# Technical potential and geographic distribution of agricultural residues, co-products and by-products in the European Union

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## ABSTRACT

Value waste chain generates a significant amount of different agricultural wastes, co-products and by-products (AWCB) that occur during three major stages of a complex path, from farm to fork. This paper presents stages where and how waste occurs along the path from the ground to the table for a period of 7 years, from 2010 to 2016 in the 28 member countries of the European Union (EU28). Considering the specific conditions of the EU28 community, four different sectors with 26 commodities and waste types that occur in those sectors were analysed: 5 commodities in the Fruit sector, 10 commodities in the Vegetable sector, 7 commodities in the Cereal sector and 4 commodities in the Animal sector. The analysis consists of three stages of waste appearance: production (harvesting, farming), processing and consumption (raw, uncooked food). Production data were taken from Eurostat, import and export data were taken from FAOSTAT. Methodology and calculations consist of relations between specific values. Those specific values for every commodity are the production data, import and export data, and consumption of raw food by the inhabitants of a country. Total consumption of raw food by inhabitant is calculated from the specific consumption per capita and population. The results of the study showed that from 2010 to 2016 in the EU28 the estimated quantity of the AWCB appeared to be around 18.4 billion tonnes, with the sector percentages as follows: Animal ~31%, Vegetable ~44%, Cereal ~22% and Fruit ~2%. In the Animal sector, the most dominant were developed countries, with high population density and high level of industrialisation. The Cereal, Fruit and Vegetable sectors have shown to generate higher AWCB quantities in the countries with more available land area and appropriate climate conditions.

**Keywords**: EU28; Agricultural co- and by- products, Resource availability, AgroCycle

# 1. Introduction

The EU28 community presents a group of countries sharing the unique market of goods in Europe (European Union, 2018). Favourable climate conditions of some European countries and available land area lead to possibilities of high production of vegetables, fruits and cereals. Furthermore, the countries that are able to produce food for people and animals also focus on farming with the aim to produce meat, meat products and dairy products (Andersen, 2017). With a population of approximately 511.8 million (3/4 living in the cities and towns), the EU28 shows reputable status in the world economy and politics (Eurostat, 2019a). Agricultural production in the European Union is spread over a large area and includes diverse types of climate. Also, it is the main component of the primary sector in all Member States. Around 10 million people in the EU28 work in the agriculture sector. Almost 3/4 of the total agricultural workers are present in the countries in which the economy and politics provide good living standard and development opportunities (Eurostat, 2015).

According to the research (Esparcia, 2014), most of the waste comes from the construction sector (33.5%) and the mining and quarrying sector (29.8%) while households take up to 8% of the total waste production. Agriculture, forestry and fishing are at the bottom of the list with 1.4% of the total waste production. Authors in (Corrado et al., 2019) have estimated that the 1/3 of the food produced globally is wasted along the food chain. An important factor that was addressed in the study is the broad understanding of the context in which food waste is generated. For instance, marital status and education have a high impact on the quantity of wasted food. The analysis of food waste/losses in the supply chain models has been studied in (Muriana, 2017). The results have indicated that legal constraints, political decisions, climatic and economic factors play an important role in the minimisation and the reduction of food waste/losses. The study (Porter et al., 2016) has shown the 50-year longitude analysis (1961–2011) of food loss and waste (FLW) and the associated greenhouse gas (GHG) emissions through the entire food supply chain. The results have shown that developing economies cause an increase in food/waste losses, primarily due to increasing losses in fruits and vegetables. Authors in (Feil et al., 2017) have studied separate collection systems of plastic waste from municipal solid waste at the level of the European Union. Even though politically preferred solutions in sustainable waste management require separate collection systems, economic factors indicate that plastic recycling will hardly ever reach cost neutrality. However, the other fraction of municipal solid waste − the organic material - could be used for the production of renewable energy in the form of biogas (Mondal and Banerjee, 2015). It has been shown that pre-treatment methods increase the potential of waste used in the biogas production, and in that way reduce the negative impact of disposing waste on landfills. Furthermore, the application of vegetable and animal waste together with fractions of municipal solid waste in the anaerobic digestion, gasification and incineration has been studied in (Massimo and Montorsi, 2018). The numerical tool developed in the study proved to be helpful in improving the efficiency in the exploitation of the region-available biomass for energy recovery purposes.

Agricultural Waste, Co-products and By-products (AWCB) could have a significant role in the world's production of animal feed. In (San Martin et al., 2016) authors have reported that vegetable by-products can be potentially served as animal feed since their nutrition and sanitary properties and the report (Sortino et al., 2014) showed that municipal bio-waste could replace synthetic chemicals for the remediation of contaminated soil and waters. Furthermore, the production of medicine and high-value-added chemicals from the mixture of potato and orange peel waste has shown potential due to high protein content in the aforementioned feedstock (Matharu et al., 2016). At the same time, orange peel could be used in the production of bioelectricity via microbial fuel cell technology (Miran et al., 2016). Biomass residues have shown an important role in the production of bioenergy in the European Union (Ajanovic and Haas, 2014). The use of residue biomass improves the $CO_2$ balance, but resource availability, economy and policy on their utilisation have a high impact on the technical and economic potential of residue biomass. Authors in (Pereira et al., 2016) showed that the use of poplar biomass as an alternative feedstock to coal in power plants in Southern Portugal could reduce $CO_2$ emissions between 8.2% and 16.5%. In (Bentsen et al., 2018) authors determined that the geographical analysis of the straw used for energy purposes is highly influenced by weather conditions. Furthermore, the biomass potential from forest and agricultural residues are strongly related to the location and ecosystem services (Ooba et al., 2016) as well as on logistical, chemical, technological, economic and social issues (Scarlat et al., 2010). When considering agricultural biomass residues as a source of energy, it is important to valorise material properties (Mikulandrić et al., 2016). Authors in (Spaccini et al., 2019) have shown that biological properties and pre-known molecule structure of composted material from lignocellulose waste make a good basis for the selection of derivatives from composted materials to provide sustainable agricultural practice. In (Boeykens et al., 2018) authors have shown that agro-industrial waste could be used as a biosorbent for removal of lead and chromium as a low-cost alternative method for treating effluents. The utilisation of the olive mill wastewater (primarily carbon content) for the synthesis of luminescent nanomaterials that can be used in biological processes has been analysed in (Sousa et al., 2019). Except for the biomass residues, a high quantity of plastic waste is generated as a product of the agricultural activities, and if the plastic waste is correctly collected instead left on the ground or burned, environmental damage and economic losses can be prevented (Vox et al., 2016).

The quantities of AWCB have been estimated for 26 different commodities, previously selected according to the rate of use in each EU28 country from 2010 to 2016. The waste value chain has been divided into three characteristic groups according to the point where it occurs; harvesting and cultivation, processing and consumption. Eurostat and FAOSTAT databases have been used for the analyses, as explained in the following section, where the applied materials and methods have been described. Estimate of the generated AWCB has been based on the specific relation of the generated

AWCB per kg of the commodity in each group. The result of this study gives an overview of the distribution of the technical potential of AWCB across the countries of the European Union. The interpretation of the estimated quantities of AWCB is further linked to the socioeconomic and physical factors like level of development, population density, climate conditions and available land area.

## 2. Materials & methods

This section gives an overview of the applied methods in calculating the AWCB quantity, made by using relations between the analysed commodity and the specific AWCB production. Key parameters for estimating the quantity of the AWCB were: produced commodity, exported and imported commodity and consumed commodity, each of them for a specific EU28 country. Consumed quantities of the commodity were calculated considering the specific consumption of a commodity per capita and year. The key assumption was that the quantity of the consumed commodity does not change over a given period. When there were two or more different values of consumption, the average value was used for calculation. The AWCB value chain was assumed to consist of the following stages: harvesting and cultivation, processing and consumption.

The notation of specific values needed for the calculation of commodity and their relations is shown below. For a country *(n)*, notations for commodities *(i)* from the Fruit sector, Vegetable sector and Cereal sector were given by the expressions (I) and (II):

$$PRC_{(i)} = \left[ PRD_{(i)} + IMP_{(i)} \right] - \left[ CON_{(i)} + EXP_{(i)} \right] \qquad (\text{I})$$

$$CON_{(i)} = POP_{(i)} \times PC_{(i)} \qquad (\text{II})$$

where:

*PRD* = Production of commodity (tonnes) ( 1 )

*CON* = Consumption of raw commodity (tonnes) ( 2 )

*IMP* = Imported quantity of commodity (tonnes) ( 3 )

*EXP* = Exported quantity of commodity (tonnes) ( 4 )

*PRC* = Quantity of processed commodity (tonnes) ( 5 )

*PC* = Consumption of commodity per capita per year (kg) ( 6 )

Additionally, in the Animal sector methodology differs compared to the previous sectors. Waste value chain covers the process of breeding of animals (farming), slaughtering and consumption of meat and meat products.

Expression (III) shows the relation between values in the Animal sector:

$$MAN_{(i)} = SPECMAN_{(i)} \cdot FARM_{(i)} \quad \text{(III)}$$

where:

*FARM* = Number of farmed animals (heads) ( 7 )

*SPECMAN* = Manure production per animal in a year (tonnes) ( 8 )

*MAN* = Total manure production in a year (tonnes) ( 9 )

# 3. Case study

In this paper, the applied methodology refers to the EU28 countries. The analyses were conducted for the period from 2010 to 2016. The data for a produced commodity were taken from the Eurostat (Eurostat, 2019b), and the data for imported and exported quantities of commodities were taken from the FAOSTAT (FAO, 2019). The population of the EU28 Member States (2010–2016) was taken from the Eurostat (Eurostat, 2019c). Consumption per capita of fresh (raw) or processed food on a national level was given in the reports of the AgroCycle project (Ćosić et al., 2018).

## 3.1 Commodities in the EU28

In order to select the most important commodities for analysis on the EU28 level, the FAOSTAT data of top commodities by quantity in 2016 were used (FAOSTAT, 2019). Top commodities in the EU28 community were cow milk, sugar beet and cereals. Also, some commodities were related to the geographical position of the country. Variety in size and population of countries along with a variety of top commodities together result in a variety of type and quantities of the AWCB throughout the EU28.

## 3.2 Commodity sectors and characteristic of AWCB

There were four analysed commodity sectors: Fruit, Vegetable, Cereal and Animal. The animal AWCB required a slightly different approach in calculation compared to the methodology shown. As it follows, a different notation was used. Stages in the animal AWCB value chain were farming, slaughtering and processing, and consumption. In the next section, characteristic of AWCBs for every commodity from every sector and for every step are briefly described.

### 3.2.1 Fruit sector

The Fruit sector consists of the following commodities: apples, grapes, oranges, peaches and tangerines. During the cultivation and harvesting, a certain amount of fruit is eaten or destroyed by animals (birds, rabbits, deer, wasps), or due to bad weather conditions and cannot be used as food. Furthermore, different diseases harm fruit products, stalks and trees, which can result either in lower income from the sale of fruit or in total devastation of the plant. Fruit intended for processing can result in different products depending on the type and purpose of the process. All analysed fruits can be used in the preparation of juice, whether concentrated or not. Furthermore, apples can be used for vinegar production (Viana et al., 2017), such as grapes. Citrus fruits are commonly used for food additives production, such as aroma (Madrera et al., 2015). Table 1 contains a mass ratio of the main AWCB to product ratio for the Fruit sector. The main fruit AWCB in the harvesting and cultivation step are pruning residues and leaves. The literature data estimate that citrus fruits have lower values of prunes compared to the grape. Also, many different AWCB appear in the processing step, mainly pomace and marc waste remained after pressing raw fruit.

Table 1 Main AWCB produced from the Fruit sector

| **Commodity/Fruit** | **Harvesting/Cultivation ratio** | **Source** |
|---|---|---|
| **Apple** | Pruning residues and leaves to product ratio − 0.10 kg/kg | (Pellizzi, 1985) |
| **Grape** | Stalks to product ratio − 0.055 kg/kg | (Bacic, 2003) |
| | Pruning residues and leaves to product ratio − 0.30 kg/kg | |
| **Orange** | Pruning residues and leaves to product ratio − 0.085 kg/kg | (Velázquez-Martí et al., 2013) |
| **Peach** | Pruning residues and leaves to product ratio − 0.12 kg/kg | (Extension, 2017) |
| **Tangerine** | Pruning residues and leaves to product ratio − 0.065 kg /kg | (Extension, 2017) |
| **Commodity/Fruit** | **Processing ratio** | **Source** |
| **Apple** | Pomace (peel, core, seed, calyx, stem) to product ratio − 0.25 kg/kg | (Dhillon et al., 2013) |
| | Sludge to product ratio − 0.10 kg/kg | |
| **Grape** | Marc waste (skin, pulp, seed and stems) to product ratio − 0.22 kg/kg | (Bacic, 2003) |
| | $CO_2$ to product ratio − 0.07 kg/kg | |
| | Lees to product ratio − 0.03 kg/kg | |
| **Orange** | Orange pomace to product ratio − 0.37 ÷ 0.60 kg/kg | (Saravacos and Kostaropoulos, 2002), (Bates et al., 2001), (Goodrich and Braddock, 2006), (Siles et al., 2016) |
| | Orange processing water to product ratio − 4.4 ÷ 38.2 L/kg | (Bharati et al., 2017) |
| **Peach** | Processing water to product ratio − 16.4 ÷ 21.8 L/kg | (Bharati et al., 2017) |
| | Peach stone to product ratio − 0.10 ÷ 0.27kg/kg | (Loizzo et al., 2015), (Folinas et al., 2015), (Ordoudi et al., 2018) |
| | Peach pomace to product ratio – 0.30 kg/kg | (Loizzo et al., 2015) |
| **Tangerine** | Tangerine pomace to product ratio − 0.20 ÷ 0.30 kg/kg | (Nitayapat et al., 2015), (Hwang et al., 2017) |
| | Tangerine processing water to product ratio − 4.4 ÷ 38.2 L/kg | (Bharati et al., 2017) |
| **Commodity/Fruit** | **Consumption ratio** | **Source** |
| **Apple** | Rotten apples to product ratio – 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Grape** | Rotten grapes to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Orange** | Rotten oranges to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Peach** | Rotten peaches to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| | Peach stone to product ratio − 0.10 ÷ 0.27 kg/kg | (Ordoudi et al., 2018) |
| **Tangerine** | Rotten tangerines to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |

AWCB that occur along the supply chain from the ground to table can be valorised in different ways. Peach stone has been investigated as an adsorption material for contaminants in aqueous solution (Torrellas et al., 2015). Citrus peel waste has been studied as a feedstock for anaerobic digestion and further production of biochar (Fagbohungbe et al., 2016). Sugars present in grape stalks have shown to be interesting substrates for the fermentation process and the production of bioethanol (Egüés et al., 2013). After the fermentation of apple pomace, the remaining material can be used as a feed additive in the animal breeding (Ajila et al., 2015). In the last step of the waste value chain, the estimated quantity of rotten fruits takes up to 20% of the total fruit intended for consumption (Parfitt et al., 2010). The quantity of processed fruits is calculated for every country in each given year, using expressions (I-II). An example of the calculation of the apple AWCB quantities for Germany in 2016 is given below:

PRD = 1,032,910 t

IMP = 610,955 t

EXP = 88,972 t

CON = 1,314,914 t

PRC = (1,032,910+610,955) − (88,972+1,308,938) = 239,979 t

The quantity of pruning residues is 0.10 kg per kg of harvested apples: for Germany, it was 103,291 t in 2016. Apple pomace that occurs in processing step takes 0.25 kg per kg of processed apples: for Germany, the quantity of apple pomace was 59,995 t in 2016. The quantity of the consumed apples in Germany was 1,314,914 t, and 210,386 t of apples in Germany in 2016 went mouldy (spoiled, rotten).

### 3.2.2 Vegetable sector

As for the Vegetable sector, the following commodities were analysed: tomatoes, cabbages, cauliflowers and broccoli, onions, carrots, potatoes, sunflower seeds, rapeseed, sugar beet and olives. Vegetables are mainly used as food for people or animals. Also, like fruits, different diseases that decrease the income and quality of the products impact vegetables. Vegetables are also used as an initial source in the production of different products and semi-products (sauces, preserved and frozen products). Table 2 contains a mass ratio of the main AWCB to product ratio for the Vegetable sector. Many different AWCB occur during the harvesting and cultivation stage. Due to the diversity of commodities that are included in the Vegetable sector, some of the AWCB primarily appear during the cultivation stage (twigs, leaves and woody branches from olives or sugar beet leaves and stones) and some during the harvesting period (damaged vegetables).

Table 2 Main AWCB produced from the Vegetable sector

| Commodity/Vegetables | Harvesting/Cultivation | Source |
|---|---|---|
| **Tomato** | Damaged tomatoes to product ratio − 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Cabbage** | Damaged cabbage to product ratio − 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018), (Munhuweyi et al., 2016) |
| | Leaves to product ratio − 0.20 ÷ 1.51 kg/kg | (Munhuweyi et al., 2016), (Stoffella and Fleming, 1990), (Haque et al., 2016), (Nurhidayati et al., 2016), (Bajgai et al., 2014) |
| **Cauliflower and broccoli** | Damaged cauliflower and broccoli to product ratio − 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Carrot** | Damaged carrot to product ratio − 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Onion** | Damaged onion to product ratio − 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Potato** | Damaged potatoes to product ratio − 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Sunflower seed** | Damaged sunflower seed to product ratio − 0.10 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| | Straw to product ratio – 1.00 kg/kg | (Bakker, 2013) |
| **Rapeseed** | Stalks to product ratio – 1.76 kg/kg | (Islam et al., 2018) |
| | Damaged rapeseed to product ratio − 0.10 kg/kg | |
| **Sugar beet** | Sugar beet leaves to product ratio − 0.14 ÷ 0.91 kg/kg | (Krick, 2019) |
| | Stones to product ratio − 0.001 ÷ 0.04 kg/kg | |
| **Olives** | Twigs and leaves to product ratio – 2.68 ÷ 5.15 kg/kg | (Russo et al., 2016), (Acampora et al., 2013), (Sansoucy et al., 1985), (European Commission, 2012) |
| | Woody branches to product ratio – 2.68 kg/kg | |
| **Commodity/Vegetables** | **Processing** | **Source** |
| **Tomato** | Tomato skin to product ratio − 0.10 kg/kg | (Kao and Chen, 2016) |
| | Tomato pomace to product ratio − 0.03 ÷ 0.07 kg/kg | (Del Valle et al., 2006) |
| | Wastewater to product ratio − 8.20 l/kg | (Loehr, 2012) |
| | Total suspended solids to product ratio − 0.06 kg/kg | (Loehr, 2012) |
| **Cabbage** | Outer cabbage leaves to product ratio − 0.35÷ 0.40 kg/kg | (Prokopov et al., 2015), (Agati et al., 2016) |
| **Cauliflower and broccoli** | Wastewater to product ratio − 8.20 l/kg | (Loehr, 2012) |
| | Total suspended solids to product ratio − 0.0025 kg/kg | (Loehr, 2012) |
| | Leaves to product ratio − 0.50 kg/kg | (Pankar and Bornare, 2018) |
| **Carrot** | Pomace and peel to product ratio − 0.12 kg/kg | (Loehr, 2012) |
| | Wastewater to product ratio − 11.10 l/kg | |
| **Onion** | Wastewater to product ratio − 21.00 l/kg | (Loehr, 2012) |
| | Total suspended solids to product ratio − 0.01 kg/kg | (Loehr, 2012) |
| | Peel to product ratio − 0.25 kg/kg | (Committee, 2016) |
| **Potato** | Peel to product ratio − 0.10 kg/kg | (Loehr, 2012) |
| | Process water to product ratio − 16.00 l/kg | |

| | | |
|---|---|---|
| | Suspended solid to product ratio − 0.27 ÷ 0.50 kg/kg | |
| **Sunflower seed** | Sunflower cake meal to product ratio − 0.60 ÷ 0.64 kg/kg<br>Slurry (ugido) to product ratio − 0.015 ÷ 0.045 kg/kg | (Mogala, 2012) |
| **Rapeseed** | Cake meal to product ratio − 0.67 kg/kg | (Ivanova et al., 2016) |
| **Sugar beet** | Stones to product ratio − 0.001 ÷ 0.005 kg/kg<br>Beet soil to product ratio − 0.04 ÷ 0.10 kg/kg<br>Molasses to product ratio − 0.032 ÷ 0.035 kg/kg<br>Sugar beet pulp to product ratio − 0.05 kg/kg<br>Wash water to product ratio − 0.75 l/kg<br>Sugar beet factory lime to product ratio − 0.04 kg/kg<br>Sugar beet tops & tails to product ratio − 0.007 kg/kg | (Krick, 2019) |
| **Olives** | Twigs and leaves to product ratio − 2.68 ÷ 5.15 kg/kg | (Abaza et al., 2015), (Ahmad and Ayoub, 2014) |
| | Olive mill wastewater to product ratio − 0.50 ÷ 1.50 kg/kg | (Barbera et al., 2013) |
| | Olive pomace to product ratio − 0.25 kg/kg | (Manzanares et al., 2017) |
| **Commodity/Vegetables** | **Consumption** | **Source** |
| **Tomato** | Rotten tomatoes to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Cabbage** | Rotten cabbage to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Cauliflower and broccoli** | Rotten cauliflower and broccoli to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Carrot** | Rotten carrot to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Onion** | Rotten onion to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Potato** | Rotten potatoes to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |
| **Sunflower seed** | Not applicable, as sunflower seed are not consumed directly by humans | n/a |
| **Rapeseed** | Not applicable, as rapeseed is not consumed directly by humans | n/a |
| **Sugar beet** | Not applicable, as sugar beet are not consumed directly by humans | n/a |
| **Olives** | Wasted olive oil to product ratio − 0.12 ÷ 0.20 kg/kg<br>Rotten olives to product ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |

AWCB that occur along the supply chain from the ground to table can be valorised in different ways. Olive leaves have shown to be a natural source of antioxidants and sugars (Romero-García et al., 2016). With different way of processing for a certain type of vegetable, different AWCB are pomace, wastewater, skin, wash water, meal. Tomato processing waste has shown to be the source of lycopene (Poojary and Passamonti, 2015). Furthermore, onion skin has been recognised as a source of biosugars and quercetin (Choi et al., 2015). In the consumption stage, the estimated percentage of rotten vegetables matches the one in the fruit consumption stage. It has been shown that vegetable waste can be utilised for the synthesis of silver nanoparticles with antibacterial activity (Mythili et al., 2018). For non-edible vegetables, there is no data in the consumption stage. The quantity of processed vegetable is calculated for every country in each given year, using expressions (I-II). An example of the calculation of the tomato AWCB for Spain in 2016 is presented below:

PRD = 5,233,540 t

IMP = 145,013 t

EXP = 911,106 t

CON = 673,381 t

PRC = (5,233,540 + 145,013) − (911,106 + 673,381) = 3,794,066 t

The quantity of damaged tomatoes during cultivation and harvesting is 0.20 kg per kg of harvested tomatoes: for Spain, it was 1,046,708 t in 2016. Tomato skin that is separated during processing takes 0.10 kg per kg of processed tomatoes. For Spain, the quantity of tomato skin in 2016 was 379,407 t. Tomato pomace takes 0.05 kg per kg of processed tomatoes, and for Spain it was 189,703 tonnes in 2010. The volume of wastewater that appears in processing is 8.2 l per kilogram of processed tomatoes. For Spain, in 2016 the volume of wastewater from tomato processing was 31,111,338 $m^3$. The quantity of suspended solids from tomato processing was 227,644 t. The quantity of tomatoes consumed in 2016 in Spain was 673,381 t, out of which 107,741 t went mouldy.

### 3.2.3 Cereal sector

The Cereal sector includes the following commodities: barley, maize, triticale, oats, rice, rye and wheat. Certain amounts of cereals are eaten or destroyed by animals (birds, rabbits, deer, wasps) and in that form cannot be used as food. Furthermore, cereals are the type of crops that generate huge amounts of AWCB during harvesting, especially straw in the case of barley, triticale, oat, wheat. Straw is mostly used as a material that provides clean area and thermal isolation for stable animals. Bran is a by-product of a multi-stage process of flour production. Husks and cobs are by-products that also often end up as burning material. Table 3 contains mass ratio of main AWCB to product ratio for the Cereal sector.

Table 3 Main AWCB produced from the Cereal sector

| Commodity/Cereals | Harvesting/Cultivation | Source |
|---|---|---|
| **Barley** | Straw to product ratio − 0.68 ÷ 1.75 kg/kg | (FAO, 2018), (McCartney et al., 2006), (Gelaw et al., 2014), (Mali et al., 2017), (Weiser et al., 2014) |
| **Maize** | Stalks to product ratio − 0.80 ÷ 3.77 kg/kg | (FAO, 2018), (Gelaw et al., 2014), (Barten, 2013), (Szalay et al., 2018) |
| | Husk to product ratio − 0.20 ÷ 0.30 kg/kg | (Barten, 2013), (Galanakis, 2015) |
| | Cobs to product ratio − 0.15 ÷ 0.86 kg/kg | (Galanakis, 2015), (Borrelli et al., 2014), (Blandino et al., 2016) |
| **Triticale** | Straw to product ratio − 0.90 ÷ 4.00 kg/kg | (FAO, 2018), (Weiser et al., 2014), (Adolfsson, 2005) |
| **Oat** | Straw to product ratio − 0.75 ÷ 2.00 kg/kg | (FAO, 2018), (McCartney et al., 2006), (Weiser et al., 2014) |
| **Rice** | Straw to product ratio − 0.42 ÷ 2.15 kg/kg | (FAO, 2018), (Weiser et al., 2014), (Szalay et al., 2018) |
| **Rye** | Straw to product ratio − 0.90 ÷ 2.00 kg/kg | (FAO, 2018), (McCartney et al., 2006), (Weiser et al., 2014) |
| **Wheat** | Straw to product ratio − 0.50 ÷ 2.37 kg/kg | (FAO, 2018), (McCartney et al., 2006), (Gelaw et al., 2014) |
| **Commodity/Cereals** | **Processing** | **Source** |
| **Barley** | Bran to product ratio − 0.15 ÷ 0.49 kg/kg | (Galanakis, 2015), (Izydorczyk et al., 2013), (Singh et al., 2015) |
| | Hull to product ratio − 0.14 ÷ 0.40 kg/kg | (Youssef et al., 2017), (Rosentrater and Evers, 2017) |
| **Maize** | Bran to product ratio − 0.11 ÷ 0.15 kg/kg | (Galanakis, 2015), (Puma et al., 2015) |
| **Triticale** | Bran to product ratio − 0.15 ÷ 0.17 kg/kg | (Galanakis, 2015), (Peña, 2018) |
| **Oat** | Bran to product ratio − 0.15 kg/kg | (Galanakis, 2015) |
| | Hull to product ratio − 0.25 ÷ 0.32 kg/kg | (Rosentrater and Evers, 2017), (Decker et al., 2014), (Mahapatra and Yubin, 2007) |
| **Rice** | Bran to product ratio − 0.08 ÷ 0.12 kg/kg | (Galanakis, 2015), (Puma et al., 2015), (IRRI, 2014) |
| | Husk to product ratio − 0.04 ÷ 0.36 kg/kg | (FAO, 2018), (Rosentrater and Evers, 2017), (IRRI, 2014), (Zareei et al., 2017), (Glushankova et al., 2018) |
| **Rye** | Bran to product ratio − 0.05 ÷ 0.15 kg/kg | (Galanakis, 2015), (Singh et al., 2015) |
| **Wheat** | Bran to product ratio − 0.13 ÷ 0.20 kg/kg | (Galanakis, 2015), (Puma et al., 2015), (Chalamacharla et al., 2018), (Hemdane et al., 2016) |
| **Commodity/Cereals** | **Consumption** | **Source** |
| **Barley** | Not applicable, as barley is not consumed directly by humans | n/a |
| **Maize** | Not applicable, as maize is not consumed directly by humans | n/a |
| **Triticale** | Not applicable, as triticale is not consumed directly by humans | n/a |
| **Oat** | Not applicable, as oat is not consumed directly by humans | n/a |
| **Rice** | Rotten rice to consumed ratio − 0.12 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018) |

| | | |
|---|---|---|
| **Rye** | Not applicable, as rye is not consumed directly by humans | n/a |
| **Wheat** | Not applicable, as wheat is not consumed directly by humans | n/a |

Main AWCB during the harvesting period of cereals is straw. Also, harvesting technology affects the quantities of the straw and ability to collect and properly dispose of the straw. During the processing step, the main AWCB is bran, part of the grain that could be used in a further milling process, but in the past few years, it has become an ingredient in food consumption. For rice, as the only raw cereal directly used for food consumption, estimate shows that one quarter becomes rotten and not used. The amount of fruit defected due to harvesting and handling errors is an important factor in the AWCB calculation. Traditional method using harvest workers is slow and its efficiency depends on workers' skills. Modern methods with appropriate machinery are useful in greater agricultural areas where a larger quantity of crops and fruit are being produced. Modern methods are more expensive than the traditional ones and harvesting losses can vary depending on the quality of the machinery (Magagnotti et al., 2013). The main by-product generated in the first stage of the waste value chain of Cereal sector – straw/stalk - is usually utilised as an energy source (Muazu and Stegemann, 2015). However, some further applications of those by-products have also been studied, as a construction material (Bouasker et al., 2014), or as an adsorption material (Cao et al., 2017). Cereal bran has shown to be a very interesting source of polymer macromolecules (Lee et al., 2017) and a potential resource in the production of biodiesel (Chhabra et al., 2017). The quantity of the processed cereals is calculated for every country in each given year using expressions (I-II). An example of the calculations of barley AWCB for Slovenia in 2016 is presented below:

PRD = 91,650 t

IMP = 22,117 t

EXP = 5,524 t

PRC = (91,650 + 22,117 − 5,524) = 108,243 t

Per 1 kg of harvested barley, between 0.68 and 1.75 kg of straw is left. With an average mass of straw of 1.22 kg per kg of harvested barley, for Slovenia, it was produced 111,813 t of straw in 2016. Bran that occurs in processing step takes 0.15 ÷ 0.49 kg per kg of processed barley. With the average value of 0.32 kg/kg for Slovenia, there were 34,638 t of bran. Furthermore, a hull that occurs in the processing step takes from 0.14 to 0.40 kg per kg of processed barley. The average value is 0.27 kg/kg, and for Slovenia, it was 29,226 t in 2016.

#### 3.2.4 Animal sector

The last sector analysed is the Animal sector: cattle, dairy cows, pigs and chickens (broilers). Animal manure presents one of the most used by-products during the long tradition of animal farming. Before urea, the only fertiliser for crop treatment was manure. Nowadays, people still use manure as a fertiliser, but due to methane production, it should be avoided. Another source of by-products that are classified as waste is the slaughterhouse remains. In slaughterhouses, huge quantities of different types of AWCB occur, which is potentially dangerous for the environment. To decrease environmental pollution, these by-products must be safely used and disposed of. Furthermore, dairy cows are farmed for milk production. After the milk is processed for different products different types of waste occur, primarily whey. Whey must be pre-treated before disposal because of environmental protection. Table 4 contains mass ratio of the main AWCB to product ratio for the Animal sector.

Table 4 Main AWCB produced from the Animal sector

| Commodity/Animals | Farming | Source |
|---|---|---|
| **Cattle** | Tonnes of manure per cattle per year – 18.25 ÷ 19.71 | (Shaffer and Walls, 2002), (Vegricht et al., 2017), (Mullo et al., 2018) |
| **Dairy cow** | Tonnes of manure per dairy cow per year – 16.1 ÷ 18.8 | (Shaffer and Walls, 2002), (Nennich et al., 2003) |
| **Pig** | Tonnes of manure per pig per year – 1.1 ÷ 1.3 | (Shaffer and Walls, 2002), (Scheftelowitz and Thrän, 2016) |
| **Chicken** | Tonnes of manure per chicken per year – 0.013 ÷ 0.095 | (Shaffer and Walls, 2002), (Recebli et al., 2015) |
| **Commodity/Animals** | **Slaughtering/Processing** | **Source** |
| **Cattle** | Blood to product ratio – 0.016 ÷ 0.060 kg/kg<br>Fatty tissue to product ratio – 0.010 ÷ 0.070 kg/kg<br>Hide or skin to product ratio – 0.051 ÷ 0.085 kg/kg<br>Feet to product ratio – 0.019 ÷ 0.021 kg/kg<br>Tail to product ratio – 0.001 ÷ 0.0025 kg/kg<br>Brain to product ratio – 0.0006 ÷ 0.002 kg/kg<br>Bones to product ratio – 0.08 ÷ 0.30 kg/kg | (Irshad and Sharma, 2015), (Alao et al., 2017), (Ali et al., 2013), (Sannik et al., 2015) |
| **Dairy cow** | Whey to produced cheese ratio – 5.10 ÷ 6.10 kg/kg | (Nath et al., 2016), (Cheese, 2018) |
| **Pig** | Blood to product ratio – 0.02 ÷ 0.08 kg/kg | (Irshad and Sharma, 2015), (Alao et al., 2017), (Sannik et al., 2015), (Jayathilakan et al., 2012), (Nordberg and Edström, 2003) |
| | Fatty tissue to product ratio 0.013 ÷ 0.11 kg/kg | (Irshad and Sharma, 2015), (Romans et al., 2018) |
| | Organs to product ratio – 0.018 ÷ 0.077 kg/kg | (Irshad and Sharma, 2015), (Nordberg and Edström, 2003) |
| | Feet to product ratio – 0.015 ÷ 0.024 kg/kg | (Irshad and Sharma, 2015), (Sannik et al., 2015), (Romans et al., 2018) |
| | Tail to product ratio – 0.001 kg/kg | (Irshad and Sharma, 2015), (Sannik et al., 2015), (Romans et al., 2018) |
| | Hide or skin to product ratio – 0.023 ÷ 0.08 kg/kg | (Irshad and Sharma, 2015), (Alao et al., 2017), (Romans et al., 2018) |
| | Bones to product ratio – 0.085 ÷ 0.30 kg/kg | (Irshad and Sharma, 2015), (Amisy, 2018) |
| **Chicken** | Feathers to product ratio – 0.06 ÷ 0.08 kg/kg | (Irshad and Sharma, 2015), (Alao et al., 2017), (Acda, 2016) |
| | Heads to product ratio – 0.025 ÷ 0.03 kg/kg | (Irshad and Sharma, 2015), (Alao et al., 2017) |
| | Blood to product ratio – 0.032 ÷ 0.04 kg/kg | (Irshad and Sharma, 2015), (Bah et al., 2013), (Barbut, 2015) |
| | Feet to product ratio – 0.035 ÷ 0.084 kg/kg | (Irshad and Sharma, 2015), (Sannik et al., 2015) |
| **Commodity/Animals** | **Consumption** | **Source** |
| **Cattle** | Rotten beef to consumed beef ratio – 0.11 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018), (Grace, 2019), (Ministry of Economic Affairs, 2013) |

| | | |
|---|---|---|
| **Dairy cow** | Rotten milk to consumed milk ratio – 0.07 ÷ 0.20 kg/kg | (Grace, 2019), (Ministerio de Agricultura Alimentacion y Medio Ambiente, 2013), (Stenmarck et al., 2016) |
| | Rotten butter to consumed butter ratio – 0.133 ÷ 0.20 kg/kg | |
| | Rotten cheese to consumed cheese ratio – 0.133 ÷ 0.20 kg/kg | |
| **Pig** | Rotten pork meat to consumed pork meat ratio – 0.11 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018), (Grace, 2019), (Ministry of Economic Affairs, 2013) |
| **Chicken** | Rotten chicken meat to consumed chicken meat ratio – 0.11 ÷ 0.20 kg/kg | (Parfitt et al., 2010), (Conrad et al., 2018), (Grace, 2019), (Ministry of Economic Affairs, 2013) |

Types of AWCB that appear in the Animal sector are entirely different from those in the previous sectors. The main AWCB that occurs in the farming step is manure, which has been well-known to people for a significant period. As the petrochemical industry developed and still continues to grow, fertilisers have replaced manure progressively. In some rural areas, people still use manure as a natural fertiliser in the gardens and smaller fields. Cow manure can also be used in a co-composting process that can be used for biodegradation of petroleum hydrocarbons (Ahmadi et al., 2016). Chicken manure has chemical properties which have proven to be applicable to produce catalysts for the production of biodiesel from waste cooking oil (Maneerung et al., 2016). In the processing step, slaughtering remains that occur, present potential danger to the environment in case of non-adequate treatment and disposal (Um et al., 2016). As an example of the slaughterhouse by-products utilisation, slaughterhouse water has been studied as feedstock for the production of biodiesel (Hernández et al., 2016). Application of cruor (coagulated blood) in the extraction of haemoglobin and its potential use as a preservative has been studied in (Przybylski et al., 2016). In the last step, quantities of rotten meat are primarily a result of human habits and behaviour, as it was the case for all the analysed sectors. The number of processed animals is calculated for every country in each given year using expressions (I-III). An example of the calculation of the cattle AWCB for Belgium in 2016 is presented below:

FARM = 2,501,350 heads

SLAUG = 535,330 heads

SPECMAN =18.98 t/year

MAN = 47,511,875 t

CON = 205,862 t

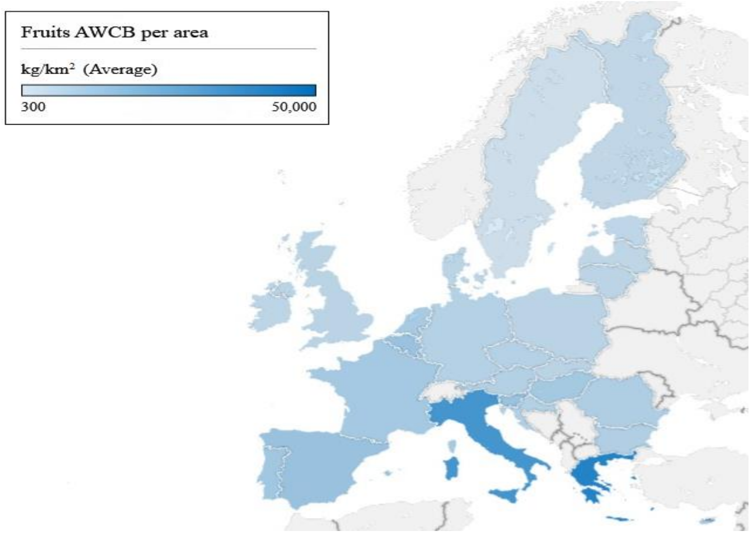
The average quantity of manure that one animal produces during a year is 18.98 t, and the total quantity of manure that the Belgian farmers produced was 47,511,875 t in 2016. The AWCB quantities that occurred in Belgian slaughterhouses were: 11,884 t of blood; 9,315 t of fatty tissue; 21,841 t of skin; 6,424 t of feet; 578 t of tail; 450 t of brain and 28,265 t of bones in 2016. The quantity of the consumed cattle meat in Belgium was 205,862 t in 2016, of which 16% was calculated to go mouldy (spoiled, rotten) or 32,938 t.

# 4. Results and discussion

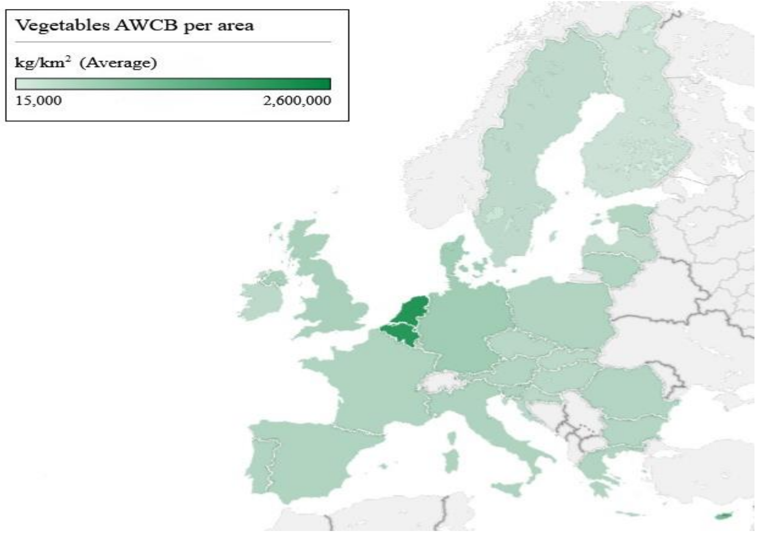
The data on the cumulative quantity of AWCB from all the sectors, generated from 2010 to 2016, has been calculated as described in the previous sub-sections. The average quantity of AWCB per population of the country and per area of the country is shown in Figure 1 and Figure 2.

## 4.1 The average quantity of AWCB per area in the EU28 countries

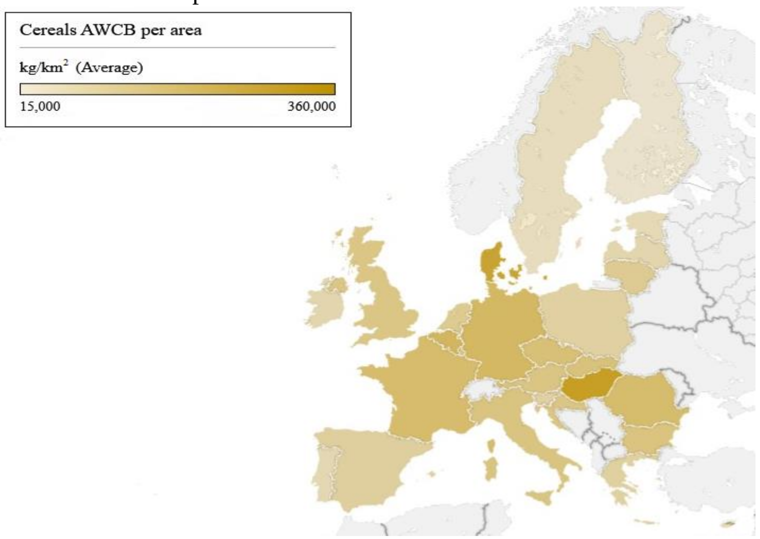
Figure 1 from a to d presents the estimated quantity of the AWCB per area for selected commodities grouped in four Sectors. In the Fruit sector (Figure 1 a), the quantity of the AWCB per area below 1 t/km$^2$ has been estimated in countries such as Sweden, Finland, Latvia, Estonia, Ireland and Lithuania. Such a low value is the result of low agricultural activities regarding the production of analysed fruit commodities due to inappropriate climate conditions and a large country area. Smaller countries with a high level of industrialisation like the Netherlands, Belgium and Austria have shown the yields of the fruits AWCB between 4 t/km$^2$ and 12 t/km$^2$. Since analysed commodities are mostly citrus fruit, it is expected that the Mediterranean countries show the highest quantities of the fruits AWCB. Therefore, Italy (ca. 40 t/km$^2$) and Greece (50 t/km$^2$) are the most dominant countries in the EU considering the technical potential of the fruits AWCB per km$^2$.



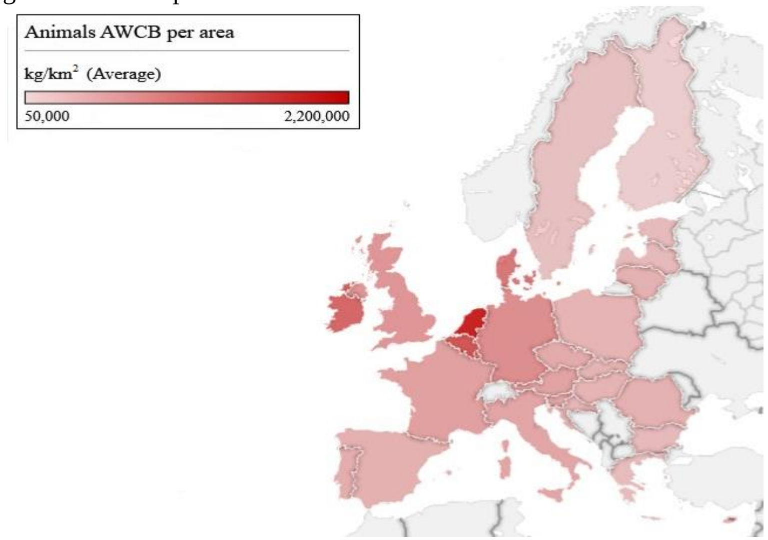
a. Fruit AWCB per area



b. Vegetable AWCB per area



c. Cereal AWCB per area



d. Animal AWCB per area

Figure 1 a to d. The average quantity of AWCB from all sectors per area in the period 2010–2016. Fruits AWCB (a), Vegetable AWCB (b), Cereal AWCB (c), Animal AWCB (d)

The highest quantities of AWCB per area for the Vegetable sector (Figure 1 b) have been estimated for the Netherlands at 2,600 t/km$^2$ and for Belgium at 2,525 t/km$^2$. Since both countries have highly developed vegetable production and low land area, it brings them to the top. Other countries with more than 300 t of the vegetable AWCB per km$^2$ are the UK, Germany and Denmark. The lowest quantity of the vegetable AWCB has been estimated for Sweden (ca. 30 t/km$^2$), Latvia (ca. 23 t/km$^2$) and Finland (ca. 17 t/km$^2$), which is the result of low agricultural activities and high land area. In this analysis, highly developed European countries with high agricultural activities have shown the greatest values of the technical potential of vegetable AWCB.

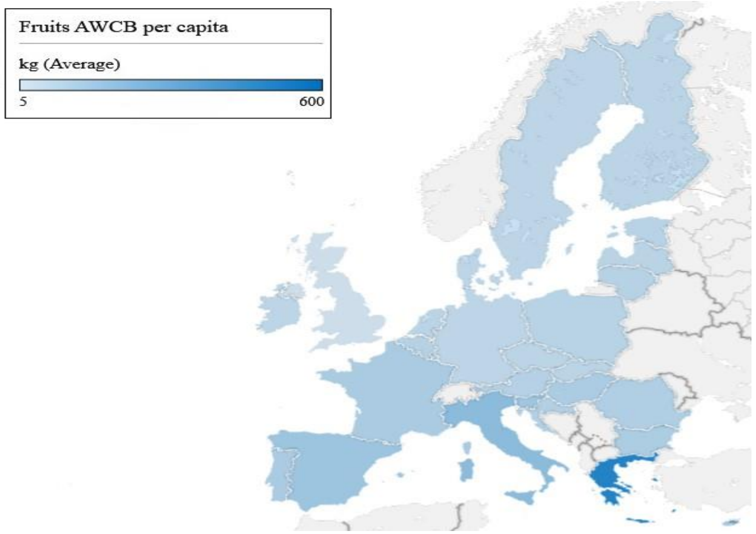
The highest quantities of AWCB per area for the Cereal sector (Figure 1 c) have been estimated in Hungary (ca. 360 t/km$^2$), Denmark (ca. 330 t/km$^2$), Belgium (ca. 225 t/km$^2$) and Germany (ca. 220 t/km$^2$). The reason for such results lies in the fact that these countries have strongly developed agriculture sector regarding cereals production and lower land area, except for Germany. Romania and Bulgaria have also shown a high level of cereal production with the generated AWCB in Cereal sector slightly below 200 t/km$^2$. Again, the countries located in the north of Europe, Finland and Sweden, have shown the lowest AWCB quantities, below 20 t/km$^2$. Countries with high available land area and favourable climate conditions for cereals production and high population density have shown to be dominant in the Cereal sector.

For the Animal sector (Figure 1 d), the highest AWCB production has been estimated for the Benelux countries: the Netherlands (ca. 2200 t/km$^2$), Belgium (ca. 1500 t/km$^2$) and Luxembourg (ca. 1100 t/km$^2$). Denmark and Ireland generate between 1000 ÷ 1200 t/km$^2$ of the animal AWCB. This data points to the fact that high level of farming activities and animal processing is in the highly populated countries of Western Europe. Germany and France have also shown relatively high quantities of the animal AWCB with the average values of ca. 450 and 700 t/km$^2$, respectively. Countries of Central and Eastern Europe like Poland, Czech Republic, Slovakia, Slovenia, Croatia and Hungary have shown the yield of the animal AWCB between 150 ÷ 300 t/km$^2$, while the lowest quantities of the animal AWCB have been estimated for Northern European countries Sweden and Finland with the yield of around 50 t/km$^2$.

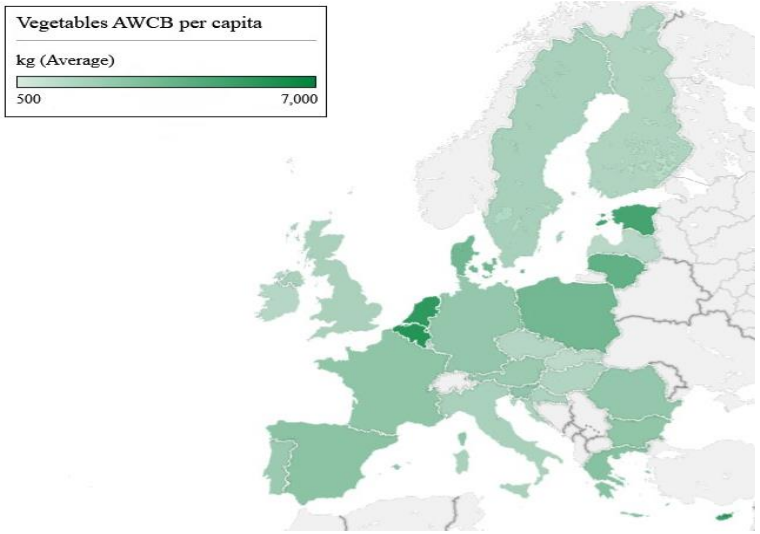
## 4.2 The average quantity of AWCB per area in the EU28 countries

Figure 2 from a to d presents the estimated quantity of AWCB per capita for selected commodities grouped in four Sectors. In the Fruit sector (Figure 2 a), Greece, Italy and Spain have shown the highest quantity of the AWCB per capita and year, 600 kg, 200 kg and 130 kg. A similar trend has been reported for the estimated yield of the fruit AWCB per area. This point to the fact that the highest potential of the fruit AWCB is presented in the Southern European countries. The lowest quantity of the generated AWCB for the Fruit sector (below 10 kg per capita and year) has been estimated for Northern and Western European countries (Denmark, Finland, Sweden, Latvia, Estonia, Lithuania, Germany, the UK and Ireland). It is important to emphasize that selected Fruit commodities, except apple, are dominantly cultivated in Mediterranean climate conditions.

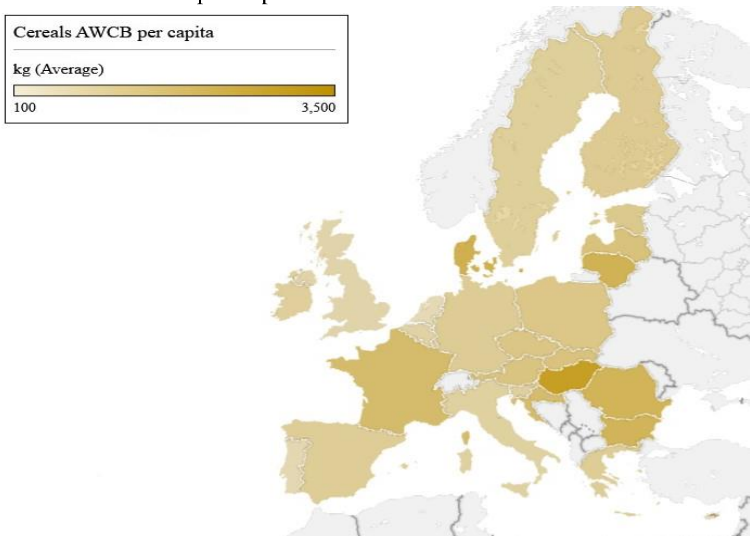
The highest quantity of AWCB per capita and per year for the Vegetable sector (Figure 2 b) has been estimated at around 7.0 t for the Netherlands and Belgium. Both countries have shown the highest yield of the vegetable AWCB per area, as well. This data indicates that there is high potential in the use of the residues of vegetable production, processing and consumption in those countries. Denmark follows the Benelux countries with the estimated quantities of the vegetable AWCB of ca. 3.7 t per capita. Countries of Central and Eastern Europe in this analysis have shown greater quantities of the vegetable AWCB, such as Poland, Estonia, Lithuania and Romania. This result is probably related to the low population density in the Baltic countries and high agricultural activities in Poland and Romania. The lowest yield of the vegetable AWCB per capita has been estimated in Slovakia (ca. 600 kg) and the Czech Republic (ca. 850 kg).



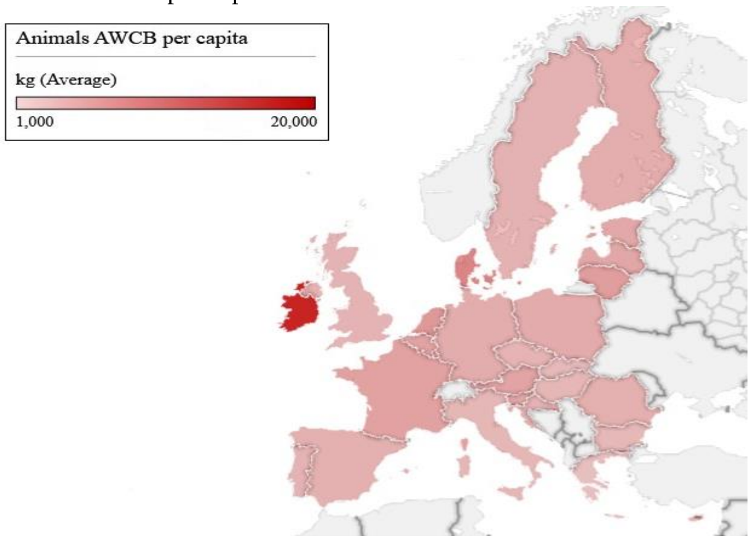

a. Fruits AWCB per capita




b. Vegetables AWCB per capita




c. Cereals AWCB per capita




d. Animals AWCB per capita

Figure 2 a to d. The average quantity of AWCB from all sectors per capita in the period 2010-2016. Fruit AWCB (a), Vegetable AWCB (b), Cereal AWCB (c), Animal AWCB (d)

In the Cereal sector (Figure 2 c), the highest quantity of AWCB per capita and per year is estimated for Hungary, with around 3.5 t. Denmark is second with around 2.5 t per capita and year, followed by Romania and Bulgaria, each with 2.3 t of the cereal AWCB. Central and Eastern European countries have favourable climate conditions for the growth of cereals and therefore high technical potential for the cereal AWCB to be used. Northern European countries on average have shown the AWCB yield of 1.0 t per capita. The lowest production of the cereal AWCB per capita and per year is estimated for Malta (100 kg).

In the Animal sector (Figure 2 d), the results have shown that only six countries produce less than 2.0 t of the animal AWCB per capita (Bulgaria, Greece, Italy, Hungary, Malta and Slovakia). The Czech Republic, Spain, Croatia, Cyprus, Portugal, Romania, Germany, Sweden and the UK belong to a group of countries that produce between 2.0 and 3.0 t of the animal AWCB per capita per year. Other countries produce much bigger quantities of the animal AWCB, whereas Belgium, France, Netherlands and Denmark have shown on average between 4.0 and 7.0 t of the animal AWCB. The highest producer of the animal AWCB is Ireland, where almost 20 t of the animal AWCB is produced per capita in a year. In general, highly-developed countries of Western Europe generate the largest quantities of animal AWCB.

## 5. Conclusions and future research

This study gives an overview of the technical potential of agricultural co- and by- products generated from the top EU28 commodities in the agricultural value chain. The results presented in this study should be carefully analysed. The commodities have been selected due to their usage rate in the EU28. Even though they have been sorted into four different sectors, the estimated quantities of the AWCB do not represent the real situation in these sectors. The quantities of the AWCB have been calculated for every EU28 country, but their distribution over the country has not been shown, such as on the NUTS3 level. In total, this study has shown that the dispersion of the AWCB quantities is the result of land activities, climate conditions and human eating habits (consumption of goods). Countries with less available land areas, a significant number of industrial zones and high population density were the biggest producers of the AWCB in the Animal sector – Belgium, France, Germany, Ireland and the Netherlands. Those countries have also shown a respective yield of AWCB generated in the Vegetable sector. Since the Animal and Vegetable sectors are highly connected due to the transfer of vegetable residues to animal feeding, the estimated distribution of their AWCB was expected. Therefore, Western European countries show a high potential of the use of co- and by- products generated in animal farming and vegetable cultivation activities. On the other hand, South European countries, with lots of land areas and mild weather conditions were shown to be more dominant in the quantities of the generated fruit AWCB. Therefore, the use of citrus fruit co- and by- products in that area should be taken for more detailed observation in further studies. The Cereal sector has shown the potential of AWCB in the countries of Central and Eastern Europe. This analysis has shown that the highest yield of the cereal AWCB was generated in the countries located in the Pannonian Basin and in France and Germany.

Future research should put the focus on the combined approach of converting the studied AWCB in biorefineries. The first stage of the combined approach should include experimental research on the production of value-added bio-applications like enzymes, biofuels, biopolymers, pigments and bioactive compounds from the studied AWCB. The second stage is GIS mapping of AWCB at national/regional level that could give a more detailed spatial distribution of AWCB. GIS mapping will be used to find an optimum transport route for AWCB utilisation in the current biorefineries, or in the planning of new biorefineries and local/regional intermediate processing facilities. Finally, the study on the techno-economic analysis of the combined approach will be used to valorise the products and the feasibility of AWCB utilisation.

In many cases, the production of value-added products from specific AWCB may not be economically feasible mainly because of the low market price of products, low quantities and seasonality of AWCB, high transportation costs and water content of AWCB. In order to overcome these problems, specific types of AWCB should be treated on-site by the same producing industry in order to produce intermediate products (such as bio-oil, biogas, bio-juice, etc.) that can be easily stored and transported to the biorefineries which production provides a large-volume product to achieve economies of scale.

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