

Urban wastewater is an important resource which must be taken into account in respect of opportunities for nutrient recovery. The majority of people in Belgium, Germany, France, The Netherlands and The UK are connected to a wastewater treatment system. **Figure 16** shows the population concerned in wastewater treatment in the five countries.

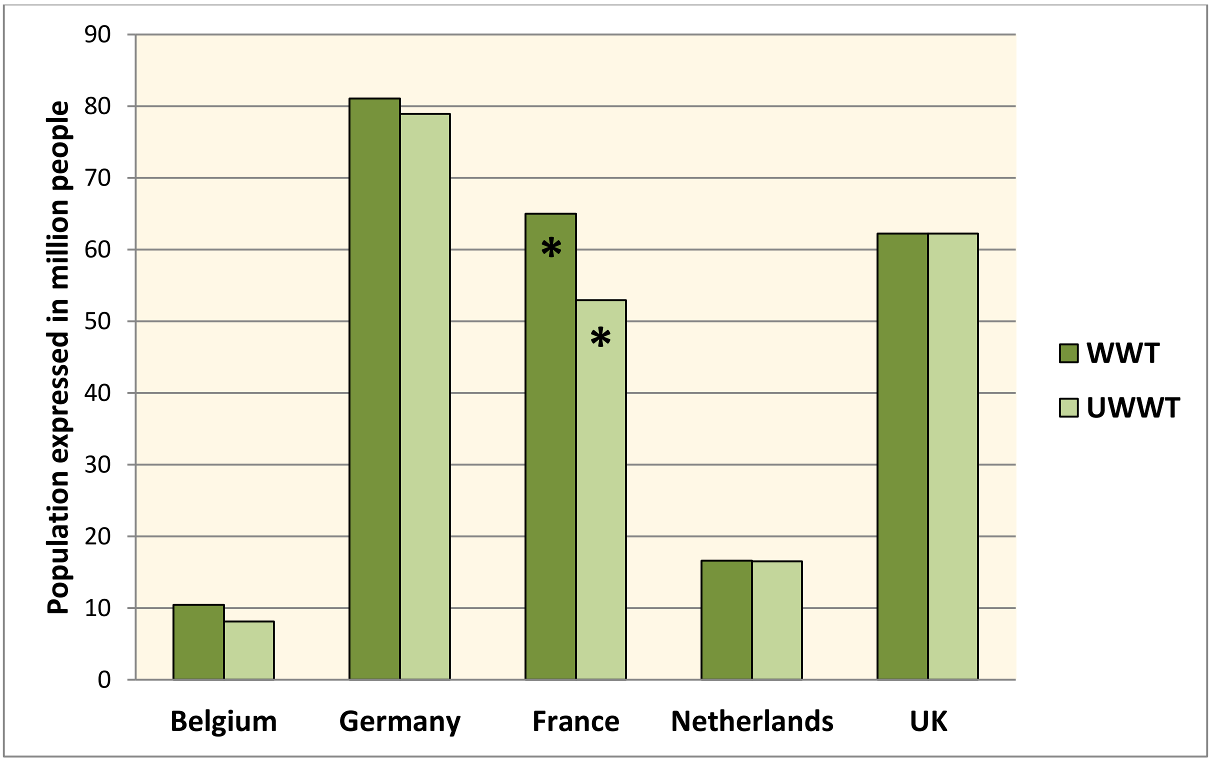

Figure 16: Population concerned in wastewater treatment in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in million people. WWT = People connected to any type of Wastewater Treatment; UWWT = People connected to Urban Wastewater Treatment Plants. * The French data relate to 2011.

Source: data collected from EUROSTAT®

In each country, almost the total populations are connected to a system of wastewater treatment. In most cases, people are connected to urban wastewater treatments plants (WWTPs). About 78, 97, 82, 99 and 100 % of people were connected to WWTPs in 2010 (2011 in France) in Belgium, Germany, France, The Netherlands and The UK, respectively.

Figure 17 shows the production of sewage sludge in the five countries.

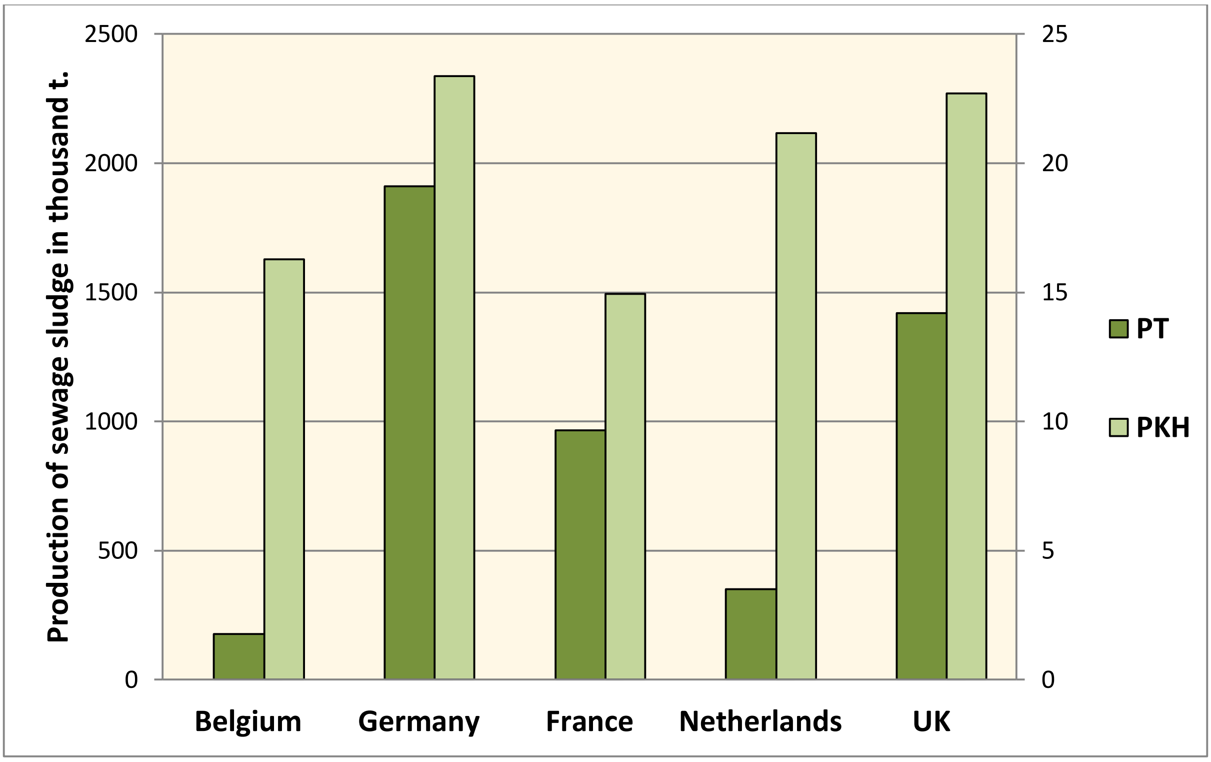

Figure 17: Total production of sewage sludge (dry matter) in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in thousand tonnes (noted PT, in dark green, left scale) and in kg per capita (noted PKH, in clear green, right scale).

Source: data collected from EUROSTAT®

The production of sewage sludge expressed in kg per capita depends on the country considered. Belgium and France showed the lowest productions with a value close to 15 kg per capita in 2010. Considering the same unit, Germany, The Netherlands and The UK produced more sewage sludge with respective values of 23, 21 and 23 kg per capita. In terms of total production, the connection of most people to WWTPs explains the correlation between the respective populations of each country with their production of sewage sludge. In this context, Belgium, Germany, France, The Netherlands and The UK produced 0.176, 1.911, 0.966, 0.351 and 1.419 million tonnes of sewage sludge in 2011.

Another important parameter to be considered is the treatment of sewage sludge in each country. **Figure 18** shows the different treatments applied to sewage sludge in the five countries.

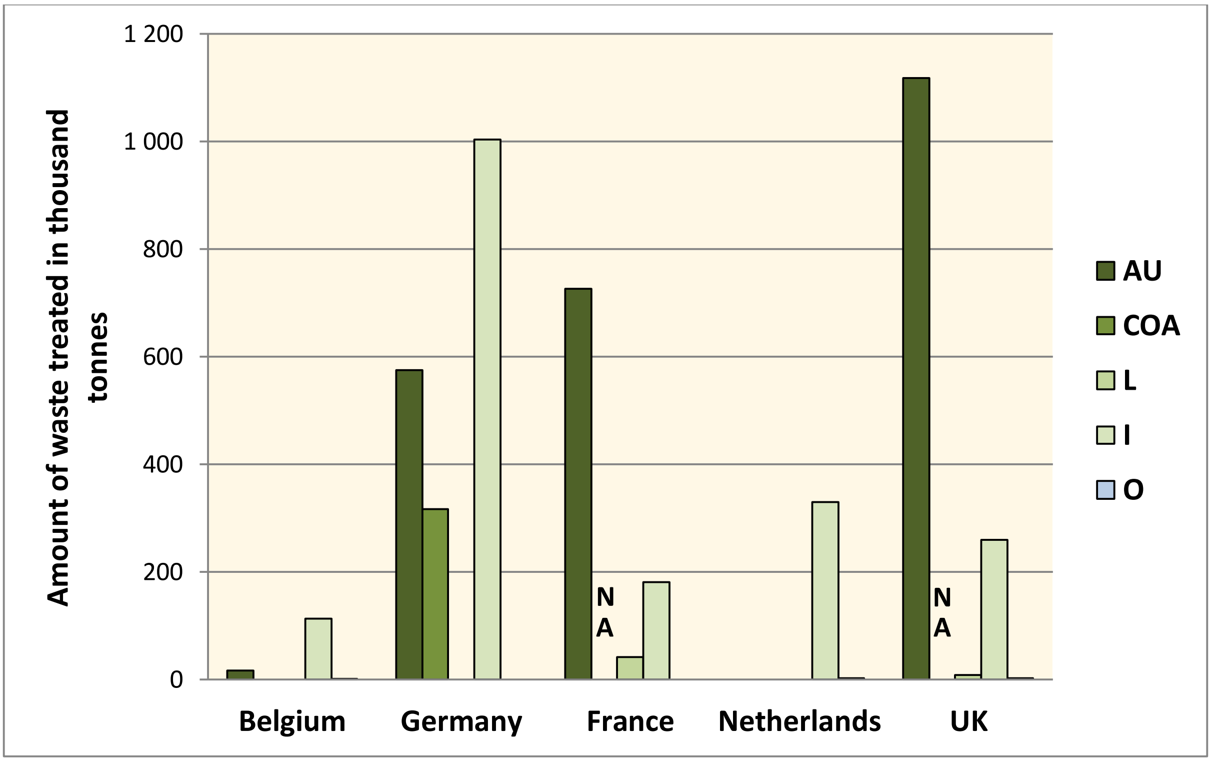

Figure 18: Treatment applied to sewage sludge in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in thousand tonnes. AU = Agricultural Use; COA = Compost and Other Applications; L = Landfilling; I = Incineration and O = Other techniques. NA = not available (data of COA relating to France and The UK).

Source: data collected from EUROSTAT®

The category "COA" relates to all application of sewage sludge after mixing with other organic material and compost production in parks, horticulture, etc. Each country shows a specific profile of sewage sludge treatment. Belgium and Germany mostly use incineration to eliminate this waste, while France and The UK mainly valorize sewage sludge through agriculture. Incineration is quite common among the different countries, with respective quantities of 0.113, 1.004, 0.181, 0.33 and 0.26 million tonnes of sewage sludge burnt in Belgium, Germany, France, The Netherlands and The UK in 2010, respectively. This incineration process generates ashes. Landfilling was used in France and The UK with respective amounts of 42 and 9 thousand tonnes, but the other countries used other alternatives. Germany also valorized sewage sludge through agriculture (575 thousand tonnes) but also compost production (317 thousand tonnes). Belgium only valorized 13 % of its total production of sewage sludge in agriculture. This low percentage is due to the legal constraints.

Figure 19 shows the production of common sludges in the European countries in 2012. This category includes wastewater treatment sludges coming from municipal sewerage water and organic sludges from food preparation and processing. They mainly originate from households and industrial branches with organic wastewater (mainly pulp and paper as well as food preparation and processing). They can also occur in wastewater treatment plants or in the anaerobic treatment of waste. All common sludges are considered as non-hazardous. However, it must be kept in mind that comparability can be problematic between countries using different statistical units as they do not assign the waste to the same economic sector (Eurostat, 2010).

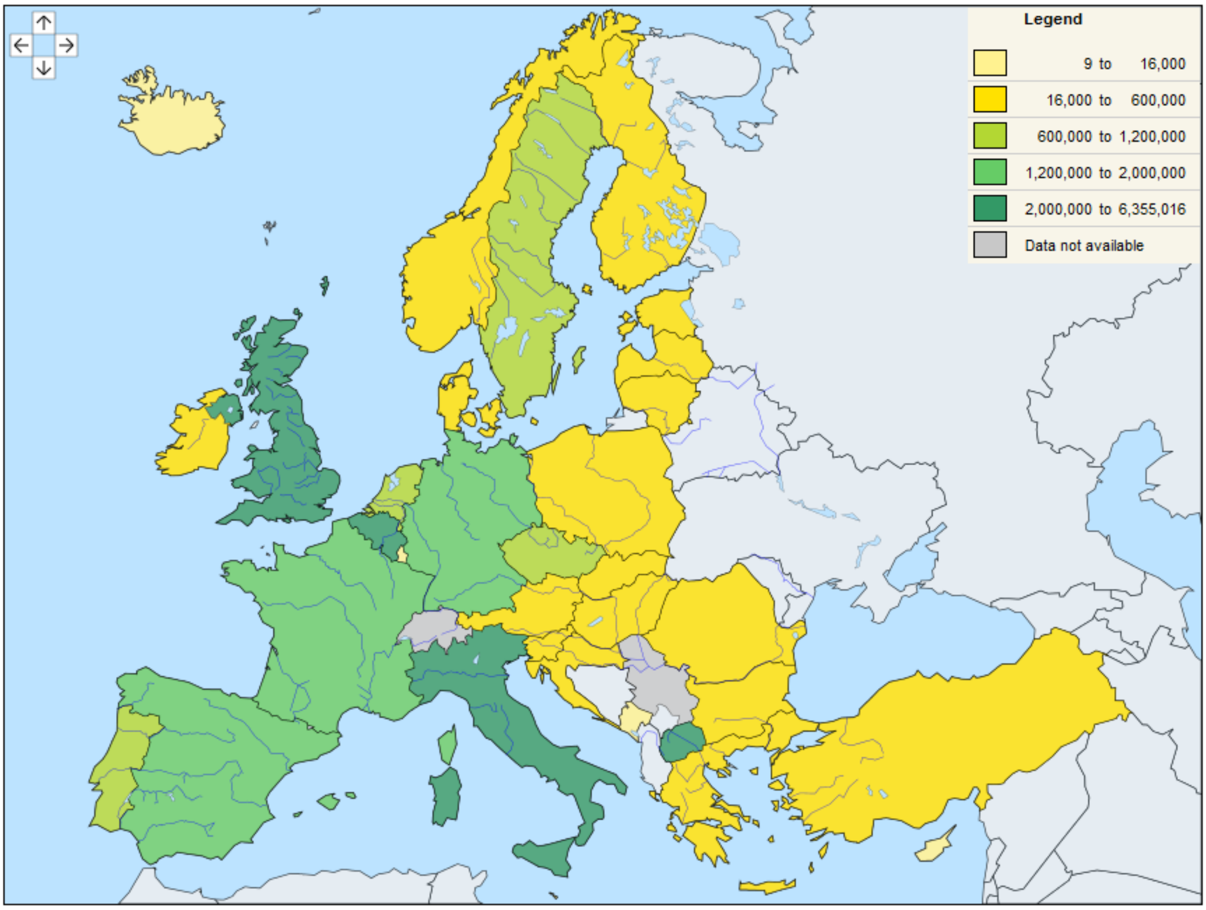

Figure 19: Total production of common sludges (2012) in European countries in tonnes.

Source: EUROSTAT®

7 Ashes

7.1 Composition

Waste incineration is commonly used inside the countries of EU-28, with or without energy recovery. This process consists in an oxidation of organic materials contained in wastes, leading to a considerable reduction of volume. Different types of incineration are defined:

- Mixed municipal waste incineration,
- Pretreated municipal or other pretreated waste incineration,

- Hazardous waste incineration,
- Sewage sludge incineration,
- Clinical waste incineration (European Commission, 2006).

Incineration leads to the loss of nitrogen. However, phosphorus and potassium are concentrated in the combustion wastes. Ashes also contain important concentrations in heavy metals. Here, we will only consider two types of ashes presenting interesting opportunities: wood ashes and poultry manure ashes. Sewage sludge was already considered in **section 6**, and incineration leads to the increase of dry matter, phosphorus and potassium concentrations.

Table 5 shows the composition of ashes obtained by incineration of different types of wastes: forestry chips, untreated wood, barks, wastes coming from wood industry and poultry manure. These data are only informative and were obtained from a small number of samples.

Table 5: Composition of different types of ashes (non-exhaustive data). * These data were obtained from one sample only.

Source: Bureau d'études environnement et analyses (BEAGx)

Parameter	Forestry chips	Untreated wood	Barks	Wastes from wood industry	Poultry manure
pH	12.5-12.8	10.5-12.3	11.9	11.9-12.3	13 *
N_{tot} (%)	0.07-0.12	0.09-0.38	0.03	0.08-0.13	0
P_2O_5 (%)	3.39-4.98	1.21-4.54	0.91-2.15	0.6-3.7	11.3-12.5
K_2O_t (%)	3.9-6.72	3.3-4	3.94-5.31	1.91-6.07	11.8-14.1
MgO (%)	4.17-4.2	2.89-5.6	3.96	1.25-5.66	4.5-5.6
CaO (%)	34.38-45.9	18.6-25.5	39.02	20.16-48.23	20.8-27
As (mg/kg)	2.99-6.8	44-61.5	6.6	3.16-5.2	<3 *
Cd (mg/kg)	1.3-2.7	7.5-9	2-3.8	0.2-2.06	0.8 *
Cu (mg/kg)	96.3-2796	124-994	138-175	64.6-101	350 *
Ni (mg/kg)	24-83.4	84.3-123	37.5-56.6	21.6-27.4	17 *
Pb (mg/kg)	15.95-78.6	316-680	126-152	28.7-94.6	10 *
Zn (mg/kg)	152-330	559-2332	421-745	116-168	1550 *
Hg (mg/kg)	0-0.1	0.3-0.36	0.13	0.02-0.2	<0.05 *
Cr (mg/kg)	21-1956	243-569	53.5-91.8	45.8-57.3	13 *
Mo (mg/kg)	1.1-1.4	8.4-9.2	2.8-4	0.87-1	-
C (%)	8-8.54	5.6-6.75	1.6	2.06-6.3	0
C/N ratio	67-110	42-62.6	53	26-48.8	-

7.2 Production

Incineration is a process widely used inside the European countries to eliminate various types of wastes and reduce their volume. As a consequence, these countries generate considerable amounts of combustion wastes. Incineration can be considered as a thermal pre-treatment which produces secondary wastes, subsequently recovered or landfilled (Eurostat, 2010). **Figure 20** shows the production of combustion wastes in 2010 and 2012 in Belgium, Germany, France, The Netherlands and The UK. In this figure, combustion wastes are considered as wastes from flue gas cleaning (desulphurization sludges, filter dust and cakes, fly ashes), slags, drosses, skimmings, boiler dusts and ashes from thermal processes. They originate from any thermal and combustion process (power stations and other combustion plants, thermal metallurgy, casting of ferrous and non-ferrous pieces, manufacture of glass and glass products, manufacture of ceramic goods, bricks, tiles and construction products, manufacture of cement, lime and plaster). Combustion wastes are hazardous when containing organic pollutants, oil and heavy metals (Eurostat, 2010). In **Figure 20**, only the non-hazardous combustion wastes are considered.

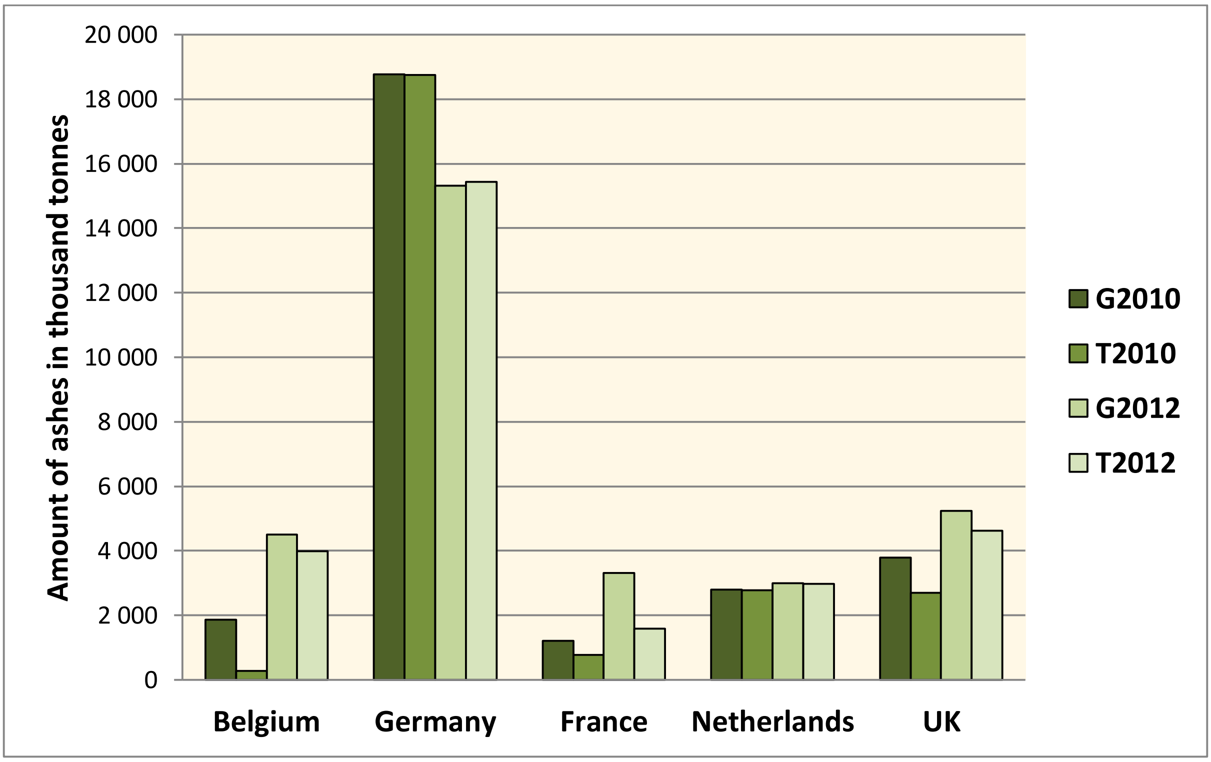

Figure 20: Production and treatment of non-hazardous combustion wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 and 2012 expressed in thousand tonnes. G2010 = Amount generated in 2012; T2010 = Amount treated in 2010; G2012 = Amount generated in 2012 and T2012 = Amount treated in 2012.

Source: data collected from EUROSTAT®

Germany is the most important producer of combustion wastes (more than 18,000 and 15,000 tonnes in 2010 and 2012, respectively). All these wastes were treated. The Netherlands produced approximately the same amount of combustion wastes in 2010 and 2012, and also treated the major part of these wastes. Belgium showed an impressive increase of waste production from 2010 to 2012 (about 143 %), but the treatment rate also evolved from 15 % in 2010 to 89 % in 2012. France was the smallest combustion wastes' producer in 2010 (about 1.205 million tonnes), but this production considerably increased in 2012 (about 3.320 million tonnes). Finally, The UK also showed an increase of production between 2010 and 2012 (38 %). These figures show the importance of quantities of combustion wastes in Belgium, Germany, France, The Netherlands and The UK.

Figure 21 shows the different treatments which are applied to combustion wastes in the five countries.

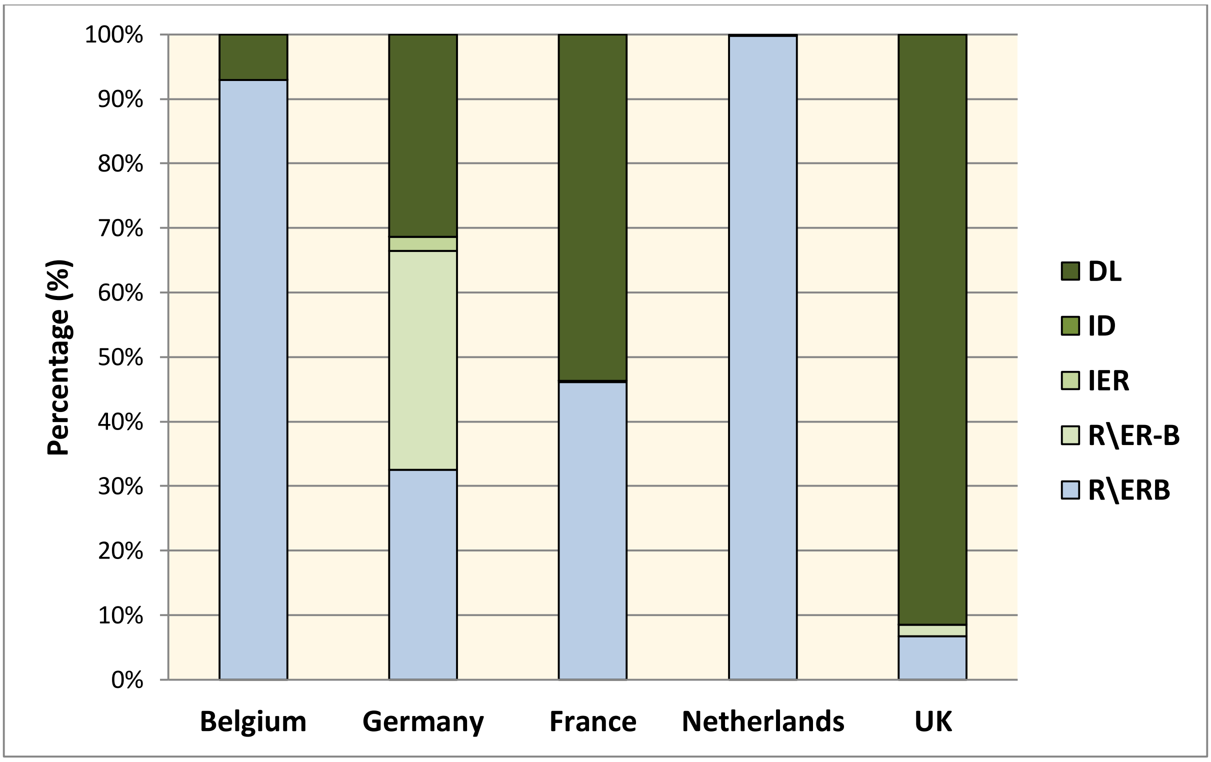

Figure 21: Treatment applied to non-hazardous combustion wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in percentage. DL = Deposit onto or into Land; ID = Incineration/Disposal; IER = Incineration/Energy Recovery; R\ER-B = Backfilling; R\ERB = Recovery other than Energy Recovery, excluding Backfilling.

Source: data collected from EUROSTAT®

Backfilling is an important way of elimination of combustion wastes in Germany (about 34 % for this type of waste).

This country also uses simple disposal onto or into land, and recovery techniques other than energy recovery to eliminate combustion wastes. This latter way of elimination is widely used in Belgium and The Netherlands to valorize these materials (93 and almost 100 %, respectively). In France, the simple disposal in or on land is the main application of combustion wastes (about 54 %), and 46 % are valorized through various recovery techniques, except energy recovery. Disposal in or on land is also widely used in The UK (about 91 % of combustion wastes).

Combustion wastes are mainly obtained from incineration processes. In this context, some specific wastes are particularly interesting in the field of nutrient recovery. Wood wastes, for example, offer many opportunities. **Figure 22** shows the production of wood wastes in the five countries in 2010 and 2012.

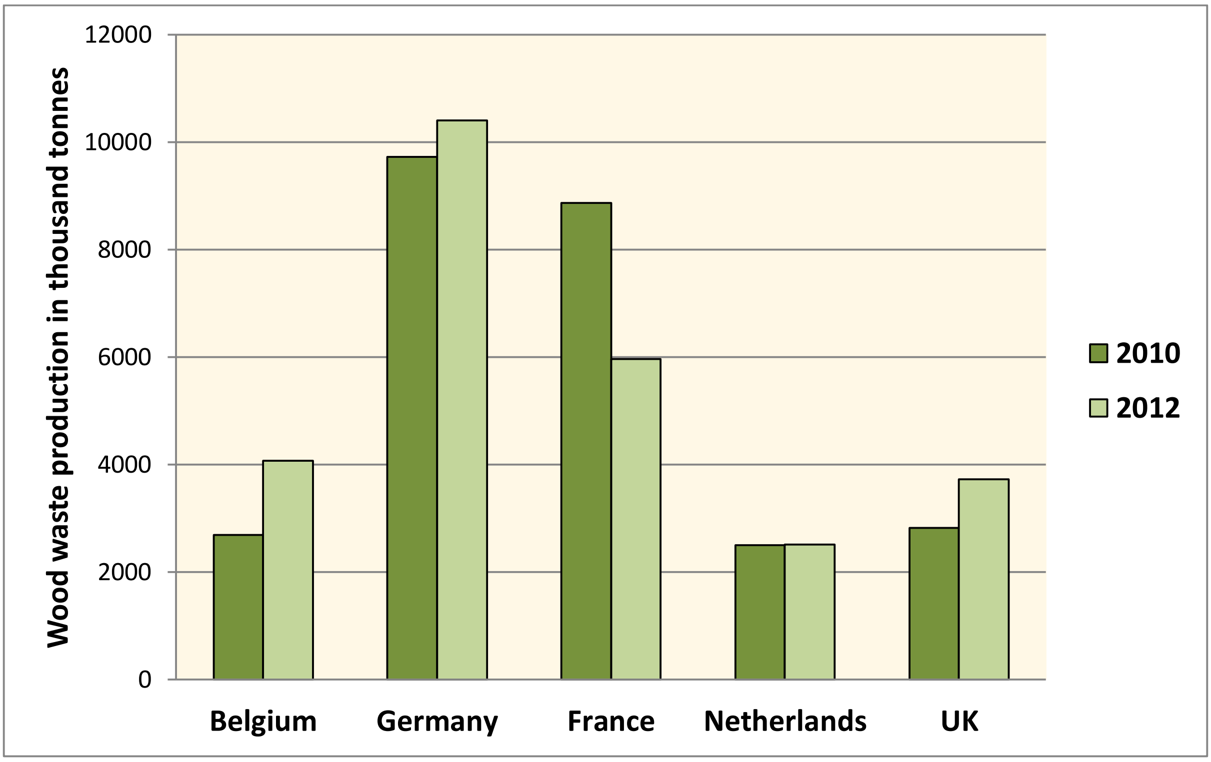

Figure 22: Production of non-hazardous wood wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 and 2012 expressed in thousand tonnes.

Source: data collected from EUROSTAT®

Here, wood wastes consist of wooden packaging, sawdust, shavings, cuttings, waste bark, cork, and wood from the production of pulp and paper, wood from the construction and demolition of buildings, and separately collected wood waste. They mostly originate from wood processing, the pulp and paper industry, and the demolition of buildings but can occur in all sectors in lower quantities due to wooden packaging.

Non-hazardous wood wastes are not supposed to contain hazardous substances, such as mercury or tar-based wood preservatives (Eurostat, 2010). It must be kept in mind that Belgium, Germany, France, The Netherlands and The UK produce relatively low amounts of hazardous wood wastes (respective productions of 0.125, 1.308, 0.088, 0.061 and 0.015 million tonnes in 2012). The most important producers of non-hazardous wood wastes are France and Germany. The French production decreased of 49 % between 2010 and 2012. The Netherlands generated close amounts of wood wastes in 2010 and 2012 (about 2.5 million tonnes). The production of wood wastes significantly increased between 2010 and 2012 in Belgium (51 %) and The UK (32 %). An important parameter to be highlighted is the relatively low production of wood wastes in The UK, in comparison with the population.

Figure 23 shows the different treatments applied to wood wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010.

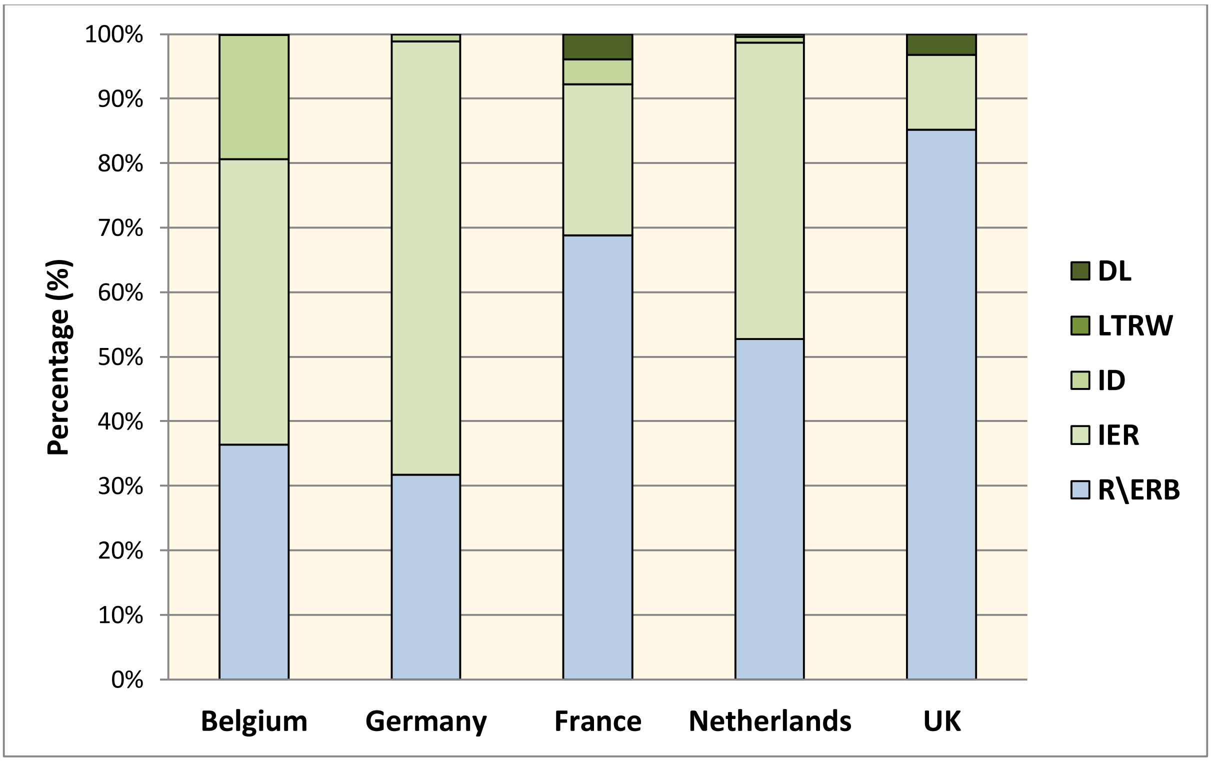

Figure 23: Treatment applied to non-hazardous wood wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in percentage. DL = Deposit onto or into Land; LTRW = Land Treatment and Release into Water bodies; ID = Incineration/Disposal; IER = Incineration/Energy Recovery; R\ERB = Recovery other than Energy Recovery, excluding Backfilling.

Source: data collected from EUROSTAT®

Recovery techniques other than energy recovery are used by the five countries to valorize wood wastes. Incineration, with or without energy recovery, is also common in Belgium, Germany, France, The Netherlands and The UK with respective percentages of 64, 68, 27, 47 and 12 %. These processes generate considerable amounts of wood ashes. The other treatments are quite minority.

Household wastes and sewage sludge also generate ashes through the incineration process. These data are presented in **sections 8.2** and **6.2**, respectively.

8 Municipal wastes

8.1 Composition

The composition of household wastes is much more difficult to characterize because this category includes many types of materials. The main categories are:

- Glass wastes,
- Paper wastes,
- Plastics,
- Metals,
- Organic materials,
- Other materials (Beigl et al., 2008).

In the context of nutrient recycling, organic materials are the most promising resources. The composition of this global category is hard to assess, and each of its constitutive wastes shows a specific concentration in N, P and K. Consequently, establishing tables of concentrations is not applicable here. The complexity of household wastes caused a real interest in establishing models to characterize the production of municipal solid wastes. In this context, Beigl et al. (2008) explained 45 different types of modelling of household wastes' production based on economic, socio-demographic or management-orientated data.

8.2 Production

Municipal wastes consist to a large extent of waste generated by households, but may also include similar wastes generated by small businesses and public institutions and collected by the municipality; this latter part of municipal waste may vary from municipality to municipality and from country to country, depending on the local waste management system (Eurostat, 2015). The mean production of municipal wastes in EU-28 was 481 kg per capita in 2013. This figure progressively decreased with productions of 503, 497 and 488 kg per capita in 2010, 2011 and 2012, respectively. **Figure 24** shows the total production of municipal wastes in the five countries. In Belgium, Germany, France, The Netherlands and The UK, the production was comprised between 439 (in Belgium) and 617 kg per capita (in Germany) in 2013.

The global production, expressed in thousand tonnes, depended on the country considered. Belgium produced the smallest amount of municipal wastes (4.905 million tonnes in 2013), while Germany produced the most important quantity among the five countries (49.78 million tonnes in 2013). The production of municipal wastes inevitably depends on the population.

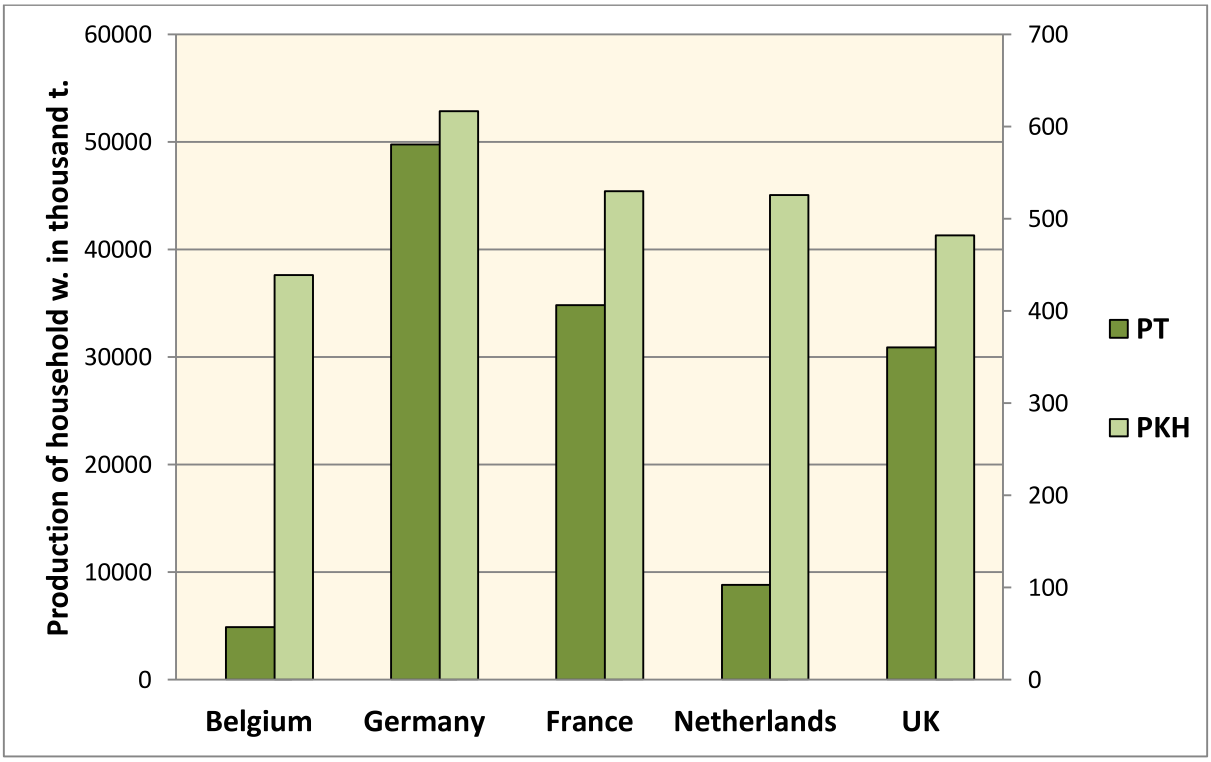

Figure 24: Total production of municipal wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2013 expressed in thousand tonnes (noted PT, in dark green, left scale) and in kg per capita (noted PKH, in clear green, right scale).

Source: data collected from EUROSTAT®

The treatment of municipal wastes also depends on the country considered. **Figure 25** shows the different treatments applied to municipal wastes in Belgium, Germany, France, The Netherlands and The UK.

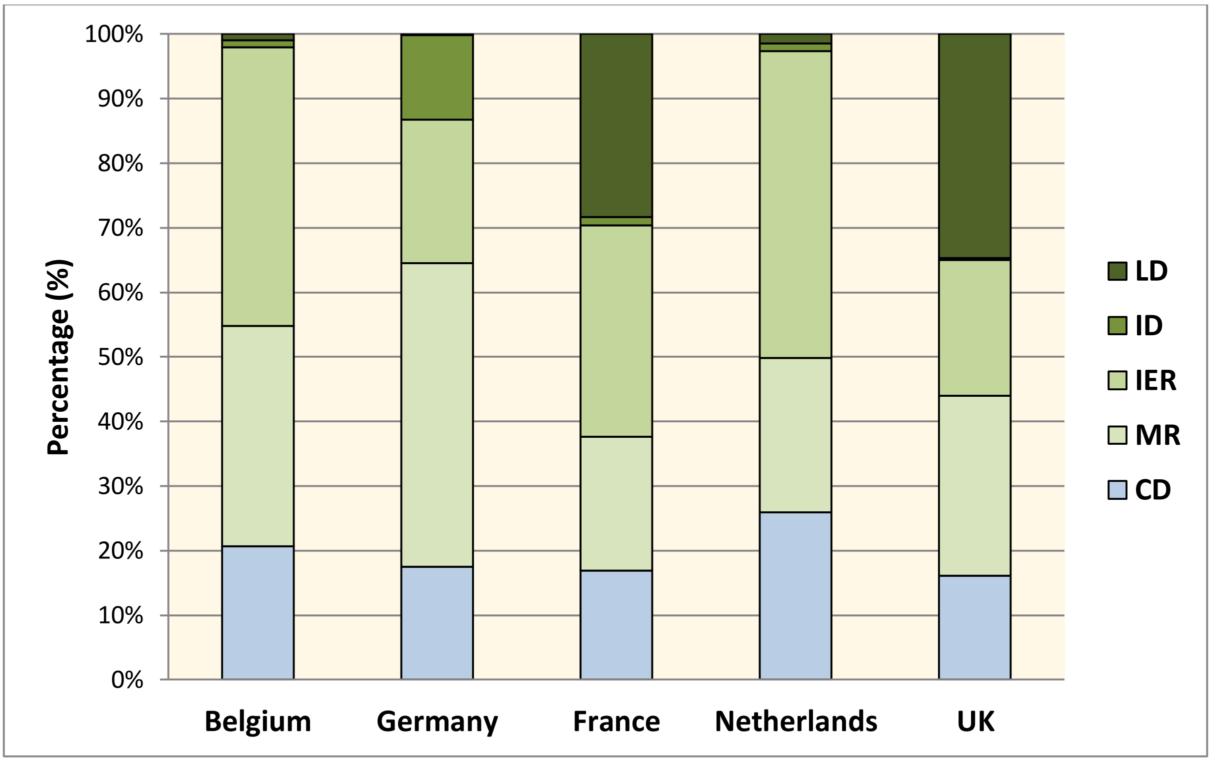

Figure 25: Treatment applied to municipal wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2013 expressed in percentage. LD = Landfill/Disposal; ID = Incineration/Disposal; IER = Incineration/Energy Recovery; MR = Material Recycling; CD = Composting/Digestion.

Source: data collected from EUROSTAT®

In 2013, three treatment processes were quite common among the five countries: incineration coupled with energy recovery, material recycling and composting/digestion. It must be kept in mind that incineration (with and without energy recovery) and anaerobic digestion generate other wastes in smaller quantities. These three techniques accounted for 98 %, 87 %, 70 %, 97 % and 65 % of the treatment applied to municipal wastes in Belgium, Germany, The Netherlands and The UK, respectively. Incineration and/or disposal were quite common in Germany, still concerning about 13 % of total waste treatment. France and The UK also showed a quite developed elimination of municipal wastes through landfilling, with respective percentages of 28 % and 35 % in 2013.

Figure 26 shows the evolution of recycling rates of municipal wastes in the five countries.

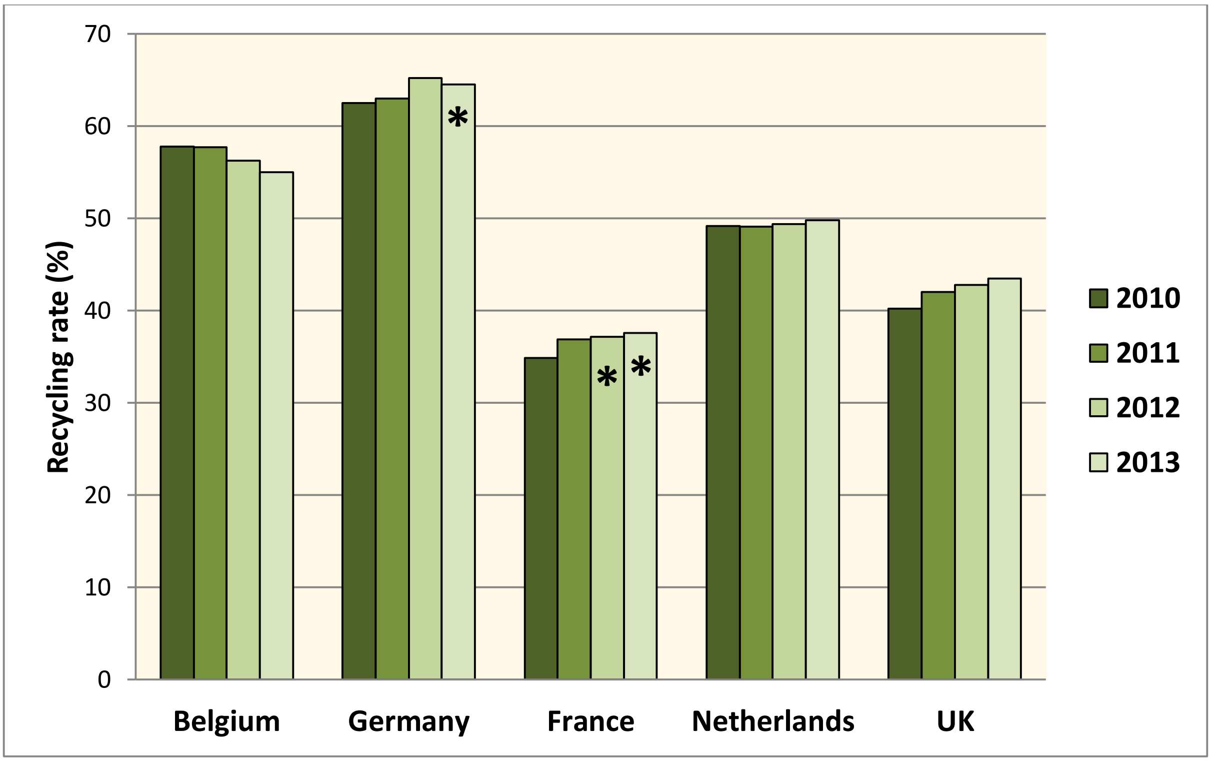

Figure 26: Recycling rate of municipal wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010, 2011, 2012 and 2013 expressed in percentage. * relates to data that were estimated.

Source: data collected from EUROSTAT®

The recycling rate is the tonnage recycled from municipal waste divided by the total municipal waste arising. Recycling includes material recycling, composting and anaerobic digestion. For areas not covered by a municipal waste collection scheme, the amount of waste generated is estimated (Eurostat, 2015). The highest recycling rate was reached by Germany in 2012, with 65.2 % of municipal wastes recycled. The recycling processes are also well developed in Belgium, with a maximal rate of 57.8 % in 2010. The Netherlands, The UK and France come 3rd, 4th and 5th in this field with respective maximal recycling rates of 49.8, 43.5 and 37.6 % in 2013.

Figure 27 shows the production of municipal wastes in the European countries.

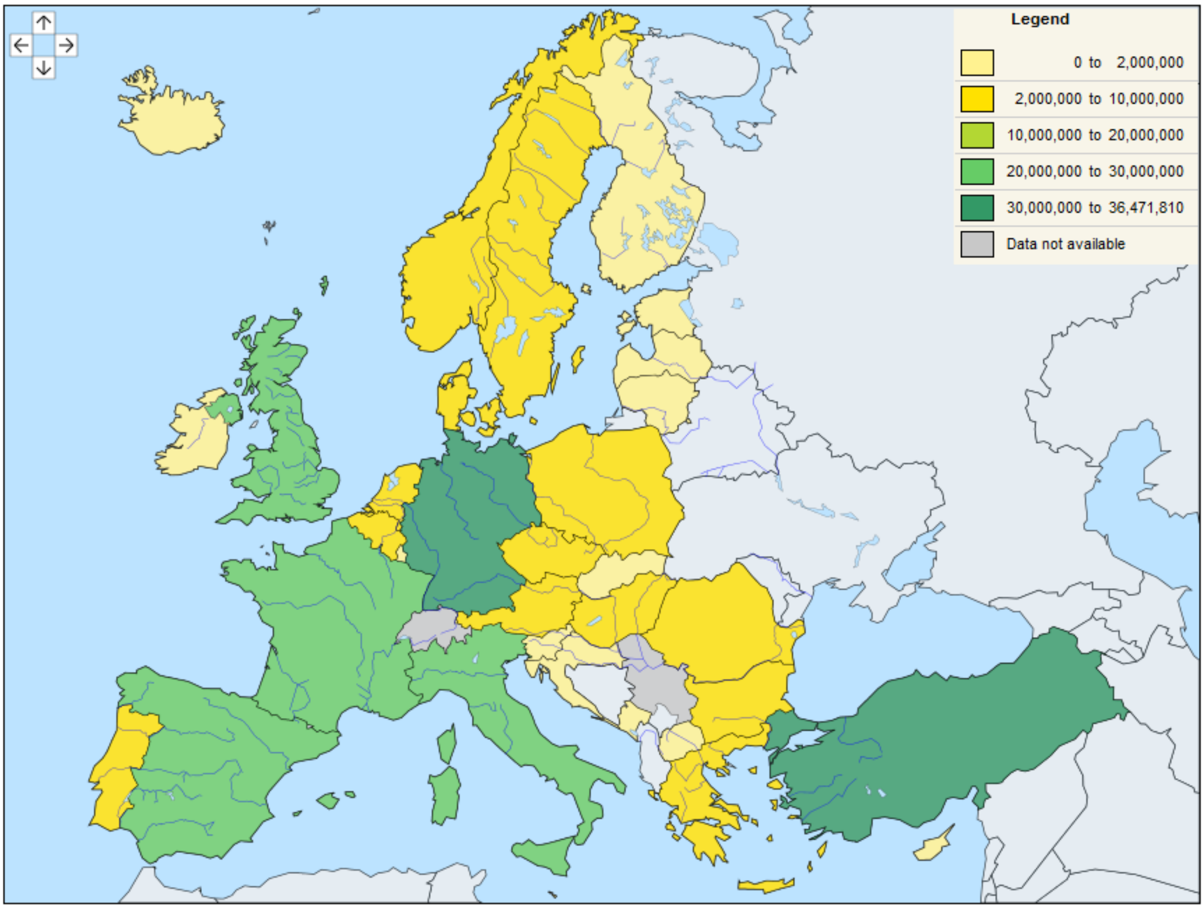

Figure 27: Total production of municipal wastes (2012) in European countries in tonnes.

Source: EUROSTAT®

Germany and Turkey were the main producers of municipal wastes in 2012, with respective amounts of about 50 and 31 million tonnes. These two countries accounted for 33 % of the total production of municipal wastes in EU-28. France, The UK, Italy and Spain generated about 14, 12, 12 and 9 % of the total production of EU-28. Belgium and The Netherlands can be considered as small producers due to their respective low populations, with productions accounting for 2 and 4 % of the total quantity of municipal wastes in EU-28 in 2012, respectively.

9 Industrial wastes

9.1 Composition

Industrial wastes are really diversified and their composition depends on the industry and the activity considered. Unfortunately, no data are available at this level.

9.2 Production

Figures 28 and **29** show the total production of non-hazardous wastes in Belgium, Germany, France, The Netherlands and The UK in 2012. These figures consider all economic activities (industries and other sectors) inside the European countries (excluding municipal wastes):

- Agriculture, forestry and fishing,
- Mining and quarrying,
- Manufacture of food products, beverages and tobacco products,
- Manufacture of textiles, wearing apparel, leather and related products,
- Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials,
- Manufacture of paper and paper products; printing and reproduction of recorded media,
- Manufacture of coke and refined petroleum products,
- Manufacture of chemical, pharmaceutical, rubber and plastic products,
- Manufacture of other non-metallic mineral products,
- Manufacture of basic metals and fabricated metal products, except machinery and equipment,
- Manufacture of computer, electronic and optical products, electrical equipment, motor vehicles and other transport equipment,
- Manufacture of furniture; jewelry, musical instruments, toys; repair and installation of machinery and equipment,
- Electricity, gas, steam and air conditioning supply,
- Water collection, treatment and supply; sewerage; remediation activities and other waste management services,
- Waste collection, treatment and disposal activities; materials recovery,
- Construction,
- Services including wholesale of waste and scrap.

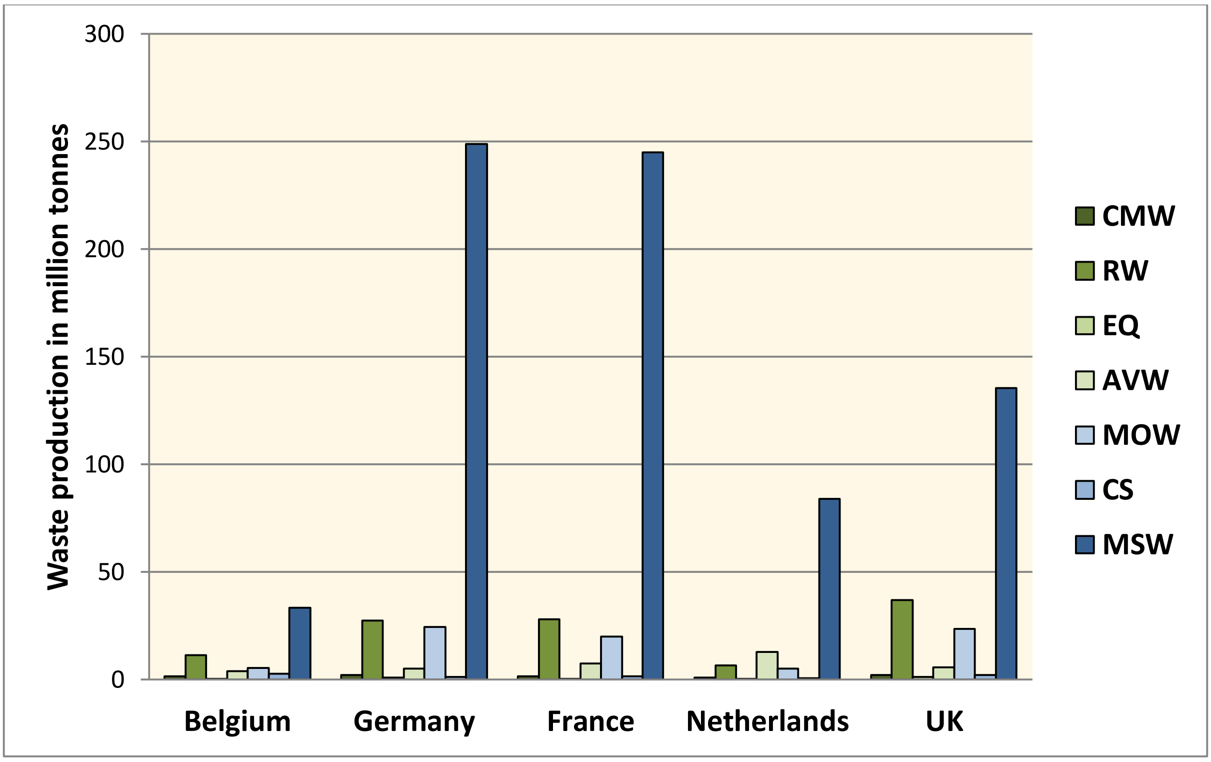

Figure 28: Waste production stemming from economic activities in Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 according to the type of waste expressed in million tonnes. The following wastes are considered: Chemical and Medical Wastes (CMW), Recyclable Wastes (RW), Equipment (EQ), Animal and Vegetal wastes (AVW), Mixed Ordinary Wastes (MOW), Common Sludges (CS) and Mineral and Solidified Wastes (MSW).

Source: data collected from EUROSTAT®

The categories AVW, MOW and CS were already explained in **section 3**. Here, these categories relate to the economic activities only and exclude the wastes generated by households. Chemical and medical wastes (CMW) include solid or liquid spent chemical catalysts; off-specification products and wastes like agro-chemicals, medicines, paint, dyestuff, pigments, varnish, inks and adhesives, including related sludges; chemical preparation waste like preservatives, brake and antifreeze fluids, waste chemicals; tars and carbonaceous waste like acid tars, bitumen, carbon anodes, tar and carbon waste; fuels, emulsions, sludges containing oil, like bilge oil, waste fuels oil, diesel, petrol, waste from oil water separator; aqueous rinsing and washing liquids, aqueous mother liquors; spent filtration and adsorbent material like activated carbon, filter cakes, ion exchangers and also medical wastes. Chemical wastes mainly originate from the chemical industry and from various industrial branches producing and using chemical products (Eurostat, 2010). They are hazardous when containing toxic chemical compounds, oil, heavy metals or other dangerous substances, but the figures presented above only concern non-hazardous wastes. Recyclable wastes (RW) include various types of materials: ferrous and non-ferrous metallic wastes, glass and paper wastes, rubber wastes, plastics, wood and textile wastes. Equipment (EQ) mainly includes electrical and electronic wastes, which do not offer opportunities in the field of nutrient recovery. Finally, mineral and solidified wastes (MSW) mainly originate from extraction and construction industries. These wastes do not contain interesting concentrations in nutrients.

Figure 29 shows the distribution of wastes generated by economic activities in each country, in comparison with the mean European trend (EU-28).

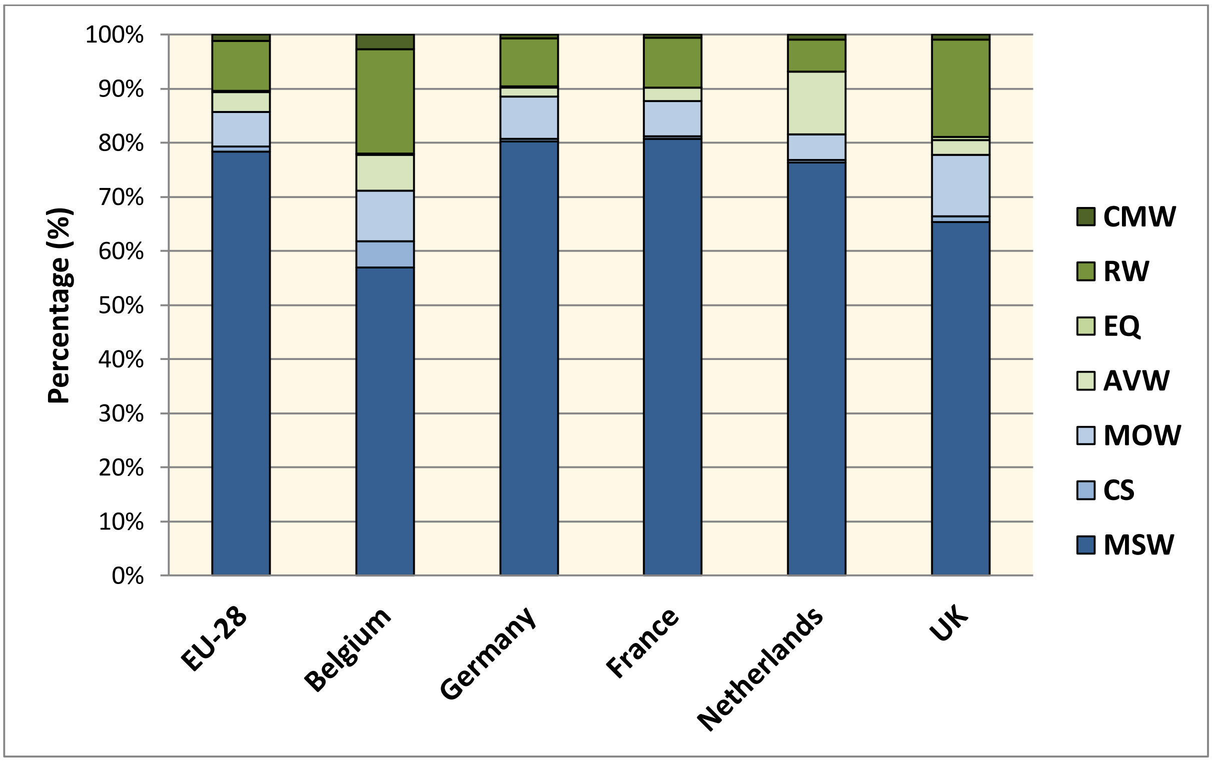

Figure 29: Distribution of waste production stemming from economic activities in Belgium, Germany, France, The Netherlands and The United Kingdom in 2012 according to the type of waste expressed in percentage. The following wastes are considered: Chemical and Medical Wastes (CMW), Recyclable Wastes (RW), Equipment (EQ), Animal and Vegetal wastes (AVW), Mixed Ordinary Wastes (MOW), Common Sludges (CS) and Mineral and Solidified Wastes (MSW).

Source: data collected from EUROSTAT®

The most promising categories are AVW, MOW and CS, coming from all types of economic activities and containing the most important concentrations in nutrients, on the basis of their sources. Animal and vegetal wastes were already investigated in **section 4**. Mixed ordinary wastes presented in this section are composed of non-hazardous materials similar to household wastes but are mainly generated by economic activities. These materials consequently include important amounts of organic materials and can be considered as nutrient sources. **Figure 30** shows the total production of mixed ordinary wastes generated by economic activities. The figures presented in **Figure 30** relate to the category of mixed and undifferentiated materials. They include mixed packaging and organic wastes coming from food industries, textile industries, combustion plants, etc. (Eurostat, 2010)

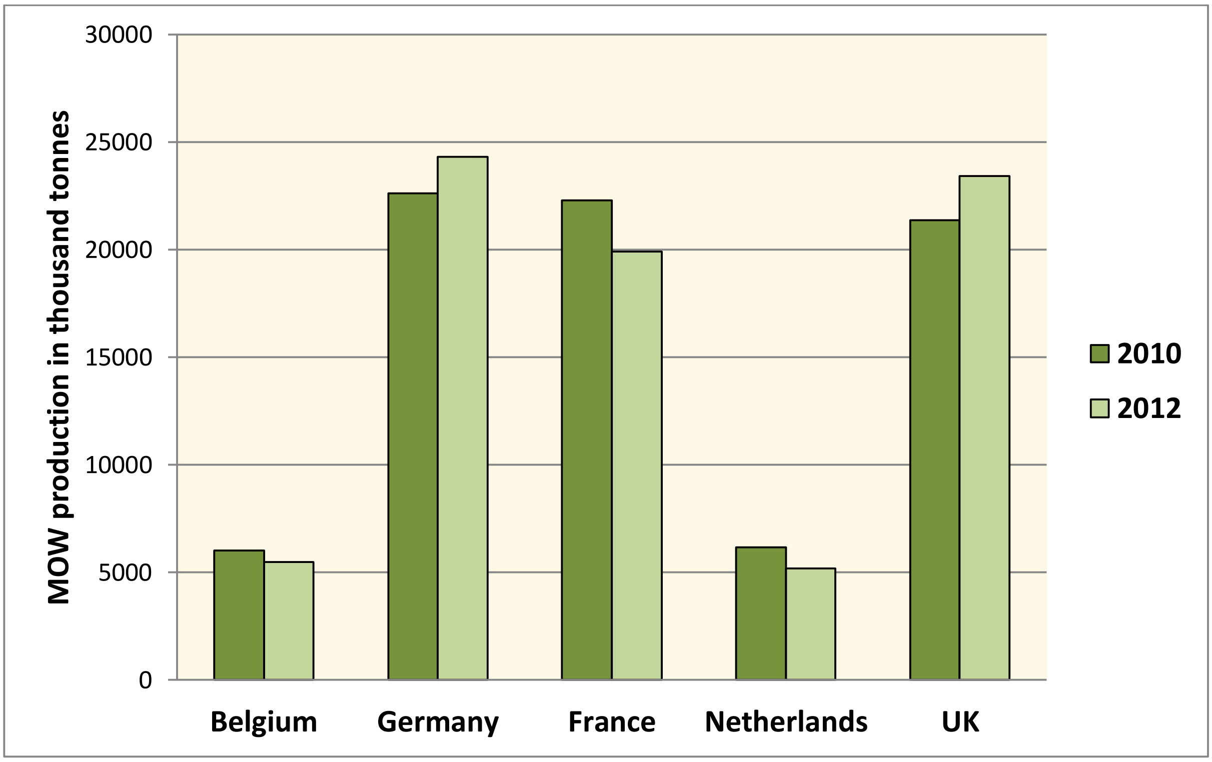

Figure 30: Production of mixed ordinary wastes mainly originating from economic activities in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 and 2012 expressed in thousand tonnes.

Source: data collected from EUROSTAT®

Germany, France and The UK generated close amounts of mixed ordinary wastes in 2010 and 2012 (about 20-24 million tonnes). Belgium and The Netherlands produced much less wastes of this category, with respective amounts of 5.5 and 5.2 million tonnes. These figures are comparable with the ones relating to the household wastes generated by the five countries in 2012. Belgium, Germany, France, The Netherlands and The UK generated about 5, 50, 35, 9 and 31 million tonnes of municipal wastes in 2012, respectively. Both sources can consequently be considered as interesting nutrient stocks.

Figure 31 shows the treatments applied to the mixed ordinary wastes in 2010.

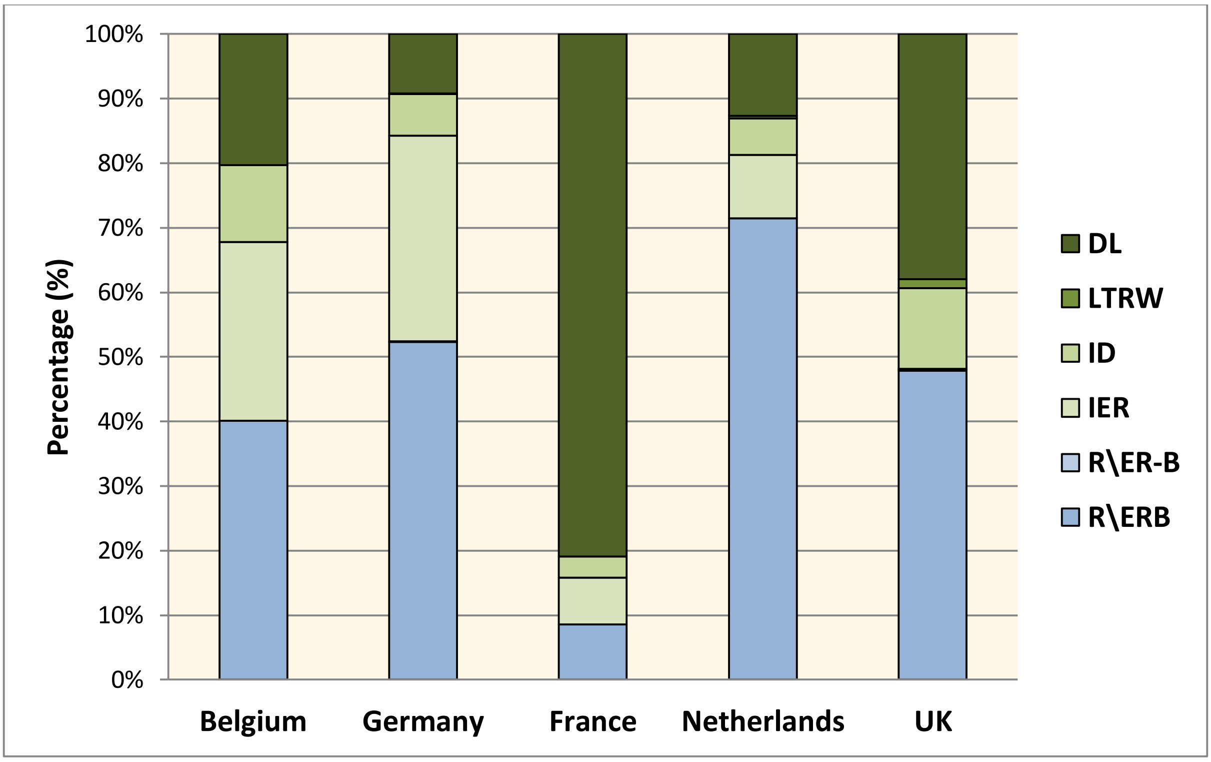

Figure 31: Treatment applied to non-hazardous mixed ordinary wastes in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in percentage. DL = Deposit onto or into Land; LTRW = Land Treatment and Release into Water bodies; ID = Incineration/Disposal; IER = Incineration/Energy Recovery; R\ER-B = Backfilling; R\ERB = Recovery other than Energy Recovery, excluding Backfilling.

Source: data collected from EUROSTAT®

The interpretation of these data is not feasible because of the complexity of waste composition; mixed ordinary wastes include various materials. However, some trends can be observed. Backfilling is widely used in Belgium, Germany, The Netherlands and The UK, while France only uses this elimination technique with less than 10 % of MOW. However, this country uses deposit into or onto land with about 80 % of these materials. Incineration is also common in the five countries, mainly in Belgium. Once again, the incineration process leads to ashes which can be recycled or sent to landfills (Eurostat, 2010).

Industrial effluent sludge is the final type of waste to be considered. It is considered hazardous when it contains oil and/or heavy metals. Here, only the non-hazardous sludge will be considered. Industrial effluent sludge includes sludges and solid residues from industrial wastewater treatment including external/physical treatment; solid and liquid wastes from soil and groundwater remediation; sludges from boiler cleaning; wastes from cooling water preparation and cooling columns; and drilling mud. Wastewater treatment takes place in many industrial manufacturing sectors. A problem of comparability among countries must be highlighted, as the wastewater treatment processes might not be geographically isolated and the sludges might not be attached to the primary activity (Eurostat, 2010).

Figure 32 shows the production of industrial effluent sludge in Belgium, Germany, France, The Netherlands and The UK.

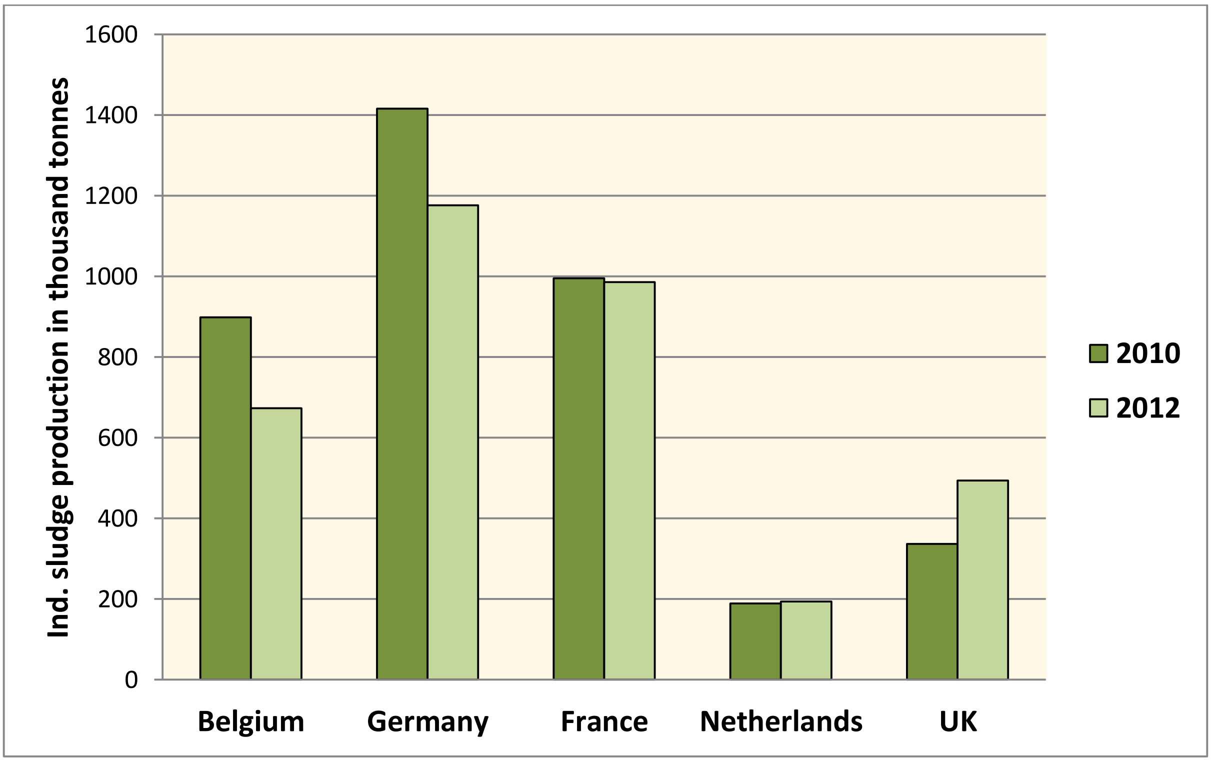

Figure 32: Production of industrial effluent sludge in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 and 2012 expressed in thousand tonnes.

Source: data collected from EUROSTAT®

The production of industrial sludge is not correlated with the local populations but depends on the industrial activities. Germany produces the highest amounts of industrial sludge out of the five countries, while The Netherlands come in the 5th position with less than 200 thousand tonnes in 2010 and 2012. An important observation is the relatively high production of industrial effluent sludge in Belgium, in comparison with Germany, France and The UK, which show much higher populations and areas. The amounts of industrial effluent sludge produced in the five countries should be considered for recycling applications in the field of nutrient recovery, taking account of the variability of composition. Each type of industry and activity generates its own types of residues, but few data is available at this level.

Figure 33 shows the treatments applied to industrial effluent sludge inside the five countries.

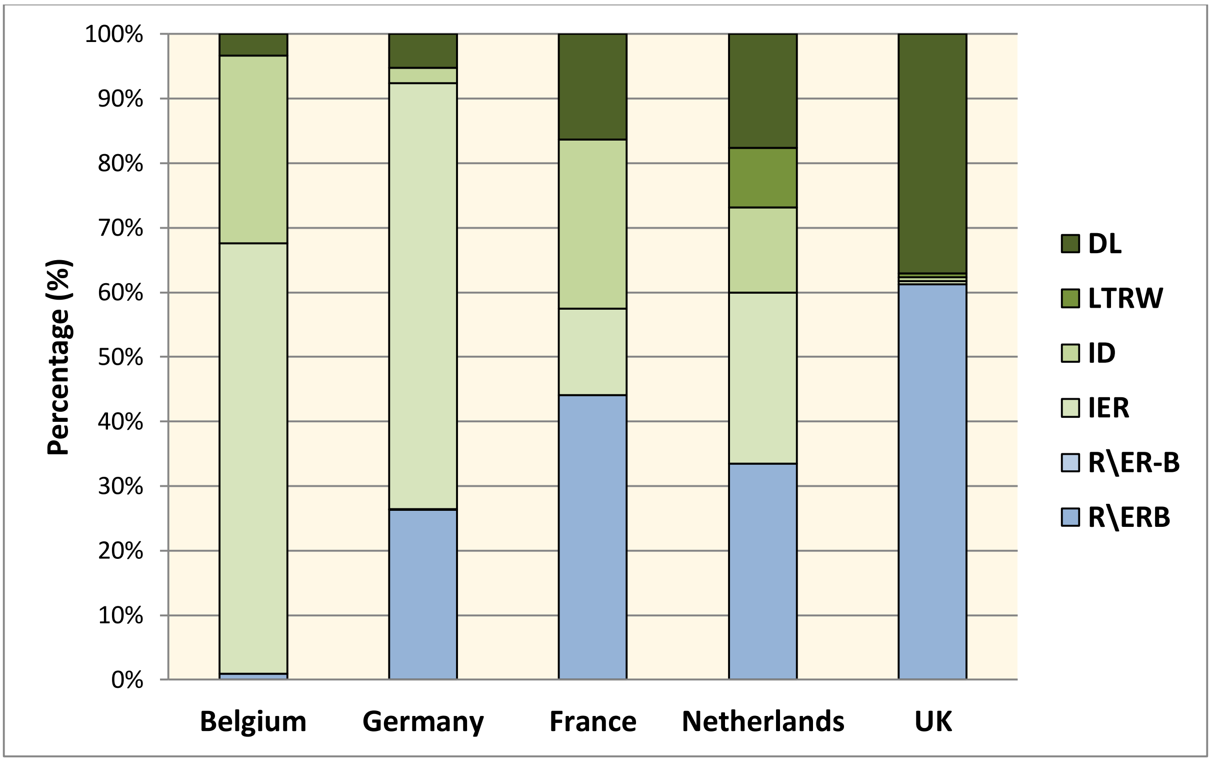

Figure 33: Treatment applied to non-hazardous industrial effluent sludge in Belgium, Germany, France, The Netherlands and The United Kingdom in 2010 expressed in percentage. DL = Deposit onto or into Land; LTRW = Land Treatment and Release into Water bodies; ID = Incineration/Disposal; IER = Incineration/Energy Recovery; R\ER-B = Backfilling; R\ERB = Recovery other than Energy Recovery, excluding Backfilling.

Source: data collected from EUROSTAT®

Incineration (with or without energy recovery) and landfilling are widely used in Belgium (applicable to about 95 % of industrial sludge). Germany also uses incineration processes with 68 % of the total production of industrial sludge. Backfilling is widely used with respective amounts of 26, 44, 33 and 61 % eliminated by this pathway in Germany, France, The Netherlands and The UK. However, this type of elimination is mostly applicable to inert wastes.

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