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Biomass based energy intermediates boosting biofuel production

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The feedstock potential assessment for EU-27 + Switzerland in NUTS-3

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Publishable Summary

1. Summarised feedstock potential

This report presents the analysis of the biomass potential in the EU-27 and Switzerland along with their possible use for energy purposes. Estimates were made for the following types of biomass:

•agricultural (straw, orchard's pruning, hay) and animal residues (manure surplus),
•forestry residues,
•natural conservation matter (urban maintenance of green areas, hay and shrubs),
•roadside vegetation,
•urban and industrial waste (biodegradable municipal waste, selected waste from the food and wood industry).

Estimates were made for spatial unit's NUTS-3, which are small regions with geocode standard for referencing the subdivisions of countries for statistical purposes. This is the first work, which comprehensively reviews the options for obtaining different ranges of biomass in such spatial scale. NUTS-3, due to the approximate representation of the basic economic potentials, are fairly typical units for the development of distributed energy scenarios. The main assumption for the potential modelling of these regions was to use only waste and residues biomass, thus not competing with food production and to respect the principles of sustainable production and environmental protection. This approach is in the line with current trends in the use of biomass, such as the implementation of second-generation fuels and the development of methods to optimise the bioenergy production.

The modelled results of the biomass potential, derived from waste and residues, are illustrated by maps of theoretical and technical potentials in NUTS-3. Additionally normalized potentials are presented for visualisation of the biomass density and spatial variability in larger regions.

On this basis, one can specify the amount of biomass and its spatial density and energy content. In conclusion of this evaluation, it can be said that the most prosperous regions include:

•in France: Pays de la Loire, central region Ile-de-France, Picardy, Champagne,

•in Germany: Nordrhein-Westfalen, Niedersachsen, Sachsen-Anhalt,

•in Great Britain: East Midlands, East Anglia, South East

•Hungary and W-Slovakia

•in Italy: Lombardy and Veneto (in the Po river valley),

The largest potential in the biomass provision based on residues and waste is straw, because of its share related to mass (37%), as well as to energy content (48%). The second largest potential could be generated from residues from forestry (29%, both in terms of biomass weight and energy). The third place is taken by biodegradable municipal waste (17% of the biomass, and 12% of the energy). Other types of biomass do not have much significance in the European energy sector. In certain areas, individual types of biomass may play a regional role.

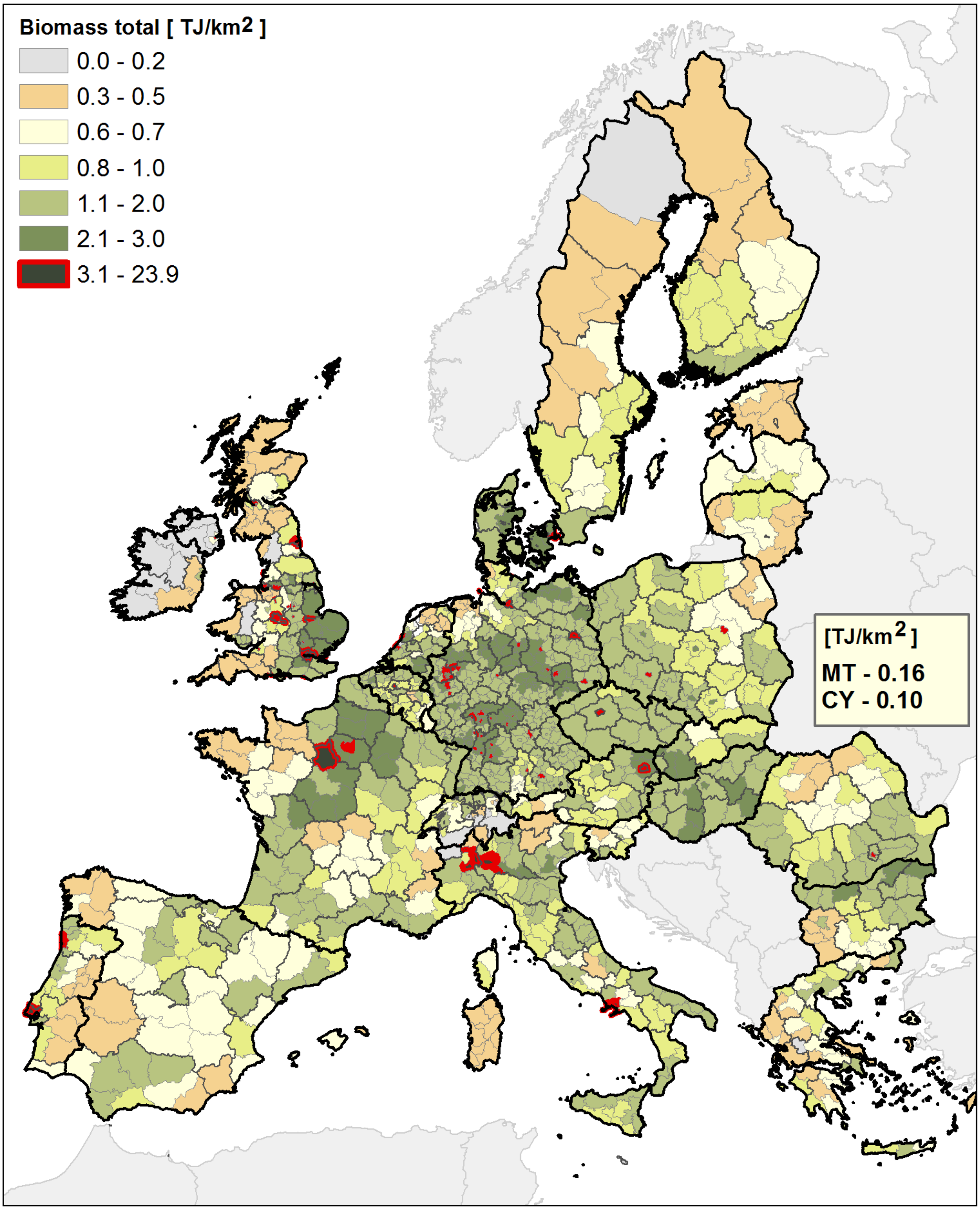

Fig. Energy potentials (density) of biomass in NUTS-3

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Introduction

This report presents the analysis of the biomass potential in the EU-27+ Switzerland, and the possibility of their use for energy purposes. Estimates were made for the following types of biomass:

- agricultural (straw, orchard's pruning, hay) and animal residues (manure surplus),
- forestry residues,
- natural conservation matter (management of urban green areas, hay and shrubs),
- roadside vegetation,
- urban and industrial waste (biodegradable municipal waste, selected waste from the food, and wood industry).

Estimates were made for spatial unit's NUTS-3. This is the first work, which was a comprehensive review of the possibility for obtaining different ranges of biomass in such spatial scale. NUTS-3 due to the approximate representation of the basic economic potentials are fairly typical units for the development of distributed energy scenarios. The main assumption for the potential modelling of these regions was to use only waste and residues biomass, thus not competing with food production and to respect the principles of sustainable production and environmental protection. This approach is in the line with current trends in the use of biomass, such as the implementation of second-generation fuels and the development of methods to optimise the bioenergy production.

A review of existing estimates into the potential of biomass for energy purposes

The Kyoto arrangements drew attention to renewable energy sources. The opportunities of extensive renewable energy sources use have created a need to identify those resources. The primary source of data for global biomass estimation seemed to be FAOSTAT and Eurostat for Europe. However, soon it was realised that the statistics are not sufficient, as accurate modelling requires a completion of a database with spatial data, forecasting scenario as well as specification of raw biomass according to suitability for different applications.

The work, which initiated research on the estimation of demand for biomass energy and its potential, was the analysis published by Lashof and Tirpak, 1990; Halls et al., 1993; Fujino et al., 1999; the Intergovernmental Panel on Climate Change (IPCC), 2000; Rogner, 2000.

This chapter summarises the most important studies on estimates of biomass resources for energy purposes, made mainly in Europe. It also summarises the estimates that were made in recent years for the EU energy policy.

The first results of the modelling were made mainly for the "old Member States" of the EU. In the following years, the study has been extended to other countries with their accession to the Community. From the point of view of covering the identified needs, the former Soviet Union, especially Ukraine was identified as an important partner in obtaining biomass with a great potential of straw and other residues from agricultural sources, as well as Belarus with its high potential of forest biomass. In 2001, Fischer and Schrattenholzer published estimates of the global potential of biomass: residues of plant and animal production, energy crops, forestry and municipal waste. Modelling was carried out over a period up to 2050, taking into account projected changes in land use and the assumption of avoiding conflicts between food and energy production. The bioenergy potential in the base year 1990 was estimated as the equivalent of 5.4 Gtoe, with the actual consumption of 1.1 Gtoe in the base year. The projected growth of this potential on a global scale by 2050, according to the authors should reach 8.8 - 10.8 Gtoe. Modelling was performed for 12 regions, where two regions were representing Europe: Region of Western Europe (WEU) and the region of Central and Eastern Europe (EEU) (excluding the former Soviet Union). In these regions, biomass acquisition opportunities were estimated at a level of between 50 (EEU) and 110 (WEU) million hectares of arable land and 20 (EEU) and 130 (WEU) million hectares of grassland.

The European Environment Agency (EEA) in 2002 published a report on waste management (EEA, 2002). The report characterised the different types of waste and identified their land use strategies. Estimates of waste generation were performed for 15 European countries, especially the "old" EU ones. Based on the statistical data, the base year 1995 was calculated at 115.5 million tonnes. According to the statistical modelling, waste production is expected to rise to 184.4 million tonnes in 2016, but about 80% of the waste must be recovered for recycling (including energy production).

In 2003, a report from the Centre for Renewable Energy Sources and Saving (CRES) was developed for the EU's energy policy (Nikolaou et al., 2003). In this paper, a possibility for using biomass energy, which is residues from agricultural, forestry and municipal waste, were assessed. Subsequently, the estimated potential resources for European Union (EU16) countries and the 10 accession countries (AC) were made. Based on existing data, mainly statistics and regional research, the following types of biomass of agricultural origin which are possible to obtain as a residues for conversion into usable energy were tabulated: lignocellulosic biomass (mainly straw and crop maintenance residues), wet and dry residues biomass from livestock production, energy crops (lignocellulosic, oil crops for biodiesel and starch crops for bioethanol production). Estimates into the availability of raw material have been completed by cost analysis and evaluation of the biomass trend for the availability of biomass between 2010 and 2020. The overall potential of the residues from the plant production in Europe was assessed at 1,064 PJ / year (about 25 Mtoe) for the "old" EU and 306 PJ (about 7 Mtoe) for other countries. Animal residues productions were as follows: 514 PJ EU16 and 132 PJ in other countries. The calculation that corresponds to the current EU is approximately 2,000 PJ in total, which is equivalent to approximately 49 M tonnes of oil (Mtoe). Estimates were supplemented with determination of forest biomass resources. According to the authors, the overall potential is around 1600 PJ per year (EU 16 + 10 AC), of which 650 PJ can come from residues. In the case of biomass from industrial waste, the full potential of this sector has been estimated at around 1,117 PJ and other wastes (municipal and demolition wood) to 846 PJ. Together, on the basis of these estimates from analysed biomass in 26 countries, one can obtain 4,579 PJ. After a year, the report from Nikolaou et al., (2003) has been updated and included in the next report prepared for the European Commission (Siemons et al., 2004). This work after detailed analysis and qualitative parameters of biomass was re-published in 2009 (Panoutsou et al., 2009). Finally, the authors estimated that the overall potential of biomass fuels in the "new EU" in 2010 should be 160 Mtoe and rise to 186 Mtoe in 10 years' time. In the case of agricultural biomass, its potential for 2010 was set at 36.2 Mtoe for solid residues, 15.6 Mtoe for manure and slurry (wet manure) and 2.5 Mtoe for manure (dry manure). According to forecasts for 2020, these values should be increased accordingly to 39.9 Mtoe, 17.3 Mtoe and 2.7 Mtoe.

The modelling methodology of agricultural and forest lands (Agro-ecological zoning approach) usage was introduced by van Velthuizen (2003) at a workshop organised in Ispra by the Joint Research Centre (Join Research Centre - JRC) and the European Commission. This methodology has taken into account a number of criteria for determining the nature and characteristics of production: climate, soil conditions, previous use, the principles of sustainable production and aspects of political, socio-economic and demographic factors. The presentation included a series of thematic maps, summarising the agricultural production capacity in Europe, including land suitability map for the production of energy crops. The analyses were used for the first time by the specific cartographic materials (Fischer et al., 2002). As a base map that defines the production areas, was the map of land cover with a resolution of 1 ha on a European scale (Corine Land Cover).

Renewable energy sources are usually geographically dispersed and call for distributed energy generation. This is reflected in locating power plants with a capacity adapted to local possibilities of using wind, water, solar and biomass resources. In 2004, a report was released on the implementation of ECN REBUS ADMIRE project (de Noord et al., 2004). The report gives information on the technology to generate electricity from renewable energy sources and renewable energy resources potential in wind energy on and off shore, photovoltaic, hydropower and geothermal, biomass and biodegradable waste. These resources are rated in the time horizon to 2050 (2000, 2030 and 2050). In addition, the costs of the various ranges of biomass were estimated. Despite the many studies on the scale of the Netherlands, Europe and the world, this report is not very consistent. The different types of renewable energy were estimated for different individuals, different scenarios and different time horizons. There is also a lack of a summary for the results.

In 2005, at a request from the German Ministry for the Environment, Nature Conservation and Nuclear Safety, a report was developed on the strategy for the sustainable use of biomass in the European context (Thran et al., 2005). This document was created as a contribution to the debate about the German plan for developed policy guidelines for the use of biofuels. The authors in detail modelled the different scenarios for obtaining biomass for energy in Germany, and then compare the obtained results with the estimates made for the other countries of the European Union and the candidate countries too. This work has characterised in detail the potential of forest biomass, agricultural residues and biomass, current and future demand for this type of renewable energy. Economic and prognostic scenarios were used for estimating the possibility of obtaining biomass in the future to 2020. As a result, time stability has been demonstrated for forestry and forest residues as biomass resources at 7500 PJ for EU-28. In the case of agricultural biomass, the instability of the time was indicated. In this case, the possibility of obtaining such material will be determined by many factors such as economics, politics (mostly tax), advances in technology and the growing global demand for food. Therefore, the possible potential of agricultural biomass in 2020 may range from 2600 to 7800 PJ, and 75% of supply should come from the countries of the "old Member States".

In 2005, two important works were published, which analysed the potential of the most important types of solid biomass from agricultural sources, which can be a by-product or target product. In both of these papers is an important part for the use of geographic information systems as a tool for data geoprocessing. In the first case, the availability of straw was estimated, and in the second part, the production capacity of lingo-cellulolytic perennial plants was found. Straw seems to be the most available source of biomass derived from the cultivation of cereals. In the work of Edwards et al. (2005), they estimated a surplus that can be used for energy production, and pointed out the best locations for power plants with a capacity of 38 MW. Localisations were identified, taking into account the resource base and the cost of transportation. The authors assumed that one plant size of 38 MW requires 200,000 tonnes of straw per year, which should be obtained from no further than 50 km distance from the power plant. In general, the energy potential of straw in the 27 EU countries was set at 820 PJ, while guided by the above assumptions, effectively can be used only part of it giving 230 PJ of energy. An analysis of the straw potential was done by the Institute of Environment and Sustainable Development under JRC scientific and technical support to EU policies in the field of environmental protection and sustainable development. In addition to straw, a rich biomass source of energy crops can be provide. Growing energy crops however, carries serious implications for the environment and even local and global economy’s. With this in mind, estimates into potential energy crops carry many limitations, in both environmental and economic. The most complete modelling of the potential production of this type of biomass to date has been conducted by Fischer (2005). The modelling was based on assumptions determining agro-ecological zones. The construction of a database is geared towards the possibility of using geoprocesing spatial analysis tools. Thematic layers to the system were introduced such as: soil map, digital terrain model, physiographic map, map land cover map of settlement, communication and administration. These layers allow the modelling of space availability for scenarios in locating bioenergy crops. Climate data and climate change scenarios allowed refining the estimates of potential yields and cultivation changes associated with projected climate change. Modelling was supplemented with information on agronomic and environmental restrictions. The results were taken from the assessment of cereals, willow, miscanthus and poplar potential sources for the production of energy for the regions of Eastern Europe, the former Soviet Union and Mongolia. The modelling was carried out in the spatial resolution grid of size 1 km to 5 km in Europe and other regions. For ten Eastern European countries (BG, CZ, EST, H, LT, LV, PL, RO, SK, SLO), the assessed potential of bio-energy crops amounted to 2018 PJ of energy, whereas 354 PJ was calculated for Poland. An assessment into the feasibility of biomass production in Central and Eastern Europe was detailed in next work of scientific groups, cooperating with the International Institute for Applied Systems Analysis (IIASA) and the Copernicus Institute, which have used detailed national data (van Dam et al., 2007). The estimates were performed for nine countries: EST, LT, LV, PL, RO, BG, H, CZ and SK, taking into account the use of residues from agriculture, forestry, wood and biomass from energy crops. For some scenarios, the potential of bioenergy from 2 to 11.7 EJ was obtained. The cooperation of group was led by Gunther Fischer (IIASA) and Andrea Faaij (Copernicus Institute) and summaries of this work were published in the journal "Biomass and Bioenergy" (Fischer et al., 2010 a, b). The first part characterises the capacity to produce biofuels from agricultural biomass, most of which is lignocellulosic, and derived from industrial crops. Analyses were performed using geoprocessing methods for geographical databases with a resolution of 1 km^2 in the pan-European scale. The results were summarised for the EU, Switzerland, Ukraine and Belarus. In the second part of this work, simulating the possible potentials of three scenarios was carried out by: (i) a baseline scenario, reflecting the assumptions advocated by the European Union's energy policy and respects trends in environmental protection, (ii) a pro-environmental scenario, which assumes sustainable agricultural practices and the need to preserve biodiversity, (iii) the ability of the pro-energy, assuming the increased use of agricultural area, including the extraction of biomass from grasslands. Modelling global biomass resources, initiated by Fischer and Schrattenholzer's in 2001 was completed four years after with Hoogwijk group (Hoogwijk et al., 2005). The time horizon was extended from 2050 to 2100. The energy crops potential was modelled for the three categories of land use: arable land uncultivated, land with low productivity and set-aside land. Four SRES prognostic scenarios (A1, A2, B1, B2) developed by the IPCC (2000) were used and implemented to the model IMAGE 2.2 (Nakićenović and Swart, 2000, de Vries et al., 2000). The study was conducted at grid resolution of 0.5 x 0.5 degrees of latitude and longitude. Potentials were determined as:

• theoretical - corresponding to the upper ceiling of potential net productivity (Hall et al., 1993),

• geographical - by which the authors understand the biomass obtained from the area available for the production of energy crops including the exclusion of areas intended for other uses (e.g. food). The main feature of the simulation is to model the spatial conducted using mapping data and the resulting map of the established scale,

• technical - as a Geographical potential reduced by losses associated with the conversion of primary biomass resources for energy feedstocks. In the design of the algorithms for the conversion of biomass to electricity, results from Faaij et al., 1998; Dornburg and Faaij 2001, while for the production of fuels, results from van Hooijdonk, 2002; Tijmensen et al., 2002; Hamelinck et al., 2004 were used,

• economical - a subset of technical capacity, meeting the criteria of economic efficiency of converting biomass into energy (Hoogwijk et al., 2004)

• implementation potential - the maximum economic potential resource that can be used due to demand and the technical and logistical capabilities.

The results are summarised for 17 regions, including Western Europe and Eastern Europe (excluding the former USSR). The main premise of the research is expected to be the cost effective production of energy crops on farmland characterised by low productivity. The greatest potential are demonstrated for cultivated agricultural land, and depending on the scenario in Western Europe it will be the possible to obtain 9-17 EJ per year, respectively, in Eastern Europe 9-12 EJ per year. In the case of fallow land in Western Europe, the potential was estimated at 4-5 EJ (scenarios A1 and A2) and one EJ scenario B1 and B2. The continuation of these studies was the potential prediction of forest biomass in 2050, carried out by Smeets and Faaij (2007). Theoretical modelled potentials, technical, economic, environmental, ecological and economic results are presented for 11 regions (FAO, 2013).

There are also results for the individual countries. In the same year, work from those authors was published, endearing comprehensive modelling of the global potential of bioenergy in 2050 (Smeets et al., 2007). At the beginning of the first decade of the twenty-first century, a number of studies regarding biomass and renewable energy potentials were made. In the initial phase, the studies had significantly different methodology, which resulted in a variety of estimates. During these years, there was also the enlargement of the European Union with new countries. Therefore, a common strategy for the use of renewable energy required re-estimates of potential for the "new" EU countries. Ericsson and Nilsson (2006) undertook the work to systematize the methodology and carry out a more detailed assessment of the agricultural biomass potential in Europe. Analyses were performed for the 15 European Union countries (EU-15), eight of the new Member States and two candidate countries as well as for Belarus and Ukraine. They described five scenarios for short, medium and long-term horizons for the use of agricultural raw materials (crop residues, energy crops) and a surplus of agricultural land that can be used in the production of biomass. The authors showed a possibility to collect in the "new" EU, up to 17.2 EJ of energy per year. In light of these estimates, the European Commission in 1997 set up a White Paper for a Community Strategy and Action Plan, which stated that producing 5.6 EJ "green" energy per year (plan to 2010) should not be a problem. However, it also drew attention to delays in the implementation of the use of bioenergy in order to achieve its objectives.

In 2006, the European Environment Agency published its first complete report on the possibilities for the production of bio-energy in Europe (EEA, 2006). The main objective of the report and undertaken analysis was to evaluate the technical potential realizable biomass for energy purposes, while assuming no increase in adverse effects on the environment. The modelling assumes a number of environmental demands. The main ones are:

• at least 30% of agricultural land we be dedicated for suitable agricultural production and will not threaten environment,
• green areas, pastures and olive groves have been planted extensively will not be converted to arable land,
• approx. 3% of intensive cultivation will be set aside for the establishment of ecological habitats (until 2030)
• energy crops cultivation that do not pose a threat to the environment will be implemented,

• the area of forest under protection will not be reduced, and also in this area the acquisition of residues biomass from cutting and cleaning of forests will not take a place,

• in the remaining areas of forest, biomass residues are removed in a sustainable way, without acquiring leaves and roots,

• tree logging in forest areas will be reduced and there will be an increase of protected areas,

• strategies will be implemented to minimise the generation of waste.

The implementation of these guidelines according to the authors will allow the possibility of increasing the biomass potential with the forecast of 2010, to about 190 Mtoe to 295 Mtoe in 2030. The increase of gathering biomass capacity will take place through the conversion of production in rural areas (energy crops), with no increase in the use of forest (40 Mtoe), and the receipt of other residues (agricultural, industrial and municipal) constant at around 100 Mtoe. The analysis did not include the balance of the carbon cycle and GHG emissions associated with the operation and use of biomass. EEA report of 2006 was supplemented in the following year for three consecutive reports: forest biomass resources that can be mobilised for energy without negative impact on the environment (EEA, 2007a), obtaining sustainable energy from agriculture (EEA, 2007b), and the forecasts of the municipal waste size generated in the period 2005-2020 (EEA, 2007c).

In 2008, the results of research on the spatial diversity of biomass productivity in grassland were published (Smit et al., 2008). This work gave rise to the geographical diversity of the theoretical potential of biofuels based on hay surplus and for modelling the technical and economic potential of this raw material sourcing.

Forests are a huge reservoir of biomass. However, due to environmental considerations and the need to allocate high quality wood for various industries (not related to energy), the use of forest biomass as an energy resource must be limited and subject to many restrictions. Direct firing of wood, as well as the extraction of biomass energy from agricultural areas and its imports from the 'third' world is questionable from a moral point of view. This is reflected in the reports of humanitarian organisations as well as national and European legislation (reports, Action Aid, Article 17 of Directive RED). For these reasons, most scenarios estimate and take into account the potential of forest biomass in the foreground need to ensure an existing forest area (or the systematic increase) and mainly sourcing and wood residues for energy purposes. The most important developments in recent years devoted to the possibility of obtaining forest biomass was the work of Asikainen et al., 2008; Mantau et al., 2008 and

2010; Steierer, 2010. A wide collection of data on forests and forestry are in the database: TB FRA (2000, 2005) and FORESTATA.

The accession of the new Member States to the EU, and a more forceful conduct of environmental policies as well as the implementation of renewable energy as a competitor to the existing conventional fuels, has created a need for a more complete resource of estimates for renewable energy sources, especially biomass. This was achieved by the financing of large projects, mainly from funds of 6th and 7th Framework Programme of the European Union, and directly by the European Commission in the framework of the mechanism for the Intelligent Energy - Europe: for a sustainable future (IEE). The most notable projects include: RENEW, BEE, REFUEL, BiomassFuture.

RENEW project (6FP, 2004-2007), the primary mission of the project was to characterise the different concepts of fuel production from biomass. Estimates of straw potential and energy crops were made for NUTS-2units. The potential of forest biomass residues as well as the waste from the timber industry were made for NUTS-0 units. The possibility of obtaining biomass also characterised regionally for individual countries. The project results are published on the website (http://www.renew-fuel.com).

BEE Project (7FP, 2008-2010), the project was to collect and harmonise the existing methodologies to assess biomass energy in the EU and neighbouring countries, as well as existing databases (Böttcher et al., 2010). The project results are published on the website (http://www.eu-bee.com). The BEE twinning project was the CEUBIOM project, which includes geographic data classification methods and data obtained remotely, to assess the potential of biomass (http://ceubiom.org).

The REFUEL Project (IEE, 2006-2008) was designed to identify the biofuels market, the creation of biofuels 'road map' consistent with EU policy in collaboration with stakeholders from fuel industry and biomass producers. The result of the project was also estimating the potential of European biofuel production (de Wit and Faaij, 2010, Fischer et al., 2010 a, b). According to the authors, Europe can produce from 1.7 to 12.8 EJ per year from energy crops biomass. In addition, residues from agriculture and forestry should provide fuel at a rate of 1.4-5.4 EJ and 3.1-3.9 EJ per year. In these calculations, the costs of such energy conversion 5-15 euro / GJ for the first-generation fuels; 1.5-4.5 euro / GJ for second-generation fuels and 1-7 euro / GJ for agricultural residues and 2 - 4 € / GJ for forestry residues were taken into

account. Similar to previously cited estimates in the REFUEL project were assumed different scenarios, resulting in fairly wide ranges specified energy potentials and expected costs.
The Biomass Future project (IEE, 2010-2012), was made to identify the key factors that may affect the biomass supply, demand and utilisation over the next twenty years (meeting the objectives RED). In addition, it is a recognition of the European market for heat, cogeneration and transport markets, the dynamics of supply and demand, the impact of indirect land use change, water use and social aspects of the future supply of biomass, etc. One of the important results of the project is the Atlas of the biomass potential in Europe (Elbersen et al., 2012).

In the paper are summarised a number of cartographic studies presenting a diversity of potentials of biomass generalised for individuals NUTS-2. Estimates were performed for time horizons 2010, 2020, 2030, assuming various scenarios.

The current perspective for biomass use seems to move from energy crops and forest wood with high competition to food or material biomass wood use towards lignocellulosic crops, residues from agriculture and forestry and bio-wastes. This direction is the most environmentally friendly option and does not cause moral controversies, as in the case of burning grain or importing timber from tropical and subtropical regions for the purposes of its co-firing with coal in boilers. The development of technology for efficient conversion of bio-waste to bioenergy (electricity, gaseous, liquid or solid fuels) is supported by the European Commission, mainly in the form of funding for research and development projects (e.g. BioBoost: http://bioboost.eu). On behalf of the Commission, assessments are also carried out into the residues of biomass by the JRC. The result of this work was preliminary an assessment of the straw potential carried out by Edwards et al. (2005), which was completed in the work of Scarlat et al. (2010). The JRC analyses had focused on an assessment into the amount of residues generated by agriculture, the collection, use and availability for energy purposes. The studies take into account the production of cereals, long-term variability of yield, differences in crop-harvest residues and the need to preserve the fertility of the soil by leaving necessary amounts of crop residues on the field. The results showed a significant spatial and temporal variability of the availability of biomass for energy purposes. The average potential of this product in 27 EU countries was estimated at 1,530 PJ per year. However, in subsequent years, these values can range from 1090 to 1900 PJ. These values are an average of 3.2% of the consumed energy. Taking into account the possible variation in the supply of biomass, there is an expected shortage of raw materials in some years when the cereal production is e.g. weather impacted.

Table 1. Chronological list of the most important work with the potential of biomass in Europe

Year	Authors	Biomass type	Period	Spatial range
2001	Fischer and Schratten-holtzer	Plant production, biomass from grasslands, forest biomass, animal production residues, and municipal waste	1990, 2050	11 regions, including three regions EU: EU West, EU Central and East, the former Soviet Union
2002	EEA	Biodegradable municipal waste	1995, 2016	AT, BE, DK, FR, DE, EL, IE, IT, LU, NL, NO, PT, SP, SE, UK
2003	Nikolaou et al.,	Residues from crop production, livestock, forestry, industrial and municipal waste	2000	EU 16 + AC: (EE, LV, LT, PL, CZ, SK, SI, HU, RO, BG, CY)
2003	van Velthuizen	Agricultural biomass, perennial energy plantations	2000	EU
2004	Siemons et al.,	Residues from crop production, livestock, forestry, industrial and municipal waste	2000	16 EU + AC: (EE, LV, LT, PL, CZ, SK, SI, HU, RO, BG, CY)
2004	de Noord et al.,	Energy crops, forest biomass, manure (cattle + poultry, pigs and sheep), residues from production of cereals and oilseeds, municipal waste, industrial waste	2000, 2030, 2050	15 EU + NO
2005	Fischer et al.,	Cereals grain miscanthus, poplar	2005	EU 10: BG, CZ, EE, HU, LT, LV, PL, RO, SK, SI
2005	Edwards et al.,	Straw	2005	EU-27
2005	Thran et al.,	The potential of forest, agricultural and biomass residues	2000, 2010, 2030	EU 25 + BG + RO + TR
2005	Hoogwijk et al.,	Theoretical, geographical,	2050-	Glob: 0,5^{o}x0,5^o,

		technical, implementation and economic potential of different types of biomass	2100	17 regions (including Europe W and E)
2006 2007 a/b/c	EEA	Energy crops, forest biomass, agricultural residues and waste (industrial and municipal)	2010-2020-2030	EU 15, EU 25
2006	Ericsson and Nilsson	Residues from forestry and agriculture, energy crops	2000-2010	EU 25 (EU-27 excluding CY and ML) + BU + UA
2007	Smeets and Faaij	Forest biomass and residues from forestry	2050	Global -11 regions
2007	Smeets et al.,	Energy crops, forest biomass, biomass residues	2050	Global -11 regions
2007	van Dam et al.,	Residues from agricultural production and forestry, wood, energy crops	2007	EE, LT, LV, PL, RO, BG, HU, CZ, SK
2008	RENEW	Residues from forestry and wood, straw, energy crops	2000-2020	27 EU + CH – (MT + CY)
2008	Mantau et al.,	Forestry biomass	2005-2010-2020	EU-27
2008	Asikainen et al.,	Forestry biomass	2007	EU-27
2008	Smit et al.,	Grassland productivity	2008	EU + TR
2009	Panoutsou et al.,	Residues from production crops, livestock, forestry, industrial and municipal waste	2010-2030	EU-27
2010 a/b	Fischer et al.,	Agricultural biomass (energy crops, industrial crops, straw)	2000-2030	EU-27, NO, CH UA, BU
2010	De Wit and Faaij	Estimates of the cost and supply of lignocellulose biomass (SCR and grass), industrial crops, agricultural residues (straw), forest biomass	2005-2030	EU27 + UA
2010	Mantau et al.,	Forest biomass	2005-2010-2020-2030	EU-27
2010	Steierer	Forest biomass	2005	EU-27
2010	Scarlat et al.,	Agricultural residues (straw)	2010	EU-27
2011	Vis et al.,	The harmonisation of all published methods and estimates of biomass resources	2010	EU-27 + neighbouring countries
2012	Elbersen et al.,	Energy crops, manure, straw, other agricultural residues, forest biomass, wood waste, biomass roadside, waste from the food industry, municipal waste,	2010-2020-2030	EU-27 (NUTS-2)

code names of countries in annex E

There is high significance in the regional studies that allow verifying and updating the pan-European models is taken into consideration. Examples of spatial studies that have been conducted may be work from:

• presenting the application of the system modelling and GIS in estimating biomass (Parikka, 2000)
• evaluating the potential of biomass for energy production (Voivontas et al., 2001, Bravo et al., 2007),
• in the field of the economics of the production and use of biomass (Ahtikoski et al., 2008),
• in the field of logistics (Frombo et al., 2009),
• evaluating the possible potential of biomass from energy crops (Fiorese and Guariso, 2010),
• evaluating the possible potential of biomass from forest management (Vainio et al., 2009).

Biomass potential by country

The potential of biomass has been analysed by many authors. The technical potential vary considerably between studies, as a result of a number of different factors taken into account in the analysis. The differences are due to the definitions of agricultural residues, different time, availability of data, various restrictions included in the models, etc. In the last few years several studies about straw potential in Europe were run (Table 2). The highest potential of straw for Europe was evaluated by Nordenstaaf and Thörnqvist, 2008 while the lowest by Bottcher et al., 2010.

Table 2. Straw potential methodology

	Statistical data	**Analised countrys**	**Resolution**	**Straw to grain ratio***	**Straw for animals**	**Environmental constraints (Straw for soil)**	**Straw for other purposes**
Edwards et al., 2006	Eurostat	EU 25+2	NUTS-2, grid 5x5 km	0.6-0.94	+	+	+
Kunikowski et al., 2006	Eurostat	EU 25	NUTS 0-1-2	0.6-1.0	+	+	+
Nordenstaaf and Thörnqvist, 2008	Eurostat	AT, DE, FI, DK, PL, SE	NUTS-1	1.2 -1.5	+	+	+
Scarlet et al., 2010	Eurostat	EU-27	NUTS-1	0.8-1.2-	+	+	+
Bottcher et al., 2010	Eurostat	EU-27	NUTS-2	0.5-0.9	+	+	+
Elbersen et al., 2012	Eurostat	EU-27	NUTS-2	-	+	+	+

‘*for cereals only

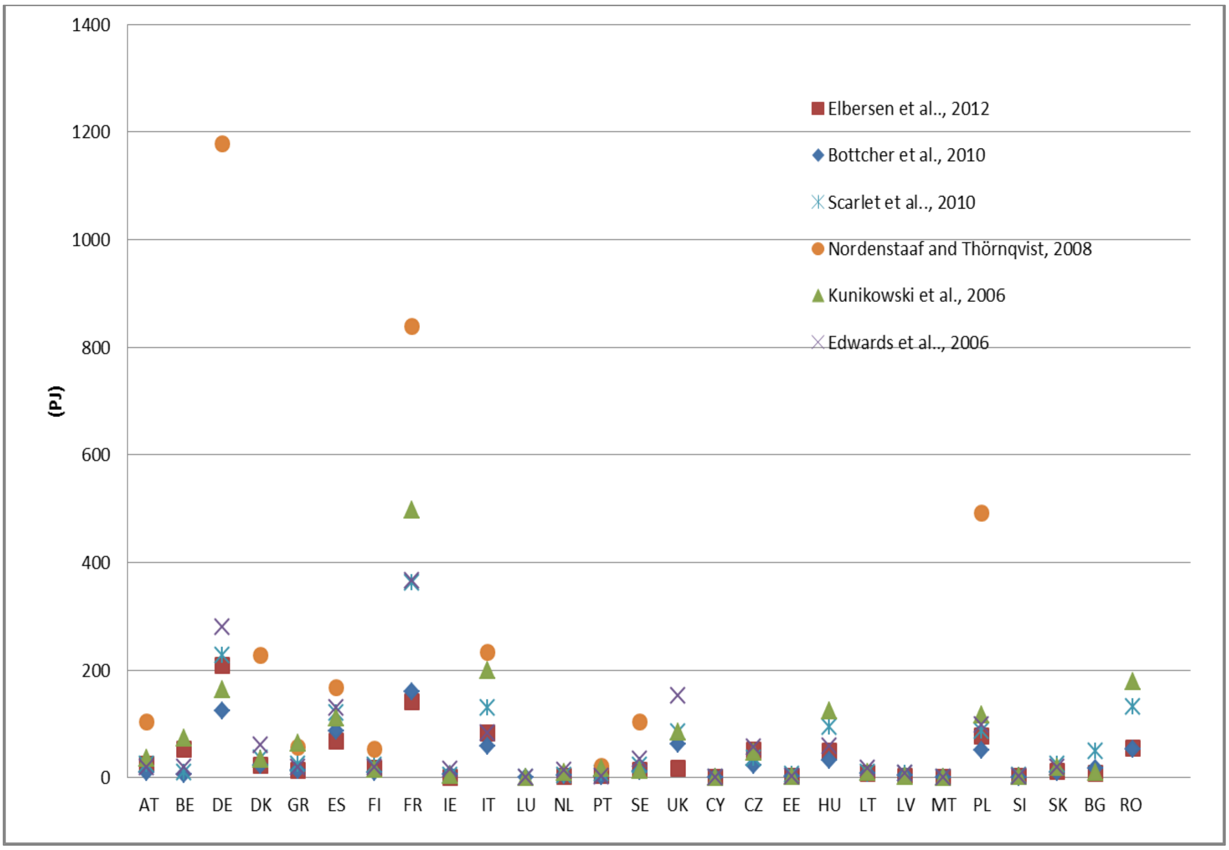

Figure 1. Straw potential – overview EU-27 + CH

Studies on the potential of forest biomass vary considerably (Figure 2). The highest potential was calculated by Asikainen et al., 2008 while the lowest by EEA 2007. The average potential of forestry residues amounted at 1695 PJ. The highest potential in all compared publication was found in AT, DE, FI, FR, IT, SE, CZ, PL.

All reviewed studies of biodegradable municipal waste are based on calculations prepared for the landfill directive (formally Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste). The directive is a European Union directive issued by the European Union to be implemented by its Member States by 16 July 2001. The Directive is intended to prevent or reduce the adverse effects of the landfill of waste on the environment. According to the Directive, the amount of biodegradable municipal waste must be reduced to 50 % in 2009 and to 35 % in 2016 (compared to 1995 levels). The landfill directive is aimed at the diversion of biodegradable municipal waste away from landfill. The targets are based on historical quantity generated in 1995.The highest biodegradable municipal waste potentials were modelled by Panoutsou et al., 2009.

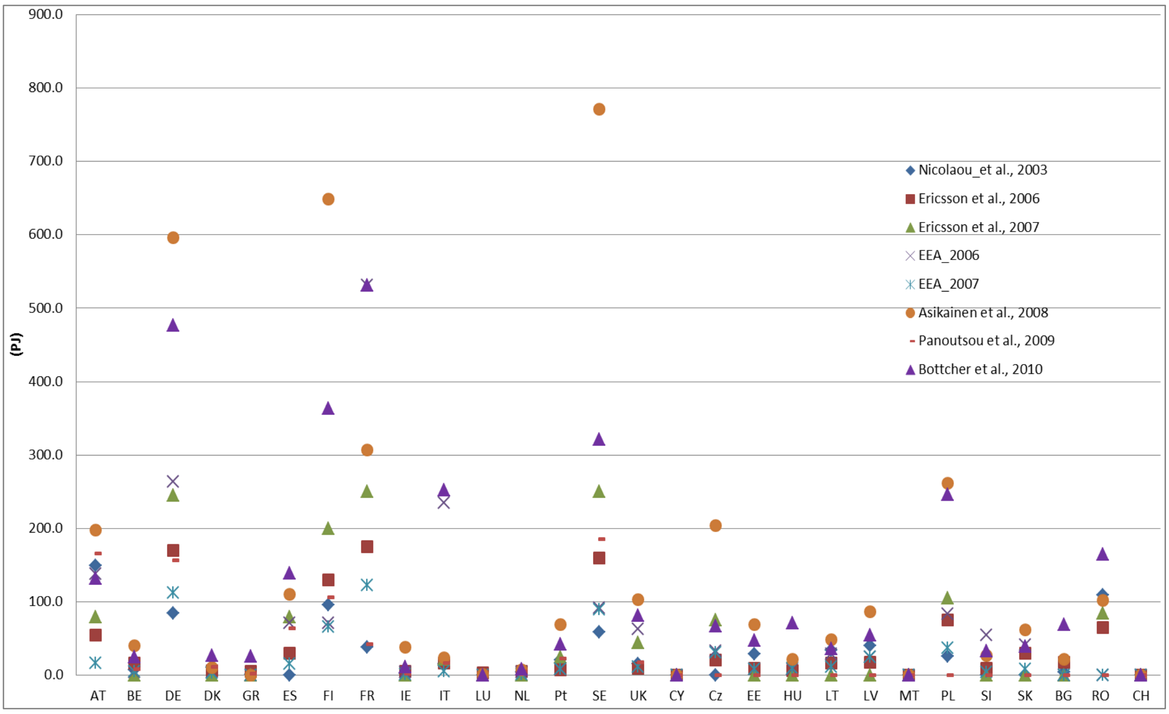

Figure 2. Forestry residues potential – overview EU-27+CH

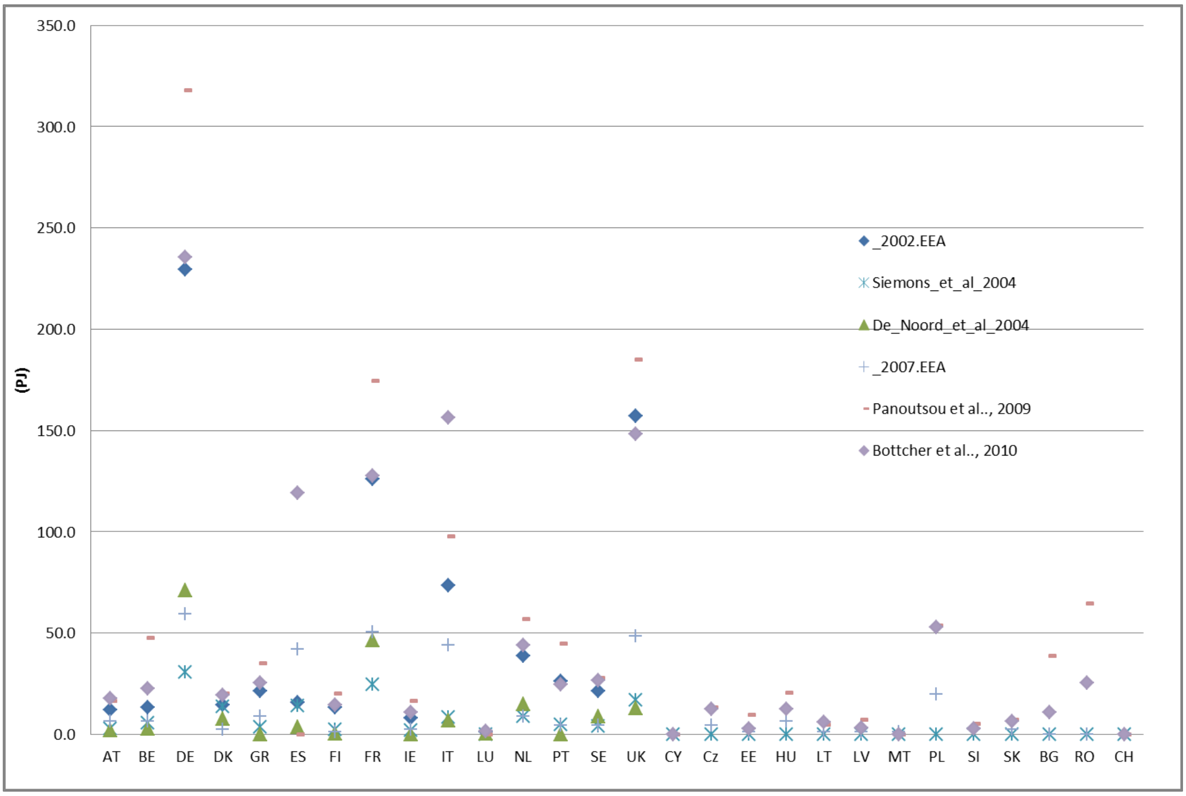

Figure 3. Biodegradable municipal waste potential – overview EU-27+CH

Databases

The databases were collected based on a review which was done according to the sub-task T.1.1.1 assumptions. Several statistical and geo-information values were collected and added into geographical information system (GIS). The crucial sources are described below:

EUROSTAT–is the statistical office of the European Union situated in Luxembourg. Its task is to provide the European Union with statistics at European level that enable comparisons between countries and regions,

Eurostat has developed statistical databases on different kinds of agricultural and forestry production, and waste production by municipalities and food industry. The data is collected for different spatial scales and periods. Because the modelling biomass feedstock is taken from many input data of Eurostat, it has to be downscaled from NUTS0-1-2 into NUTS-3. The next problem is lack of data for particular years or non-coherent methodology of data collection. http://epp.eurostat.ec.europa.eu/portal/page/portal/about_eurostat/introduction

RENEW Project

Estimations in the Renew project were performed for the EU-25 and Accessioned countries (Bulgaria and Romania) at a regional level. The Renew scenarios were applied. European statistics were used as common source of input data. The results of calculations were provided in 1000 tons or PJ/year. The RENEW project collected the following databases: straw, forestry and perennial crops.

http://www.renew-fuel.com/home.php

BEE Project

The Biomass Energy Europe (BEE) project was initiated to harmonise methodologies for biomass resource assessments for energy purposes in Europe and its neighbouring countries. The harmonisation will improve the consistency, accuracy and reliability of biomass assessments for energy, which can serve in the planning of a transition to renewable energy production in the European Union. The major focus of the project has been on the methodological and dataset harmonisations, fostered by on-going research of a multidisciplinary team of project participants, and on the opportunities of utilising both earth observation, and terrestrial data for biomass assessments in addition to the integration of multiple data sources. The relevant sectors that have been investigated are forestry, energy crops, residues from traditional agriculture and waste. The project was carried out during 2008 - 2010.

http://www.eu-bee.com/

The European Environment Agency (EEA) was established to support sustainable development and to help achieve significant and measurable improvements in Europe's environment. The European Environment Agency has the task of providing policy-making agents and the public with reliable and comparable information on the environment, in cooperation with the European Environment Information and Observation Network. The Agency provides the Corine Land Cover and Natura 2000.

http://www.eea.europa.eu/

Corine Land Cover is one of the subjects included in CORINE system to collect information on the forms of land use. The main sources of information are satellite images from Landsat 7 satellites taking pictures in 30 meters resolution and then the IRS and Spot 4 Images are interpreted by using aerial photographs and topographic maps.

Raster: http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2

Description:
http://www.dmu.dk/fileadmin/Resources/DMU/Udgivelser/CLC2000/technical_guide_addenum.pdf

Natura 2000 is the centrepiece of the EU’s nature & biodiversity policy. It is an EU wide network of nature protection areas, which was established under the 1992 Habitats Directive. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. It is comprised of Special Areas of Conservation (SAC) designated by Member States under the Habitats Directive, and also incorporates Special Protection Areas (SPAs) which they designate under the 1979 Birds Directive. Natura 2000 is not a system of strict nature reserves where all human activities are excluded. Whereas the network will certainly include nature reserves, most of the land is likely to continue to be privately owned and the emphasis will be on ensuring that future management is sustainable, both ecologically and economically. The establishment of this network of protected areas also fulfils a Community obligation under the UN Convention on Biological Diversity. Natura 2000 applies to Birds Sites and to Habitats Sites, which are divided into biogeographical regions. It also applies to the marine environment.

Organisation for Economic Co-Operation and Development (OECD) The mission of the OECD is to promote policies that will improve the economic and social well-being of people around the world. OECD have the Compendium, revised regularly, presents data linking pollution and natural resources with activity in such economic sectors as energy, transport, industry and agriculture. It shows the state of air, inland waters, wildlife, etc., for OECD countries and describes selected responses by government and enterprises.

http://www.oecd.org/document/40/0,3746,en_2649_34283_39011377_1_1_1_1,00.html

The World Data Centre for Remote Sensing of the Atmosphere, WDC-RSAT

Primary Productivity - Data on the Net Primary Productivity (NPP) were used as information about yield in the case of an estimation into biomass residues from permanent cropping areas (logging fruit trees, berry plantation, olive groves, vineyards) and potential biomass from natural conservation (protected grass lands and green urban areas). NPP values were also used for modelling possibility obtaining of biomass from road sites.

The database simulation was based on the Biosphere Energy Transfer (BETHY/DLR) model (Knorr, 1997, Wiβkirchen, 2005). It is a fixed grid map in a rectangular projection annotated with latitude, longitude and WGS84 data, with a spatial resolution of $1km^2$. The total size covering Europe and North Africa is 8,016 columns by 5,010 lines. Monthly and annual NPP is calculated for 11 different land cover classes as well as for an overall NPP. This product is currently in a preoperational status. Currently for Europe, both products are available for the years 2000 to 2007 and 2010.

The BETHY/DLR model was developed by The World Data Centre for Remote Sensing of the Atmosphere, WDC-RSAT. Since 2003, the German Remote Sensing Data Centre (DFD) of the German Aerospace Centre (DLR) hosts and operates the WDC-RSAT under the nongovernmental auspices of the International Council for Science (ICSU).

The BETHY/DLR model (Knorr, 1997, Knorr and Heimann 2001, Wiβkirchen, 2005) belongs to the family soil-vegetation-atmosphere-transfer (SVAT) models and is used to simulate NPP over Europe. Input data are the "GLC2000" land cover classification (http://bioval.jrc.ec.europa.eu/products/glc2000/legend.php) and 10-day-composites of LAI, which are both based on SPOT/VEGETATION. Meteorological data (temperature, radiation, precipitation and wind speed) are also required and are provided by the European Centre for Medium Range Weather Forecast (ECMWF). Furthermore, static information as the Harmonised World Soil Database (HWSD) from the International Institute for Applied Systems Analysis (IIASA) and an elevation model (SRTM) are used.

The model is used for simulations of the European NPP with a resolution of 1 km^2, which is the resolution of the used land cover classification and LAI. Currently, BETHY/DLR is capable of simulating NPP of 33 inherent vegetation types, including major crop and tree species (Tum and Günther, 2011). The internal parameterisation of BETHY/DLR allows a given vegetation class to be represented as a fraction of two BETHY/DLR vegetation types. The model was validated for agricultural areas in Germany and Austria (Tum and Günther, 2011) in addition to Germany′s forests (Tum et al., 2011).

For simulating the biomass potential, an average value from for the years 2000 to 2007 and 2010 was calculated. On the original map, the urban areas were masked. Because of this, in the case of urban areas, the average (major) values were estimated from the neighbourhood (at radius of 15 km) of each urban pixel.

http://wdc.dlr.de/data_products/SURFACE/npp.php

OpenStreetMap (OSM)

OpenStreetMap is a collaborative project that has been developed in order to create a free editable map of the world. Two major driving forces behind the establishment and growth of OSM have been non-restrictions on the use or availability of map information across most of the world and the advent of inexpensive portable satellite navigation devices.

The maps are created using data from portable GPS devices, aerial photography, other free sources or simply from local knowledge. Both rendered images and the vector dataset are available for download under a Creative Commons Attribution-ShareAlike 2.0 licence.

OSM generally provides information about roads network, but the other information on a land use and city's population are combined into database.

www.openstreetmap.org

ESRI data

Demographics database ensures you have the most accurate current year estimates and 5-year projections for categories including:

Population—Such as sex, age categories, population growth, population density, employed
Households (HH)—Such as total HH, persons per HH, average HH size, dwellings
Purchasing power (PP) – within and among statistical units, PP growth, GDP
In case of Europe, the data is tabulated as NUTS-3 regions.

SAGE

SAGE is a Research Centre of the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison that have developed many of maps, computer models and datasets to describe the behaviour of Earth's terrestrial ecosystems, hydrological systems, and climate.

http://www.sage.wisc.edu/mapsdatamodels.html

SAGE // Crop Calendar Dataset this dataset is the result of digitising and geo-referencing existing observations of crop planting and harvesting dates. We then derived climate statistics (e.g., the average temperature at which planting occurs in each region) by merging these crop calendar maps with monthly climatologies from CRU [Sacks et al., 2010].

http://www.sage.wisc.edu/download/sacks/crop_calendar.html

SAGE // Fertiliser dataset – this is a database where the authors calculated spatially explicit fertiliser inputs of nitrogen (N) and phosphorus (P) by fusing national-level statistics on fertiliser use with global maps of harvested areas for 175 crops. They also calculated spatially explicit manure inputs of N and P by fusing global maps of animal densities and international data on manure production and nutrient content. Significantly higher application rates were found for both fertilisers and manures in the Northern Hemisphere, with maxima centred on areas with intensive cropland and high densities of livestock. Furthermore, nutrient use is confined to a few major hot spots, with approximately 10% of the treated land receiving over 50% of the use of both fertilisers and manures. The authors' new spatial disaggregation of the rich International Fertiliser Industry Association (IFA) fertiliser-use dataset will provide new and interesting avenues to explore the impact of anthropogenic activity on ecosystems at the global scale and may also have implications for policies designed to improve soil quality or reduce nutrient runoff (Potter et. al, 2010)

TBFR-2000

TBFR-2000 is database that includes statistical and descriptive information together with analysis undertaken by high level experts in the following thematic areas: Area of Forest and Other Wooded Land, Ownership and Management Status, Wood Supply and Carbon Sequestration; Biological Diversity and Environmental Protection; Forest Condition and Damage; and Protective and Socio-Economic Functions.

Geographical Information System (GIS)

A geographic information system is a system designed to capture, store, manipulate, analyse, manage and present all types of geographical data. The acronym GIS is sometimes used for geographical information science or geospatial information studies to refer to the academic discipline or career of working with geographic information systems [ESRI 2011]. In the simplest terms, GIS is the merging of cartography, statistical analysis and database technology.

ArcGIS v.9.3 was used as a GIS application for conducting spatial analysis and geoprocessing.
SHP file format was used as a representation of vector data.
IMG file format was used as a representation of raster data.
DBF/XLS file format was used as a representation of statistic (tabulated) data.
All data were combined within the bioboost.mxd project. Geo-processing was conducted within geobase (gdb).

As one of the demands, bioboost.mxd can be converted to a free of charge Quantum GIS (QGIS). It is a user-friendly Open Source Geographic Information System (GIS) licensed under the GNU General Public License. QGIS is an official project of the Open Source Geospatial Foundation (OSGeo). It runs on Linux, Unix, Mac OSX, Windows, Android, and supports numerous vector, raster, and database formats and functionalities. QGIS is a cross-platform free and open source desktop geographic information systems application that provides data viewing, editing and analysis capabilities.

NUTS-3 – the official, Eurostat SHP map contains over 1461polygons. From this base, a subset of 1313 NUTS-3 was extracted. Selected data refer to the DOW (25EU + Switzerland). In addition, Bulgaria and Romania was included. The outlying (e.g. FR940 – Mauritius), non-EU (Norway and Turkish) NUTS-3 were extracted.

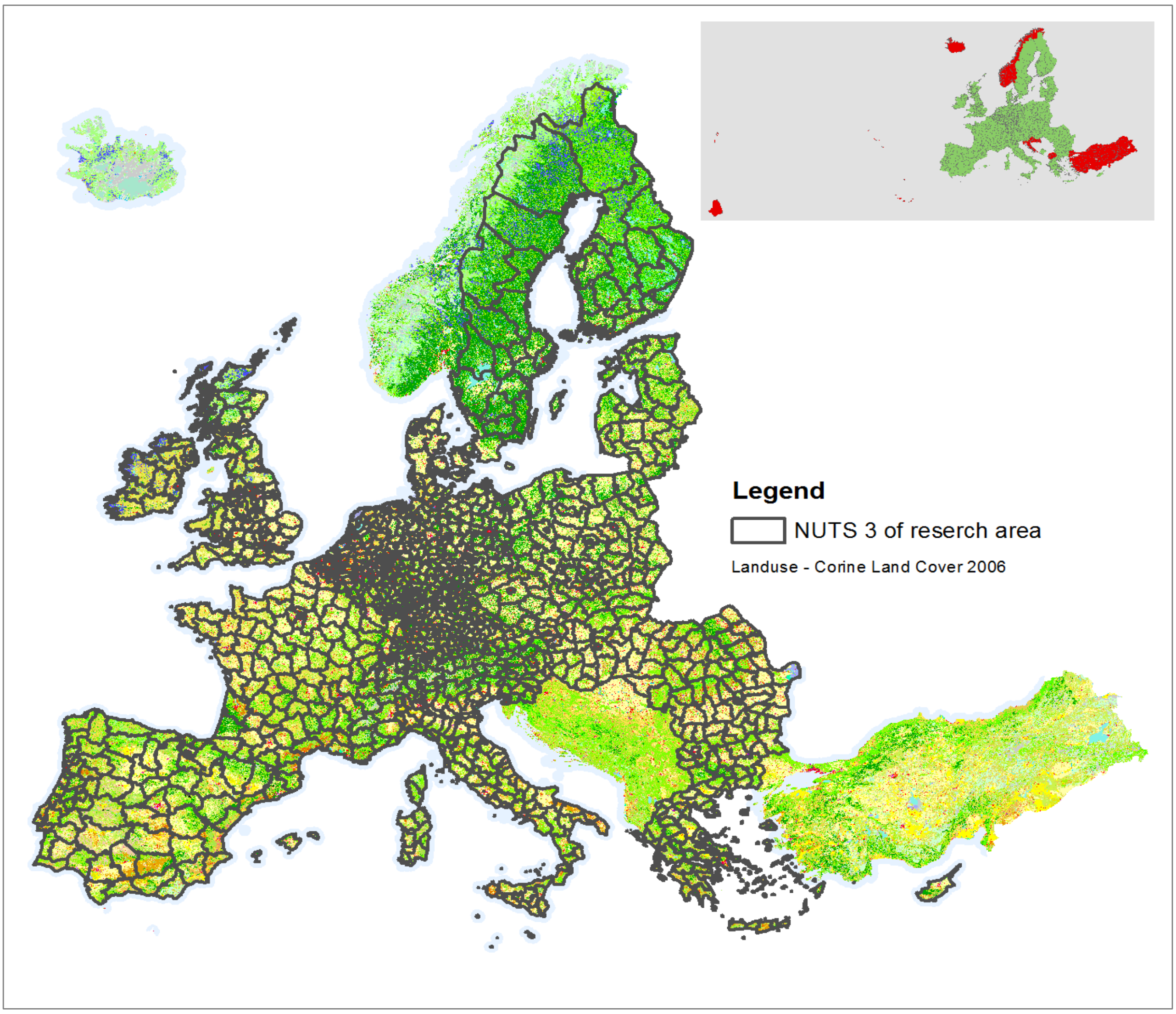

Figure 4. Official NUTS-3 region according to Eurostat. Red polygons (on the scheme) were excluded from BioBoost analysis.

1. AGRICULTURAL RESIDUES

1.1 Straw

The aim and definitions

Straw is the most available source of biomass from agricultural production, which can be used for energy purposes. Taking into account the re-use of straw resources in agriculture, the surplus can be treated as waste and used for the 'green' energy production (Edwards et al., 2005). The total resources of straw (theoretical potential) are easy to estimate on the basis of statistical data with the production of cereals (Eurostat) and the knowledge of the ratio between the yield of grain and straw (Tum and Gunther, 2011). However, the technical potential of straw available for energy is much lower due to the need for straw use in agricultural production. The main objectives of the straw use in agriculture are: straw incorporation to increase the reproduction of organic matter in the soil and its enrichment in nutrients and the purpose mulching in addition to animal feed (Scarlat et al., 2010). The amount of straw use in agriculture is dependent on production systems in the regions. However, due to the need for sustainable farming, the modelling of any straw surplus potential from plant production must assume a full compensation demand of agriculture (Kus et al., 2006). However, the use of any surplus of straw (e.g. in the food industry, construction) may provide some competition with it being earmarked for energy purposes (Kus, 2012). In this situation, the final consumption of any surplus of straw should be based on economics.

The production amount of most important crops (with straw as by-product) in the EU is shown in Figure 5. Due to the value of the straw to grain ratio which is close to 1:1 (only for rape = 2 and for sunflower = 3.3), the chart also shows the image of the theoretical potential of straw in each country and the share of individual crops, from which straw can be obtained. The share of straw in the general structure of crop production is presented in Figure 6.

The aim of the analysis was to assess the technical potential of cereals and oilseeds straw for NUTS-3. It was assumed that the estimated resources are surplus straw, minus any straw for its use in agricultural production. Estimates were based on a Eurostat database. The amount of straw was obtained by multiplying cereals yield by the appropriate factor determining the ratio between the yield of grain and straw yield. Straw for energy purposes was defined as a total production minus from the straw used in the production of animal feed and bedding (Burton and Turner, 2003), which is necessary in the maintenance of soil (Börjesson and Gustavsson, 1996; Smagacz, 2003)

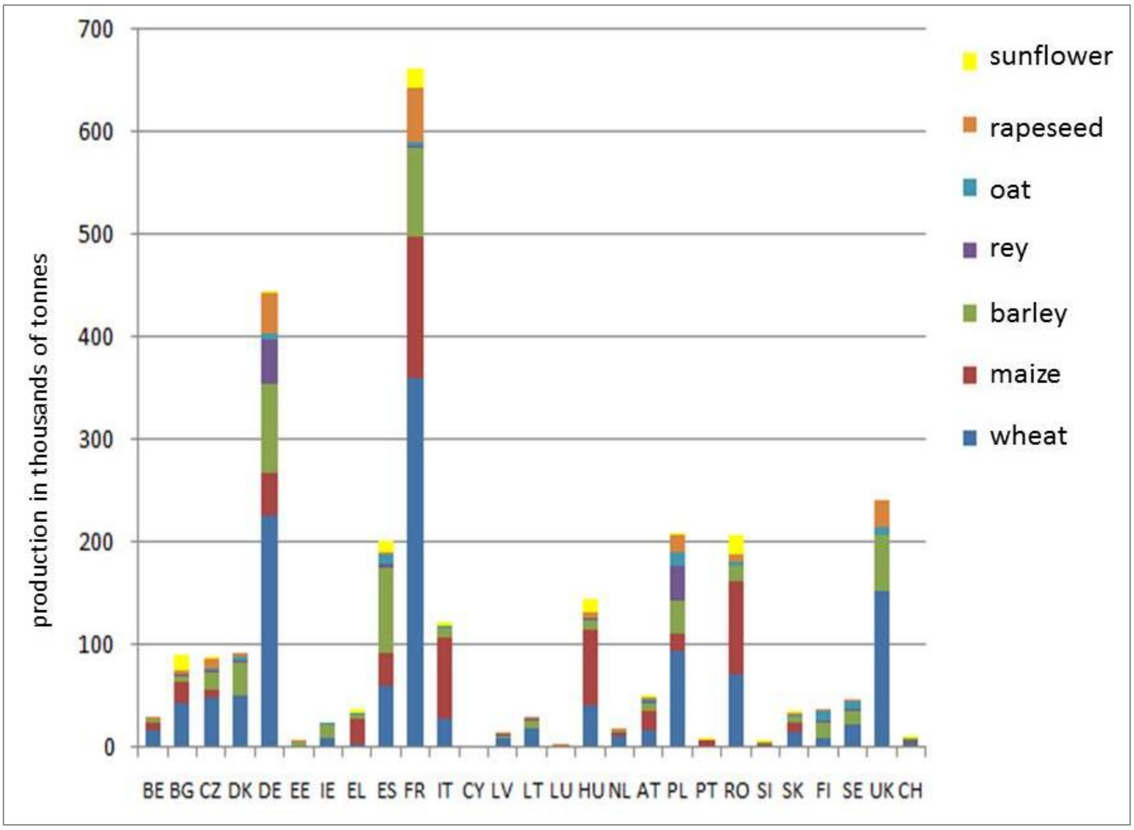

Figure 5. Crop production in EU-27 +CH (yield in kt). *Sources: Eurostat 2011*

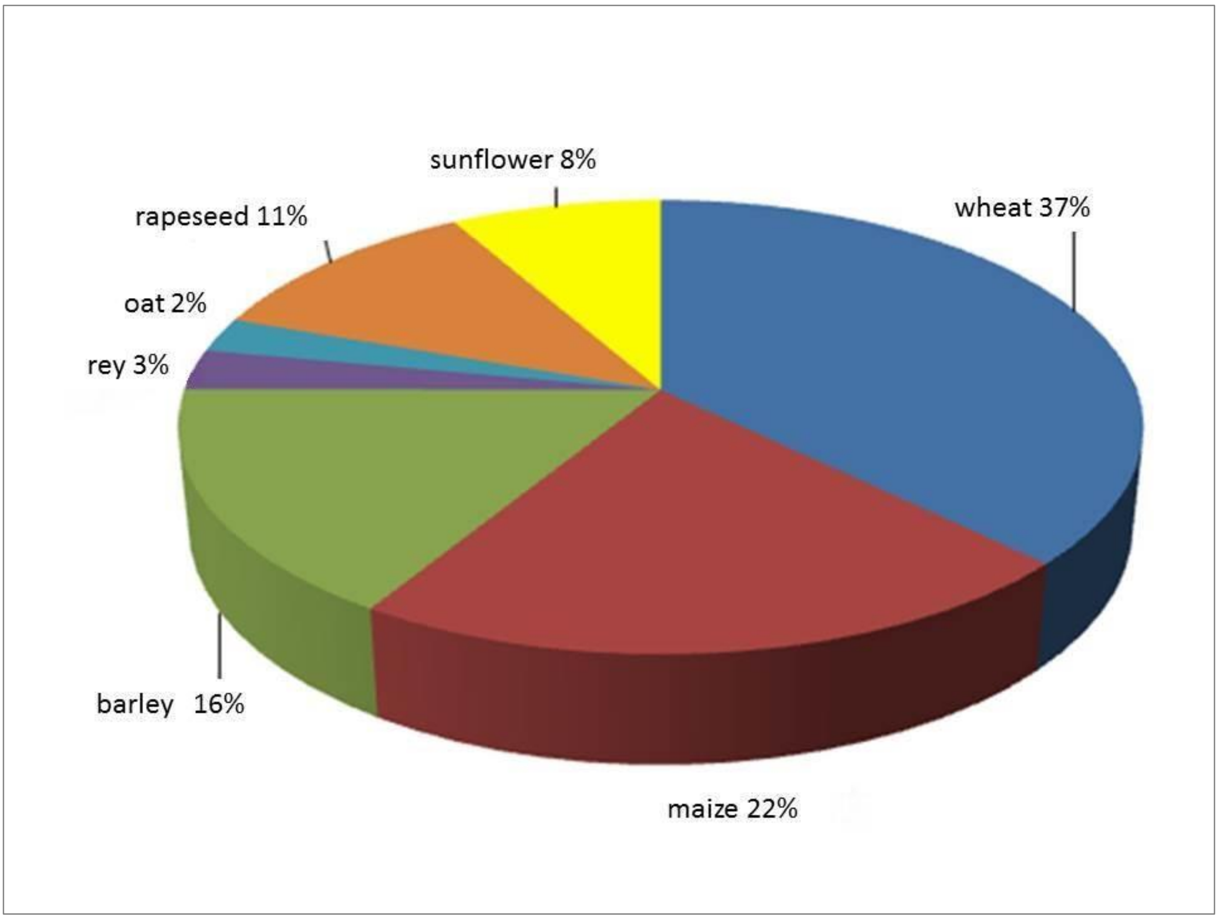

Figure 6. Share of each type of crop straw (EU-27). *Sources: Eurostat 2011*

Methods

Assessment of stationary in NUTS-2

The main problem in the modelling of any straw surplus in a surface smaller than NUTS-2 level in Europe is that there is no detailed data characterising agricultural production. The only possibility in this case is the use of auxiliary data characterised by a higher map scale (more detail) and the similarity of the distribution of traits in geographic space. It means the existence of a correlation between the modelled and at least one trait characterised by the auxiliary data (Chakir, 2009, Verburg et al. 2006). In this case, for the disaggregation of the results the Corine Land Cover map (CLC) 2006 was used. The missing regions (Greece) have been supplemented by an earlier version CLC 2000. The CLC provides information about the use of land with a resolution of 100 m on a European scale (Bossard et al., 2000). The category of agricultural land has been separated into 11 classes of use, including arable land, forming the space directly connected with the straw production.

The analysis of regression between land use in the administrative units NUTS-2 (by CLC) and the surface of cereal crops (Eurostat) showed high spatial correlations of these features (Figure 7). The coefficient of determination (R^2 = 0.92) indicates a close relationship between the two sets of data. On this basis, it can be assumed that similar relationships will be true for those relationships for entities NUTS-3.

In the model, to estimate the straw surplus in addition to the cereals production from Eurostat, other supporting data was used. Similar to the size of fields, they are also unavailable at the NUTS-3 scale.

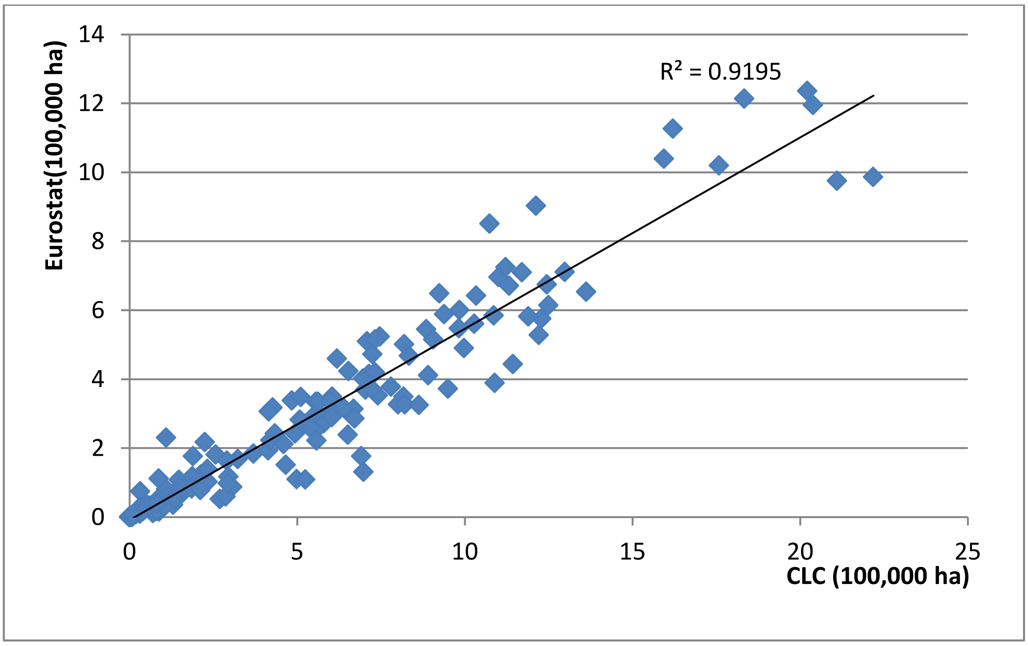

Figure 7. Correlation between the area of cereal crops (according to Eurostat) and the area of arable land (according to CLC), the NUTS-2

However, due to regionally conducted disaggregation can be assumed that for all NUTS-3 subsets within the NUTS-2 are similar conditions under which it was modelled. So there are similar systems in animal husbandry (beddings and allocation of straw for animal feed), similar varieties grown cereals (grain straw ratio), there is a similar structure in the proportion of cereal crops to oilseeds and maize, there are similar soil and climatic conditions and similar agriculture practices are used. Founded the existence of spatial data stationary, allows the use of deterministic methods for the redistribution of the NUTS-2 and NUTS-3 (Isaak and Srivastava, 1989). On those grounds, the CLC map is widely used in Europe to conduct spatial analysis, including modelling performed for biomass resources (Becca et al., 2009, Esteban et al., 2010, Fischer et al., 2010 a, b; Gobin et al., 2011, Pudełko et al., 2012).

Time trend analysis

Crops and its straw potential are varied over the years, which are influenced by the weather conditions and the economy. In the first decade of the twenty-first century, there many Central and Eastern Europe countries joined the EU. This had a noticeable impact on agricultural production. Therefore, the analysis of the trend of the production of grain was for six countries (Greece, Ireland, Germany, Poland, Switzerland, Sweden) representing the respective regions. These regions have been adopted for the separation as proposed in RENEW project (Figure 8). The potential of straw for each year from 2000 to 2011 were aggregated for each region. Then, the data were smoothed using a moving average: for each year drawn arithmetic mean of the potential in a given year and the years surrounding (one year earlier and one later). This procedure gave a time series from 2001 to 2010. The next step was to standardise the results in order to obtain comparable between regions. For this purpose, the moving average for each region is divided by the value of 2001, which was adopted as the beginning of the time series and assigned with value of 1. The results are illustrated in the following graph shown in Figure 9.

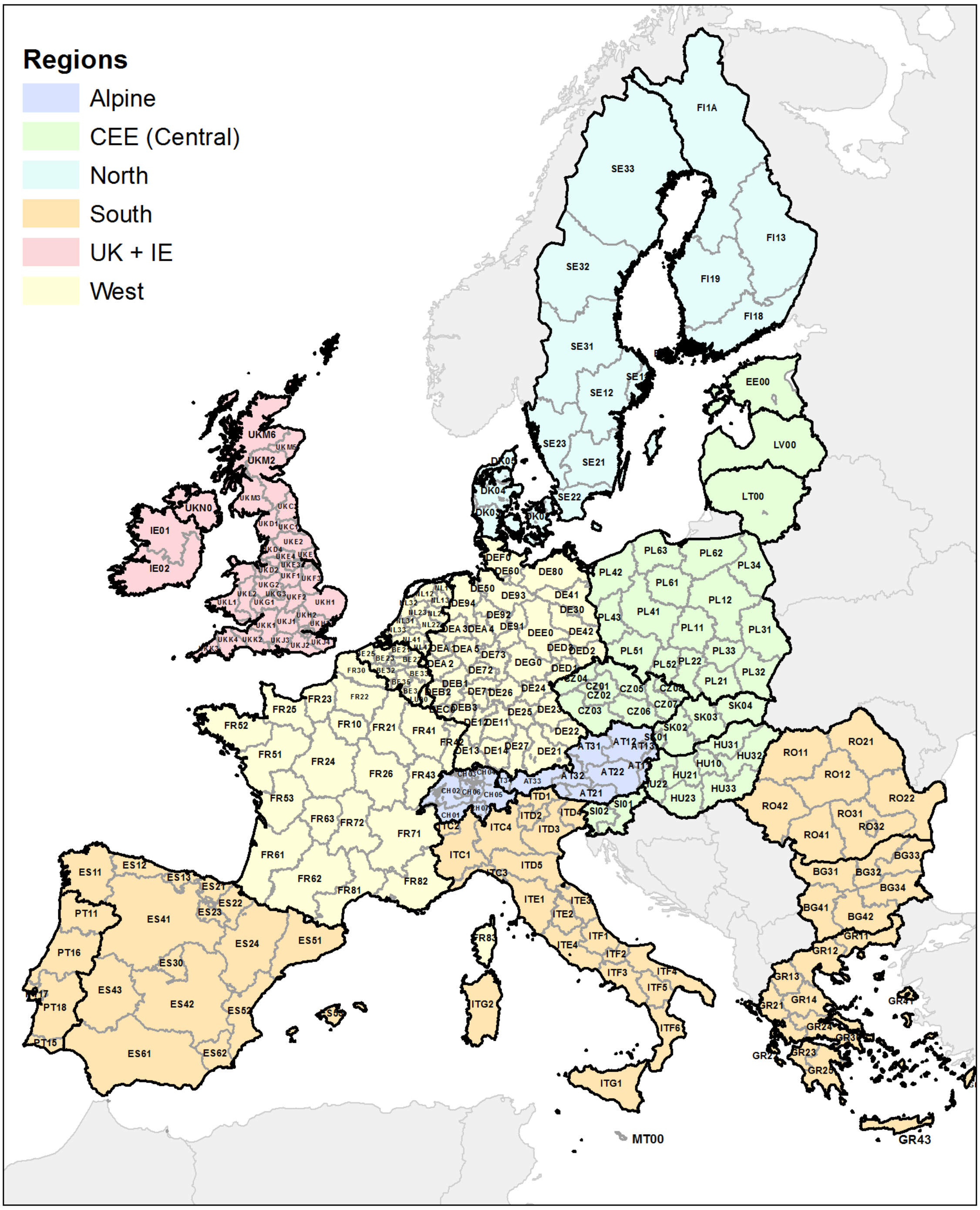

Figure 8. Boundaries of NUTS-0-2-3, and the division of Europe into regions according to RENEW (2008). Map shows the area subject to analysis. NUTS-2 were labelled.

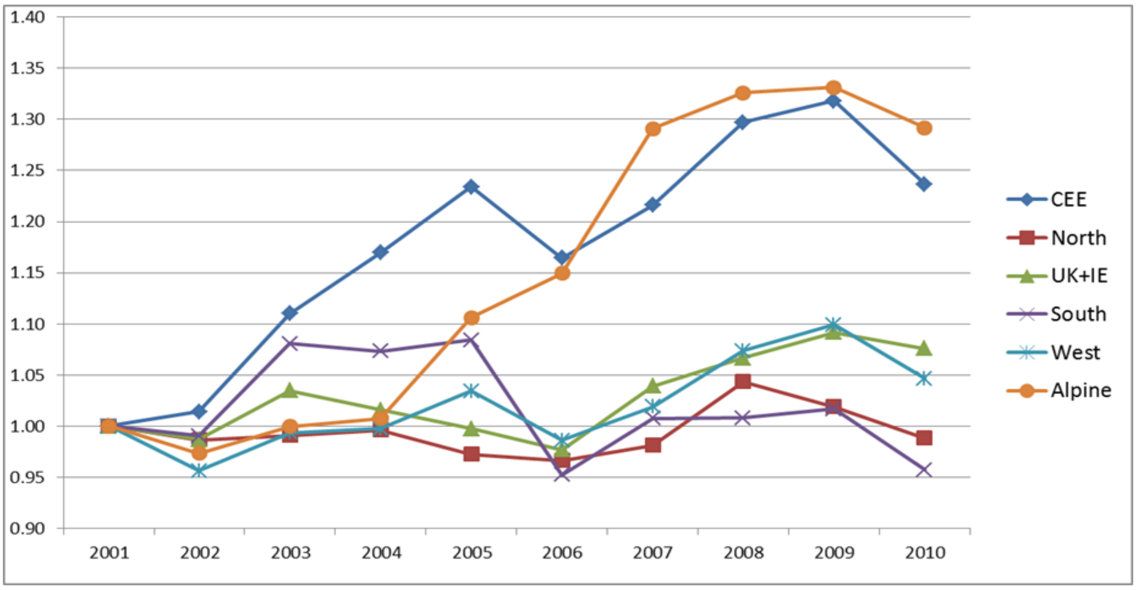

Figure 9. Cereal production in regions by RENEW (2000-2011)

Calculated time series describes the linear trends. Illustrated by the next graph (Figure 10.) For readability, the original time series is missed.

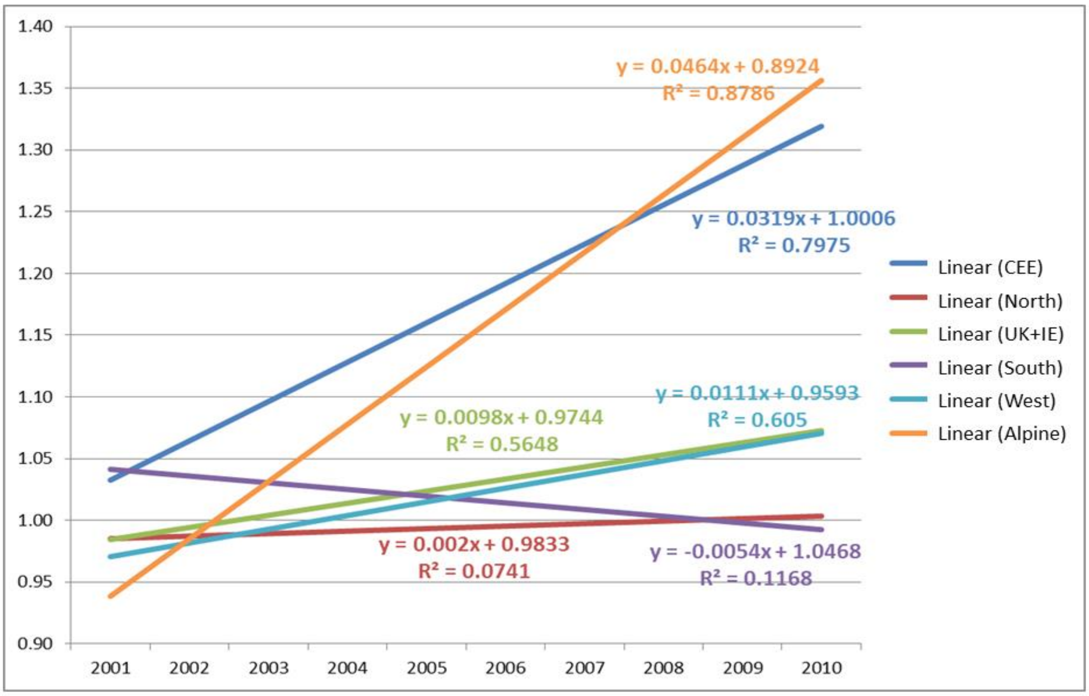

Figure 10. Trend in cereal production in regions by RENEW (2000-2011)

The standard analysis of the regression coefficients significance of these trends indicates that the statistically significant (P = 0.05), are only the coefficients associated with CEE and Alpine regions. Despite the relatively high coefficients of determination for the UK+IE and the West region, an insufficient number of points (years) makes it impossible to draw statistically significant conclusions about them. Thus, we can say that a significant increase in 2001-2010 was in the Alpine regions and CEE, which, cannot be said for the other four regions. Therefore, only in two regions were adopted in an amendment to update the data. In case of the "Alpine", the average annual increase in value, assessed by its regression, was 3.1%, while in the case of the "CEE" it was 2.8%.

The modelling of the technical potential of straw is assumed that the primary recipient of a sustainable use of this resource is agriculture. In the first stage, the optimal need for straw to animal production and soil conservation was evaluated. The remaining resources can be defined as a surplus of straw that can be used for purposes other than the production of food. This surplus does not necessarily mean that the resource consumption is only for energy production. However, the observed straw utilisation, it can be assumed that the type of the product will mainly be used as a renewable energy source.

Straw surplus was modelled by using followed scenario for assessment:

- Average grain yield for NUTS-2
- Straw feedstock
- Theoretical straw potential
- Technical straw potential

Average grain yield for NUTS-2

Summary information about crop production was based on data from Eurostat. For 242 units NUTS2, data on yield, productivity (yield / ha) and the acreage of wheat, durum wheat, barley, other cereals, grain maize, rice, rapeseed and sunflower was tabularised. The most current information was about collections for 2011, but it was not for all countries and for all crops. Therefore, the average yield for the years 2008-2011 was used. This is further justified because the yields are highly dependent on weather conditions in the growing season, resulting in large variations in successive years. The period 2008-2011 was adopted in order to determine the average account indicated yield growth trend for the Alpine region and Eastern Europe.

Straw feedstock

The straw potential was assessed by using ratio grain to straw for each evaluated crop, based on Edwards (2005) for wheat and barley and Scarlat (2010) for maize, rice, rapeseed and sunflower. For the other cereals the ratio equal to 0.9 was applied (Table 3).

Table 3. Relation straw to grain

Crop	**Algorithm: Straw to grain ratio**
Wheat and barley	Yield*(0.769-0.129*ATAN((Yield-6.7)/1.5))
Maize	-0.181*LN(Yield)+1.337
Rice	-1.226*LN(Yield)+3.845
Rape seed	-0.452*LN(Yield)+2.0475
Sunflower	- 1.1097*LN(Yield)+3.2189
other cereals: oat, triticale, mixes of cereals, etc.	0.9

Theoretical potential

Theoretical potential of straw was assessed as total straw resources possible to obtain from listed crops. The values for all NUTS were determined by Formula 1:

Theoretical straw potential = $\sum_{i=1}^{i}(Yield * ratio\ straw - to - grain)$

Where:

Yield = yield of i (i = wheat, barley ...) in ton per NUTS-2

Ratio = straw to grain ratio given in the Table 3.

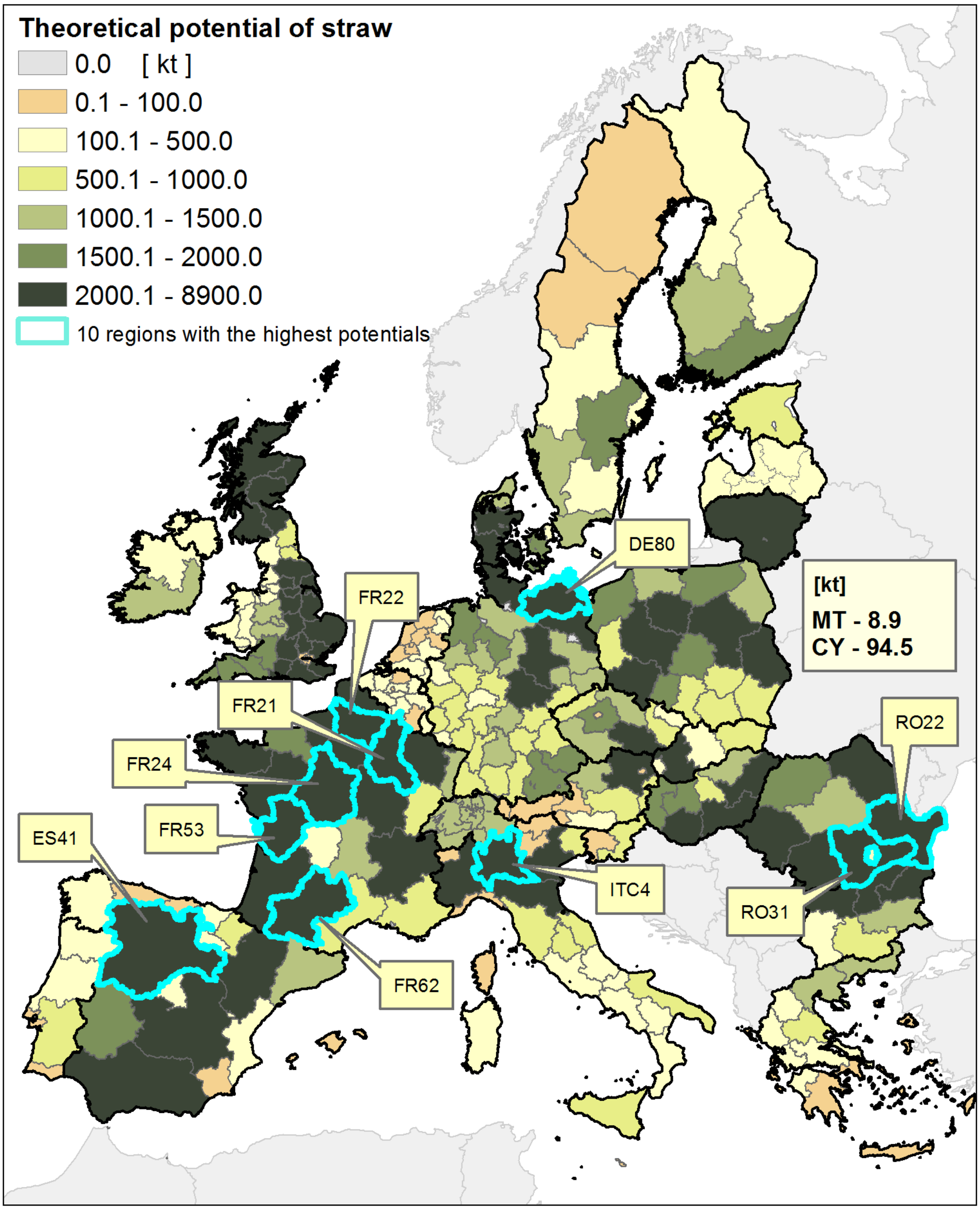

Figure 11. Theoretical potential of straw (cereal, maize and rapeseed) in NUTS-2. Values for Malta and Cyprus were given in the box.

Technical straw potential

The technical straw potential was assessed by subtraction of the amount of straw necessary for animal bedding and feeding in addition to the part of straw that is needed for incorporation into the soil.

Straw that is needed for soil protection was calculated at minimum of 30% for technical potential in each region (NUTS-2). The oilseed rape and turnip rape straw is of low suitability for combustion as it is high in ash and N-compounds. It is very brittle and baling is associated with high losses. Moreover, within the other types of straw this one is least suitable for livestock bedding. For these reasons, it was assumed that the most appropriate form of its use is incorporation into soil. The properties of straw, which also create their fertilisation quality, include no risk of fungal diseases transmission (not found on the rape) and straw that is in the soil decomposes faster than cereal straw and contains more nitrogen (no need for additional fertilisation).

The technical potential of corn (maize) straw grown for grain is calculated as 50% of the theoretical capacity, assuming the validity of ploughing at least half of its yield. This is because of the field demand for soil organic matter after this type of crop production and the common practice during the harvest, where the plant is cut in half of its length. In the case of rice, it was assumed that at least 40% of the straw must be used for ploughing (Scarlat et al., 2010).

Modelling the technical potential of other cereals was done by following scenario assuming the use of straw on soil conservation.

In the algorithm, it was assumed that the first kind of straw which could be used is coming from the crops defined in the Eurostat as "other cereals" (oat, rye, triticale, mix crops). If this amount was lower than 30 % of the total straw feedstock, the second resource (barley) was used and the last kind of straw (wheat).

The amount of straw, which can be used for animal feeding and bedding, was calculated previously, during the modelling of manure potential (see chapter 1.3). In the case of a higher demand for straw for animals than the size of the theoretical potential of straw, then the assigned value was set at zero for the technical potential. No compensation of straw between regions was modelled due to economic inefficiency of such activities. This is confirmed by practice, because it was observed that there is no straw carrying on longer routes in order to apply for animal husbandry.

In calculating the modelling technical potential this does not include the straw used in horticulture, food processing, construction, etc. The alternative use of straw is dependent on economic conditions. In some cases, instead of the straw, interchangeable materials can be used (saw dust, wood chips, plastic, etc.). Therefore, the competitiveness of the straw for energy uses with others uses outside agriculture should be estimated with calculations of the economic potential.

Results

The total assessed feedstock potential of straw residues amounts at: 149.7 Mt (1960 PJ). Average value for NUTS-3 is 113 kt. There are 885 NUTS-3 where the biomass potentials are over 10 kt. The highest potential of biomass was found in NUTS-3: FR242 (Eure-et-Loir) – 1.42 Mt, but the highest density of biomass was calculated for ITC15 (Novara) – 238 t/km^2**.**

Table 4. The most promising NUTS-3 with the highest straw potential

Theoretical			Technical			Density	
NUTS-2	**kt**	**PJ**	**NUTS-3**	**kt**	**PJ**	**NUTS-3**	**t/km^2**
FR24	8601.0	112.6.7	FR242	1414.5	18.98	ITC15	237.7
ES41	6905.5	90.5	FR213	1251.9	16.40	FR242	237.0
FR53	5489.7	71.9	CZ020	1144.2	14.99	ITC12	223.3
FR21	4803.1	62.9	FR223	1104.5	14.47	DEE0C	195.7
RO31	4747.6	62.2	DK022	1101.6	14.43	DEE0B	195.5
FR62	4575.9	59.9	FR221	1065.5	13.96	DEG0D	193.0
FR22	4423.2	57.9	FR534	1053.5	13.80	ITC49	180.8
ITC4	4412.3	57.8	FR246	1025.3	13.43	ITC4A	179.7
RO22	4397.9	57.6	ES618	1000.0	13.10	DE91B	178.9
DE80	4274.3	56.0	FR241	999.0	13.09	FR223	178.1

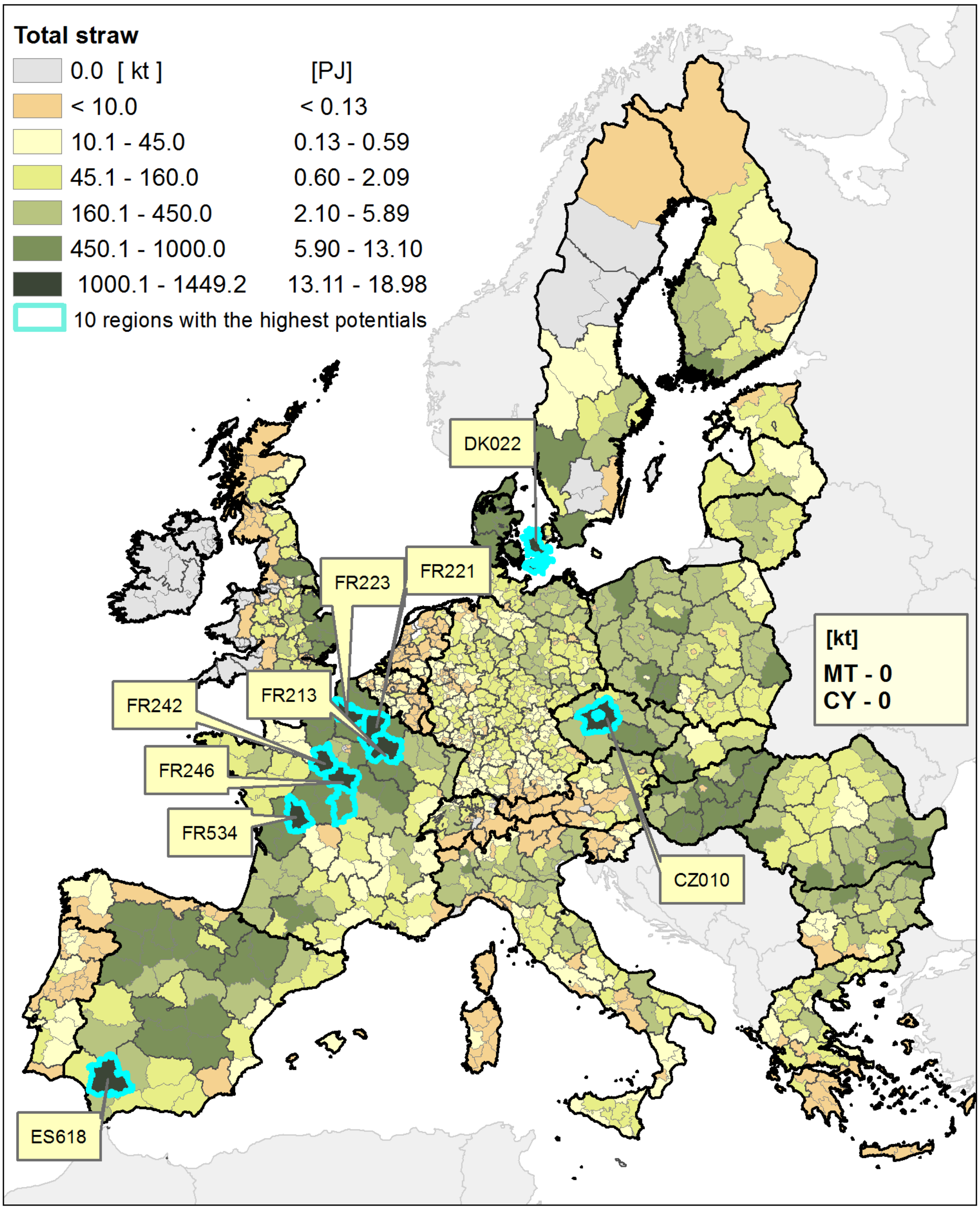

Figure 12. Technical potential of total straw in NUTS-3. Values for Malta and Cyprus were given in the box.

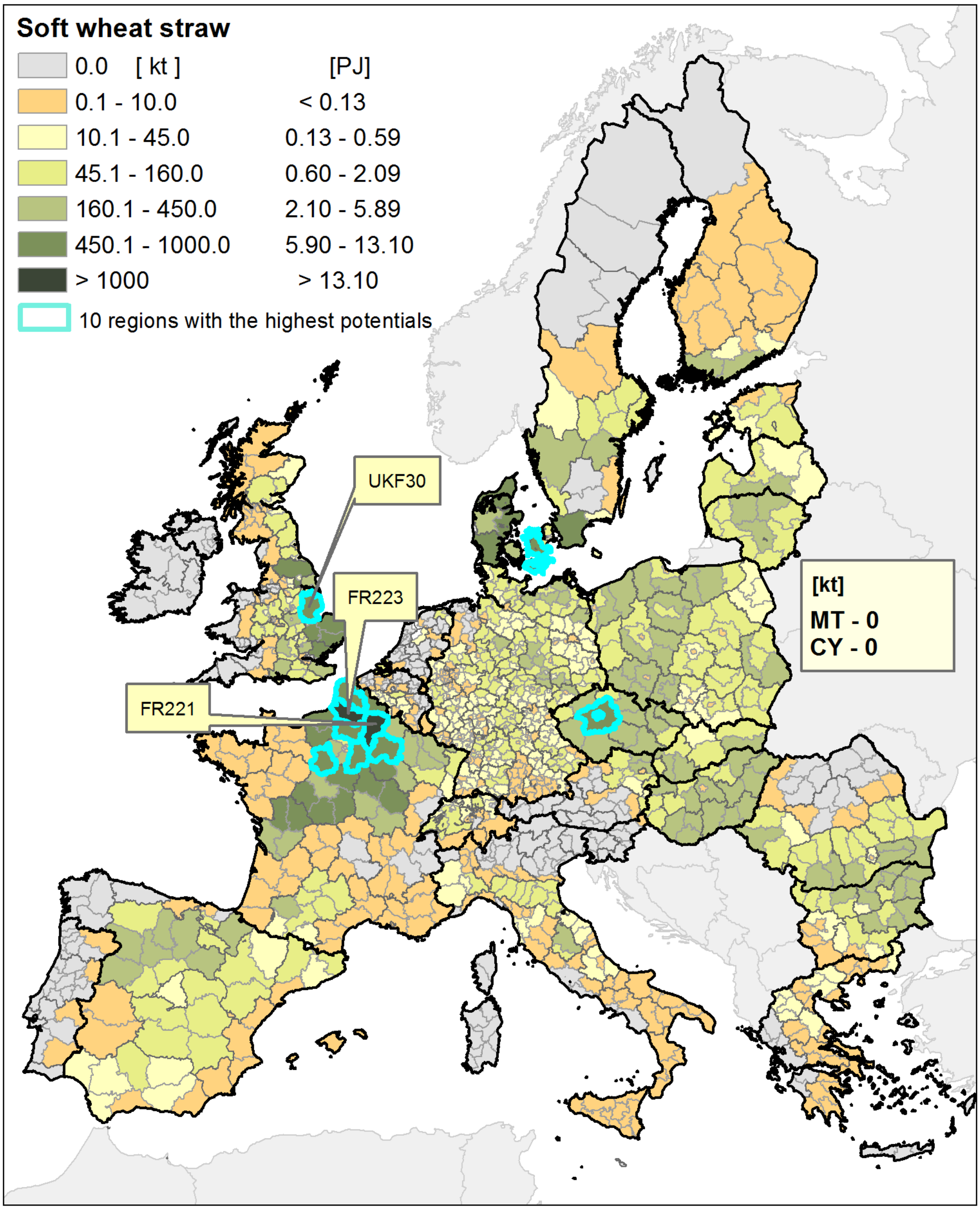

Figure 13. Technical potential of soft wheat straw in NUTS-3. Values for Malta and Cyprus were given in the box.

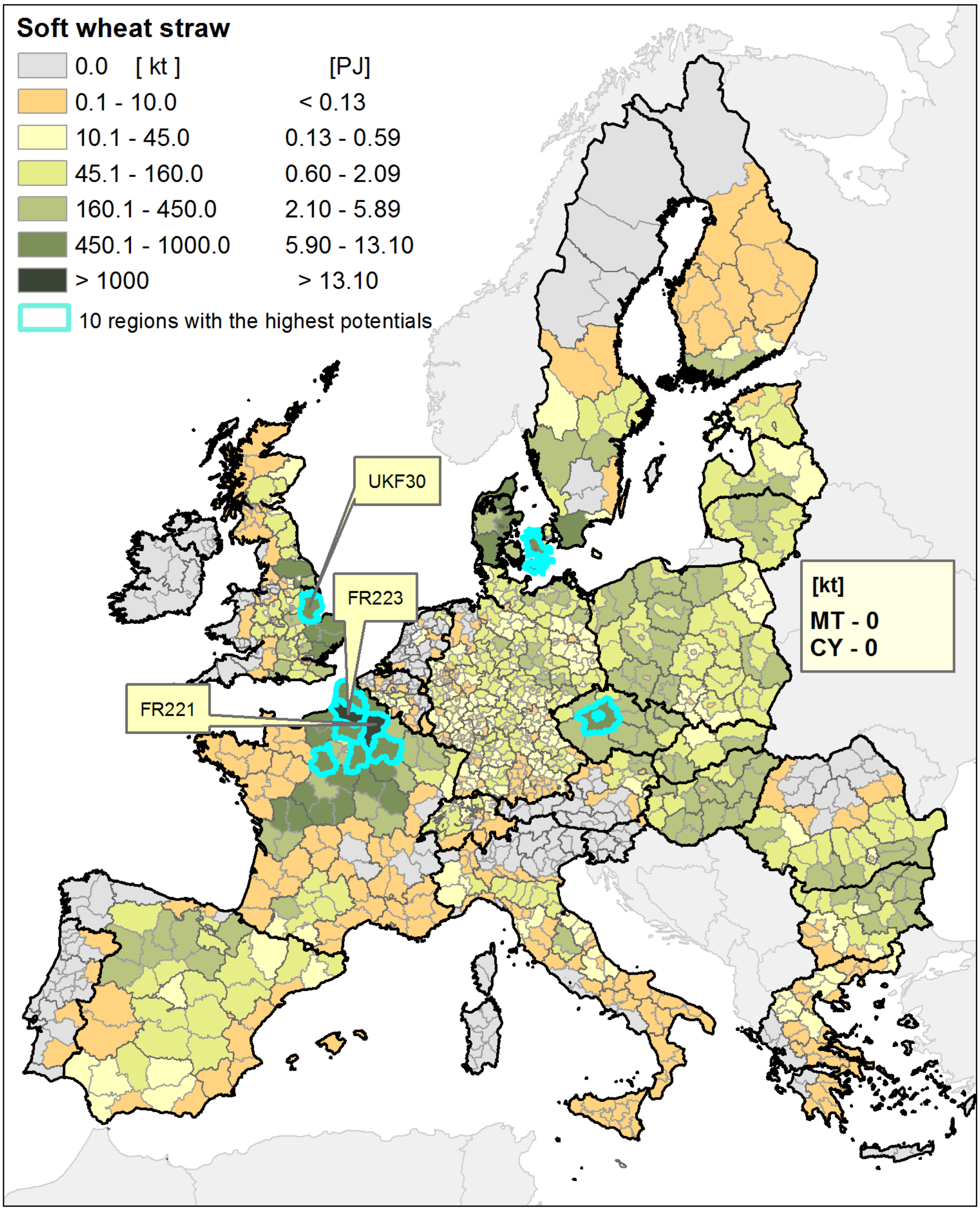

Figure 14. Technical potential of durum wheat straw in NUTS-3

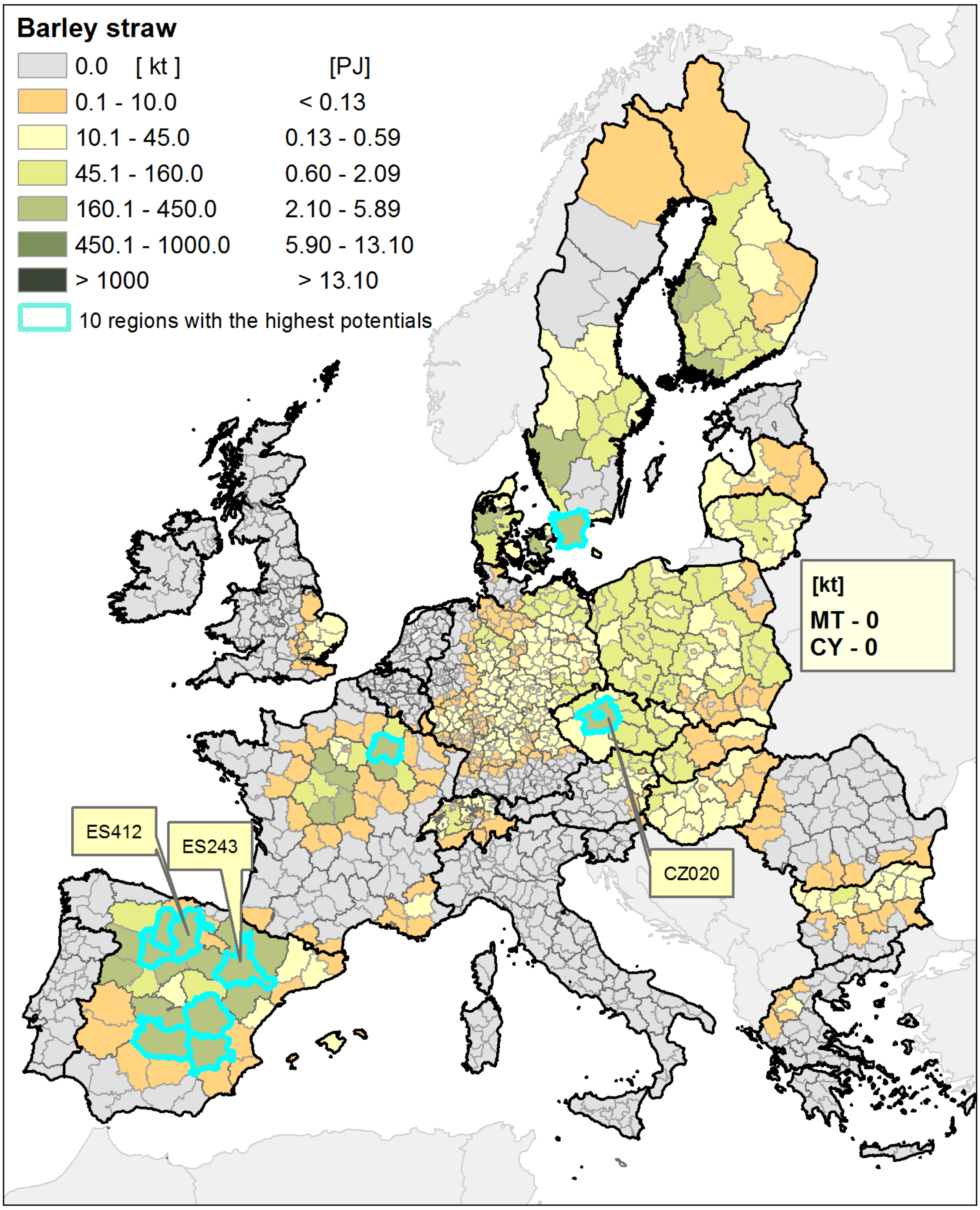

Figure 15. Technical potential of barley straw in NUTS-3

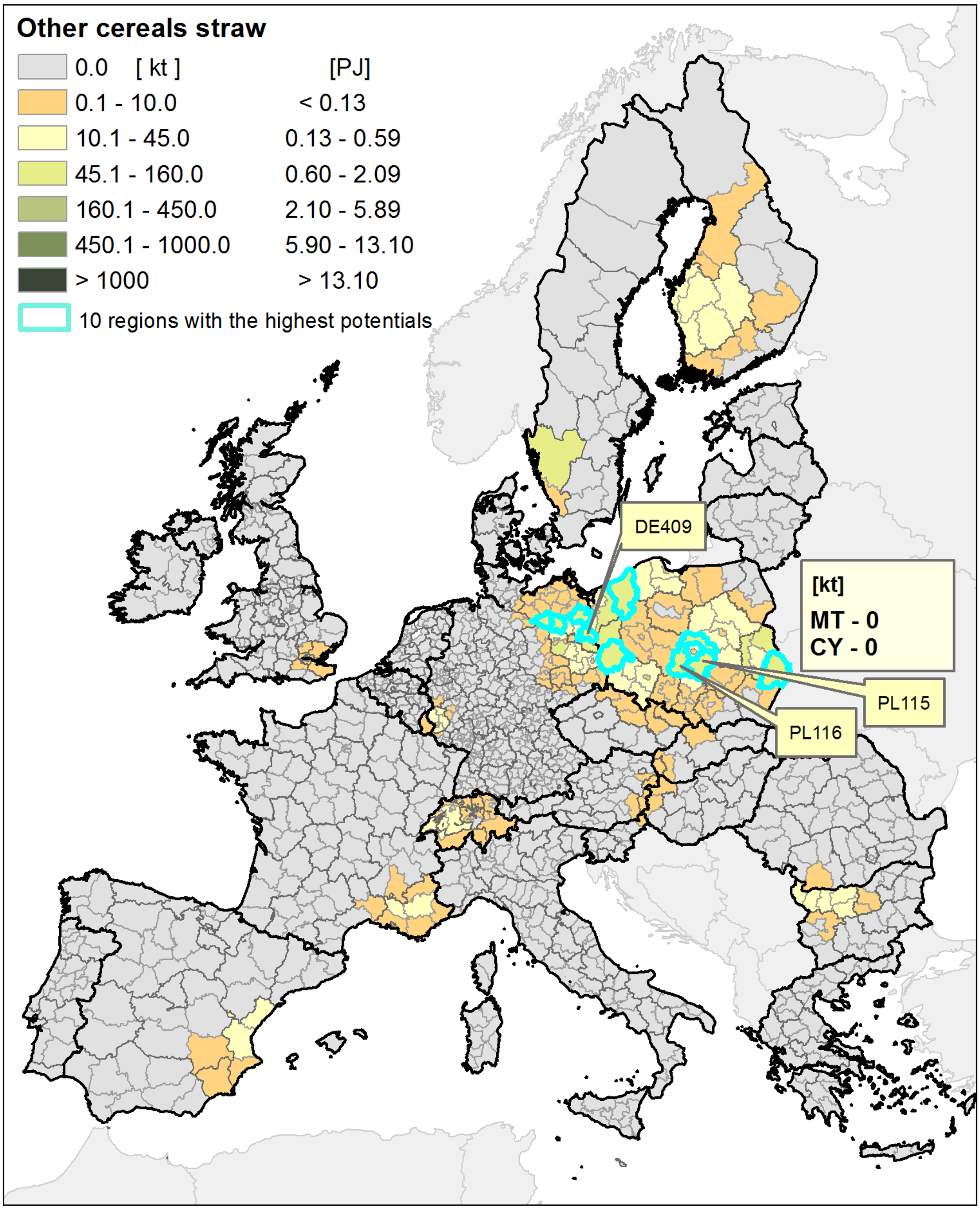

Figure 16. Technical potential of other cereals straw in NUTS-3

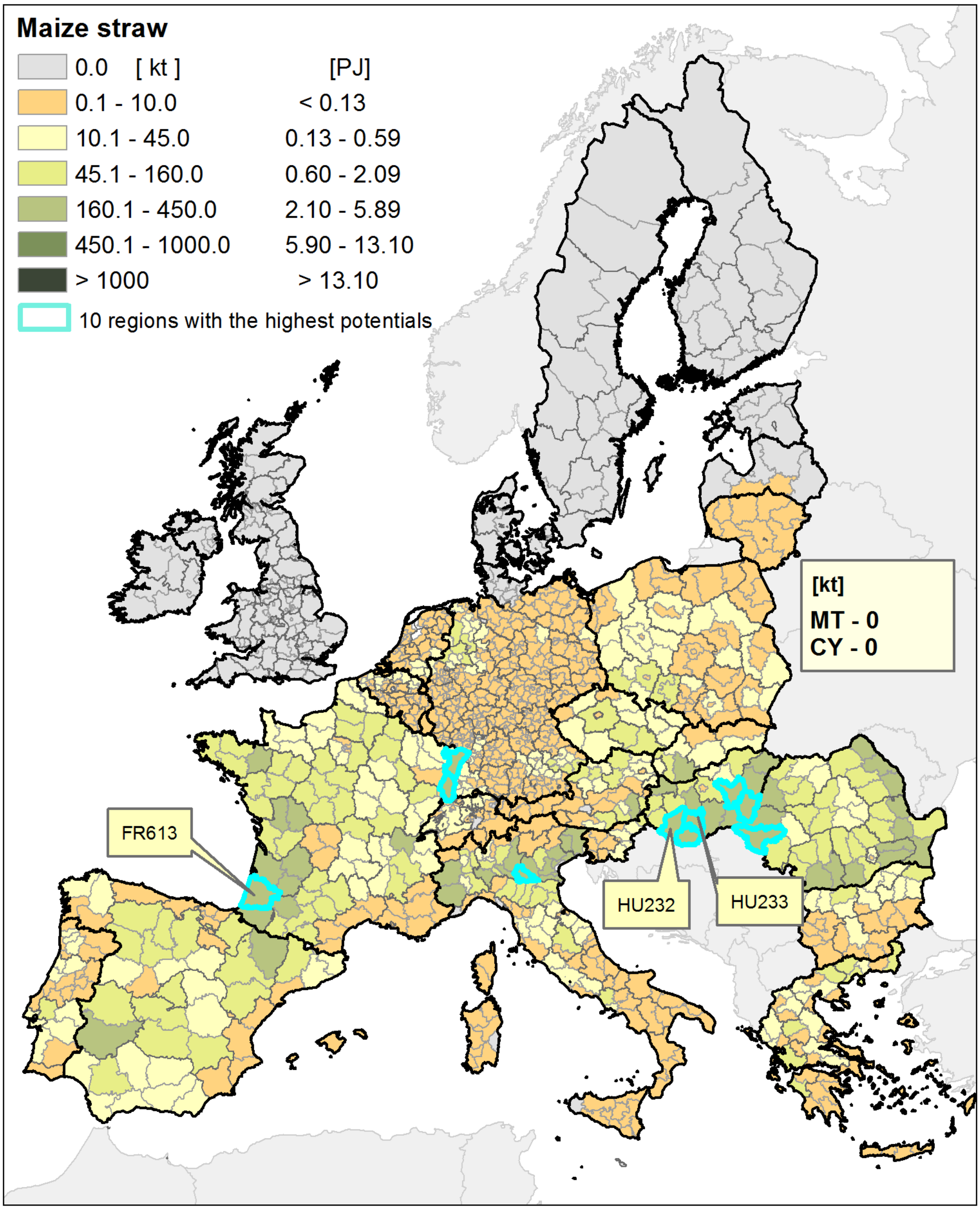

Figure 17. Technical potential of maize straw in NUTS-3

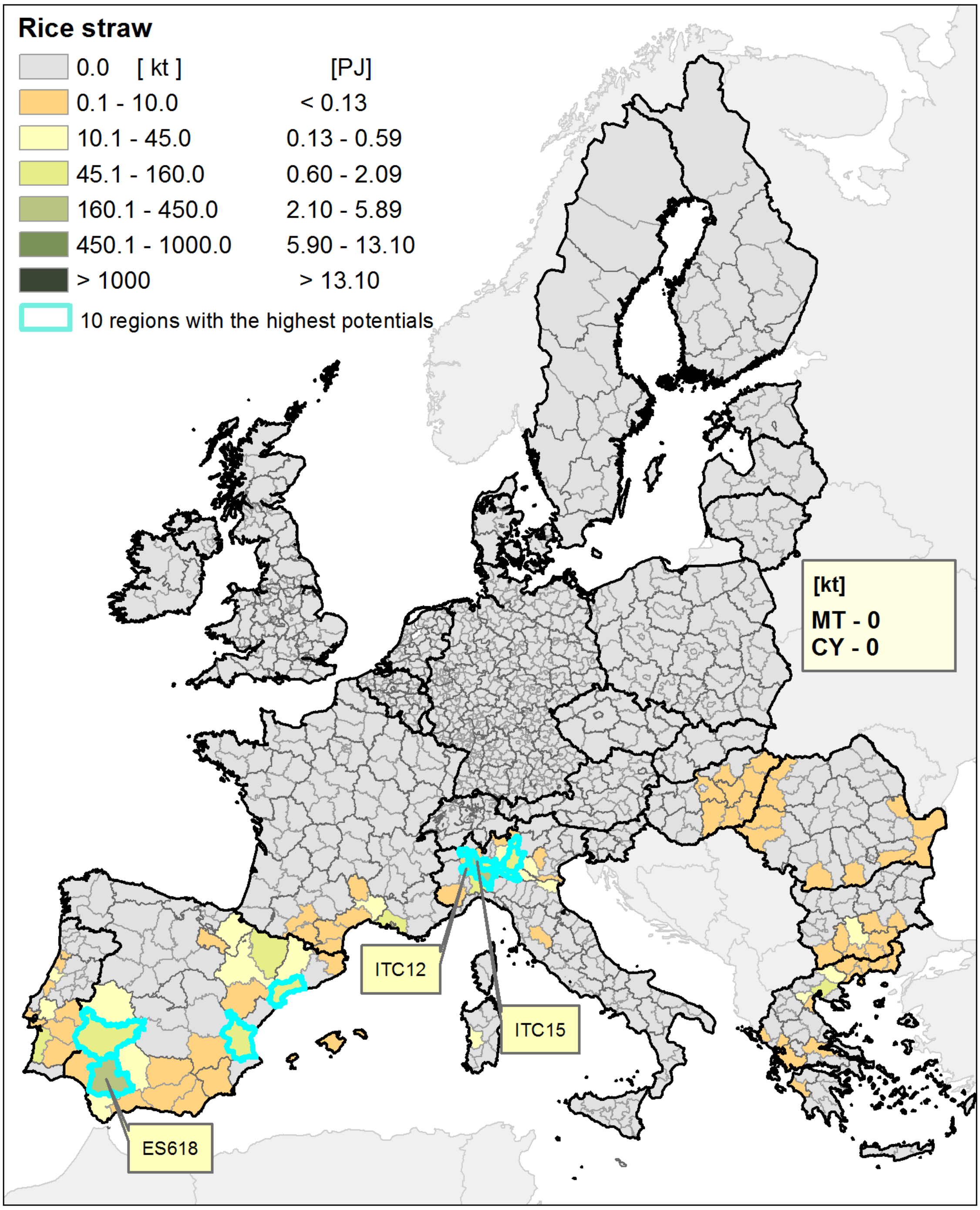

Figure 18. Technical potential of rice straw in NUTS-3

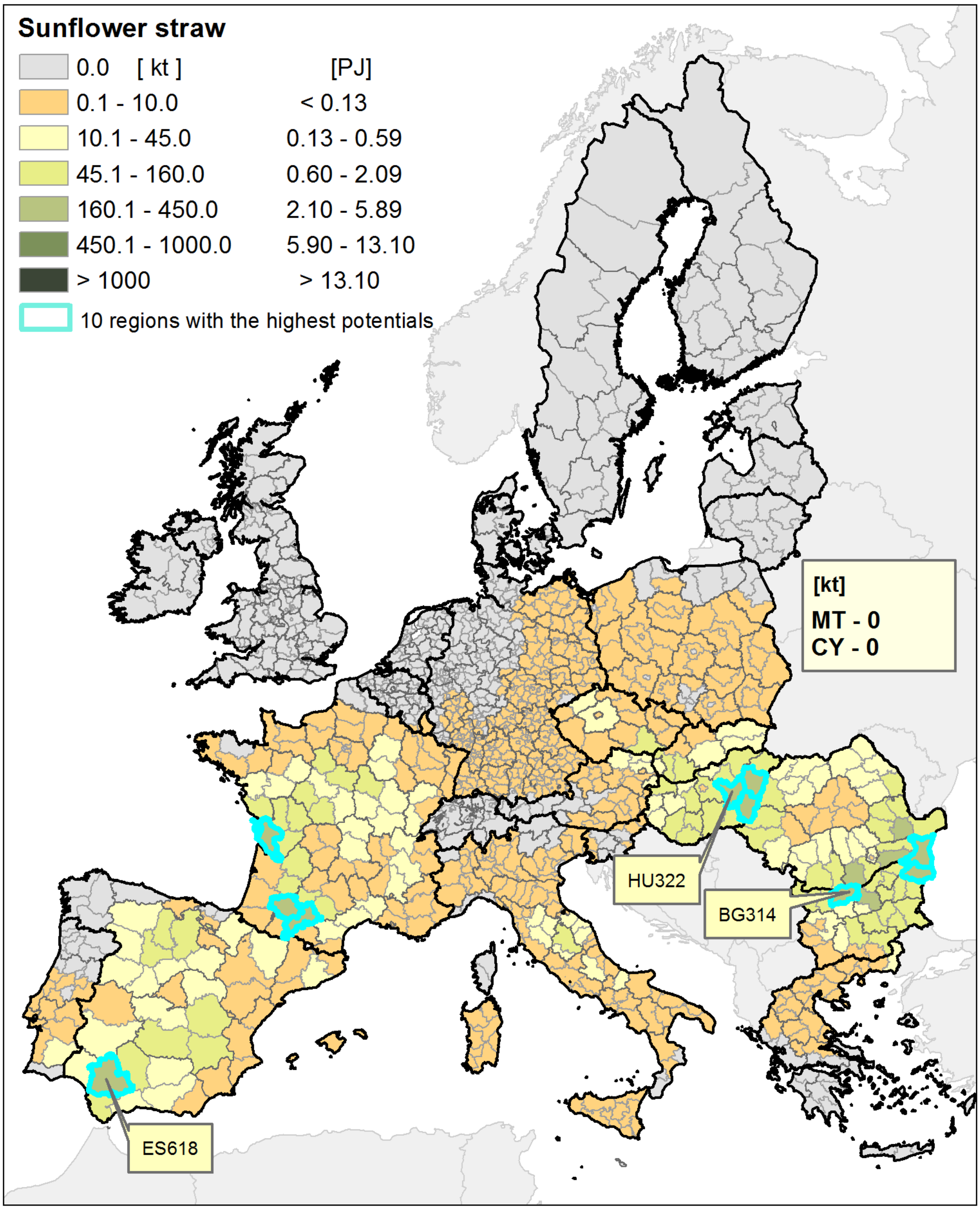

Figure 19. Technical potential of sunflower straw in NUTS-3

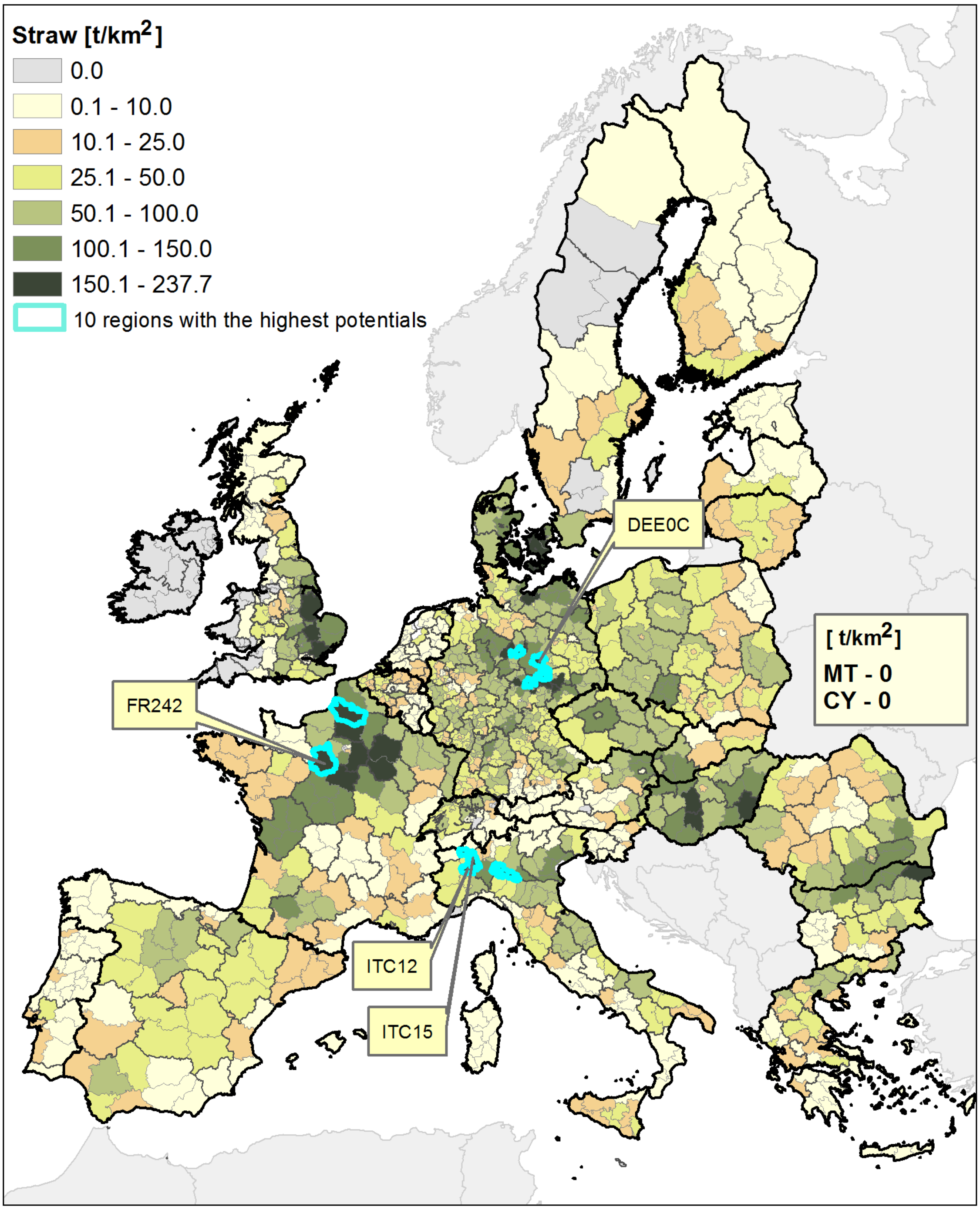

Figure 20. Normalised biomass potentials of straw in NUTS-3

1.2 Residuals of pruning

Scope and definitions

The technical potential of pruning of permanent plantations: olive trees, vineyards, fruit trees, were assessed. Residuals of pruning – the main residuals: cut branches and the other biomass, which can be treated as a year's net primary productivity (grass, shrubs).

Method

The locations of potential pruning areas were taken from CLC. Class number 15 (vineyards), 16 (fruit trees and berry plantations), and 17(olive groves) were used. Geo-processing were conducted at scale of pixel size = 100x100m. For selected areas a NPP values were assigned. Raster map was tabulated by NUTS-3 SHP file. As a technical potential, 50 percent of assessed biomass was considered. The purpose of this is that NPP values consist of many different kind of biomass, e.g. fruit yields, vegetation from the environment of permanent crop fields, natural vegetation within fields like a grass or shrubs. The indicator (0.5) was chosen based on expert knowledge, literature review and consultation.

Formula 2:

IF CLC = 15 OR 16 OR 17 ***THEN*** RoP = (0.5 * NPP) ***ELSE*** RoP = NoData

Where:
RoP = Residuals of pruning
CLC = Corine land cover, classes: 15, 16, 17
NPP = net primary productivity in location of 15, 16, 17 class of CLC

Table 5.Data source of pruning residues

Indicator	Source	Location
CLC	EEA: CORINE	http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2
NPP	WDC-RSAT	http://wdc.dlr.de/data_products/SURFACE/

Results

The total assessed feedstock potential of permanent crops pruning amounts at: **15.4 Mt (152 PJ)**. Average value for NUTS-3 is 11 kt. There are 234 NUTS-3 where the biomass potentials are over 10 kt. The highest potential of biomass was found in NUTS-3: ES616 (Jaen) – 631.7 kt, but the highest density of biomass was calculated for GR431 (Irakleio Prefecture) - 112 t/km^2.

Table 6. The most promising NUTS-3 with the highest pruning residues potential

Technical			**Density**	
NUTS-3	**kt**	**PJ**	**NUTS-3**	**t/km^2**
ES616	631.7	6.2	EL431	112
ES613	382.8	3.8	EL222	78.8
ES523	323.0	3.2	ITF44	73.4
EL431	296.5	2.9	ITF65	66.5
FR813	276.9	2.7	ITG19	65.3
ES618	266.64	2.6	ITG17	62.2
FR612	253.5	2.5	EL221	59.9
ES614	252.6	2.5	EL255	59.8
FR812	243.9	2.4	ITF45	58.2
ES514	240.9	2.4	ITG11	58.1

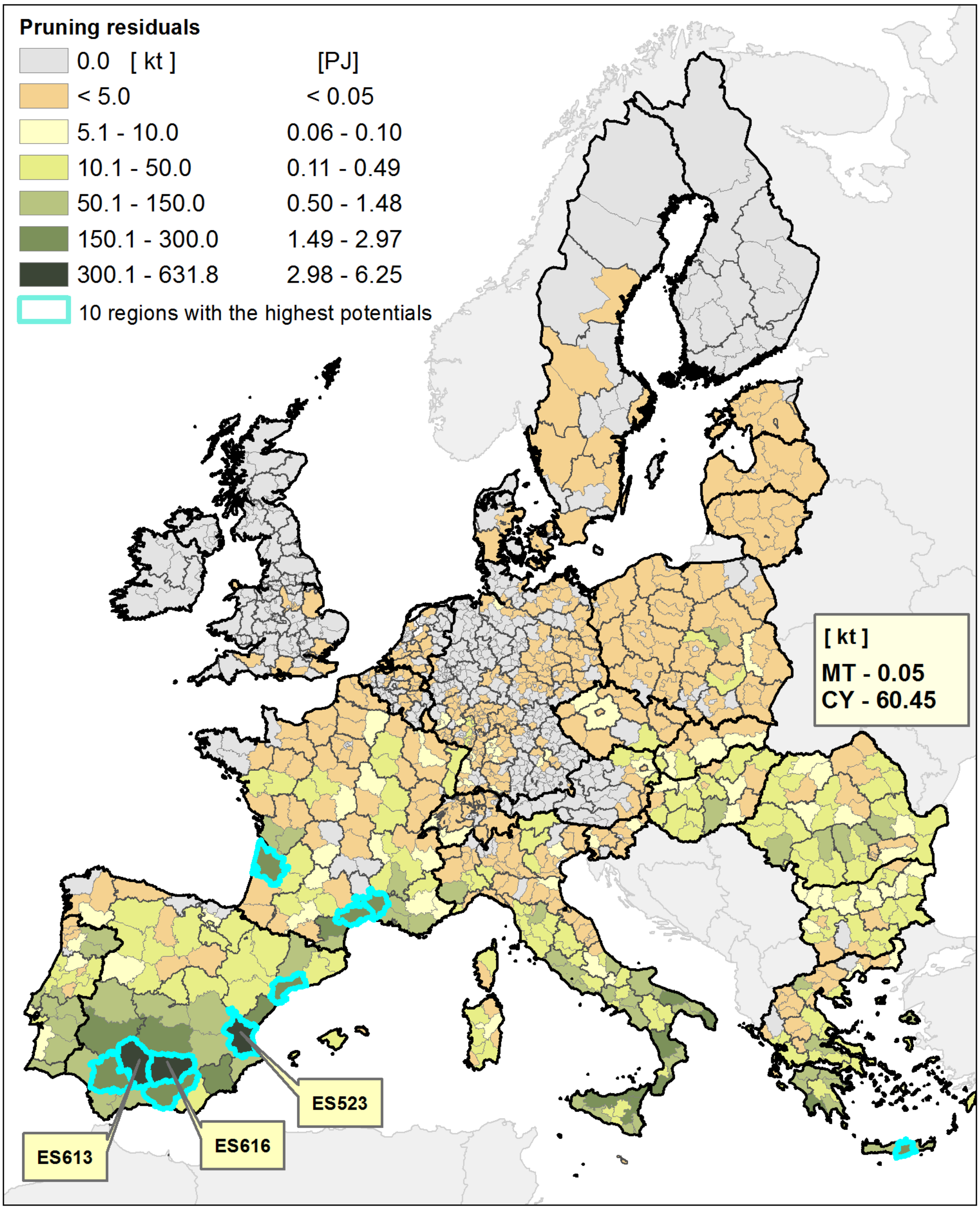

Figure 21. Technical potentials of pruning residuals in NUTS-3

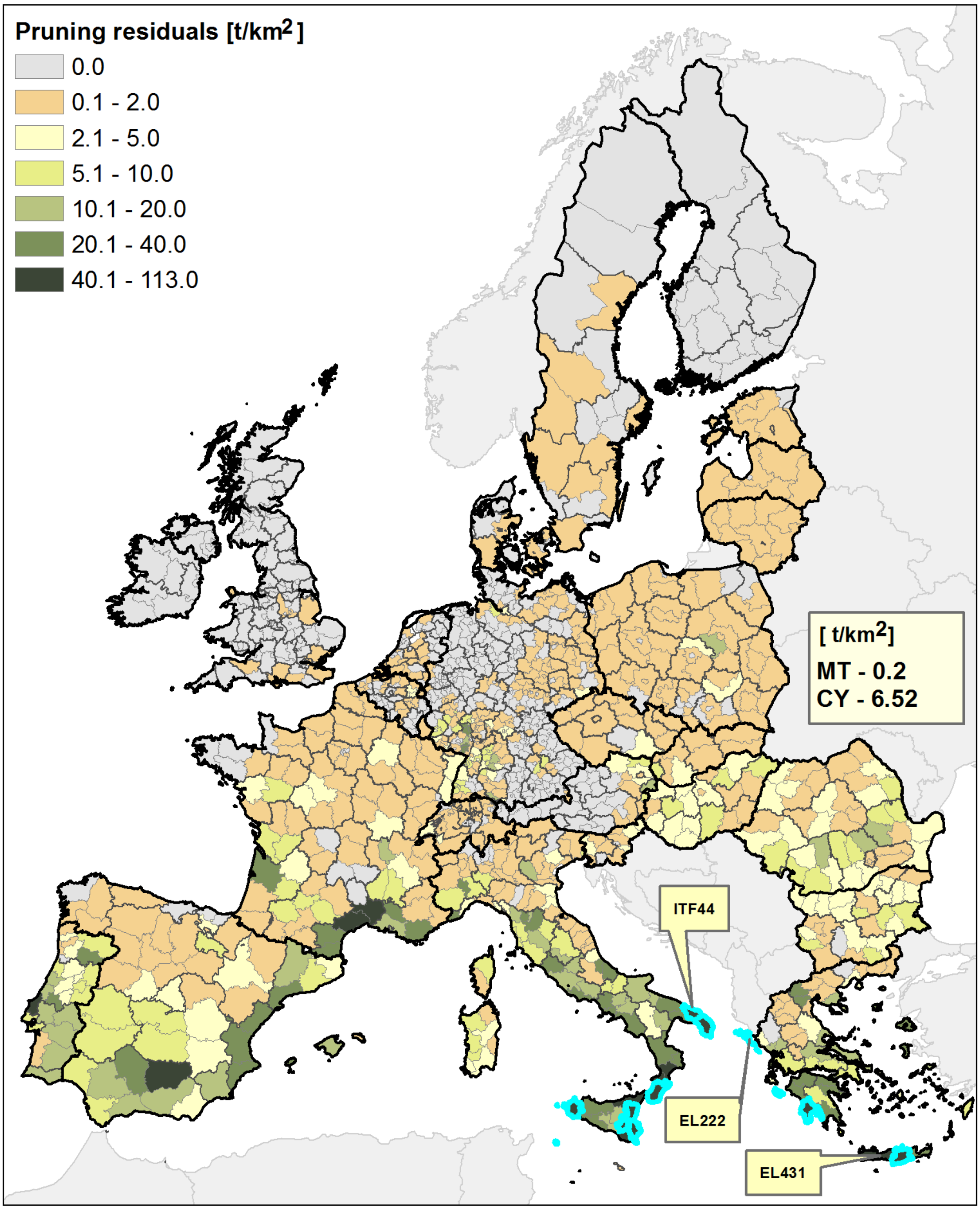

Figure 22. Normalised biomass potentials of pruning residuals in NUTS-3

1.3 Livestock Residues

Scope and definitions

The scope of this activity was to assess the technical potential of livestock residues, which is defined as livestock excreta, and associated losses, bedding, wash waters, sprinkling waters from livestock cooling, precipitation polluted by falling on or flowing onto an animal feeding operation, and other materials polluted by livestock.

An assessment into the amount and availability of residues from livestock production in Europe is difficult because of the differences in animal rearing and the use of natural fertilisers in crop production of individual European countries. These differences result from dissimilar climatic and geographical as well as economic and agricultural conditions. The comprehensive assessment of manure management was carried out in the framework of a scientific network RAMIRAN (Recycling of Agricultural, Municipal and Industrial Residues in Agriculture) – Menzi (2002). Subsequent studies were undertaken for the European Commission (Lyngsø et al., 2011). The work was carried out in order to support the implementation of the Nitrates Directive and the Water Framework Directive (91/676/EEC, 2008/32/EC). The Nitrates Directive is closely linked to the EU's policy for the protection of water, air and climate change. In the case of agriculture, it was assumed that breeding livestock contribute inter alia to the emissions of ammonia (NH_3), which has an impact on human health and the environment, as with the other pollutants (sulfur dioxide, nitrogen oxides) cause soil acidification, eutrophication and ground-level pollution of the atmosphere ozone layer. Full implementation of the Nitrates Directive is intended for a reduction of ammonia emissions by 14% until 2020 compared to 2000, as mitigation measures, mainly on fertiliser usage, positive impact on reducing nitrate loss through surface runoff and infiltration waters, as well as a reduction of ammonia emissions to air (EU Nitrates Directive, 2010). The adoption of the Nitrates Directive for agriculture for each country within the EU has to draw up a code of good practice, and not to exceed the dose 170 kg N per hectare imparted in organic fertilisers.

Natural fertilisers are a source of organic matter and rich and beneficial bacterial flora. They are versatile and flexible, because they contain all the necessary plant nutrition: nutrients, organic matter and rich microflora, which have a positive effect on soil's microbial activity.

However, in an intensive farming system, manure is not always able to replace fast-acting mineral fertilisers. Furthermore, before using the manure must be adequately fermented as well as not possessing too much straw. The composition of organic manure does not match the crop demand (N is low, P is high). The use of organic fertilisers in line with the principles of Good Agricultural Practice, may reduce the dose of mineral fertilisers, in addition, such fertiliser is cheaper. Big problem also appears in case of specialisation of holdings leading to animal production regions and crop regions.

The aim of the analysis was to assess the technical potential of residues from animal production. Surpluses were estimated for two scenarios, assuming the maximum and intensive use of manure on agricultural land. The conducted modelling assumes the priority use of manure compared to mineral fertilisers. In the first scenario, the surplus was defined as residues from animal production that remains after its use as a natural fertiliser, to a maximum dose limit set out in the Nitrates Directive (170 kg N/ha). The second, less restrictive scenario assumes that farmers may be interested in an alternative use of residues from animal production, where the production of nitrogen associated with the amount of livestock manure more than 85 kg N/ha. This value was determined as half of the maximum nitrogen dose per hectare. According to Elbersen farmers start to have problems with manure marketing from an average level of about 100 kg N/ha.

The potentials were estimated for three main types of this kind of biomass: residues from cattle, pigs and poultry, including four type fractions of manure (solid manure, liquid manure, slurry, deep litter). This division was adopted after Lyngsø et al. (2011).

Livestock manure: Organic material consists primarily of a more or less homogenous mix of faeces and urine from livestock, including bedding material, and secondarily of other material that would be discarded as residues from a livestock production such as fodder residues, silage effluents and process water. Livestock manure might also be more or less diluted with rainwater during storage.

Solid manure – Sub-group of source separated livestock manure. Normally having a dry matter content of 20-30 %, removed from the livestock stables on a daily basis and placed in a manure pad with drains to collect effluents and rainwater.

Liquid manure – Sub-group of source separated livestock manure. Normally having a dry matter content of 2-10 %, and flowing out of the livestock stables via piping systems by gravity or pumping, and placed in a liquid manure tank, which is closed/with cover in order to reduce ammonia emissions.

Slurry – Sub-group of livestock manure. This is usually, a mix of faeces and urine from livestock, bedding material with small structure like sawdust or chopped straw, washing water, water spill, etc. and originating from stables with whole or partly slotted floors. Normally having a dry matter content of 2-10 %, and flowing out of the livestock stables via piping systems by gravity or pumping, and placed in a liquid manure tank, in some cases with cover in order to reduce ammonia emissions.

Deep litter - Sub-group of livestock manure. Also known as deep bedding. Originates from livestock stables where livestock are kept on a bed of long straw or similar material, up to 1 metre thick. The bed is only removed with intervals of up to one year, when the livestock is removed from the stable for slaughter or grazing. The bedding during use undergoes a natural composting process, whereby the temperature often raises to 50°C or more. The dry matter content is therefore kept on a high level, typically over 30 %, and the deep bedding can be removed from the stable and be stored on the bare ground in field heaps without risks of leakage.

The technical potential of manure, which can be used for energy purposes, is defined as the difference between the theoretical potential, and demand for organic fertilisers in agriculture (according to the assumed scenarios).

Theoretical potential of animal residue are defined: the actual production of solid manure, liquid manure, slurry, deep litter from cattle, pigs and poultry.

Methods

Theoretical potential of residues from animal production was estimated for NUTS 3 regions based on the model developed in the BEE project (Vis and Dees, 2011). This potential informs about the absolute amount of produced manure. Because of the subsequent analysis, it has been calculated separately for manure generated from cattle (Formula 4), pigs (Formula 5) and poultry (Formula 6). The values of the coefficients are summarised in Table 7.

Formula 3: TCP_Manure = (M_cattle + M_pig + M_poultry)

Formula 4: M_cattle = $\sum NHeads_i * LUs_i * MpH_i * AHD_i * Avi * UFi / 1000$

Formula 5: M_pig =$\sum NHeads_i * LUs_i * MpH_i * AHD_i * Avi * UFi / 1000$

Formula 6: M_poultry =$\sum NHeads_i * LUs_i * MpH_i * AHD_i * Avi * UFi / 1000$

where:

TCP_Manure = Theoretical potential of manure production (tonnes / year)

M_cattle = Theoretical potential of cattle manure production (tonnes / year)

M_pig = Theoretical potential of pig manure production,

M_poultry = Theoretical potential of poultry manure production,

$NHeads_i$ = Number of heads for *i* type of livestock,

LUs_i = Number of livestock units per head for *i* type of livestock,

MpH_i = Amount of manure per livestock unit for *i* type of livestock, in kg per day,

AHD_i = Animal housing number of days per year,

i = Type of livestock,

Av_i = Availability factor: ratio of manure that can technically be collected from the stables, due to losses during storage is assumed at $Av_i = 0.75$,

UF_i = Use factor (percentage of manure that has no important alternative uses), is assumed $UF_i = 0.97$.

Table 7 Initial values of formulas Formula 4- Formula

Type of livestock (i)	LUs_i	MpH_i	AHD_i
Dairy cows	1	59.2	150
Bovine animals under 1 year old	0.4	6.4	150
Bovine animals 1 year or over but under 2 years, male	0.7	29.6	150
Bovine animals 1 year or over but under 2 years, female	0.7	29.6	150
Bovine animals 2 year old and over, male	1	32.1	150
Bovine animals 2 year old and over, heifers	0.8	32.1	150
Other cows	0.8	31.5	150
Pigs	0.3	5.5	365
Poultry	0.02	0.13	365

Sources: BEE (Böttcher et al., 2010), Eurostat

The demand for natural fertilisation was modelled in the following steps:

1. Calculation of the nitrogen content in manure fraction derived from cattle, pigs and poultry,
2. Estimation of the potential of natural fertilisation intensity by specifying the maximum N (dose due to a nitrogen content) per hectare of arable land.

Step 1

Based on the work of Lyngsø et al. (2011) the share of the four manure fractions from animal production (Table 8) was determined. In the table, the nitrogen content of the fertiliser in each fraction was presented. However, the adoption of these average values in the analyses performed for the NUTS-3 leads to significant errors in estimates, due to the wide variation in animal production systems of European countries. On the basis of the work carried out on behalf of the United Nations Food and Agriculture Organisation (FAO), by the scientific network Research Network on Recycling of Agricultural and Industrial Residues in Agriculture (Ramiro) can be stated that this is particularly the proportion of liquid fraction of pig breeding (Menzi, 2002). In Western Europe, the slurry system is common. In this production system, the national average liquid fraction of total manure is over 95%. This includes countries such as France, Belgium, Ireland, the Netherlands, Italy and Spain. In the countries of Central Europe, these values range from 65 to 80 percent, in Poland even below 50%. Similarly, a big difference can be seen in the proportion of manure fractions from cattle although this is not as significant on a regional basis (Menzi et al., 1998).

Table 8 Fractions of natural fertilisers and nitrogen content

Type of livestock	**Solid manure**		**Liquid manure**		**Slurry**		**Deep litter**		**Average N content in manure**
(i)	**% ***	**kg N /t ****	**% ***	**kg N /t ****	**% ***	**kg N /t ****	**% ***	**kg N /t ****	**kg N /t ****
Cattle	27	6.39	5	4.61	41	5.3	27	9.74	6.75
Pigs	8	11.09	5	3.08	84	4.31	3	2.41	4.73
Poultry	0	0	0	0	3	6.18	97	19.86	19.45

Sources: *Lyngsø et al., 2011 based on Bioteau et al., 2010); ** Agro Technology Atlas (2013)

Nitrogen content in the liquid and solid manure and slurry from cattle, pigs and poultry were calculated by multiplying the theoretical potential (M_cattle, M_pig, M_poultry) in the regions by the average nitrogen content in the type of fertiliser (Table 8). The share of different fractions in manure for individual countries is based on data from Menzi (2002). This publication presents only a the ratio between liquid and dry fraction, and therefore, in the absence of more detailed data in the development of self-assumed ratio between straw manure and manure and liquid manure and slurry - such as given in Table 8. The following example illustrates how to calculate the nitrogen content in the liquid manure:

Formula 7

NCCLM = M_cattle(NUTS-3) * 4,61 kg N/t *%liquid * 100

where:

NCCLM = The nitrogen content of cattle liquid manure (NUTS-3)

% liquid = average share of cattle liquid manure in animal faeces in the country based on the maps published by the Menzi (2002).

Step 2

It was assumed that fertilisers are used in the following order: bird droppings, urine, manure, pig manure, manure straw and cattle manure, pig manure. The order of use for different types of determined manure nitrogen content is shown in Table 8. In modelling, the application of natural fertilisers is carried out until the critical values is established in the scenario, i.e. 85 kg N / ha. Calculations were performed using an algorithm that can be described with the following code VB script:

Formula8.

```
sumN = 0
i = 1
          Do While  sumN < scen_max
               If   [N.i] < scen_max - sumN
               Then   sumN = sumN  + [N.i]
               Else    [P.i] = [N.i] –(scen_max - sumaN)
                       sumaN = scen_max
               End If

          i = i+1
          Loop
```

where:

sumN = variable, summing up the dose utilised (kg N/ha) on agricultural land NUTS-3

scen_max = maximum value of nitrogen application: Scenario 1 = 170 kg N/ha, Scenario 2 = 85 kg N/ha

i = counter, which assigns new types of fertiliser, according to the established order of calculation

[N.i] = max. dose of N/ha achieved with the application *i* the type of fertiliser

[P.i] = part of the dose *i* the type of fertiliser, which is a supplement to a maximum of 170 kg N/ha in the case of scenario 1 and 85 kg/ha in the case of scenario 2

The use of the above script allowed the assessment of precise livestock manure use (according to the assumed scenario). The remaining surplus can be treated as available technical potential for energy production. In order to convert the energy of the modelled biomass; it was assumed and based on data from Agro Technology Atlas (2013) and algorithms calculator ECN (Energy research Centre of the Netherlands - Ref: Phyllis2) that one tonne of compost cattle manure with a humidity of 80% correspond with a calorific value of 0.9 GJ, and the one tonne of composted pig manure with humidity 77% equivalent calorific value of 1.2 GJ. These figures are net calorific value (LHV). The calculations values have been estimated and adopted on the basis of Sweeten et al. (1986), Annamalai et al. (1987), Xiao et al. (2010) and ECN laboratory. Table 9 gives information about the source data used in the calculations.

Table 9 Data source of livestock residues

Indicator	**Source**	**Location**
NHeadsi	Eurostat	Structure of agricultural holdings by NUTS-3 regions-main indicators [ef_r_nuts], IND_FARM
LUs_i	Eurostat	Glossary:LSU http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:LSU
MpH_i, AHD_i	BEE	Böttcher et al., 2010
UF_i	Raport	Weiser et al., 2012
Pow. UR	Eurostat	Structure of agricultural holdings by NUTS-3 regions-main indicators [ef_r_nuts], IND_FARM

Results

The total theoretical potential of residues from livestock production in Europe is about 1.23 Gt. The average value for the NUTS-3 is 935 kt. 1249 NUTS-3 units were found with a potential of more than 10 kt, 1116 with a potential of more than 60 kt and 930 with a potential of more than 200 kt. One of the most prosperous regions in the livestock manure production are: ITH2 - Trento, ITH1 - South Tyrol; ITH4 - Friuli-Venezia Giulia, NL41 - Noord-Brabant, SK01 - Bratislavský. The highest potential was estimated for the NUTS-3: ITD20 (Trento) - 24.6 Mt - Figura 23.

Table 10. The most promising NUTS-3 with the highest livestock residues potential

Theoretical			Technical			Density	
NUTS-3	kt	PJ	NUTS-3	kt	PJ	NUTS-3	t/km^2
ITD20	24567.5	24.08	NL413	1711.9	1.7	BE257	1730.09
ITD10	24557.5	24.07	ITC47	1594	1.6	BE256	1236.11
DE600	20435.1	20.03	NL414	1585.4	1.6	NL413	1234.83
ITD42	14533.9	14.24	ITC4B	1412.3	1.4	BE252	1134.91
IE024	12436.6	12.19	NL225	1186.2	1.2	NL414	1087.43
IE025	12391.5	12.14	NL213	1024.8	1	BE253	978.36
IE023	9325.2	9.14	DEA37	942.3	0.9	NL421	896.8
FR521	8268.9	8.10	NL221	814.2	0.8	BE233	835.5
FR523	8200.5	8.04	NL421	767.1	0.8	NL212	815.09
UKN05	7882.9	7.73	CH061	749.5	0.7	NL225	759.44

However, despite the high potential of the theoretical assumption of the primacy for the use of manure production, there were virtually no more possibilities of obtaining this type of biomass for energy purposes (Figure 24). Only in the three regions there is a surplus of manure, excess in terms of nitrogen, the possibility of total consumption in agriculture (by scenario 1). These are areas in the region Noord-Brabant (Netherlands), where per hectare of arable land account up to 254 kg N (NL414 and 413), NW Belgium (> 223 kg N/ha) and Portugal (Pinhal Litoral region, 180 kg N/ha).

Spatial analysis showed 36 units NUTS-3, where the estimated dose exceeds 85 kg N/ha, which indicates the existence there of the surplus production of manure that can be estimated at 21.4 Mt (21 PJ), an average of 580 kt/NUTS. These surpluses, according to scenario 2, can be used for energy purposes. Units forming a concentration found in the Netherlands (9 NUTS with the potential of 8.4 Mt, equivalent to 8.3 PJ of energy - marker 1 in Figure 25), northern and north-western Belgium (13 NUTS with the potential of 5.1 Mt , 4.9 PJ - Marker No. 2), Italy, in the region of Brescia, Mantova (3 NUTS with the potential of 3.5 Mt, 3.4 PJ - Marker No. 3), Germany (8 NUTS with the potential of 3.4 Mt, 3, 3 PJ - marker 1). Regional, but much smaller, surplus manure was also found in Portugal (344 kt, 0.3 PJ) and Malta (96 kt, 0.1 PJ).

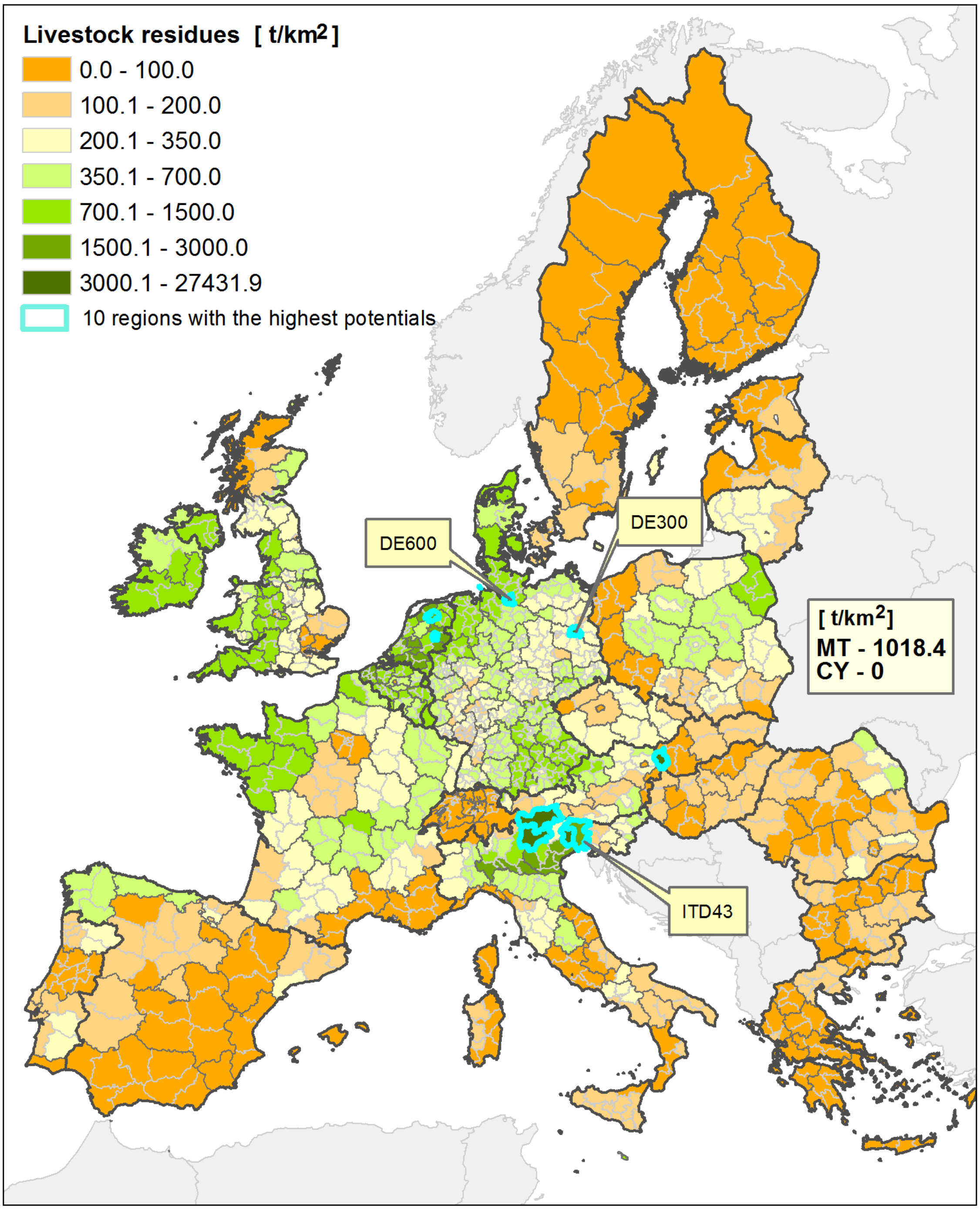

Figure 23 Theoretical potential of residues from animal production in NUTS-3, indicating the regions with the greatest potential

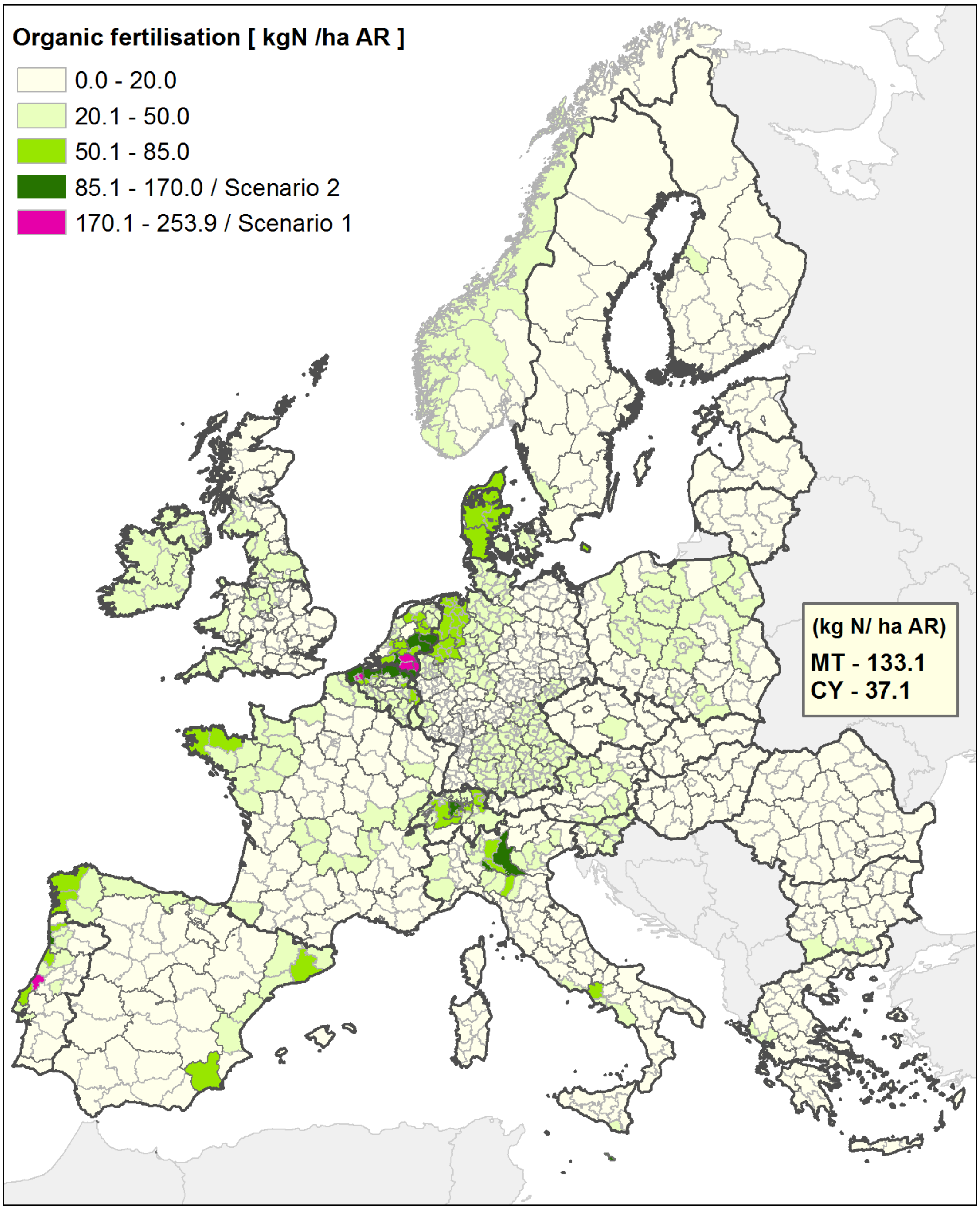

Figure 24. The amount of nitrogen in livestock manure expressed as kg N/ha total agricultural area

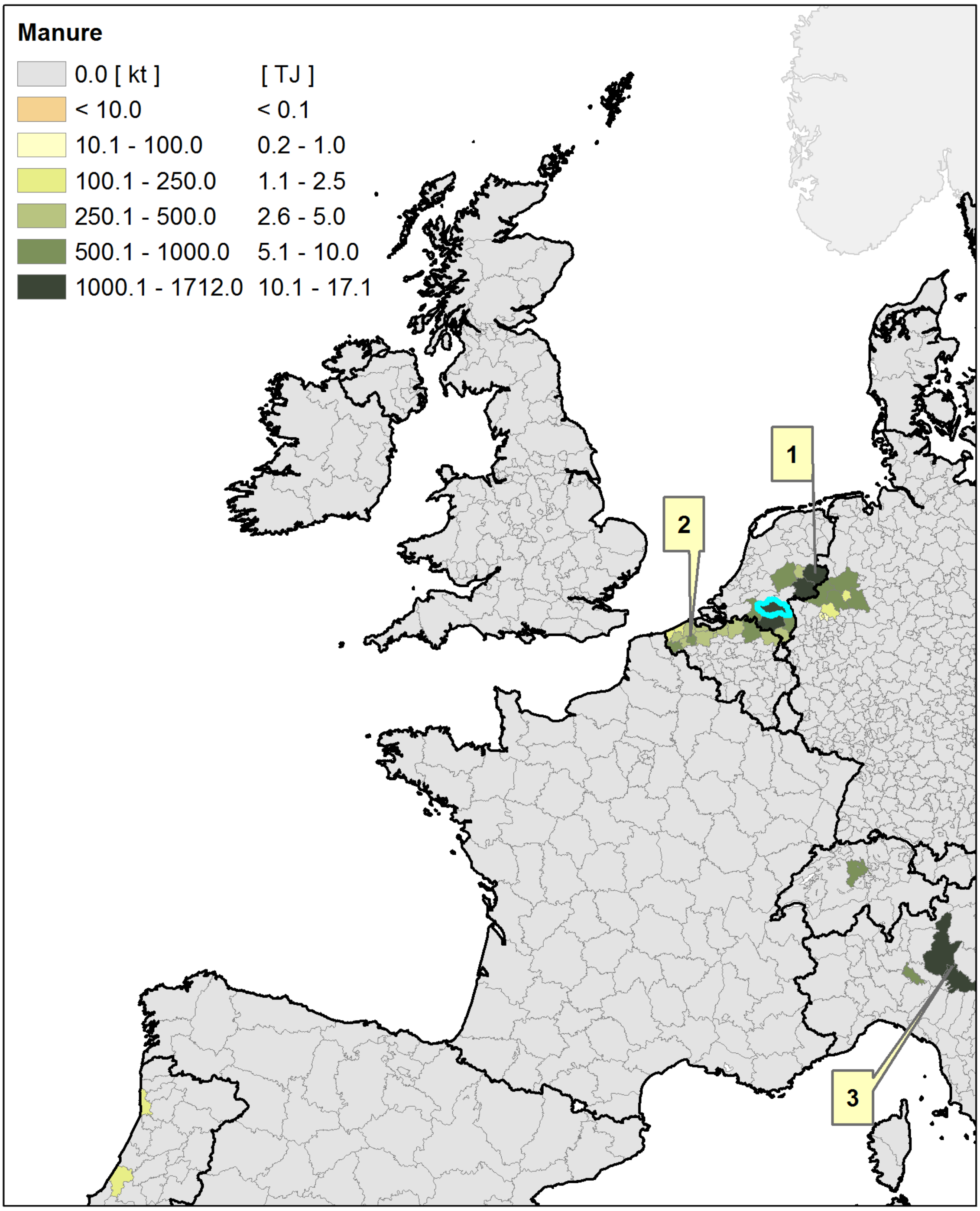

Figure 25 The technical potential of manure surplus

1.4 Hay from permanent grassland

Scope and definitions

Hay derived from permanent grassland, due to the large acreage, can be found as a theoretically significant potential of biomass. Regions with a high proportion of pastures and meadows are used for intensive livestock, mainly cattle. In these regions, pastures are used for grazing animals, and for feeding in fresh form or as hay, and silage).

The aim of the analysis was to assess the technical potential of biomass, which is a surplus of hay in NUTS-3. It was assumed that the excess hay is estimated as the difference between the potential productivity of biomass under permanent pasture and hay demand associated with the farming of ruminants.

The potential productivity is defined as the average yield of hay (Smit et al., 2008), converted into an area of permanent pasture. For the 27 EU countries, data was obtained from Eurostat, while the grassland area of Switzerland was based on land cover map (CLC) and national statistics (FSO, 2012).

The demand of hay for livestock was specified for ruminants, based on data from Eurostat. Due to the lack of a European regional database, which characterise animal feed, the optimal scenario was adopted. It was assumed that ruminants are actively feeding on the resource growing on the meadows and pastures. Regardless of whether in the region the grazing animals or feeding processed hay were present, a daily dose of 20 kg per head was assumed, which annually, assuming a 20% reserve, gives 8.76 tons of hay. These estimates are based on Winnicki et al. (2012) and the recommendations of the Agricultural Advisory Centres (Kwiatkowski, 2010).

Methods

The technical potential of hay surplus in each NUTS-3 was based on the following algorithm Formula 9:

$$PTNS = (PS\_s * PowUZ) – (LU_{Si} * SK)$$

where:

PTNS = technological potential of hay surplus (t)
PS_s = average yields of hay in the region ($t*ha^{-1}$)
PowUZ = grassland area (ha)
LUSi = number of livestock units per head for the i type of livestock (cows, sheep, goats)
SK = amount of hay intended for LUSi (cattle, sheep, goats)

In the absence of data for certain NUTS-3 units, the technical potential of surplus hay was estimated for available level of NUTS and proportionally distributed to the share of grassland in the NUTS-3 under the CLC. Sources of data were used in the modelling are summarised in Table 11. Data sources - hay potential model

Table 11. Data sources - hay potential model

Indicator	Source	Location
PS_s	Map in publication	Smit et al., 2008
PowUZ	Eurostat	regional agricultural statistic (reg_agr)
LUSi	Eurostat	regional agricultural statistic (reg_agr)
SK	Plan for fodder base	Winnicki et al., 2012; recommendations of the Agricultural Advisory Centres

In order to convert the modelled mass into energy of hay, the assumed data was based on ECN Phillis calculator where one ton of hay, with a moisture content of 15%, has an average heating value of 13.4 GJ.

Results

Hay besides crops grown on arable land and forest, is the largest resource of biomass. However, similar to the case of straw, prime hay use is determined by its need in agriculture. Total theoretical potential of hay is estimated at 116.2 Mt (Figure 26).

As a result of hay surplus modelling, which can be used for energy purposes, maps of technical capacity and density were obtained (Figure 27, Figure 28). A surplus of hay, like manure surpluses, are in a small clusters, which generally show an inability to use hay in Europe as a significant and accessible resource base. The total potential of surplus hay, which can be used for energy purposes, is only 6.9 Mt (92.6 PJ). The average value for the NUTS-3 is 80.3 kt. For the study, 50 units of NUTS-3 were found with a potential of more than 10 kt, 29 units with a potential of more than 60 kt and 12 NUTS-3 with a potential of more than 200 kt. The most important regions in which hay can be obtained are indicated in Figure 27. The highest technical potential has been estimated in the region of Teruel in Spain (ES242), 1.0 Mt, which corresponds to 13.6 PJ of energy. The highest density of this material was found in Scotland for NUTS: UKM65 and UKM31, more than 100 t/km^2 (Figure 28).

Table 12. The most promising NUTS-3 with the highest hay potential

Theoretical			Technical			Density	
NUTS-3	**kt**	**PJ**	**NUTS-3**	**kt**	**PJ**	**NUTS-3**	**t/km^2**
UKM63	5765.6	77.3	ES242	1012.6	13.6	UKM65	103.8
UKM61	5730.2	76.8	ES130	352.4	4.7	UKM31	103.6
IE025	5645.5	75.6	PT118	297.3	4	UKJ21	99.2
IE013	4961.4	66.5	RO422	252	3.4	AT321	98.1
IE011	4373.0	58.6	UKM27	248.8	3.3	ITC44	75.4
IE024	4148.1	55.6	ITC44	241.3	3.2	SI015	72.2
IE023	4107	55.0	ES220	236.7	3.2	UKD41	72.1
UKL14	3270.1	43.8	LV005	236.4	3.2	UKK21	69.5
UKM27	3181.5	42.6	RO124	231.2	3.1	ES242	68.3
UKN05	3155.8	42.3	ES120	227.6	3.1	AT341	66.6

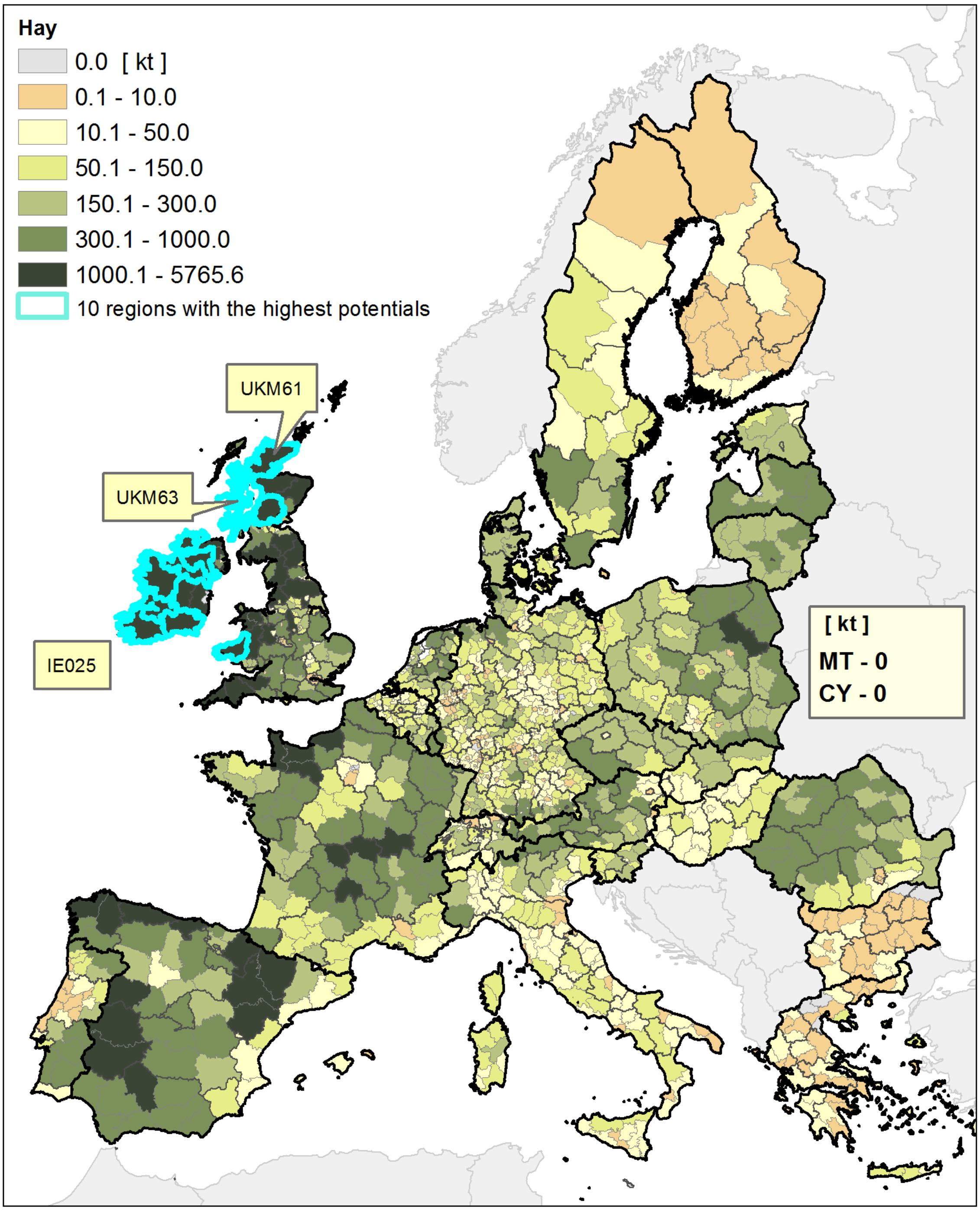

Figure 26. The theoretical potential of hay yield in NUTS-3

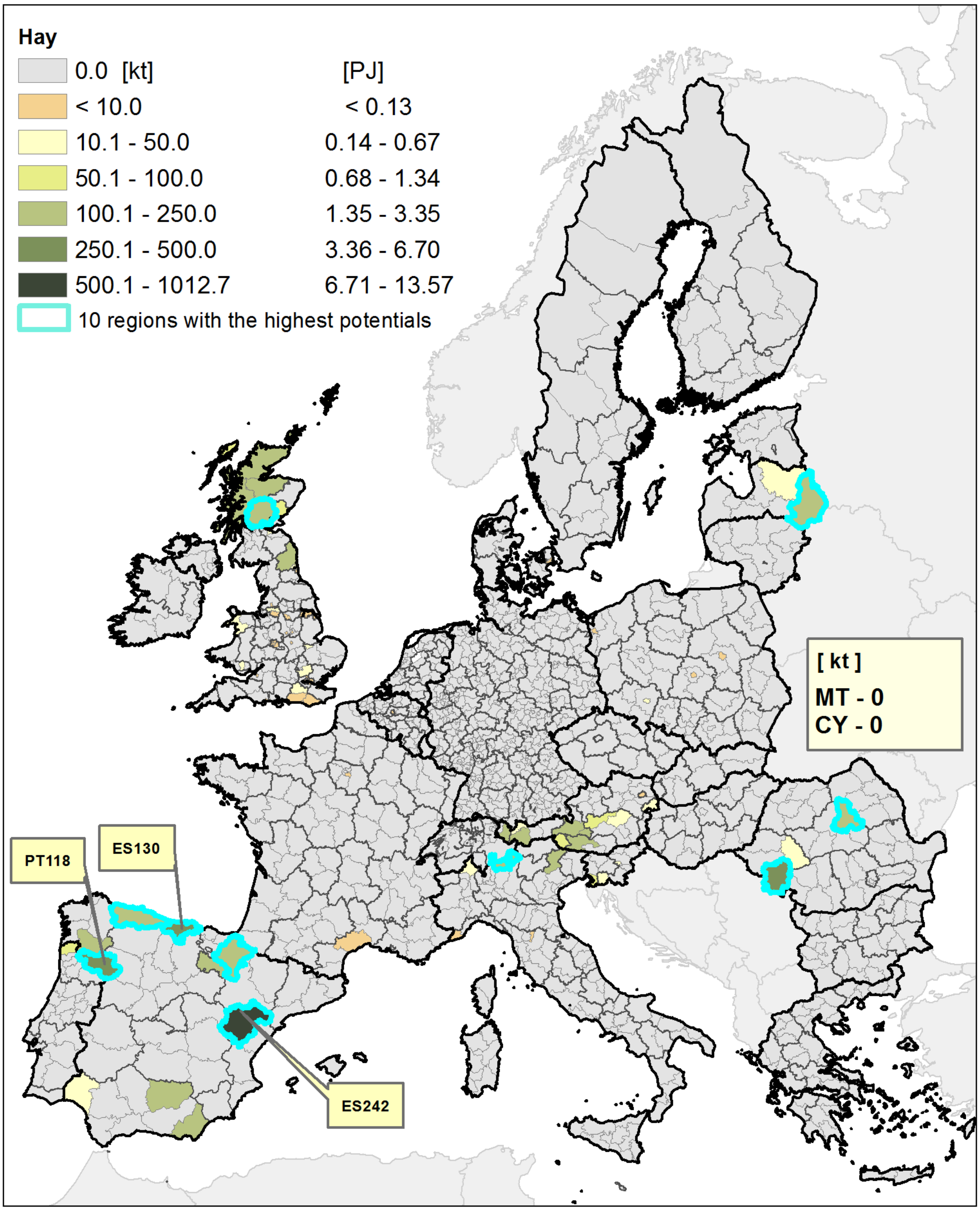

Figure 27. The technical potential of biomass and energy - hay surplus in NUTS-3

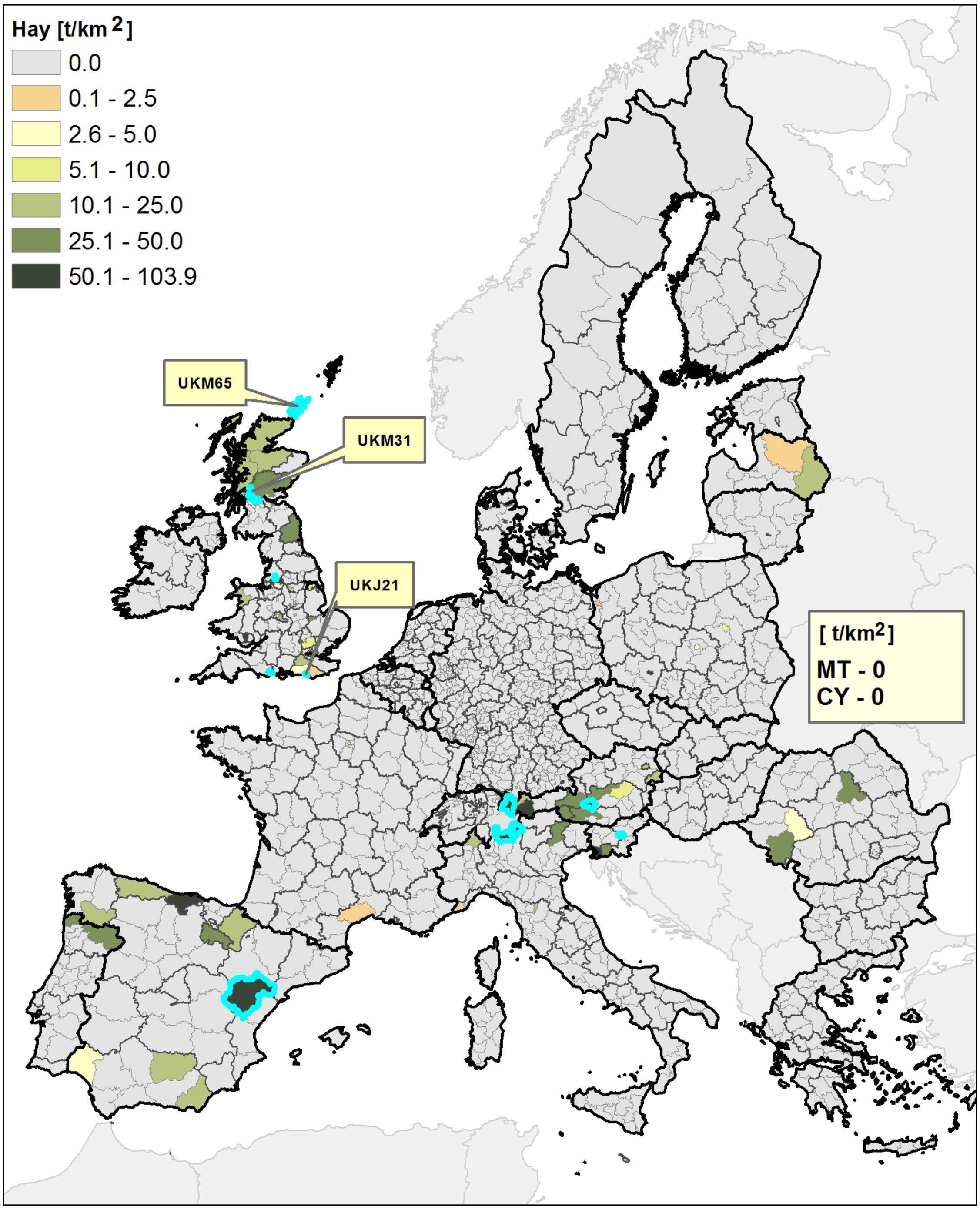

Figure 28. Biomass density– hay surplus in NUTS-3

2. FORESTRY RESIDUES

Scope and definitions

The scope of this activity was to assess the potential of forestry residues for bioenergy use. Forestry residuals were assessed based on the BEE definition and methodology (BEE (ed. Vis M.W. and van den Berg D.) 2010).

The forest residues were defined as:

- Stemwood: biomass from pre-commercial and commercial thinning and final fellings, available for energy production, including whole trees and delimbed stemwood from pre-commercial thinning's.
- Primary forestry residues: logging residues, stumps.
- Secondary forestry residues: wood processing industry by-products and residues – sawdust and cutter chips, bark, slabs, lump wood residues and black liquor.
- Woody biomass from short rotation plantations on forestlands.
- Trees outside of forests such as trees of settlement areas, along roads and on other infrastructural areas.

Method

The total theoretical potential of primary forestry residues in European countries was calculated using formula below:

THP_PFRx,y = THP_LRx,y + THP_Sx,y (Formula 10)

Where:

THP_PFRx,y = total theoretical potential of primary forestry residues in country x in year y, (m^3/year)
THP_LRx,y = theoretical potential of logging residues in country x in year y, (m^3/year)
THP_Sx,y = theoretical potential of stumps in country x in year y, (m^3/year)

Table 13. Data source used to assess the theoretical and technical potential (BEE)

Factor	Main data sources	Additional data sources used to compensate for missing values in the main data source
Net annual increment	MCPFE[1] 2007	MCPFE 2003
Harvesting loss	TBFRA[2] 2000	EFISCEN[3]
Biomass expansion factor for above ground non stem biomass without inclusion of needle and leave biomass	Empirical study published by Teobaldelli et al. (2009)	-
Biomass expansion factor for stumps	Empirical study published by Teobaldelli et al. (2009)	-
Average standing Volume per ha (Necessary to derive BEF & BEFS based on the approach of Teobaldelli et al. (2009))	MCPFE 2007	-
Wood density (To convert from cubic meter to tonne dry matter)	Fonseca, M. el al. (2010)	-

[1] MCPFE refers to the assessment of the State of European Forests by the Ministerial Conference on Protection of Forests in Europe.
[2] TBFRA and FRA refers to the Forest Resources Assessment conducted by the FAO.
[3] EFISCEN refers to the European Forest Information Scenario Model prepared by the European Forest Institute.

The assessment is based on data from 2003 to 2007. To convert one tonne dry matter to energy, an average moisture content of 35% is assumed. This results in a conversion per tonne matter (wet weight) of 10.06 MJ per kg and is equivalent to a conversion of 15.48 MJ per tonne dry matter.

In order to convert the modelled mass into energy, assumption were done that one tonne of biomass has an average moisture content of 35%, equivalent calories = 10.06 GJ and is equivalent to a conversion of 15.48 MJ per tonne dry matter..

With the approach chosen, the country and species-specific values of wood density are considered. On average, when recalculating the energy content per m^3 for the technical potential at EU level, this results in 0.173 toe/m^3 and 7.25 GJ/m^3. This conversion value is close to the 7.2 GJ/m³ that have been utilised in the EU Wood study (BEE report "Executive Summary, Evaluation and Recommendations" (BEE 2010).

Technical potential was assessed with assuming listed below specifications (BEE, 2010,

Table 13):

50 % - Recovery rate of above ground forest residues; the recovery rates have been selected in line with the level chosen by EEA (EEA 2007) and Asikainen (Asikainen, Liiri et al. 2008) but simplified to 0.5 per country

20 % - 40 % as a Recovery rate for stumps; recovery rates for stumps have been chosen lightly lower compared to Asikainen et al. (2008) and merely a very course differentiation within countries was made with reference to silvicultural and harvesting practises and species distribution

30 % - Part of the surplus complementary fellings are reserved for material use of wood

5 % - Part of the current net annual increment is reserved for an increase of standing volume to facilitate an increased carbon storage and for biodiversity purposes including an increase of the dead wood component and to increase the share of mature forests especially in protected areas

5% - Consideration of unrecorded harvests from industrial roundwood in the current harvesting statistic (thus attributing more wood from the entire harvesting potential for material use).

Spatial explicit method

Yield was estimated for forest areas determined based on CLC map. From this map, deciduous, coniferous and mixed classes were extracted. For each NUTS-3 region, the average NPP for value were found based on the WDC-RSAT data. The relative differences of net primary productivity have been used (as weighting factors) to redistribute the theoretical and technical values of potentials from countries level to the raster map.

Results

The total assessed theoretical potential of forestry residues amounts at: 321 Mt (3230 PJ).

The total assessed technical potential of forestry residues amounts at: 117,9 Mt (1186 PJ). Average value for NUTS-3 is 90 kt. There are 960 NUTS-3 where the biomass potentials are over 10 kt and 561 NUTS-3 where the biomass potentials are over 60 kt. The highest potential of biomass was found in NUTS-3: FI1D7 (Lappi) – 2.5 Mt, but the highest density of biomass was calculated for DEB3K (Südwestpfalz) – 147 t/km2.

Table 14. The most promising NUTS-3 with the highest forestry residues potential

Theoretical			Technical			Density	
Nuts 3	**kt**	**PJ**	**Nuts 3**	**kt**	**PJ**	**Nuts 3**	**t/km2**
FI1D7	5770.7	58.1	FI1D7	2466.1	24.8	DEB3K	147.2
FI1D6	3234.3	32.5	FI1D6	1382.2	13.9	DE71B	132.9
SE331	3201.4	32.2	SE331	1355.2	13.6	DE229	131.8
SE332	3105.4	31.2	SE332	1314.6	13.2	DE269	130.2
FI193	2887	29	FI193	1233.8	12.4	DE264	129.7
FI1D1	2838.7	28.6	FI1D1	1213.1	12.2	DE12C	127
SE232	2752.5	27.7	SE232	1165.2	11.7	DE26A	126.3
FI1D3	2586.4	26	FI1D3	1105.3	11.1	DE12A	125.4
FI1D2	2482.7	25	FI1D2	1061	10.7	DE71D	121.8
SE322	2471	24.9	SE322	1046	10.5	DEB3C	121.5

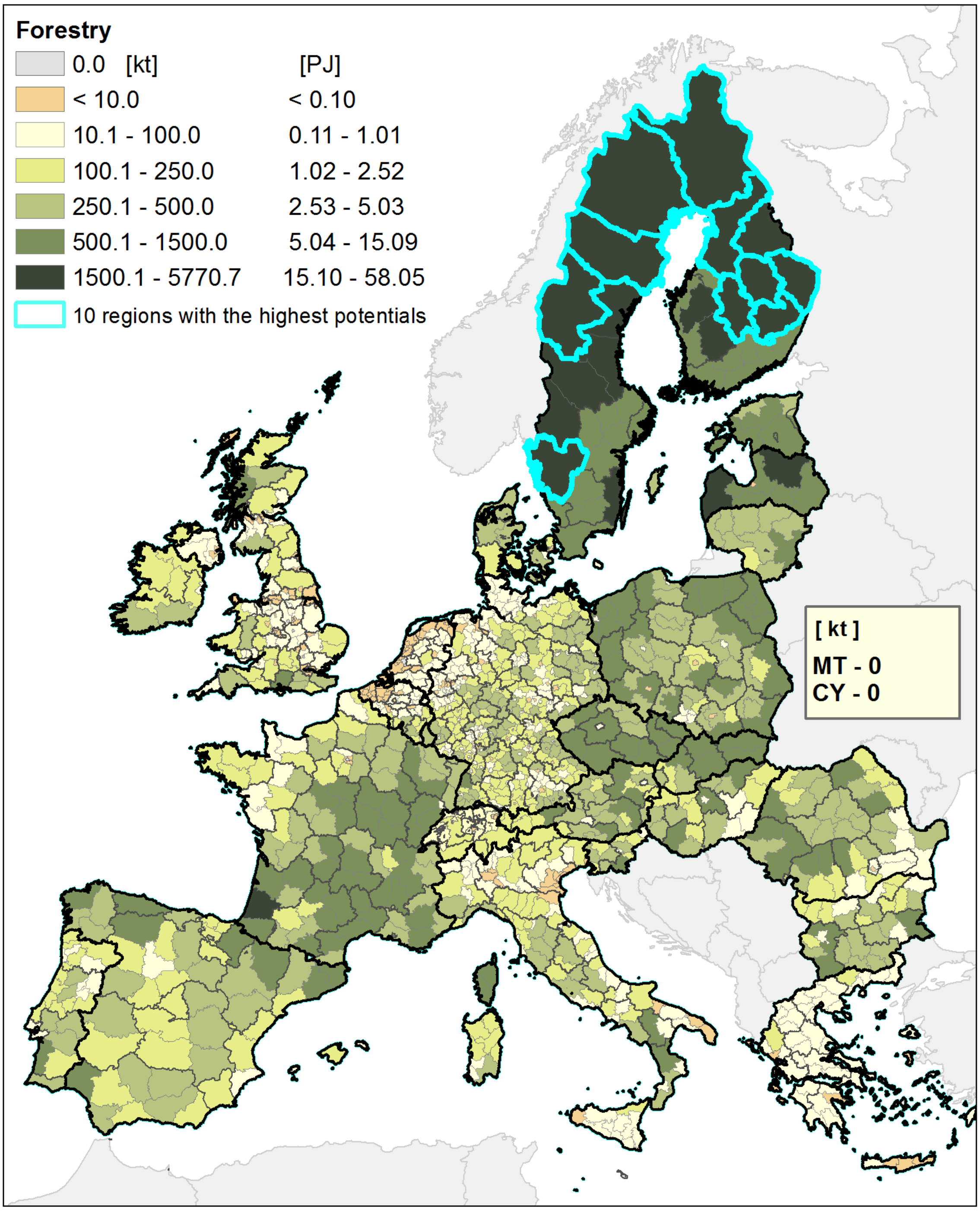

Figure 29. Theoretical forestry residues potentials in NUTS-3

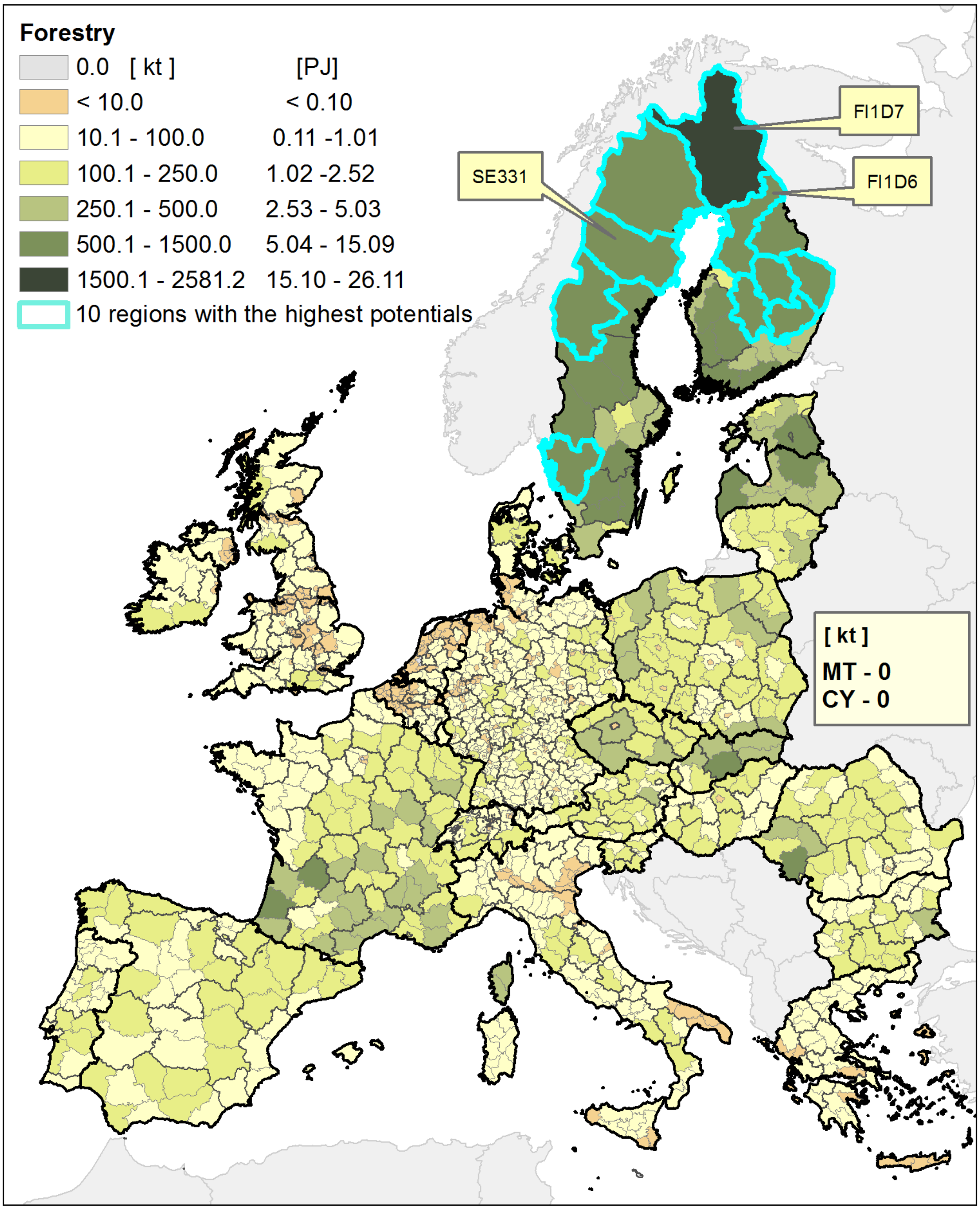

Figure 30. Technical biomass potentials of forestry in NUTS-3

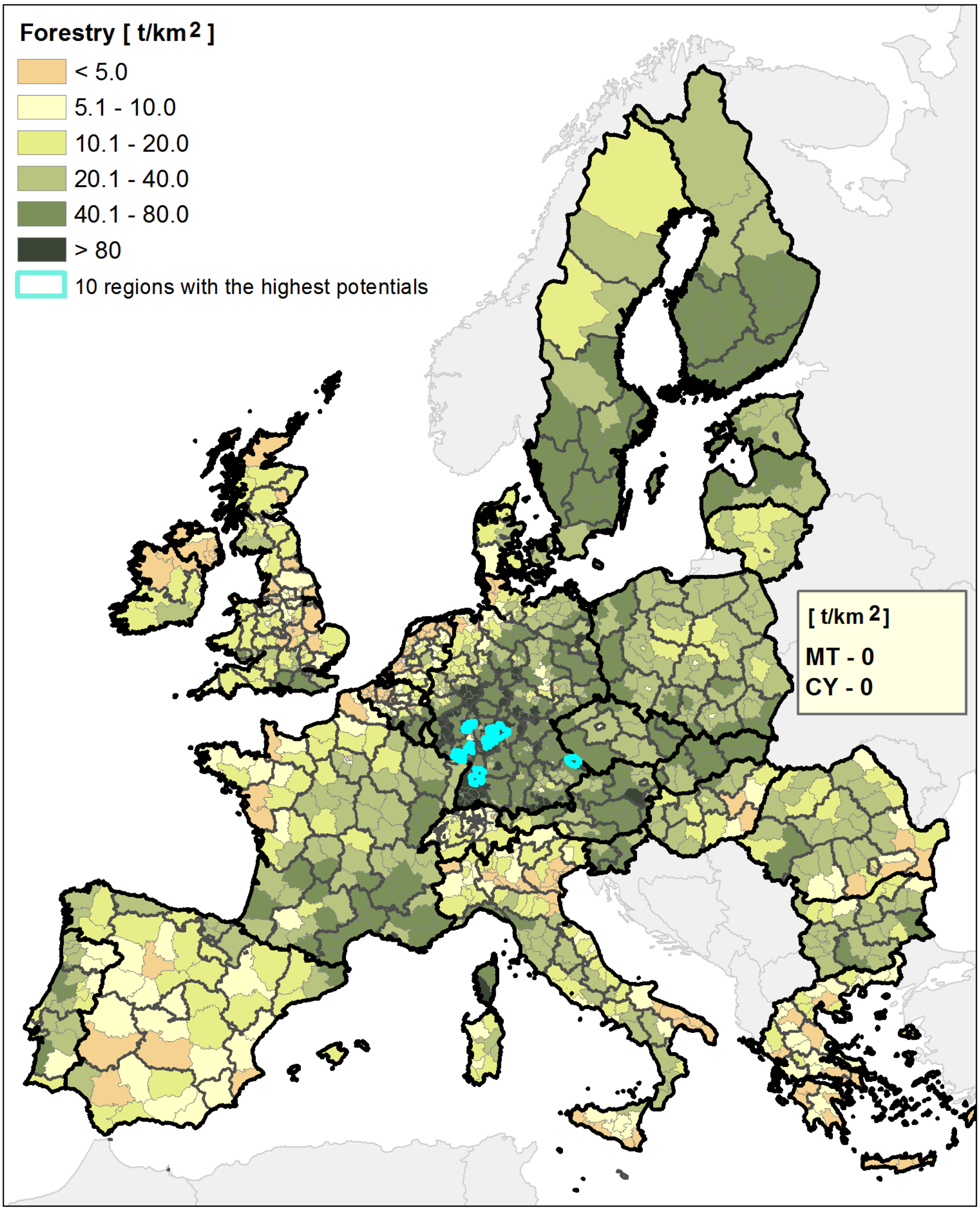

Figure 31. Normalised biomass potentials of forestry residues in NUTS-3

3. NATURAL CONSERVATION MATTER

3.1 Green urban areas

Scope and definitions

The scope of this activity was to assess the potential of biomass, which can be obtained as a natural conservation matter on the artificial, non-agricultural vegetated areas. Biomass that is composed of leaves, shrubs and grass, can be obtained as residues from the conservation of green urban areas, port and leisure facilities.

Method

The potential is assessed based on CLC. This map allows determining green urban areas (class 10) and Port and leisure facilities (class 11). For selected pixels, the values of NPP were re-written. Analysis was conducted at a scale of 100x100m for 27EU + Switzerland.

As a technical potential 50 percent of NPP was assumed for each pixel.

Formula 11:

IF CLC = 10 OR 11 ***THEN*** GUA = (0.5 * NPP) ***ELSE*** GUA = NoData

Where:

GUA = Residuals of natural conservation of green urban areas
CLC = Corine land cover, classes: 10, 11
NPP = net primary productivity in location of 10, 11 class of CLC

Table 15. Data sources of natural conservation matter. Green urban areas

Indicator	Source	Location
CLC	EEA: CORINE	http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2
NPP	WDC-RSAT	http://wdc.dlr.de/data_products/SURFACE/

Results

As a result, a raster map of biomass potential from green urban areas was assessed. Values determined as a grid 100x100m were tabulated for 1313 BioBoost NUTS-3 regions.

The total assessed feedstock potential of green urban areas amounts at: **1.18 Mt (17 PJ)**. Average values for NUTS are 0.96 kt. There are 7 NUTS-3 where the biomass potentials are over 10 kt. The highest potential of biomass was found in NUTS-3: DK022 (Vest-og Sydsjalland) – 13 kt, but the highest density of biomass was calculated for FR101 (Paris) - 19 t/km^2.

Table 16. The most promising NUTS-3 with the highest green urban areas potential

Technical			**Density**	
NUTS-3	**kt**	**PJ**	**NUTS-3**	**t/km^2**
DK022	13.8	0.2	FR101	19.32
PT150	13.4	0.2	UKI23	13.76
HU102	12.9	0.19	UKI22	13.58
DK050	11	0.16	PL514	12.31
UKJ23	10.6	0.16	DK012	12.26
SE110	10.4	0.15	DE712	11.79
UKJ42	10.3	0.15	UKI11	11.71
CY000	9.5	0.14	FR105	11.38
SE224	9.4	0.14	UKI21	11.23
DK013	8.9	0.13	DEF02	11.17

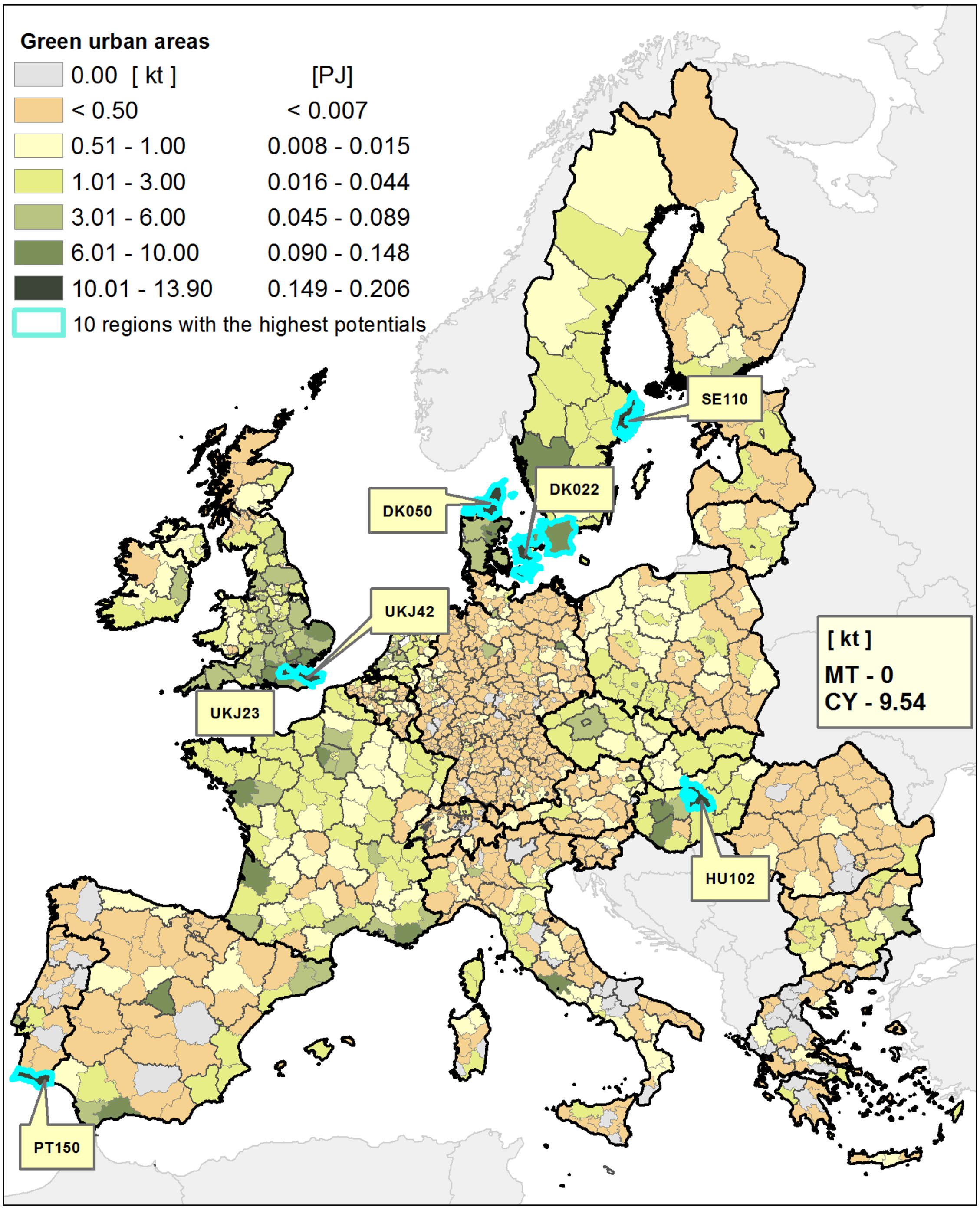

Figure 32. Technical biomass potentials of green urban areas in NUTS-3

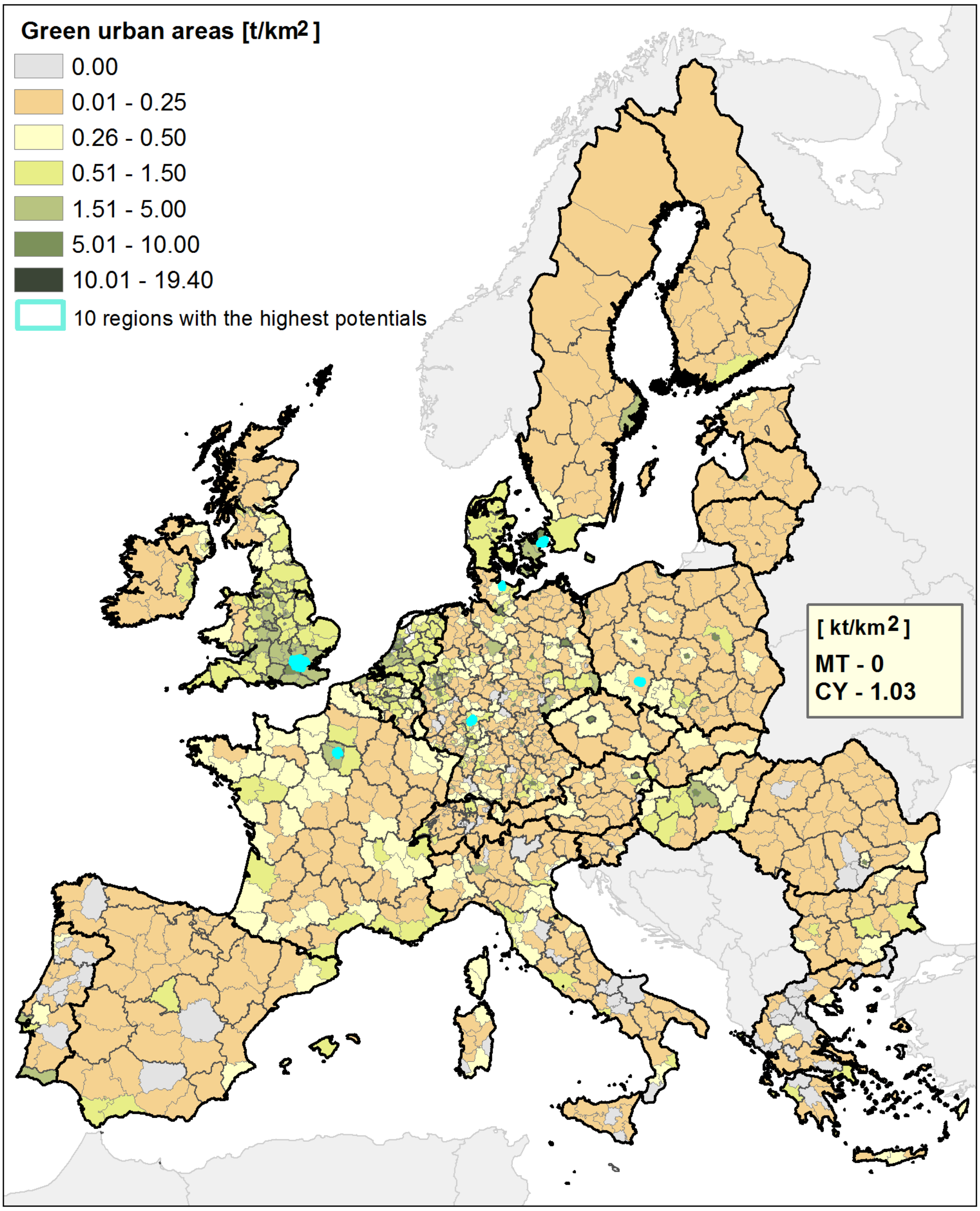

Figure 33. Normalised biomass potentials of green urban areas in NUTS-3

3.2 Hay and shrubs

Scope and definitions

The scope of this activity was to assess the potential of biomass that can be obtained as a natural conservation matter on the green lands. Biomass that is composed of shrubs and grass can be removed from pastures located on NATURE 2000 areas (SPA). Methodology was developed base on the framework of Polish agri-environment scheme, where 9 agri-environmental packages are implemented, of which the two following are strictly oriented on protection of biodiversity:

1. Package 4. Protection of endangered bird species and natural habitats outside of Natura 2000 areas;

2. Package 5. Protection of endangered bird species and natural habitats in Natura 2000 areas

Within these two packages, there are a set of different detailed variants. One of them is:

Variant 4.1/5.1. Protection of bird breeding habitats

Description: This variant includes: breeding bird species characteristic for nature-value and endangered types of permanent grasslands, among others wet and mesic meadows mostly found in river valleys, as well as sedges and peat meadows mostly found in peat bogs. The bird species supported under this variant have their nests on the ground or among herbaceous vegetation and too early mowing or too intensive grazing may lead to the destruction of their breeding grounds. On the other hand, in not continuing the use of the aforementioned permanent grasslands leads to degradation of bird breeding habitats.

Requirements included in Variant 4.1. are supposed to adjust the use to the needs of selected bird species nesting on meadows and pastures. The area covered by Variant 4.1. may be used as a meadow, pasture or used as hay and pasture land. The change of land utilisation during the agri-environmental obligation period is possible in one of the following ways.

Requirements of Variant 4.1/5.1.:

Mowing:

- every year between 1 August and 30 September;
- obligation to leave 5-10% of the agricultural plots uncut (in the case of aquatic warbler Acrocephalus paludicola 30-50%), where it should be another part each year;
- mowing height 5 - 15 cm;
- mowing in circles from the outside to the inside of the plot prohibited;
- obligation to remove or stack the cut biomass within no more than two weeks' time after mowing (except justified cases);

Grazing:

- in the case of hay and pasture land the maximum animal density is 0.2 LU per ha;
- in the case of pasture land, until 20 July the maximum animal density is 2. LU per ha, whereas after 20 July the density should remain between 0.5 and 1 LU per ha;
- maximum yield up to 5t per ha (10 LU per ha);
- grazing period: from 1 May to 15 October in areas below 300 m above the sea level, or from 20 May to 1 October in areas higher than 300 m above the sea level;
- it is allowable to mow leavings only from August to September.
- it is allowable to graze Polish primitive horse and hutsul horse for the whole year;
- beginning of the grazing period in flooded areas no earlier than two weeks after the water recedes.

Other treatment:

- liming and limited nitrogen fertilisation (up to 60 kg/ha/year) is allowable, with the exception of areas fertilised by river alluvia.
- application of agro-technical or maintenance treatment from 1 April to the time of first mowing prohibited.

Method

The potential is assessed based on CLC. This map allows determining pastures (class 18). For selected pixels, the values of NPP were re-written. An analysis was conducted at a scale of 100x100m for 27EU + Switzerland.

As a technical potential 70 percent of NPP was assumed for each pixel.

Formula 12:

IF CLC = 18 ***THEN*** HaS = (0.7 * NPP) ***ELSE*** HaS = NoData

Where:

HaS = Biomass of natural conservation on pasture areas
CLC = Corine land cover, classes: 18
NPP = net primary productivity in location of 18 class of CLC

Table 17. Data sources of natural conservation matter. Hay and shrubs

Indicator	**Source**	**Location**
CLC	EEA: CORINE	http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2
NPP	WDC-RSAT	http://wdc.dlr.de/data_products/SURFACE/

Results

As a result, a raster map of biomass potential from pastures protected by NATURE 2000 (SPA) was assessed. Values determined as a grid 100x100m were tabulated for 1313 BioBoost NUTS-3 regions.

The total assessed feedstock potential of Hay and shrubs amounts at: **3.68 Mt (49 PJ)**. Average value for NUTS is 3.8 kt. There are 104 NUTS-3 where the biomass potentials are over 10 kt.

The highest potential of biomass was found in NUTS-3: FR515 (Vendee) – 69.8 kt, but the highest density of biomass was calculated for DE404 (Potsdam, Kreisfreie Stadt) - 68,9 t/km^2.

Table 18. The most promising NUTS-3 with the highest hay and shrubs potential

Technical			Density	
NUTS-3	**kt**	**PJ**	**NUTS-3**	**t/km^2**
FR515	69.8	934.9	DE404	68.9
RO126	58	777.4	DE403	38.2
PL122	57.5	770.5	DE501	20.9
FR532	52.7	705.9	DE725	18.5
RO122	50.6	678	DE402	16.8
FR722	46.1	617.3	DE942	15.8
FR511	45.8	613.2	NL325	15.8
FR214	45.1	604	DE94G	13.7
FR724	43.9	588.9	DE408	12.5
PL431	42.9	575.2	DE732	11.3

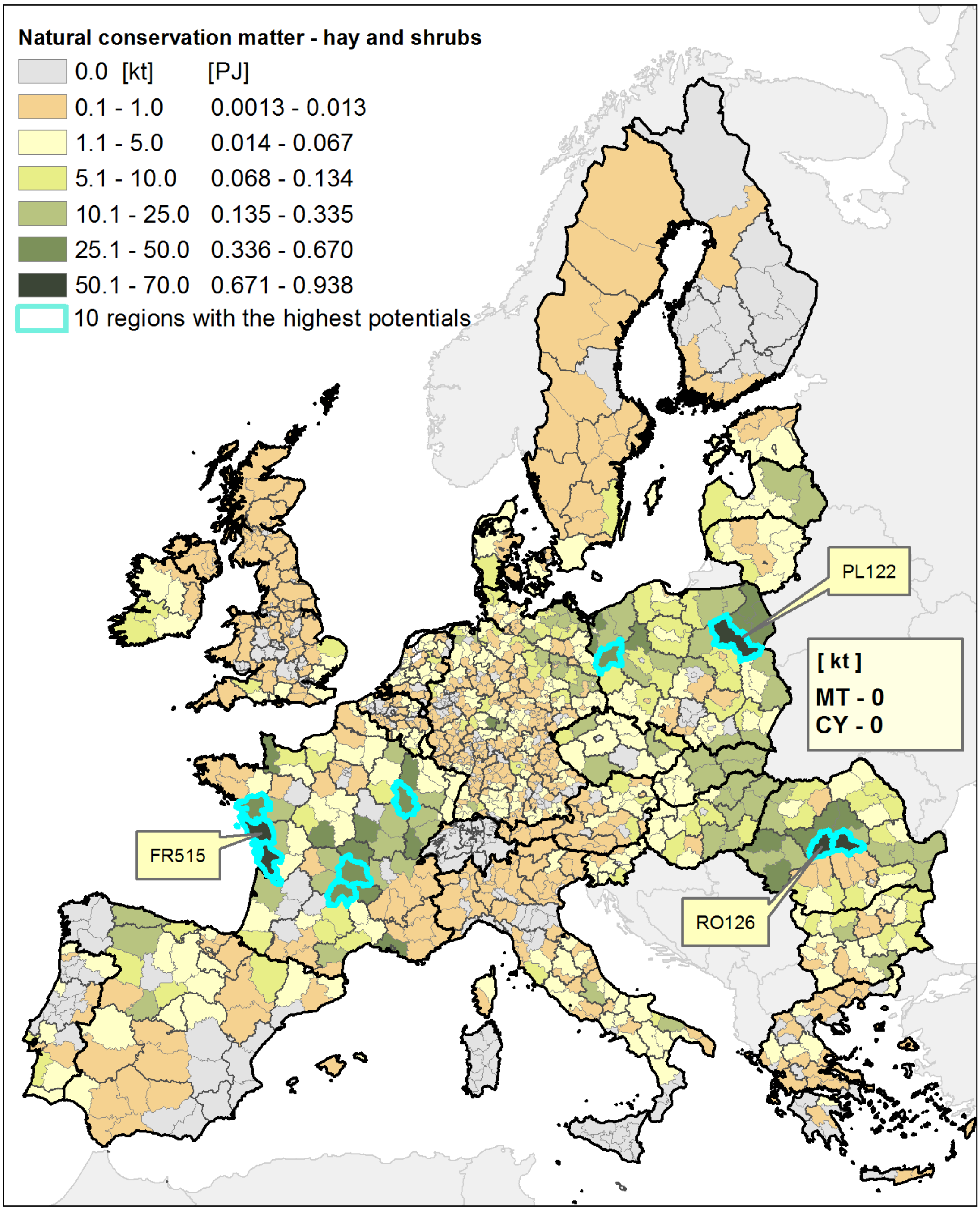

Figure 34. Technical potentials of hay and shrubs in NUTS-3

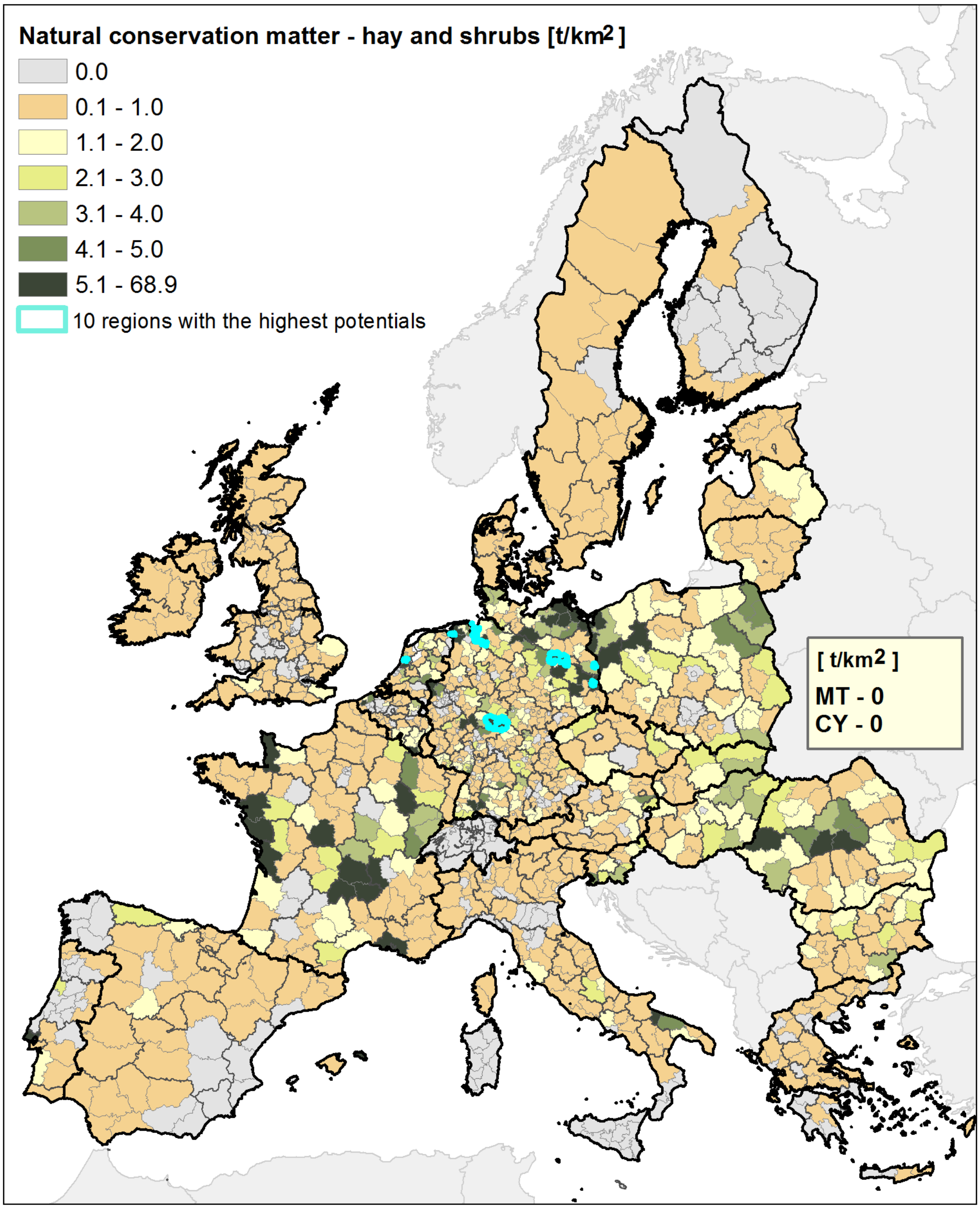

Figure 35. Normalised biomass potentials of hay and shrubs in NUTS-3

4. ROADSIDE VEGETATION

Scope and definitions

The scope of this activity was to assess the potential of biomass that can be obtained from cut grass, shrubs and trees grown by the roadside. This vegetation can be treated as new kind of biomass residues, which can be possibly used for energy purposes.

Currently, there is no collection of this biomass type in a large scale. Although there have been cases of interest in buying residuals of biomass along the road by power plants.

However, roadside biomass, due to the road network density and the limited use of roadside areas, creates a huge biomass potential. The main advantages are:

- Transport Logistics,
- Zero-cost cultivation and plant care,
- Roadside biomass is often cut and removed from the roadside strips.

The main problems in obtaining this type of biomass are the lack of technology for synchronous harvesting and loading and its local use.

Due to the large demand of biomass for energy purposes and its high theoretical potential, an attempt to estimate the possible resources was undertaken as well as including a study on the impact of roadside biomass as local biomass fuels.

The first step was to developed assumptions for estimating the biomass that surround main roads. In subsequent steps, the database was supplemented by a complete road network of Europe and a regional study for the analysis of actual unused space besides the roads of different categories.

Method

The study was based on OpenStreetMap data that provides vector maps about European roads network. For the analysis, the main classes (motor ways, primary ways and trunk ways) of roads were extracted. To this set vector map of railway network was added.

It was assumed that the biomass could be obtained from 10 m wide roadside strips. Only for 'trunk' road type the width was reduced to 5 m. As a biomass yield, we have adopted average values of NPP for NUTS-3.

The values (tons) were tabularised for NUTS-3 regions.

Formula 13:

RSV = 2*NPP*Wsp*((LR1_km* 10m)+(LR2_km*5m) +(LR3_km*10m) + (LRw_km*10m))

Where:

RSV = biomass of roadside vegetation for NUTS-3 (in 1000 tones/NUTS-3)
NPP = net primary productivity, t/ha (mean value of NUTS-3)
Wsp = 10^4, it lets to obtain value as 1000 tones, (dimensionless)
LR1 = motor way (km/NUTS-3)
LR2 = primary way (km/NUTS-3)
LR3 = trunk way (km/NUTS-3)
LRw = railway (km/NUTS-3)

Table 19. Data sources of roadside vegetation

Indicator	Source	Location
RSV	OpenStreetMap	http://planet.openstreetmap.org/
NPP	WDC-RSAT	http://wdc.dlr.de/data_products/SURFACE/

In order to convert the modelled mass into energy, assumption were done based on ECN Phillis calculator that one tonne of biomass extracted from maintenance routes with a humidity of 15%, has an average heating value of 14.8 GJ.

Results

The total assessed feedstock potential of roadside vegetation amounts at: **3.17 Mt (47 PJ)**. Average value for NUTS is 2.42 kt. There are 17 NUTS-3 where the biomass potentials are over 10 kt. The highest potential of biomass was found in NUTS-3: ITE43 (Roma) – 20.03 kt, but the highest density of biomass was calculated for CH031(Basel-Stadt) – 32.4 t/km^2.

Table 20. The most promising NUTS-3 with the highest roadside potential

Technical			**Density**	
NUTS-3	**kt**	**PJ**	**NUTS-3**	**t/km^2**
ITI43	20.0	0.3.0	CH031	32.4
FR824	16.1	0.24	DE126	18.0
ES511	15.2	0.23	DEA55	16.6
FR102	12.3	0.18	DEA17	16.3
ES432	11.7	0.17	DEA12	15.4
ES111	11.7	0.17	DE254	15.0
ES431	11.4	0.17	DEB34	14.6
CZ020	11.4	0.17	ITH44	13.9
ES523	11.2	0.17	FR107	13.9
ES300	11.1	0.16	FR101	12.8

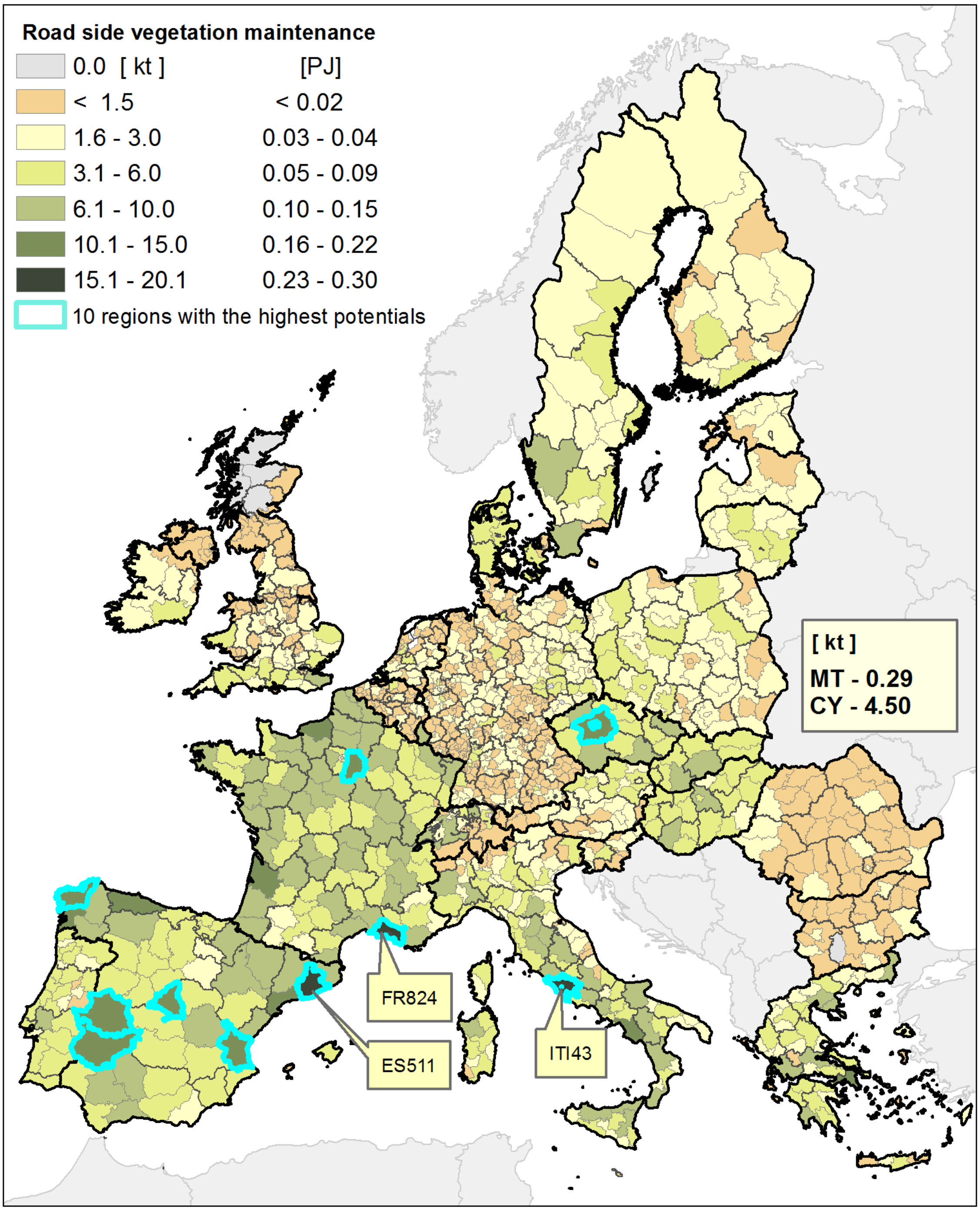

Figure 36. The technical potential of biomass and energy from the roadside vegetation maintenance in NUTS-3

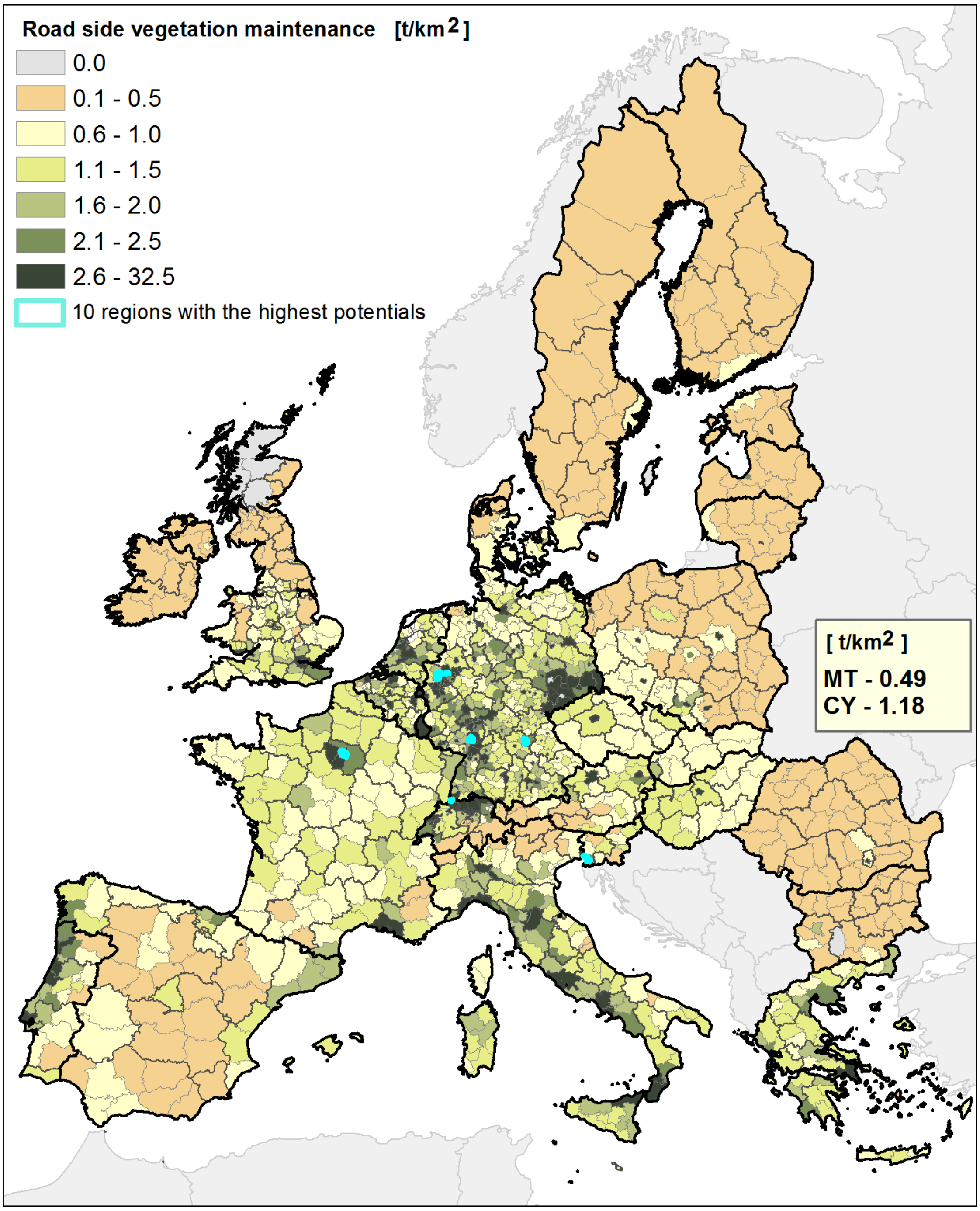

Figure 37. Normalised biomass potential from roadside vegetation maintenance in NUTS-3

5. URBAN AND INDUSTRIAL WASTE

The scope of this activity was to assess the potential of biodegradable municipal waste, bio-waste of food industry and forest industry waste.

5.1 Biodegradable municipal waste.

Scope and definitions

Short Description from Eurostat: Municipal waste consists to a larger 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 part of municipal waste may vary from municipality to municipality and from country to country, depending on the local waste management system. For areas not covered by a municipal waste collection scheme, the amount of waste generated is estimated.

Method

Biodegradable municipal wastes were assessed by using the formula described into the document: Best practices and methods handbook, vol. 1, page 116 – results of BEE project. The waste paper and the cardboard (and textile) were excluded from the municipal biodegradable waste.

Formula 14:

$$TP\_BMW_{x,y} = MSW_{x,y} * POP_{x,y} * ACC_x * OC_x * LHV_{BMW} * 10^{-6}$$

Where:

TP_BMWx,y = biomass potential of biodegradable municipal waste of country x in year y (PJ/year)

MSWx,y = municipal waste production per capita of country x in year y (tonnes/person/year)

POPx,y = population of country x in year y (persons)

ACCx = percentage of the population served by municipal waste services (%)

OCx = organic content of MSW in country x (dimensionless)

LHV_{BMW} = lower heating value of biodegradable municipal waste (GJ/tonne)

x = country

y = year

Table 21. Data sources of municipal waste

Indicator	Source	Location
MSWx,y	Eurostat	http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsien120
POPx,y	Esri; Michael Bauer Research GmbH	http://www.arcgis.com/home/item.html?id=cf3c8303e85748b5bc097cdbb5d39c31
ACCx	United Nations Statistics Division	http://unstats.un.org/unsd/environment/municipalwaste.htm
OCx	OECD Environmental Data Compendium	http://www.oecd.org/document/40/0,3746,en_2649_34283_39011377_1_1_1_1,00.html
LHVBMW	IPCC 2006 Guidelines for National Greenhouse Gas Inventories Volume 2 Energy	http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf

Analyses started with the aggregation of raster with resolution 100x100 m to resolution 1x1 km. Raster map for EU-27 countries was extended by incorporation of Switzerland. For this CLC 2006 and national statistical information were used.

Theoretical potential of biodegradable municipal waste was calculated using a formula for computing TP_BMW. In this case, all populations were included. However, the raster map of population presents big differential of spatial distribution. It is obvious because population is concentrated on urban areas. On rural areas, this kind of density is significantly lower and disappears in some kinds of natural land cover (forest, high mountain, water etc...).

To calculate technical biodegradable municipal waste potential a geostatistical and geoprocesing analyses were applied for finding the most customised barrier separating urban areas from scattered settlements. In the result the minimal area, where technical potential was taken into account, was defined as a subset of min. 3 pixels (3 km^2) with potential greater than

30 t for each one. Additionally all pixels with potential greater than 120 t were assumed. For calculating low heating value 6.7 GJ/t was assumed. As a result, two raster maps at a resolution of 1x1 km were obtained. Maps represent theoretical and technical potential. They were tabulated for NUTS-3 regions.

Results

The total assessed theoretical potential of biodegradable municipal waste amounts at: **90,0 Mt (605 PJ)**. Average values for NUTS are 69.0 kt. There are 1253 NUTS-3 where the biomass potentials are over 10 kt and 909 NUTS with potential over 30 kt. The total assessed technical potential of biodegradable municipal waste amounts at: **71,2 Mt (477 PJ)**. Average values for NUTS are 54.3 kt. There are 1164 NUTS-3 where the biomass potentials are over 10 kt and 699 NUTS with potential over 30 kt. The highest potential of biomass was found in NUTS-3: ES300 (Madrid) – 1.68 Mt, but the highest density of biomass was calculated for FR101 (Paris) – 3.5 kt/km2.

Table 22. The most promising NUTS-3 with the highest biodegradable municipal waste potential

Theoretical			Technical			Density	
NUTS-3	**kt**	**PJ**	**NUTS-3**	**kt**	**PJ**	**NUTS-3**	**t/km^2**
ES300	1305.5	8.75	ES300	1261.7	8.45	FR101	3.4
ES511	1132.6	7.59	ES511	1096.1	7.34	UKI11	1.6
EL300	956.2	6.41	EL300	933.4	6.25	UKI12	1.5
DE300	672.3	4.50	DE300	671.7	4.50	FR105	1.3
ITI43	669.3	4.48	ITI43	627	4.20	BE100	1.3
ITF33	553.6	3.71	ITF33	549.6	3.68	RO321	1.5
ITC4C	542.3	3.63	ITC4C	534.5	3.58	FR106	1
PT171	531.7	3.56	PT171	521.5	3.49	AT130	0.9
ES523	516.9	3.46	ES523	457.6	3.07	CH031	0.8
FR301	429.4	2.88	AT130	402.5	2.70	FR107	0.8

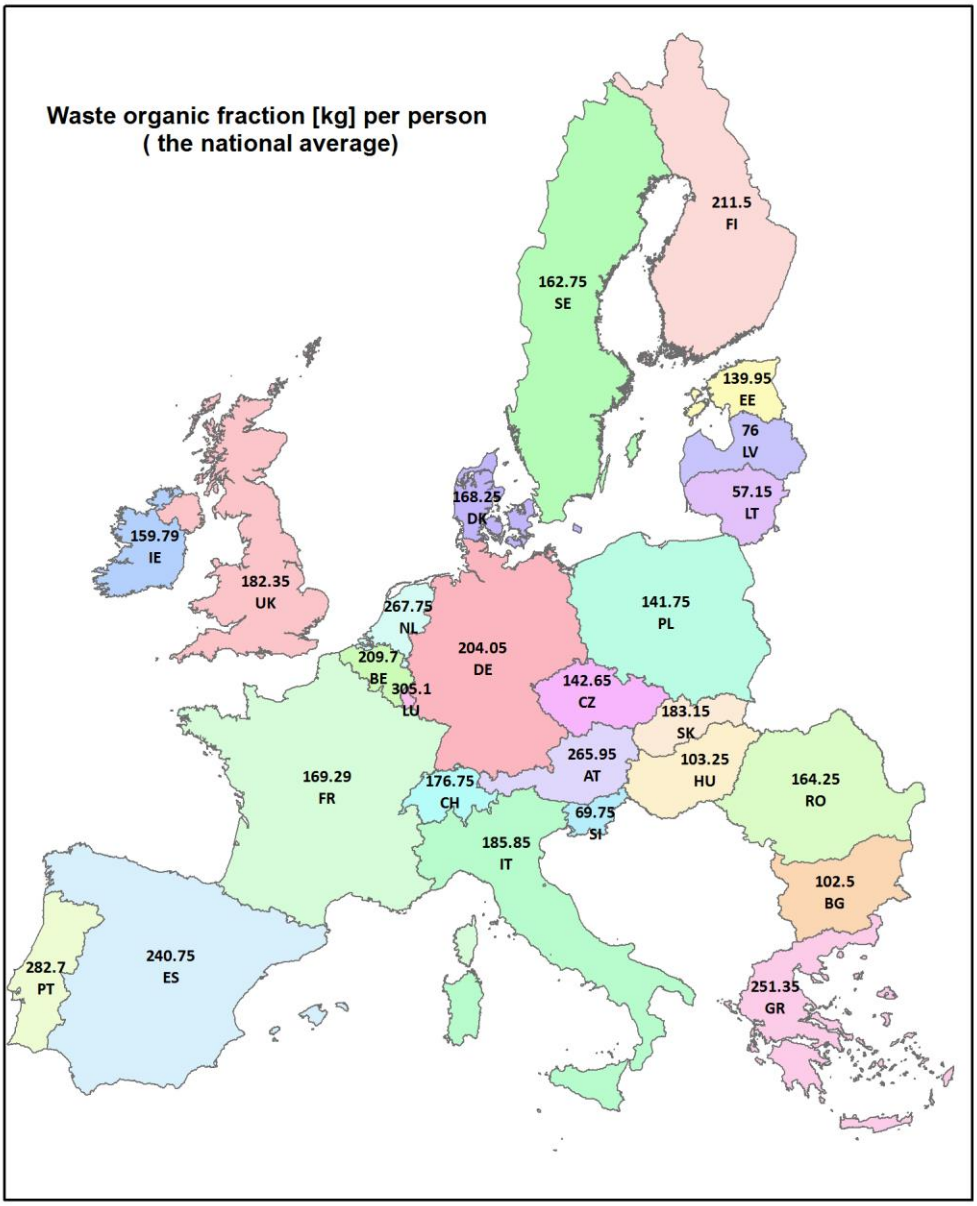

Figure 38. Waste organic fraction generated per person. *Sources: Managing municipal solid waste, EEA Report No. 2/2013*

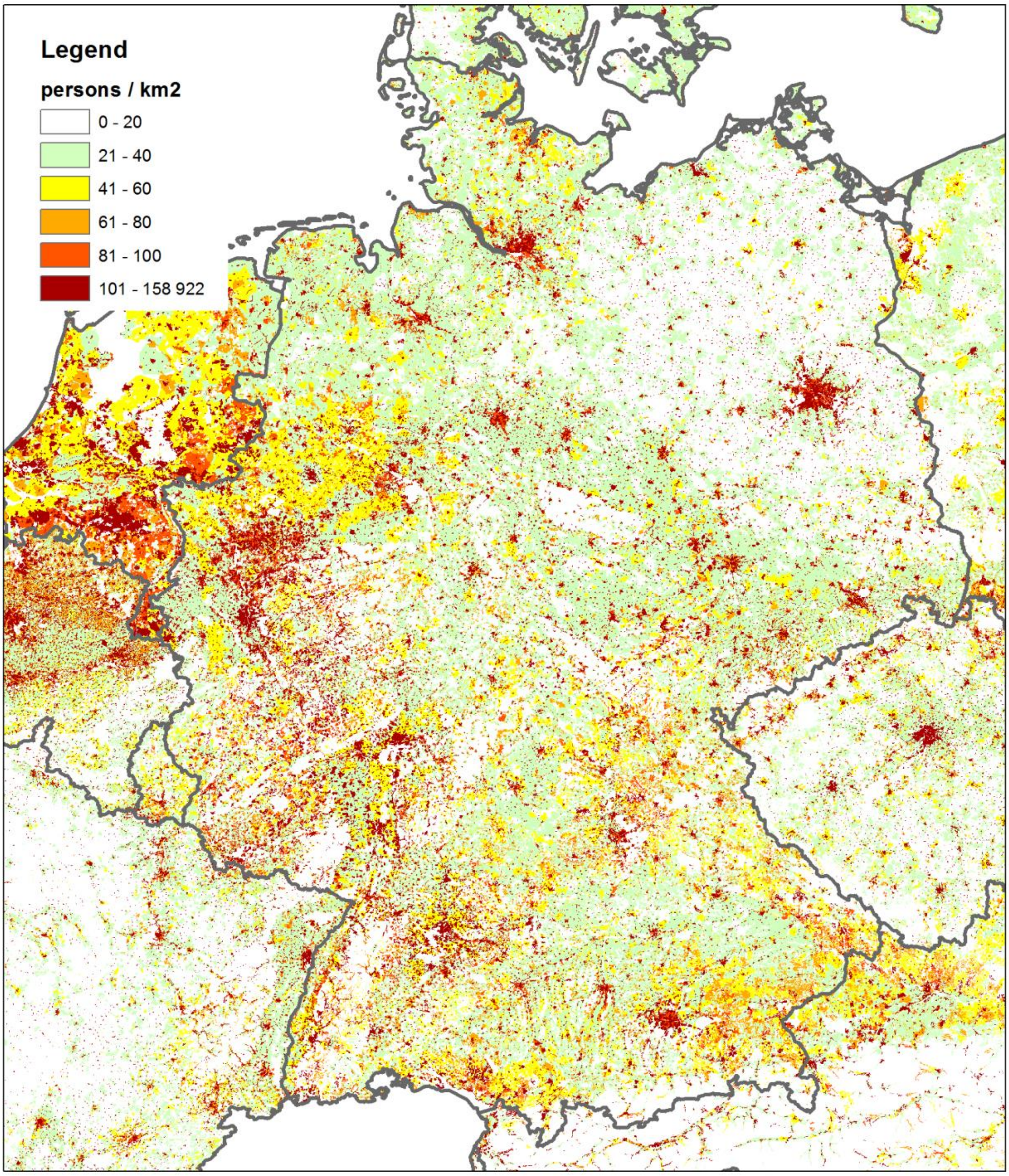

Figure 39. Density of population (1x1 km), sample for Germany

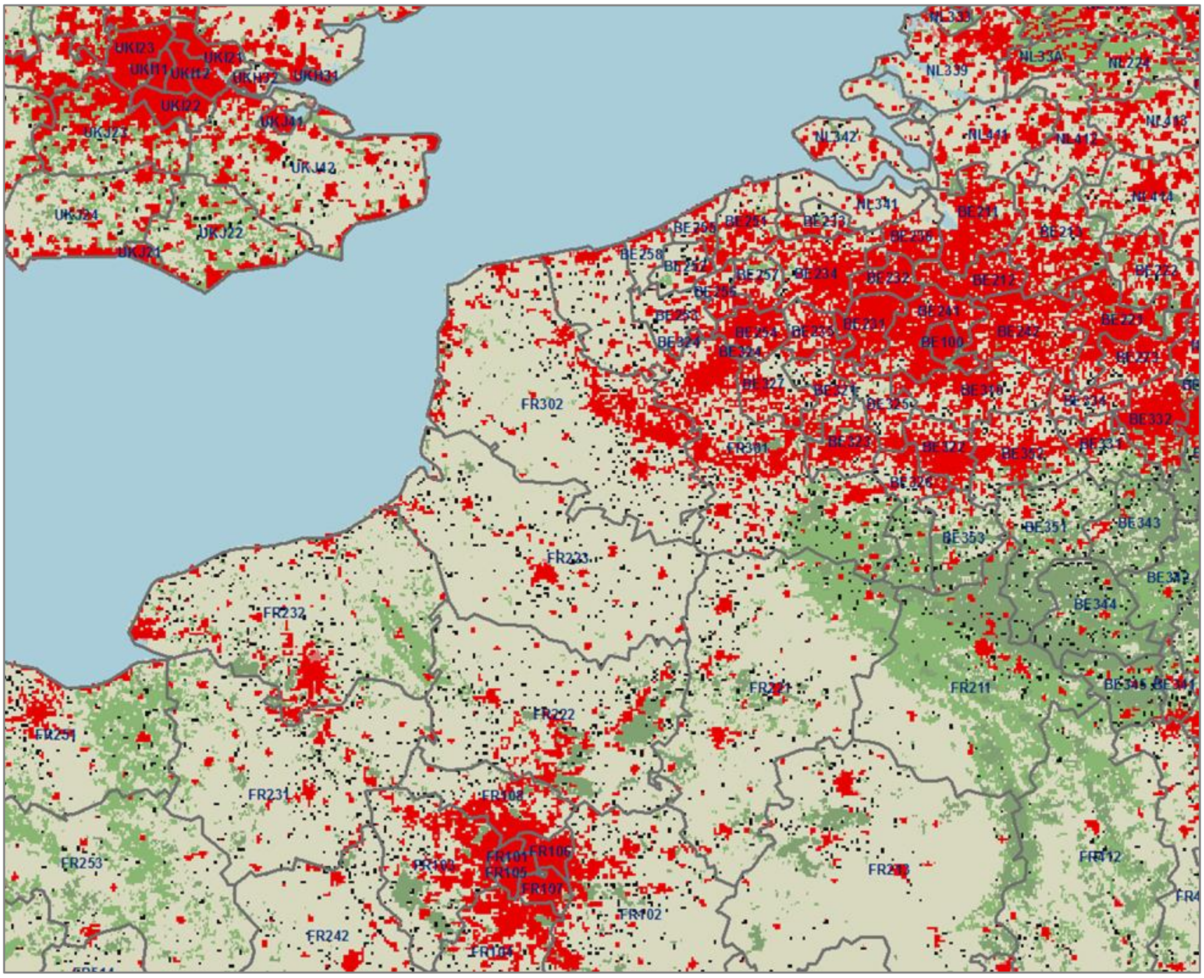

Figure 40. Sample of separation urban areas/scattered settlements, and distribution of technical-theoretical potential. Red colour – urban areas with potential greater than 30 t/km^2 (technical potential), black dots (pixels) - scattered settlements with potential greater than 30 t/km^2 (areas non-classified as a technical potential of biodegradable municipal waste).

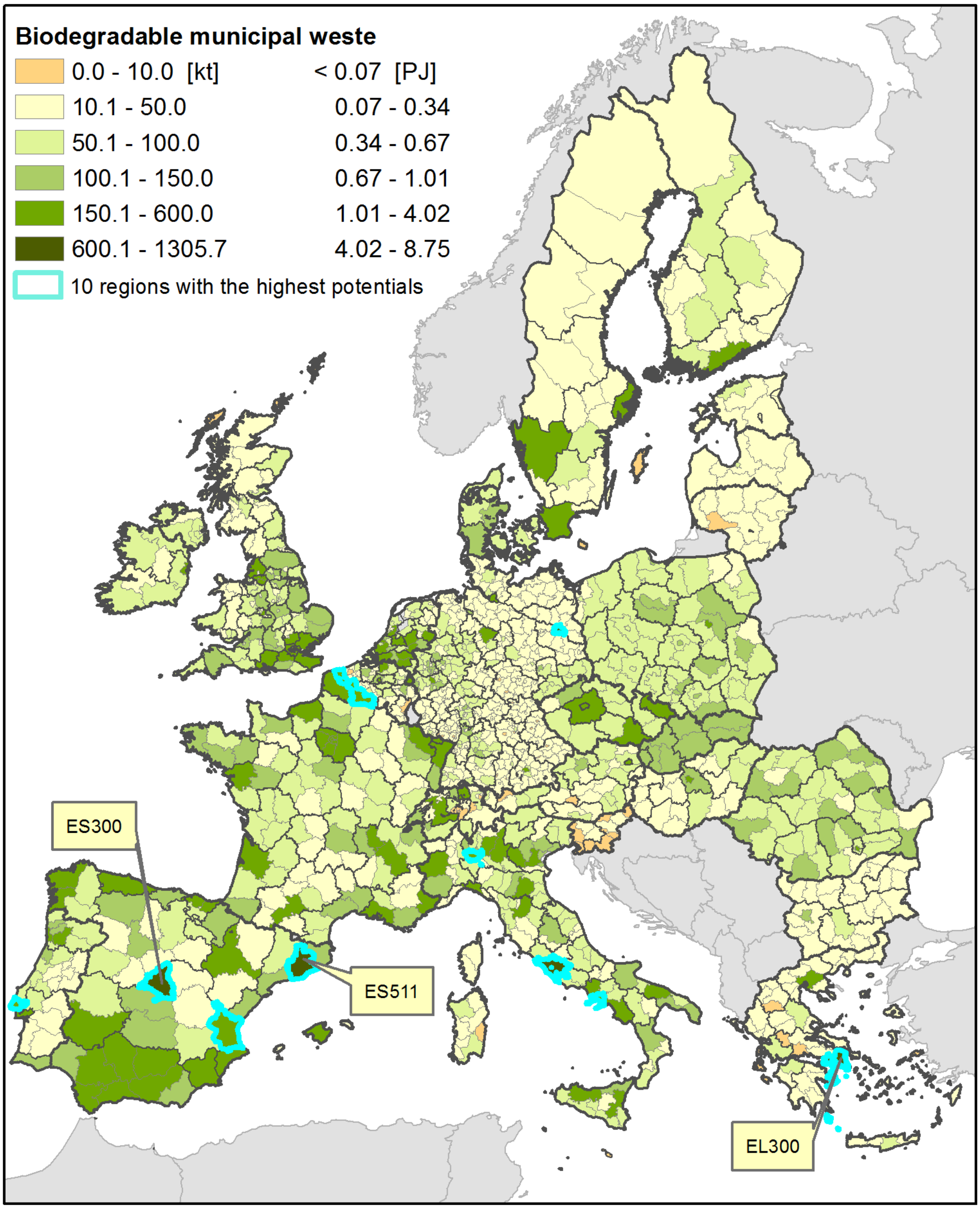

Figure 41. Theoretical potential of biodegradable municipal waste.

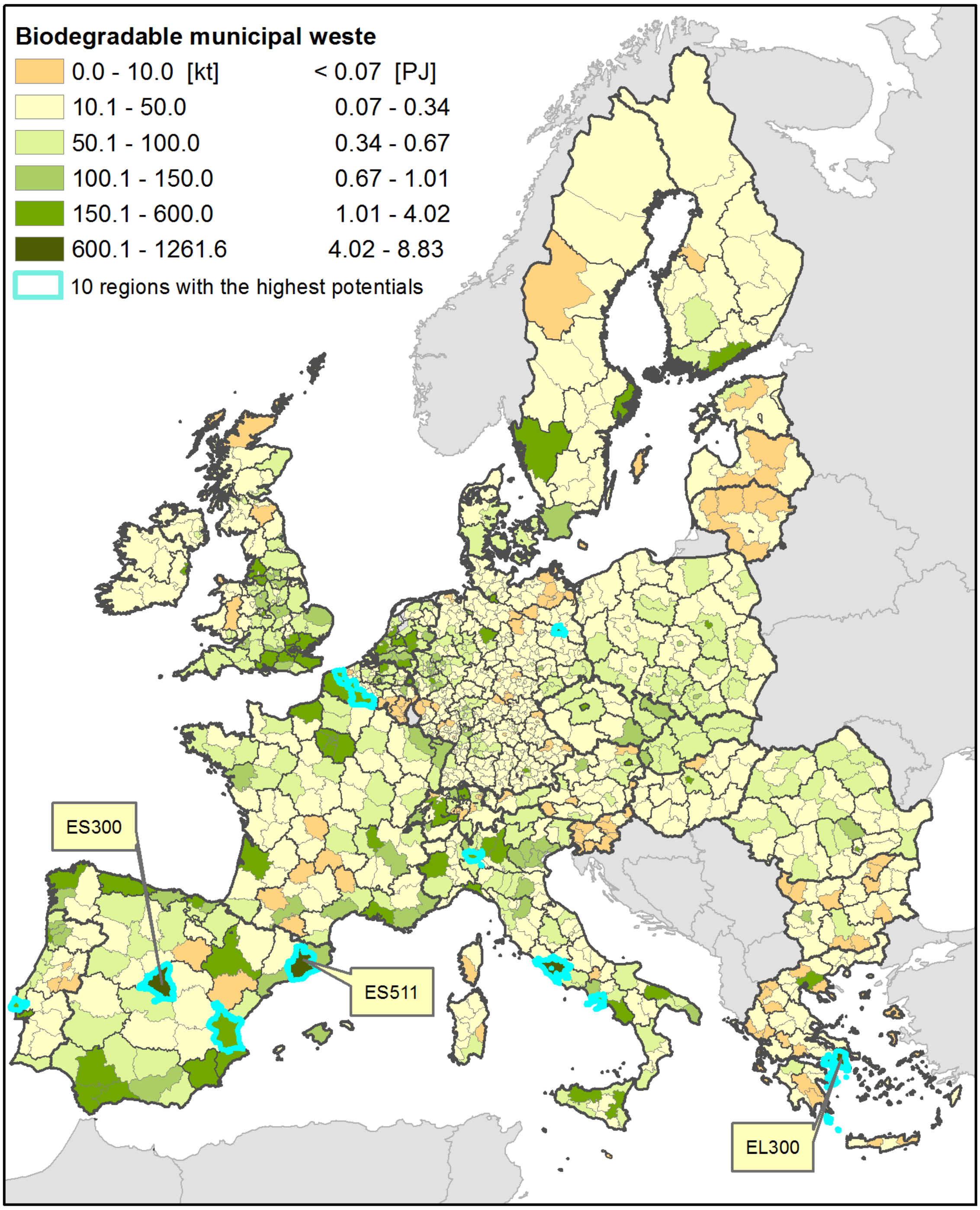

Figure 42. Technical potential of biodegradable municipal waste.

5.2 Bio-waste of food industry

Purpose and definitions

The aim of the study was to estimate the technical potential of bio-waste from food industry. Due to the limited data and the ability to conduct at regional NUTS-3, two types of waste were identified that were generated in the production of olive oil and grape processing (mainly in the production of wine). Spatial modelling of the technical potential of these types of biomass was possible due to detailed information about the location of the cultivation of grapes and olives, given on the land use map (CLC). In addition, according to a review of the literature (Blasi et al., 1997; Mahro and Timm, 2007) the processing of the raw material is done mostly locally.

The bio-waste of food industry which include other kinds as beet pulp, molasses, waste malt, meal, whey, waste from fruit and vegetables, are difficult to quantify due to the lack of regional data and their distribution. Further difficulties were found due to some use of those products as animal feed (no statistics) and in recent years, due to changes of the production structure, which were the result of the Common Agricultural Policy. This applies especially to the production of sugar and milk (Eurostat)

Methods

The technical potential of waste from the olives and grapes processing was estimated on the basis of statistical data from Eurostat (yield of the plants on a scale of NUTS-2). The results were disaggregated to NUTS-3 assuming that the data is distributed according to the proportional share of the surface of vineyards and olive groves, which were based on the CLC. The amount of the olive and grape specified as percentage waste fraction which arising from the processing were used. Factors and taken as the average values reported by Mahro and Timm (2007) were used. The values obtained were reduced by the percentage of the total production of grapes and olives, which are exported without processing. In order to assess the balance between local processing and export the Eurostat data was used. Geoprocessing analysis was carried out according to the formula 4.2. and sources of the databases are presented in Table 23.

Formula 15:

$$BFI\_N3 = ((WSP\_G * BFI\_G\ WSPpeG)+(WSP\_O * BFI\_O* WSPpeO)) *(CLC_{FI}\_N3 / CLC_{FI}\_N2)$$

where:

BFI_N3 = technical potential of food industry bio-waste for NUTS-3

WSP_G = dry bio-waste percentage from industry processing of grapes

WSP_O = dry bio-waste percentage from industry processing of olives (oil production)

BFI_G = grapes harvest for NUTS-2

BFI_O = olives harvest for NUTS-2

CLC_{FI}_N3 = area of vineyards and olive groves in NUTS-3 (subset of CLC_{FI}_N2)

CLC_{FI}_N2 = area of vineyards and olive groves in NUTS-2

WSPpeO = ratio local processing/export of olives

WSPpeG = ratio local processing/export of grapes

Table 23. Data sources for modelling of food industry waste

Indicator	Source	Location
WSP_G, WSP_O	Publication	Mahro B., Timm M., 2007: Potential of bio-waste from the food industry as a biomass resource, Eng. Life Sci., 5, 457-468
BFI_N2	Eurostat	General and regional statistic / Regional statistic / Regional agricultural statistic / Animal populations (December) by NUTS 2 regions (agr_r_animal)
CLC_{PC}_N3 CLC_{PC}_N2	EEA: CORINE	http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2
WSPpeO WSPpeG	Eurostat	Regional agriculture statistics (reg_agr)

In order to convert the modelled mass into energy was assumed that one tonne of waste biomass from grape pomace, with humidity 80%, equivalent calorific value (calorific value) = 2.2 GJ per tonne and olive pomace, with a moisture content of 65%, equivalent calorific value = 5.6% (ECN Phyllis 2, Mohro and Timm, 2007).

Results

The technical potential of residuals and waste from the olive and grape processing industry, which can be used for energy purposes, was **14.3 Mt (51 PJ).** The average value for the NUTS-3 was 10.9 kt. The study found 193 NUTS-3 units with a potential of more than 10 kt, 58 with a potential more than 60 kt and 15 NUTS-3 with a potential above 200 kt.

The greatest potential was estimated for NUTS-3: ES616 (Jaen) – 960 kt, however, the highest density was found in ITH43 – 275 t/km^2.

The following set of maps are characterised by mass, energy and the density of residuals and waste from the olive and grape processing industry.

Table 24. The most promising NUTS-3 with the highest food industry waste potential

Technical			Density	
NUTS-3	**kt**	**PJ**	**NUTS-3**	**t/km^2**
ES616	960.4	2.11	ITH43	275.4
ES613	527.3	1.16	ITI22	100.1
ITH10	506.6	1.11	ITH31	91.6
ITH20	506.4	1.11	ITH20	81.6
ES422	368.1	0.81	ITG11	79.6
ES425	337.2	0.74	ITF44	78
ITH31	283.8	0.62	ITH41	77.1
ES618	283.5	0.62	ES616	71.1
ITI21	267.7	0.59	ITF45	68.4
ES614	247.3	0.54	ITH10	68.4

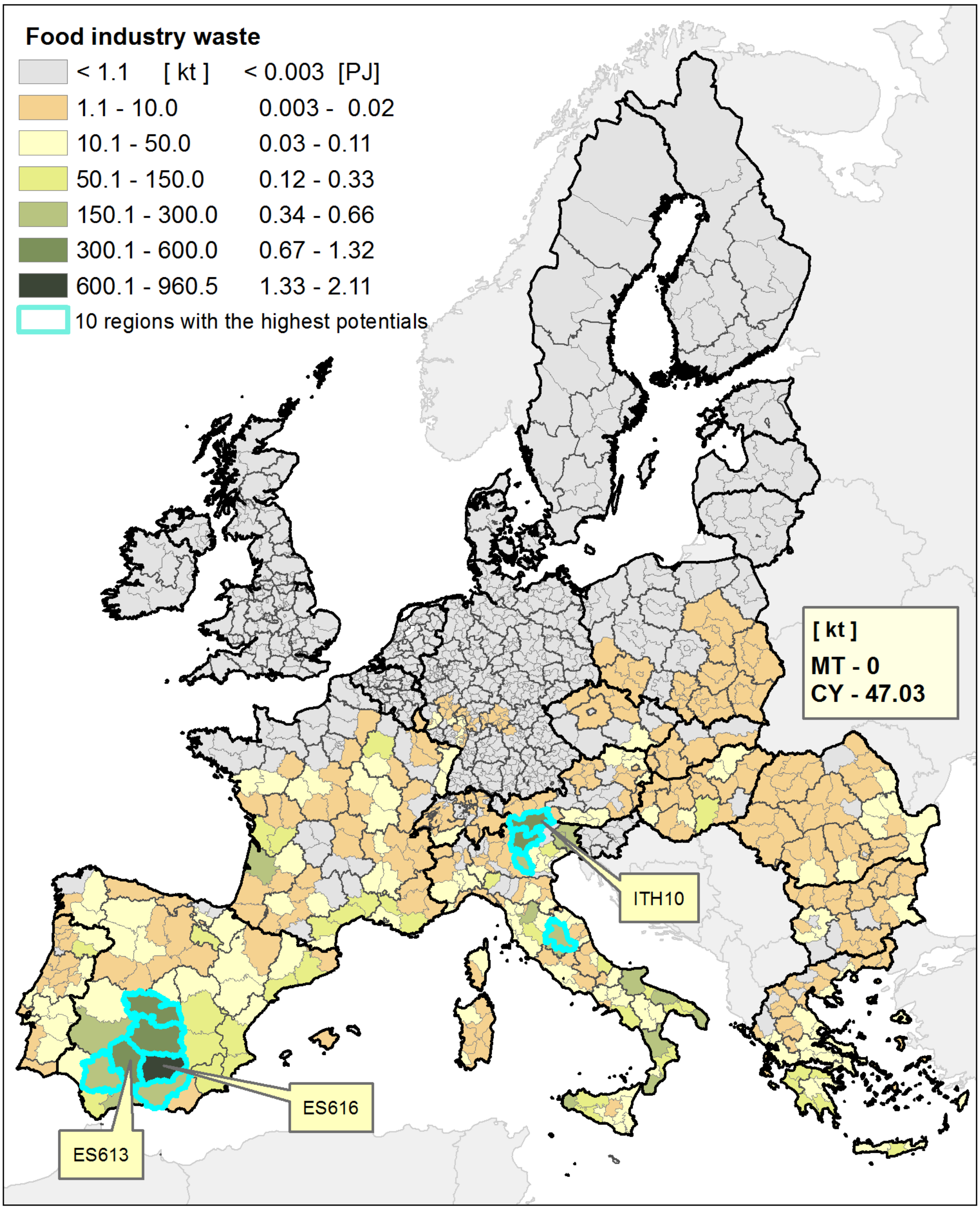

Figure 43. The technical potential of biomass and energy from residuals and waste from the olive and grape processing industry in NUTS-3

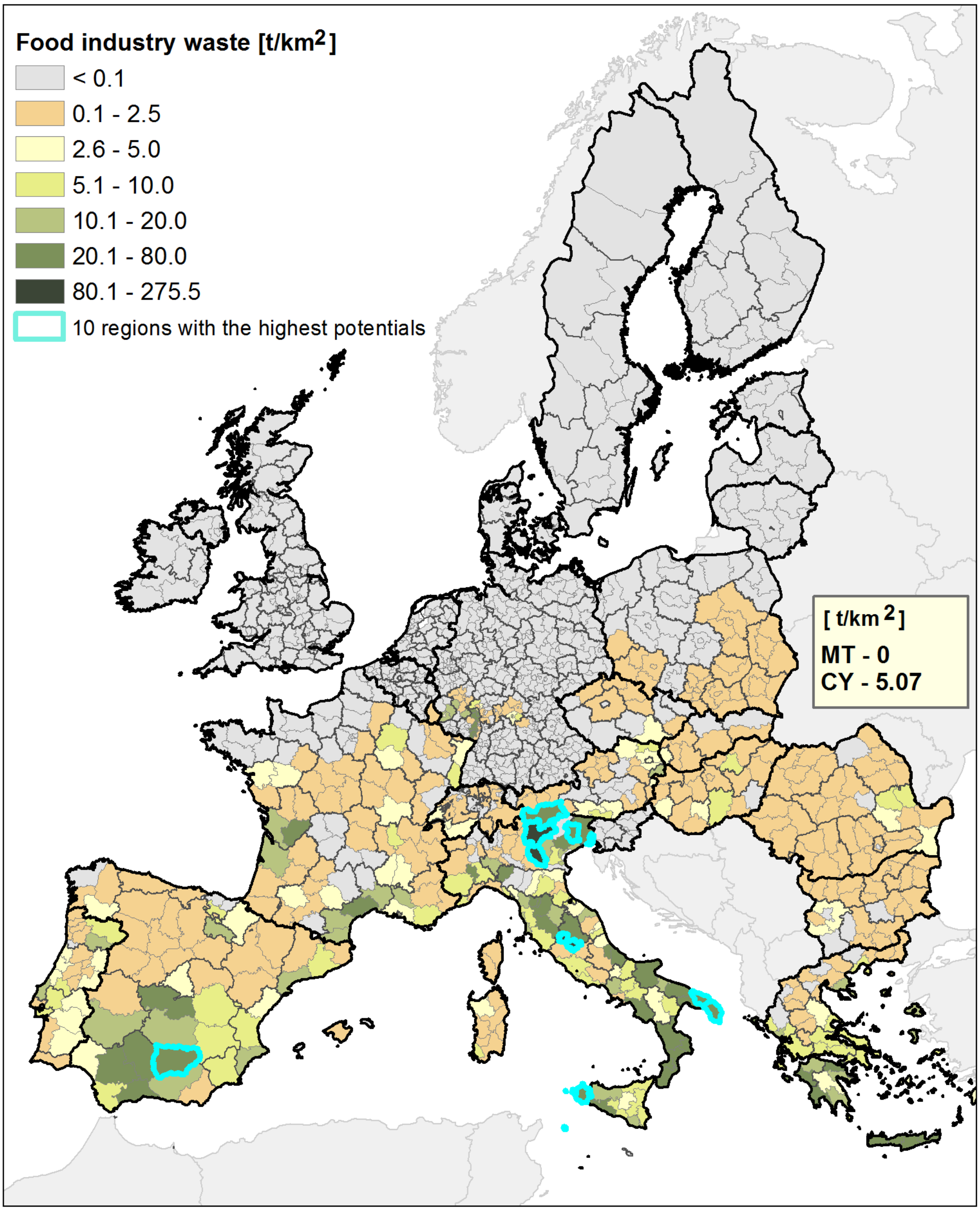

Figure 44. Normalised biomass potential of residuals and waste from the olive and grape processing industry in NUTS-3

5.3 Bio-waste of wood industry by-products

Scope and definitions

The scope of this activity was to assess the potential of wood industry by-products for bioenergy use. The data about wood industry waste was obtained from the Renew project. The potential of biomass from wood industry is grouped in four fractions:

- by-products from sawmills,
- by-products from pulp and paper industry,
- by-products from board industry,
- by-products from other wood processing industries.

The method of theoretical potential assessment was based on specific factors, which allowed conversion of input data from the international database into amounts available for BtL uses. The estimation was based on the areas covered by forest available for wood supply, net annual increment and felling rates specific for each European country (TB FRA, 2000; TB FRA, 2005). The values of regional specific factors, which were not possible to derive from the database, were taken from literature or relevant experts. If it was not possible to define the factors on a national level, the average value for Europe was used.

In order to assess the technical potential available for BtL the theoretical potential was reduced. Ecological restrictions are necessary for proper and sustainable functioning of forest ecosystem. Various difficulties make it technically or economically impossible to harvest and supply the residues (small, scattered felling areas, slopes, etc.). Finally, part of the harvestable residues is utilised by wood industry, like the fibreboard industry, and must be excluded from the total available potential for BtL if the rule that food and fibre production cannot be affected is applied.

The forestry potentials estimates were performed for three RENEW scenarios: SP, S1 and S2, which were described in the chapter 2. ‘Forest residues’.

Due to the fact that fibre production cannot be affected for each scenario wood demand for wood industry is taken into consideration.

Method

The result of the Renew project assessed for NUTS 0 were downscaled to NUTS-3 level by using land cover raster map (CLC) as information on the most probable spatial distribution. Downscaling assumes that forestry residuals are proportional to forest areas in NUTS-3 regions.

Downscaling for wood industry assessment - Formula 16:

$$WI\_N3 = FR\_N0 * CLC_{Forest}\_N3 / CLC_{Forest}\_N0$$

Where:

WI_N3 = assessed wood industry for NUTS-3

WI_N0 = wood industry by RENEW for NUTS-0

CLC_{Forest}_N3 = area of forest in NUTS-3 (subset of CLC_{Forest}_N2)

CLC_{Forest}_N2 = area of forest in NUTS-0

/// CLC_{Forest} = class 23 (Broad-leaved forest) + class 24 (Coniferous forest) + Class 25 (Mixed forest) of Corine land cover

Table 25. Data sources of wood industry residues

Indicator	Source	Location
WI_N0	RENEW Project	http://www.renew-fuel.com/fs_documents.php
CLC_{Forest}_N3 CLC_{Forest}_N0	EEA: CORINE	http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2

Results

The total assessed feedstock potential of Wood industry amounts at: 5.59 Mt (56 PJ). Average value for NUTS is 4.3 kt. There are 112 NUTS-3 where the biomass potentials are over 10 kt.

The highest potential of biomass was found in NUTS-3: FI1A3 (Lapland) – 210.6 kt, but the highest density of biomass was calculated for BE344 (Arr. Neufchateau) – 6.4 t/km^2.

Table 26. The most promising NUTS-3 with the highest wood industry potential

Technical			Density	
NUTS-3	**kt**	**PJ**	**NUTS-3**	**t/km^2**
FI1D7	210.6	1.52	BE344	6.4
SE332	192.4	1.39	BE343	5.9
SE331	133	0.96	BE345	5.8
SE322	107.2	0.77	BE353	4.9
FI1D6	83.4	0.6	BE336	4.9
SE312	75.1	0.54	DEB3K	4.8
SE321	60.2	0.43	DEA5A	4.7
SE232	60.1	0.43	BE351	4.7
LV008	56.9	0.41	DEG04	4.7
FI1D4	55.7	0.4	DE229	4.6

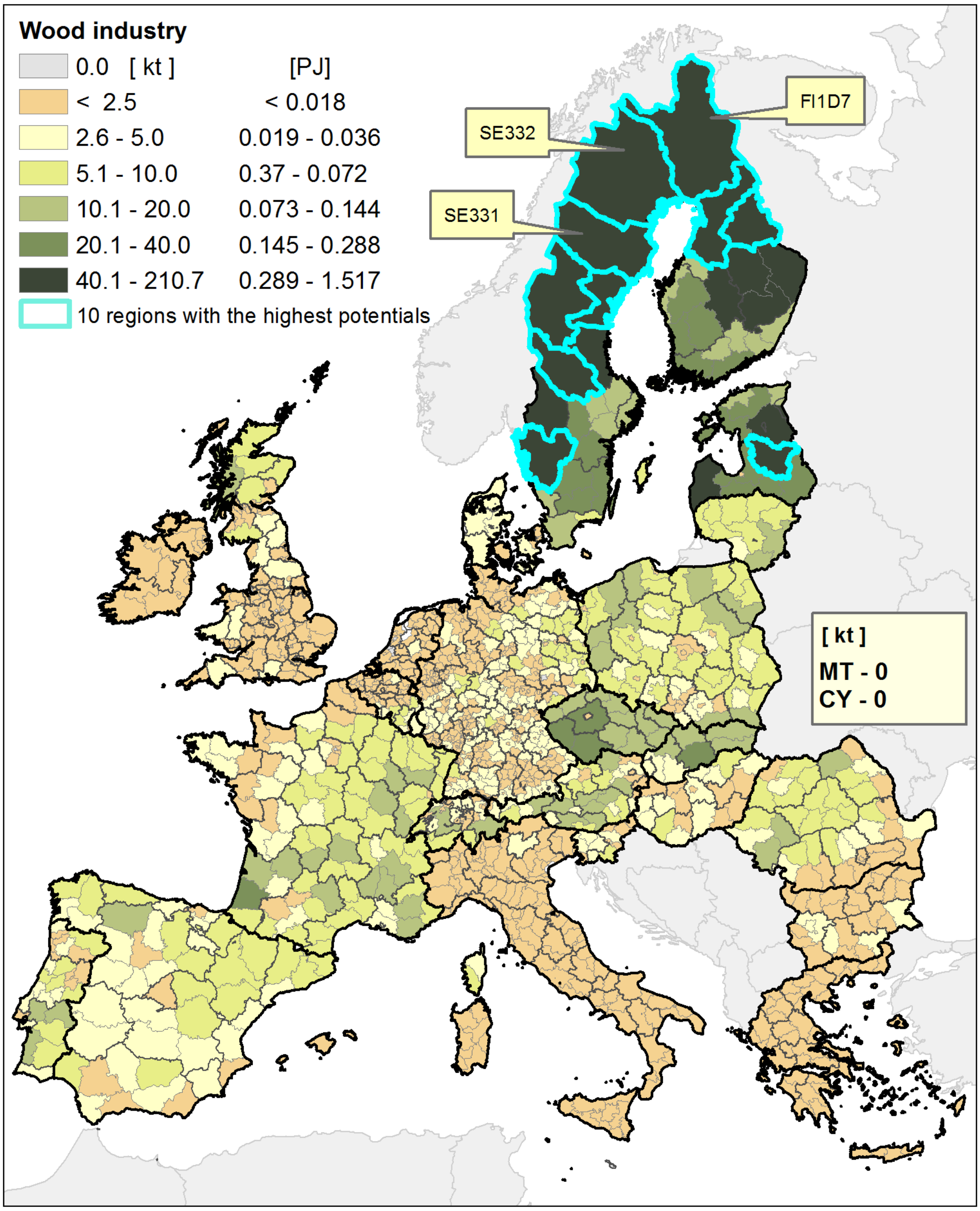

Figure 45. Technical potential of wood industry waste in NUTS-3

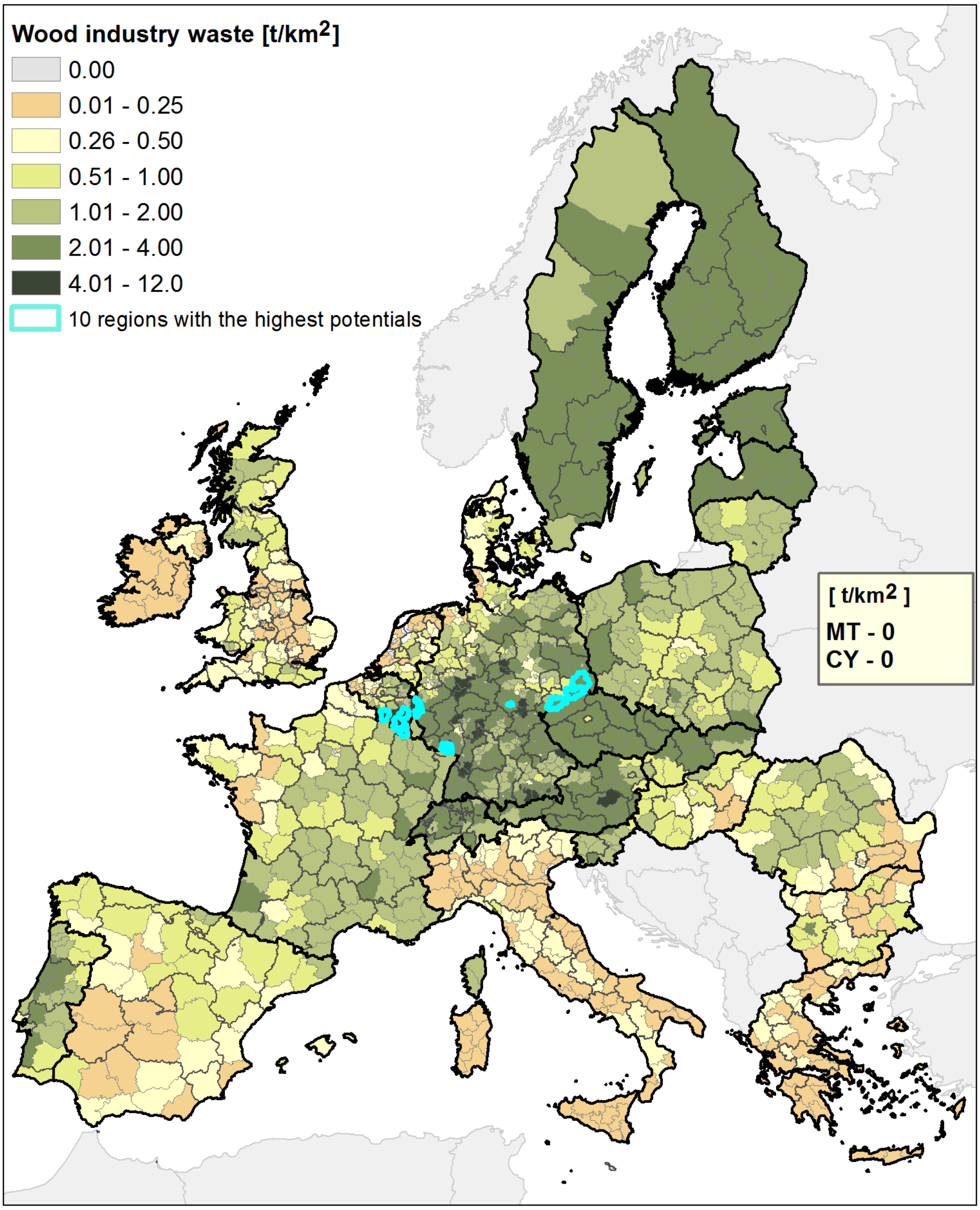

Figure 46. Normalised biomass potentials of wood industry waste in NUTS-3

The other source of biomass from food industry

During the food production process, a large number of waste is generated. Some of them are valuable for animal feed (e.g. waste from distilleries, sugar beet pulp). Sometimes a problem in terms of disposal was found (e.g. abattoir waste). Due to the lack of detailed statistics, conducting comprehensive spatial analyses in scale assumed for this study, it is not possible. In order to estimate the waste of resources can only be perform a tabular statement of the individual countries. The brewing industry generates relatively large amounts of by-products and wastes; spent grain, spent hops and yeast being the most common (Figure 47). As these are by products rather than waste products, they can be recycled and reused in the food and agricultural industries.

The estimated of by-products and waste potential from the production of beer are presented below. This production is a significant part of the total food production. Spent grain is the biggest brewing by-product, corresponding to around 85% of total by-products generated. It is assumed spent grain accounts, on average, for 31% of the original malt weight, representing approximately 20 kg per 100 l of beer produced. The net caloric values amounts at 18.64 MJ/kg of dry mass with the water content of 77-80% (Mussatto et al., 2006). Use of those values allow the assumption that each year in the EU can be gain 7.79 Mt of this kind of by-product waste which is an equivalent of 29.08 PJ.

Knowledge of the location of the breweries and their capacity in selected countries allows for a much more detailed analysis of the resource base (
Figure 48).
Similar analyses are possible to carry out the milling industry. However, based on the information obtained, all of the generated waste and by-products are utilised.

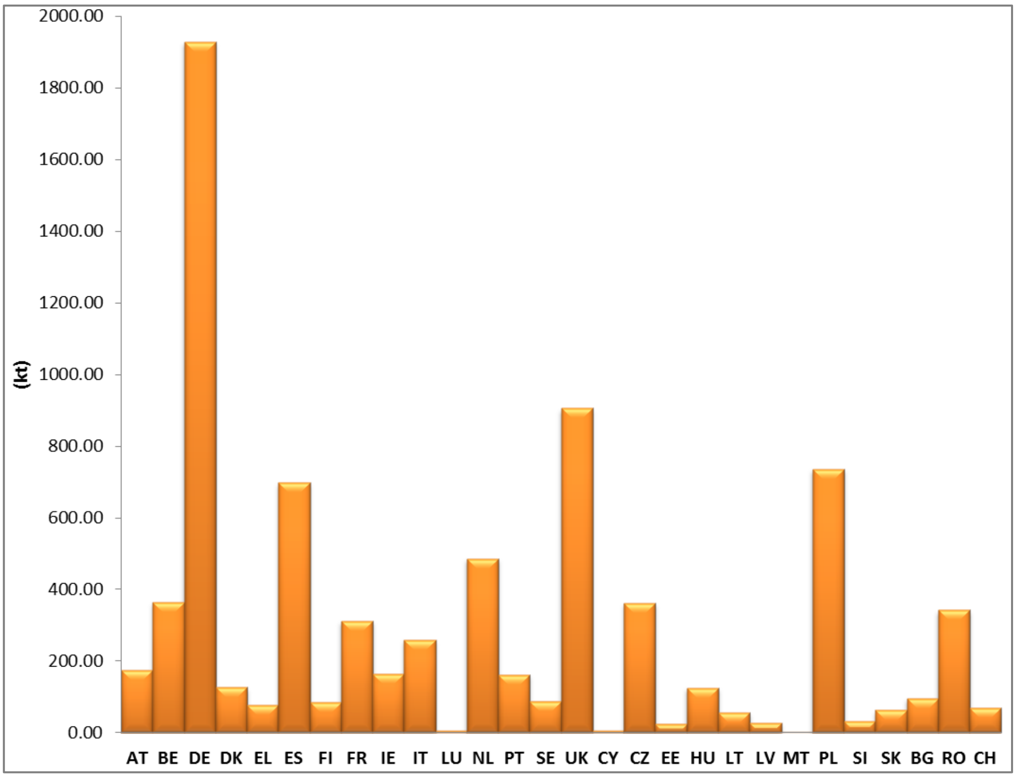

Figure 47. The theoretical potential of spent grain from beer production.

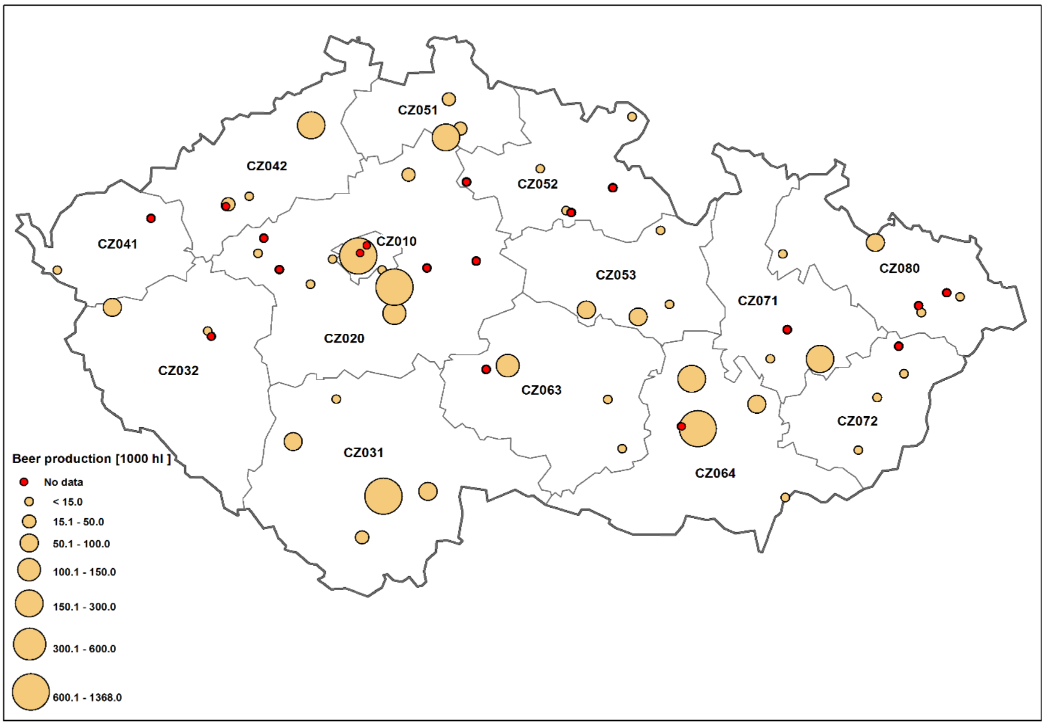

Figure 48.Example of location of the waste from the production of beer.

6. CLUSTER ANALYSIS OF BIOMASS RESIDUES AND WASTE

Estimates of the biomass potential, which can be utilised for energy purposes was performed for the NUTS-3 units to identify the base of raw materials and their structure in these administrative units and to collect the data necessary for further study of the distribution of potential in the geographic space. In Europe, the size of the resources are burdened with the influence of regional conditions (mainly geographical and economic), which is shown on the potentials maps of different types biomass, as presented in the previous sections. To enrich the content of maps an attempt was done to characterise general regionalisation of estimated resources by grouping NUTS-3 in several distinct classes of NUTS-3 regions with similar values of the features. For this purpose cluster analysis, which is a method of data mining derived from unsupervised classification (Jain et al., 1999) was used. Its objectives are: i) deriving (delimiting) homogeneous polygons for further studies, ii) reduction of a large number of raw data into a few basic categories, iii) demonstration of an unobvious structure of the analysed data, and iv) a comparison of multivariate data.

The established test scenario was primarily designed to reduce a large amount of raw data (1313 NUTS 3 regions and 10 different types of biomass) into a smaller number of groups. It was assumed that the reduced number of groups would allow a more general description of the resource base and give a basis for further analysis of the relationship between different types of biomass in the output data set. The cluster analysis was used to search for a relationship, which could enable the demonstration of unobvious data structures, mainly through a joint analysis of all types of biomass. A map visualisation of their individual potentials gave reason to believe that among the regions there was some class structure. Following this observation, the existence of such a structure was assumed and the test of the formal hypothesis for the presence or absence of this structure was omitted. (Gordon, 1999). According to Milligan (1996) and Gordon (1999), in the cluster analysis, there are four basic problems that determine the level of difficulty of the problem of classification: i) the number of classified objects, ii) the number of variables describing the test subjects, iii) the location of objects in the classification space and lack of widely acceptable definition of classes, iv) no widely acceptable and unified theory of classification. The above stated problems and their impact on the decisions taken in the choice of methods and tools for the identification and delineation of regions are discussed in the description of the subsequent stages of analysis. In the literature, seven stages of a typical cluster analysis are distinguished (Milligan, 1996; Walesiak, 2004):

1. selection of objects and variables
2. selection of formula for variables normalisation,
3. selection of distance measures,
4. selection of the classification method,
5. determination of the classes number
6. evaluation of the classification,
7. description (interpretation) of classes.

Step 1. Selection of objects and variables

Due to the computational capabilities, it was decided to cover with the analysis the whole data set, which is 1313 NUTS-3. This approach was considered appropriate for geographical reasons and the very essence of the analysis, focused on the designation of regions consisting NUTS-3 with similar structured potentials (which is significantly affected by the geographical factor). Therefore, descriptive approach was chosen (nonstochastic), i.e. one in which the object of analysis is the entire population, and the variables are not random, but in the usual sense (Walesiak and Gatnar 2009).

In the previous part of the study, ten different types of biomass potentials, which can be utilised for energy purposes, were evaluated. These were a livestock residues, hay, straw, biomass of perennial plantations, forestry residues, biomass of green areas, roadside vegetation, biodegradable municipal waste, organic waste from the food industry and waste from the timber industry. These potentials are the attributes of each NUTS-3, which means that in the case of cluster analysis, are variable objects.

In terms of methodology, the selection of variables is one of the most important and difficult issues, because its quality is a crucial factor for the reliability of the final results (Guyon and Elisseeff, 2003; Walesiak and Gatnar, 2009). For this reason, in the next step of analysis, subsets of variables were chosen which would give the greatest potential for the discriminating objects. That would give clusters that are most homogeneous and separated from each other. For this, the HINoV method (Heuristic Identification of Noisy Variables) in addition to the algorithm of the method contained in the clusterSim R package (Carmona et al., 1999; Walesiak and Gatnar, 2009) was used. It is a heuristic procedure associated with k-means or k-medoid and corrected Rand index (Walesiak and Gatnar, 2009). One of the steps in this method is not automated and requires an assessment carried out by the analyst. In the generated scree plot, where on the horizontal axis the individual variables are placed in decreasing order, it is necessary to identify the location of the steepest descent and discard it from the furthest analysis variables on the right side (Figure 49). All kinds of analysed potentials (10 types of biomass) were tested with this method. Taking into account the fact that at this stage, a cluster number has not yet been specified, and the HINoV method as the input data requires this information, the procedure was carried out for a set of numbers from 2 to 10. Since, in the present case, in accordance with expert knowledge this range covers the most appropriate number of clusters. Graphs for different numbers of clusters are shown in Figure 49. Graphs from Figure 49-d until i, indicate that variables 3, 1 and 2 (hay, animal residues and straw) should be excluded from further analysis. The resulting graph Figure 49 -c, suggesting that should be left only 8-th and 6-th variables can be regarded as overstated (too few variables for analysis), while case showed on graph Figure 49 -a considered as boundary (number of clusters – two) which yields no valuable information from an analyst's point of view and can be passed over. In the case of variable No. 2 should be noted that the potential of straw representing this variable is the most important resource of biomass (Figure 12 - Figure 20 and Figure 60 - Figure 61), and therefore its omission would have too much influence on the result and its practical interpretation. Thus, further analysis was decided upon and to carry on without the variables 1 (animal residues) and 3 (hay).

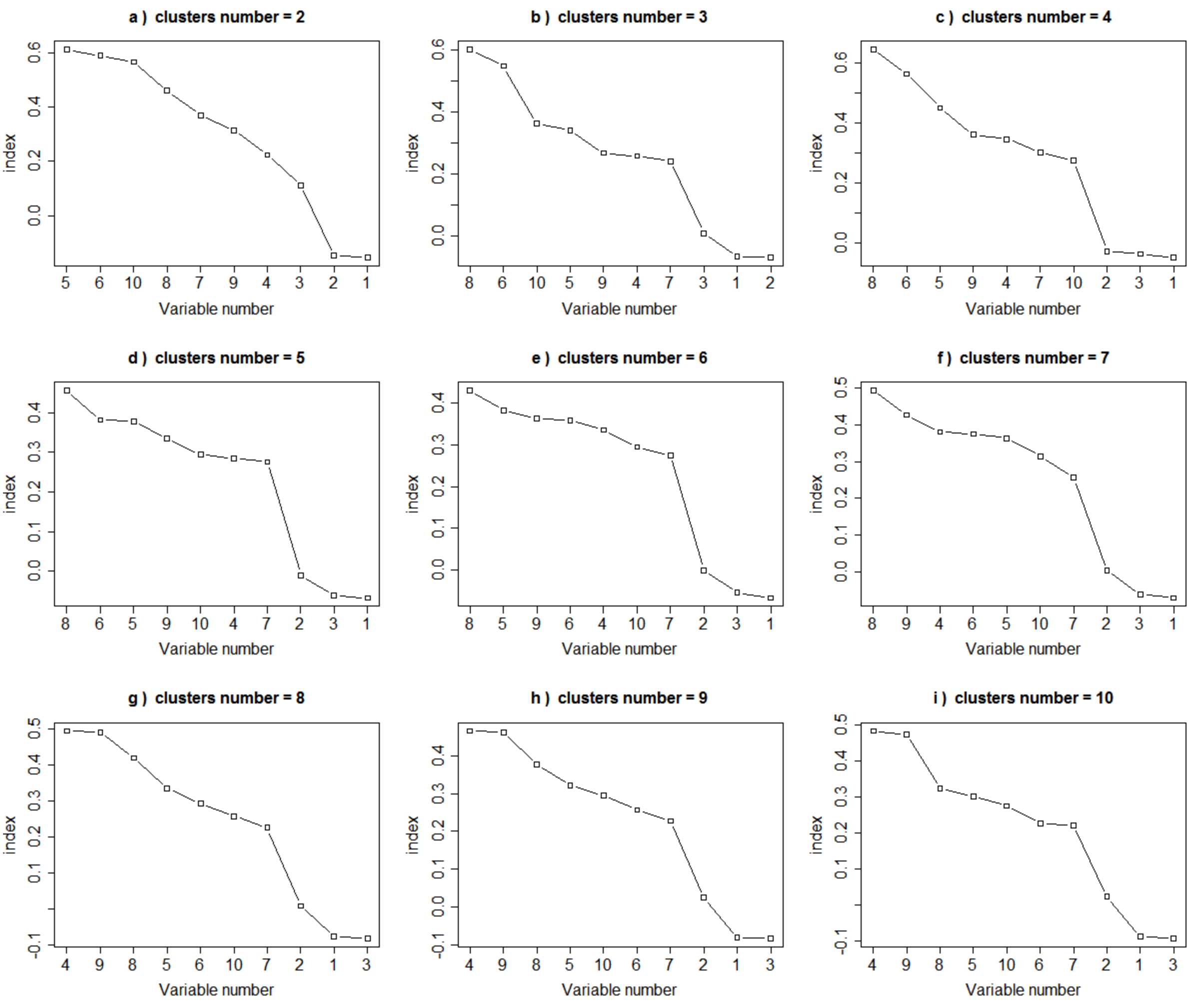

Figure 49. Scree plot - the result of the analysis carried out with HINoV method

Step 2 and 3. The choice of a normalisation procedure of the values of the variables and the choice of distance measures

Normalisation was performed by classical standardisation, i.e. from the values of the individual variables of each object, the mean of the corresponding variable was subtracted and value of these subtractions was divided by the standard deviation of that variable. Some authors mention as very efficient, standardisation defined as the quotient of the object values and range of the set of values of individual variables (max [X] - min [X]). However, this method is not appropriate for present research in the identified presence of outliers (Milligan and Cooper, 1985). Euclidean metric was selected as commonly used distance measure, as there were no particular reasons to use other measures.

Step 4 The selection of classification method

The initial test grouping was performed using agglomeration methods, but the results were not satisfactory (very unevenly distributed clusters in terms of quantity). The k-means method was used for cluster analysis, preceded by algorithmic and expert analysis of the potential number of clusters - Hartigan and Wong (1979). The analysis was performed in an R environment. As the algorithm k-means clustering requires a seed, which is used to initialise method, hierarchical clustering methods were considered one more time to give a preliminary determination of clusters. However, also in this case, results with unwanted features were obtained. Better results were obtained by using k-means algorithm with initial random clusters selected by that algorithm.

Step 5. Determination of the classes number

One of the key issues in cluster analysis is to find the correct number of classes (in terms of application and interpretation of results). This is particularly important in the selected method (k-means). Cluster analysis is expected to yield such a division into clusters, in which they will be compact and separated from each other. It is also expected that the results will be possible to interpret in terms of the specifics of a particular research problem. Therefore, a following approach was applied: one begins with the use of automatic algorithms, and then the results obtained in this way were treated as a clue to the next step, which was the expert analysis, based on the previously generated maps of individual potentials. To find the potential number of clusters five popular algorithms were selected (Walesiak and Gatnar, 2009).

1. The algorithm based on an index of Caliński and Harabasz, given by the formula (Caliński and Harabasz, 1974):

$$CH(u) = \frac{\text{tr}(\mathbf{B}_u)/(u-1)}{\text{tr}(\mathbf{W}_u)/(n-u)}$$

In the above formula $\mathbf{B}_u$ is inter-class covariance matrix, and $\mathbf{W}_u$ the intraclass covariance matrix, n - number of points, and u - number of clusters. tr(A) indicates trace of A.

The procedure is to calculate the index of a set of possible number of clusters and selecting the number of clusters for which the index takes the maximum, i.e.: $\hat{u} = \arg\max_u\{CH(u)\}$.

2. The algorithm is based on the Index of Hubert and Levin given by the formula (Milligan and Cooper, 1985):

$$HL(u) = \frac{D(u) - I_w D_{min}}{I_w D_{max} - I_w D_{min}},$$

where *D(u)* is the sum of all distances within class u, I_w - number of interclass distances, D_{min} - the shortest interclass distance, and D_{max}- the maximum interclass distance. Here, in contrast to the first algorithm, one must select the $\hat{u} = \arg\ \min_u\{HL(u)\}$.

3. The algorithm is based on the index of Krzanowski and Lai given by formula (Krzanowski and Lai, 1985; Tibshirani et al., 2001):

$$KL(u) = \left|\frac{(u-1)^{2/m}\,\text{tr}(\mathbf{W}_{u-1}) - u^{2/m}\,\text{tr}(\mathbf{W}_u)}{(u)^{2/m}\,\text{tr}(\mathbf{W}_u) - (u+1)^{2/m}\,\text{tr}(\mathbf{W}_{u+1})}\right|$$

where m is the number of variables. Other symbols - as above. As in step 1, choose $\hat{u} = \arg\ \max_u\{KL(u)\}$.

4. The algorithm is based on Davies and Bouldin index (Davies and Bouldin, 1979):

$$DB(u) = \frac{1}{u}\sum_{r=1}^{u}\max_{s,r\neq s}\left(\frac{S_r + S_s}{d_{rs}}\right),$$

where: $S_r = \left({}^{1}/_{n_r} \sum_{i \in P_r} \sum_{j=1}^{m} |x_{ij}^r - z_{rj}|^q \right)^{1/q}$, while $d_{rs} = \sqrt[p]{\sum_{j=1}^{m} |z_{rj} - z_{sj}|^p}$ x_{ij}^r is j-th

coordinate of i-th element of class r, z_{rj} - j-th coordinate of the centroid of the r-th class, and P_r-set of objects of that class, q and p are parameters usually assumed to be 1 or 2. This algorithm, as in the case of Levin and Hubert method, has to take $\hat{u} = \arg\ \min_u \{DB(u)\}$.

5. The algorithm is based on the index given by Hartigan (Hartigan, 1975):

$$H(u) = \left(\frac{\mathrm{tr}(\mathbf{W}_u)}{\mathrm{tr}(\mathbf{W}_{u+1})} - 1 \right) (n - u - 1).$$

For this algorithm, the optimal number of classes is the smallest number u for which $H(u) \leq 10$.

As a result of these tests, many different hints for choosing the number of clusters were obtained (Table 27).

Table 27. The suggested number of classes by the tested algorithms

	Algorithm	**Classes number**
1	Algorithm based on Caliński and Harabasz index	3-4
2	Algorithm based on Hubert and Levin index	10
3	Algorithm based on Krzanowski and Lai index	4-10
4	Algorithm based on Davies and Bouldin index	5
5	Algorithm based on Hartigan index	>=10

The final algorithmic stage of the classes selection for clustering, was a validation of the clusters number by using the Silhouette index, which takes values in the interval [-1.1], (Kaufman and Rousseeuw, 1990). The results obtained are summarised in Table 28. Silhouette index is computed by the formula:

$$S(u) = \frac{1}{n}\sum_{i=1}^{n}\frac{b(i) - a(i)}{\max\{a(i), b(i)\}}$$

where: $a(i) = \sum_{k\in\{P_r\backslash i\}}\frac{d_{ik}}{(n_r-1)}$, $b(i) = \min_{s\neq r}\{d_{i\,P_s}\}$, $d_{i\,P_s} = \sum_{k\in P_s}\frac{d_{ik}}{n_s}$, P_r and P_s - are respectively the set of objects of the class *r* and *s*.

Table 28. Validation of the number of classes using Silhouette index

Number of clusters	Silhouette index
1	NA
2	0.24
3	0.29
4	0.33
5	0.33
6	0.34
7	0.27
8	0.28
9	0.29
10	0.27

In the absence of a clear indication from tests 1-5, the decision about class number was taken based on the expert judgement combined with index Silhouette. This led to distinction of six classes that were selected to perform cluster analysis. The results are presented in the following map (Figure 50).

Step 6 Evaluation of the classification results

In the above classification Silhouette index amounts at 0.34, and thus it is in the range [0.25, 0.5], which according to the authors of the method, indicates weak but existing structure of classes. The authors recommend in this case considering additional methods of data analysis.

However, as demonstrated by a comparison of the spatial distribution (map) with the results obtained earlier, the structure of the classes can be regarded as sufficient for the interpretation of regionalisation of biomass potential. To some extent, it can be confirmed by analysing scatterplots of points in planes spanned by pairs of variables (Figure 51-Figure 53). Figure 51 shows the distribution of clusters of all variables for all NUTS-3. For a more transparent relationship of variables with biomass type, coded names (Table 29) were given.

Table 29. Code names of variables with biomass type potential

Code	**Biomass type**
b.1.1	Livestock residues
b.1.2	Straw
b.1.3	Hay from permanent grassland
b.1.4	Pruning residues
b.2.0	Forestry residues
b.3.1	Green urban areas
b.3.2	Roadside vegetation
b.4.1	biodegradable municipal waste
b.4.2	Bio-waste of food industry
b.4.3	Bio-waste of wood industry

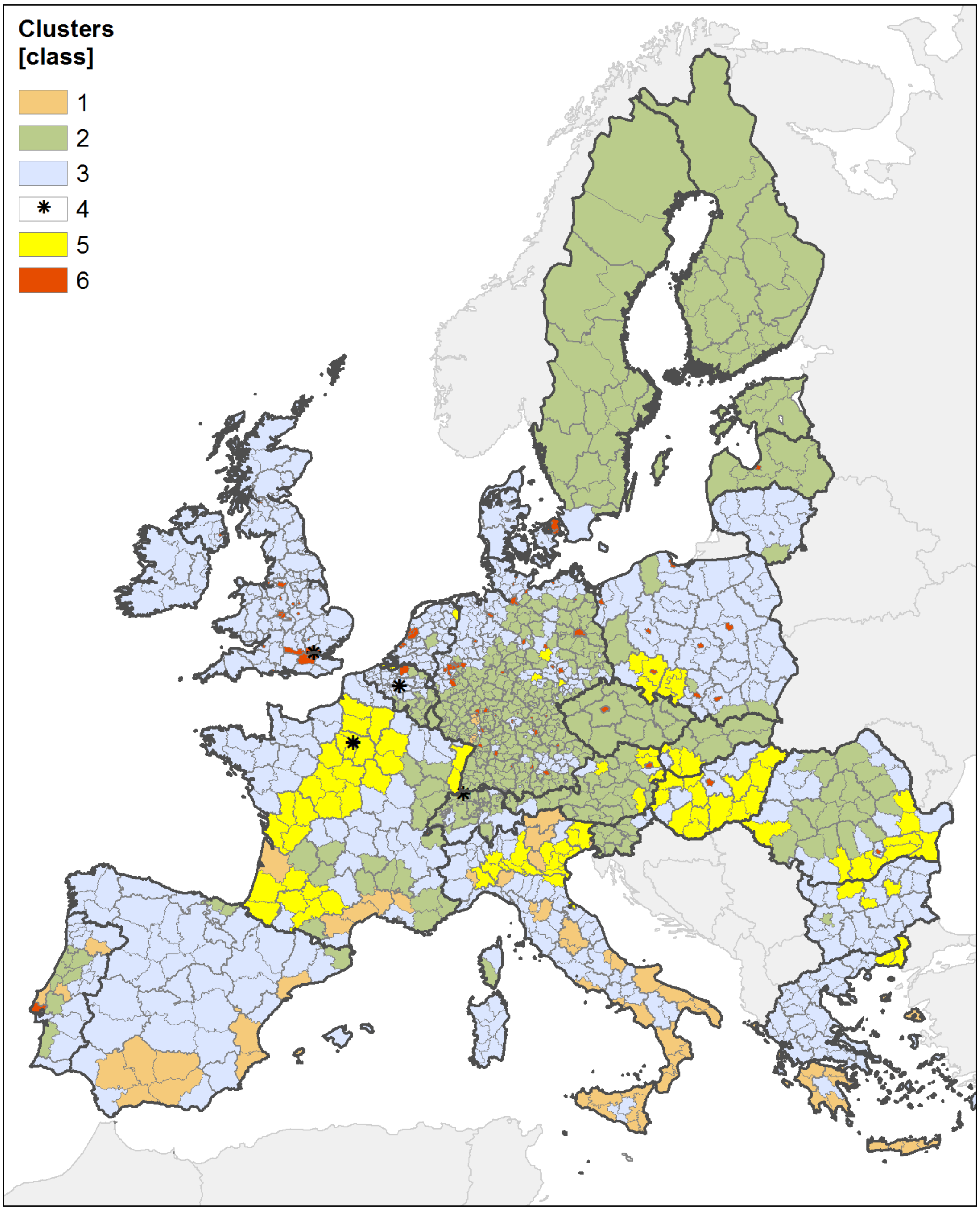

Figure 50. Map of clusters. Class 4 was marked with a signature (*) due to small area of NUTS-3, which are non-visible on the map at this scale.

Among the matrix of charts for each cluster, it can be found at least one chart where this cluster can be distinguished from others. This is sufficient for carrying out the required separation of groups. Charts also confirm the existence of previously estimated, weak but existing class structure occurring in the full data set. The only distinction with no concern is the focus of a class 4 (super-city), best seen in Figures 51, 52, 53 (b.3.2-b.4.1; black dots). The linear arrangement of green dots on the graph b.2.0-b.4.3 shows the linear correlation between biomass from forestry and waste biomass from the timber industry. This relationship has been established in the RENEW model. Visualisation of all data in Figure 51 also shows the presence of small number of objects (in most of the classes), characterised by the values much larger than average, such as: b.2.0-B.3.1, b.1.2-b.4.1. This suggests occurrence of positive skewness in the distribution of the data. For better clarity, scatter plots are shown only for NUTS for which each feature was contained in the range of six standard deviations from the mean. In this way, the decomposition into classes becomes clearer. However, due to the large number of data, there is a danger of masking in charts elements of one cluster by elements of other one and thus giving the false impression of separation occurring between classes, where it might not in fact occur. For this reason, there were randomly selected 200 NUTS-3, from ones depicted already in

Figure 52 and these 200 objects were then visualised in Figure 53 which gives a more transparent overview of the relationship of classes. The cluster distribution of variables chosen randomly as described above confirms the correctness and usefulness of the clusters analysis (Figure 53).

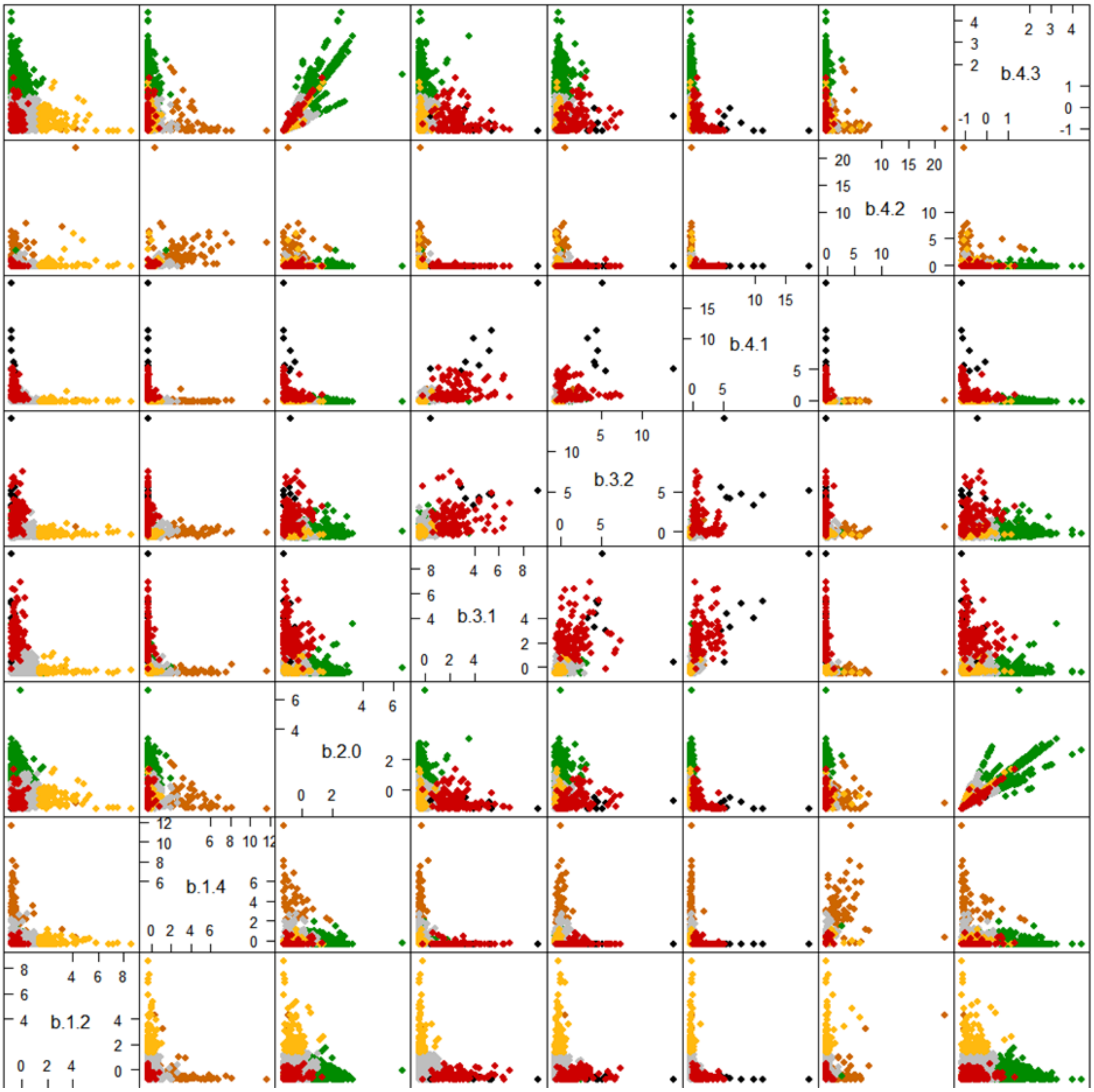

Figure 51. Eight-dimensional space of cluster analysis visualised for all classes in the symmetric matrix. Colour of points as presented on the map (Figure 50).

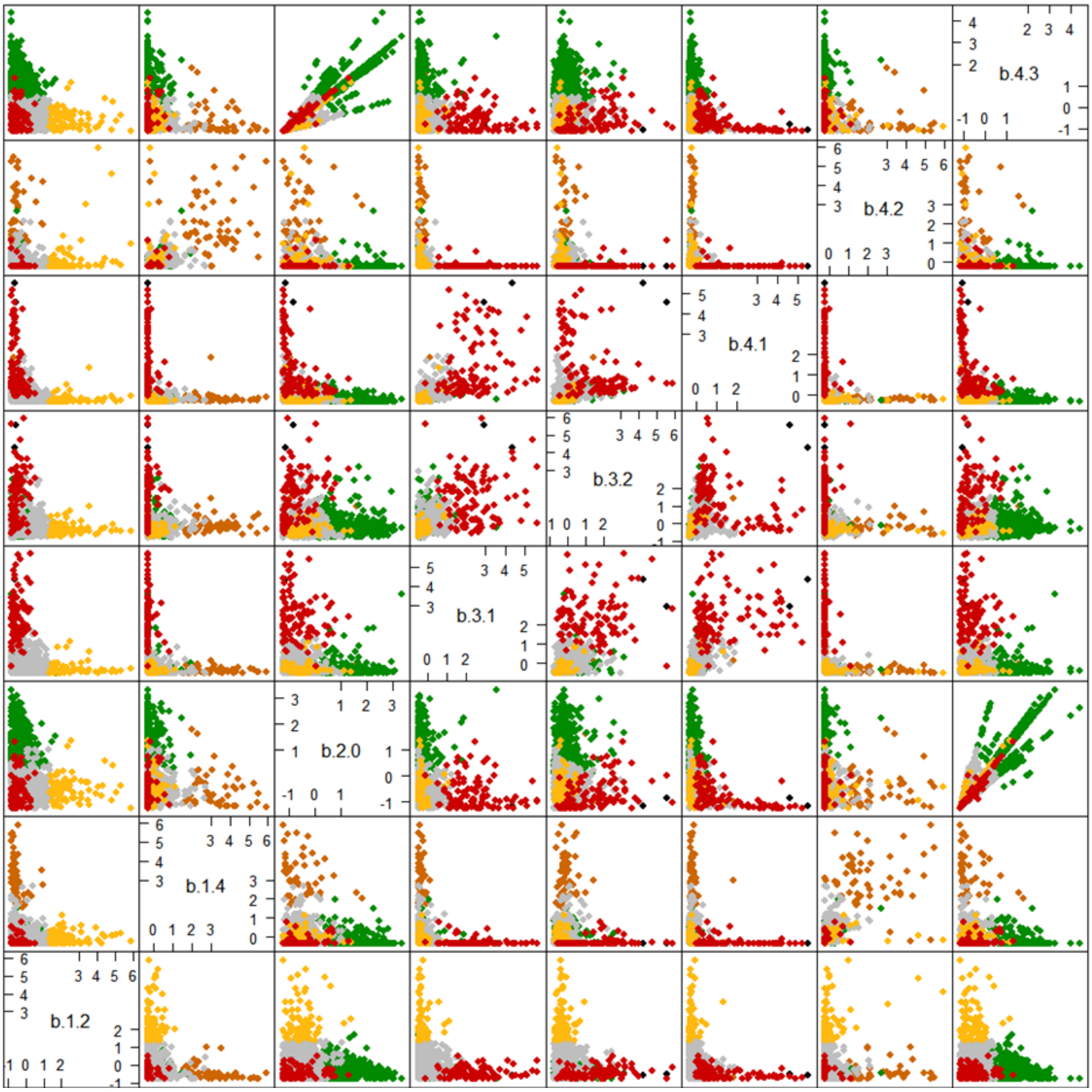

Figure 52. Enlarged image of the cluster analysis, in which each feature does not deviate from the mean by more than six standard deviations. Colour of points as presented on the map (Figure 50).

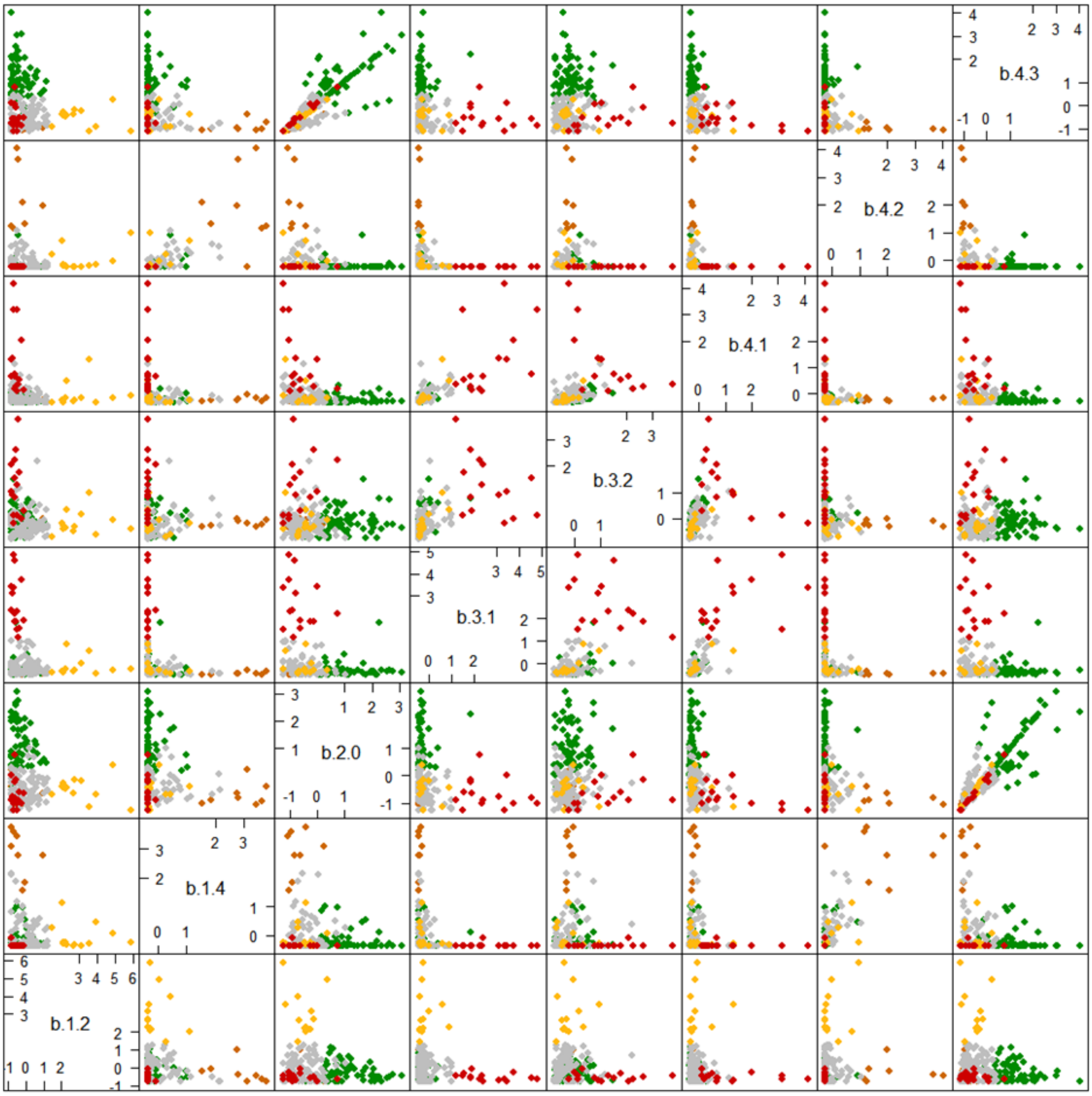

Figure 53. Randomly selected sample of 200 NUTS-3 for the situation described in Fig. 37. Colour of points as presented on the map (Figure 50).

Cluster analysis by the k-means method for the number of classes equals 6, and the 8 variable gave results which are characterised in Table 30, where the centres of gravity of obtained clusters are presented. Bold Italics mark significant variables – which are the best to interpret and characterise the obtained clusters. A broader interpretation of the characteristics of each class is described in Step 7.

Table 30. Summary of the centres of gravity of clusters of variables (standardised values in parentheses).

Biomass type/ Variable / Class	Straw b.1.2	Pruning residuals b.1.4	Forestry biomass b.2.0	Urban biomass b.3.1	Roadside vegetation b.3.2	Municipal waste b.4.1	Food industry waste b.4.2	Wood industry waste b.4.3
1	19.1 (-0.3)	**35.3** (3.4)	12.5 (-0.6)	0.2 (-0.4)	1.6 (-0.1)	33.2 (-0.2)	**38.0** (2.8)	0.4 (-0.8)
2	20.2 (-0.3)	1.0 (-0.2)	**47.0** (1.1)	0.3 (-0.3)	1.4 (-0.2)	20.1 (-0.3)	0.5 (-0.2)	**2.6** (1.2)
3	32.6 (0.0)	1.9 (-0.1)	14.4 (-0.5)	0.6 (-0.2)	1.2 (-0.2)	42.4 (-0.1)	1.3 (-0.1)	0.7 (-0.6)
4	3.0 (-0.7)	0.0 (-0.3)	5.5 (-1.0)	**9.7** (4.3)	**14.1** (5.7)	**1682.3** (8.7)	0.0 (-0.2)	0.4 (-0.8)
5	**154.1** (2.7)	2.4 (-0.1)	14.0 (-0.5)	0.4 (-0.3)	1.1 (-0.3)	24.8 (-0.2)	4.3 (0.1)	0.6 (-0.6)
6	13.8 (-0.5)	0.6 (-0.3)	10.8 (-0.7)	**6.1** (2.5)	5.4 (1.7)	**329.5** (1.4)	0.5 (-0.2)	0.6 (-0.6)

Step 7 Description (interpretation) classes

Before making the interpretation of the class, it should be noted that part of the biomass from agriculture (except straw and perennial plantation) was excluded on the basis of the HINoV analysis (Step 1) from the cluster analysis. Their spatial distribution in relation to other types of biomass is characterised by the occurrence of a few, small in area clusters, which themselves, form a specific cluster of organic fertiliser surplus and hay (Figure 25 and Figure 27). Outline of the characteristic classes, obtained by cluster analysis can be described on the basis of the results obtained in Table 30, since the designation of the cluster provides the opportunity to study the impact of different potentials on the overall structure of the biomass in each of the classes. In principle, the classes are grouping similar NUTS, so that individual classes are more homogeneous than the entire area of research. The characteristics of the distribution for each of the classes are presented graphically on Box-and-whisker chart, which shows the empirical distribution of values of the variables (potentials). Due to the asymmetry of the distribution, the more proper measure of central tendency is the median not the mean. On the charts it is indicated as a vertical line dividing the rectangle, the arithmetic mean value is marked with an asterisk on the right side. The rectangle shows the range between the first and third quartiles (Figure 54- Figure 59).

The first class represents mainly the Mediterranean, dominated by olive groves and vineyards, and materials derived from them are processed locally (high median values for the variables b.1.4 and b.4.2). It consists 68 NUTS 3, mainly the Mediterranean zone. Average biomass density in NUTS 3 units in this class are respectively 27.9 t/ha and 35.5 t/ha. Compared to the other, the first class has the highest sustainable biomass potential. As many as five kinds of potentials may find practical use. Biodegradable municipal waste biomass has the potential slightly smaller than the two most significant ones. Straw and biomass from forestry has lower potential, but in the overall structure, it is significant. A total residues and waste biomass density in the regions of the first class can be estimated at 121.4 ha/km^2, which puts the class into fourth position. In regions of the first class manure, hay, municipal biomass, roadsides and waste from the timber industry are insignificant as biomass (low values of medians and negative values for the centroids in the standardised form).

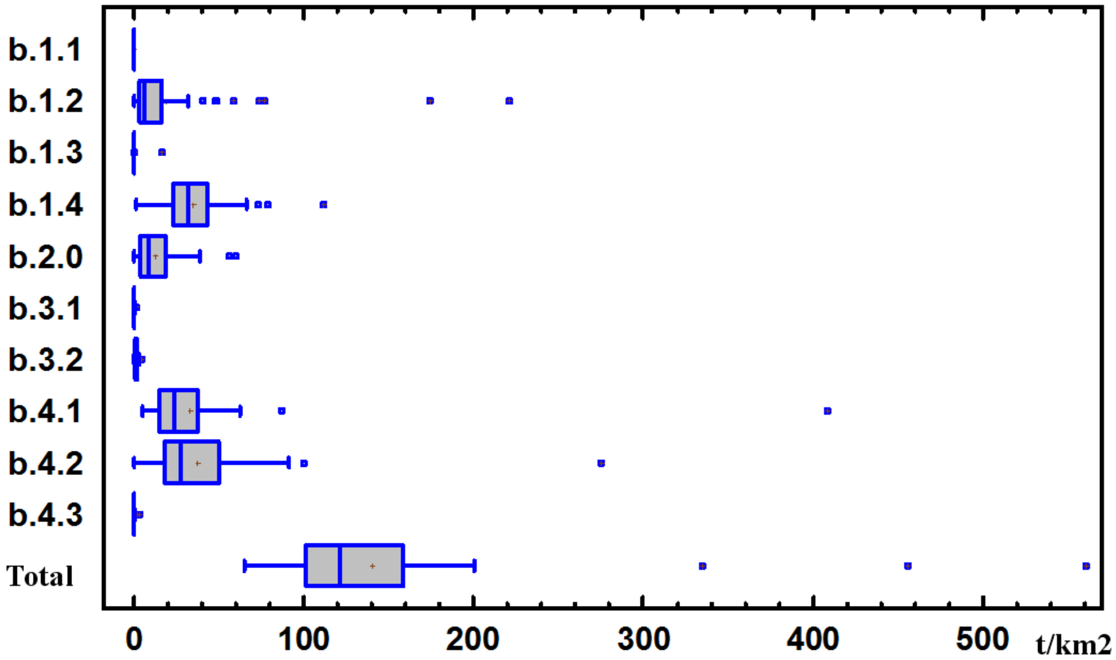

Figure 54. Box-and-Whisker chart for potential distribution in class 1 (of six clusters)

Second class can be interpreted as a region with domination of biomass derived mainly from forestry. This class consists of 434 NUTS-3. The average total biomass density in NUTS units in this class are 99 t/ha, and the most important potential (forest biomass) - 44 t/ha. In addition to forest biomass, a significant share in the ranges has straw and municipal waste. Class 2 and Class 3 are the poorest regions in the biomass (<100 t/km^2). Compared to potential map, it can be concluded that this is a class corresponding to the fullest map forest biomass density. This applies mainly to the countries of Central and Eastern Europe (Germany, Austria, Slovenia, the Czech Republic, Slovakia and Romania). In the case of Sweden, Finland and Estonia, an important criterion for membership of these countries to this class are small sources of other biomass potential. In this class, NUTS with large potentials of hay are located.

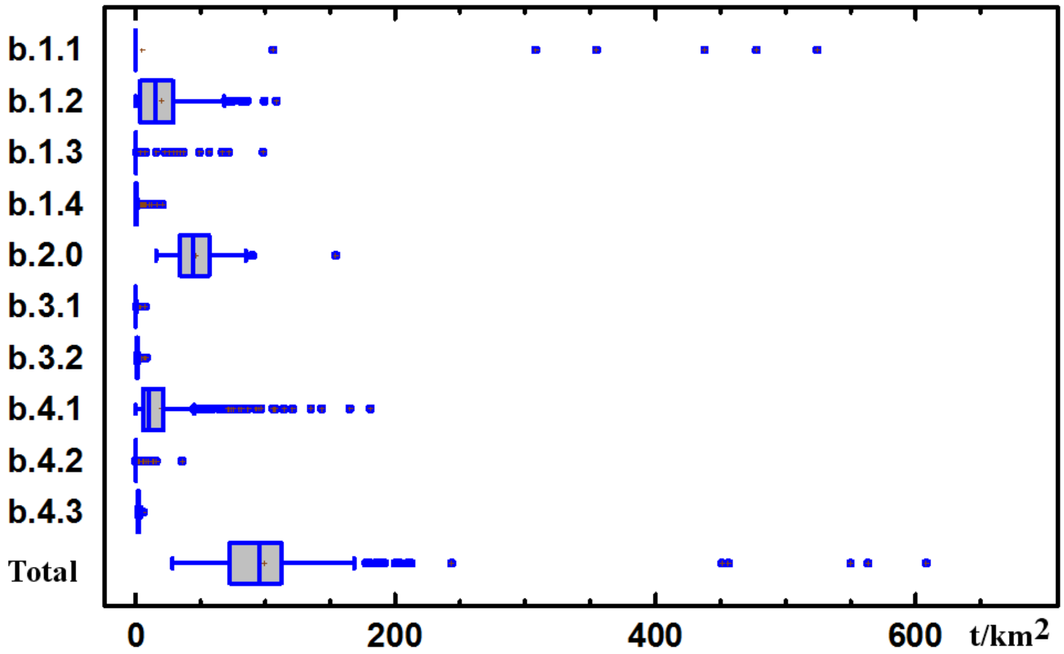

Figure 55. Box-and-Whisker chart for potential distribution in class 2 (of six clusters)

Third class is most numerous class (607 NUTS) and covering the largest area. Represents the smallest (88 t/km^2) and most average values of potentials, without a clear advantage of any of the types of biomass. Their mean in this class are arranged below the average for particular variables (negative standardised values in Table 30). Only in the case of straw can be seen the effect of this type of biomass on the structure of this class. Third class apart from Scandinavia can be found in all parts of Europe. It is not concentrated in any specific geographical location, creating dominant clusters in both Spain, UK, Denmark as well as Poland, Lithuania and in south-eastern Europe. In this class are located NUTS with large potentials of hay and most of the NUTS with significant manure potential that can be used for energy purposes. In the absence of specific characteristics should be taken as a reference point for other classes.

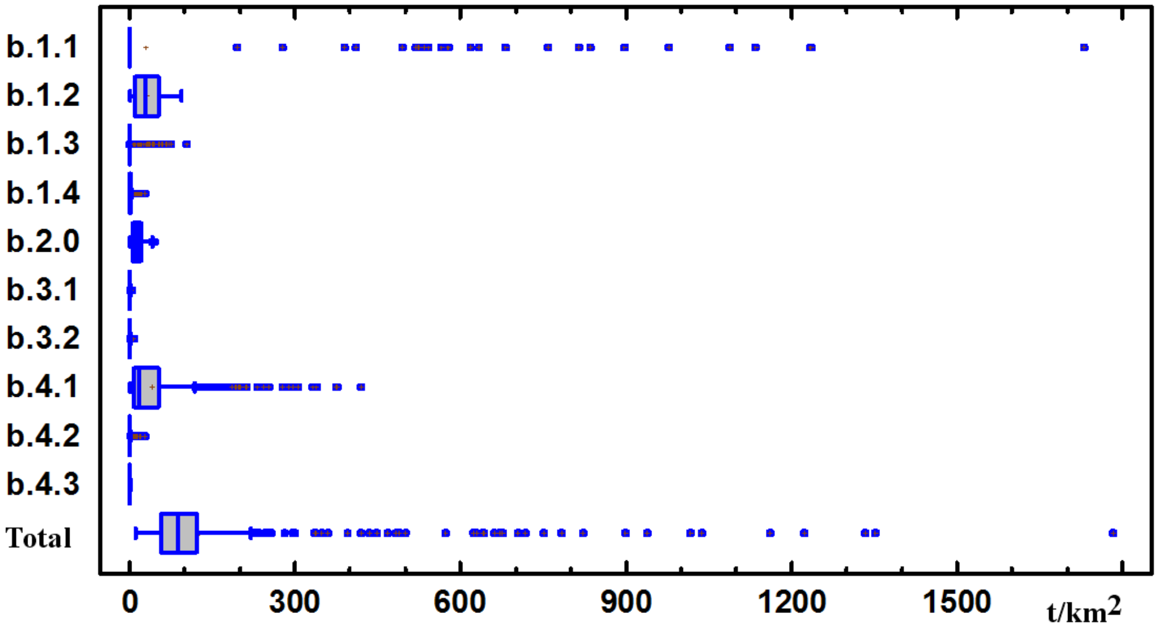

Figure 56. Box-and-Whisker chart for potential distribution in class 3 (of 6 clusters)

Fourth class, which can be called 'super-city' class, contains only eight NUTS-3 units of large and dense urban areas, which is dominated by biomass from biodegradable municipal waste. For geographical reasons, this class refers only to four regions, as in the case of Paris and London NUTS-3 are close to each other. The average density of biomass in the NUTS is 1370 t/km^2 and a maximum in Paris 3600 t/km^2. When compared to other classes, these enclosed regions have the greatest biomass potential. However, due to their relative small size, the regions are not of special importance. This class may be combined with the sixth class, because both classes have an identical structure.

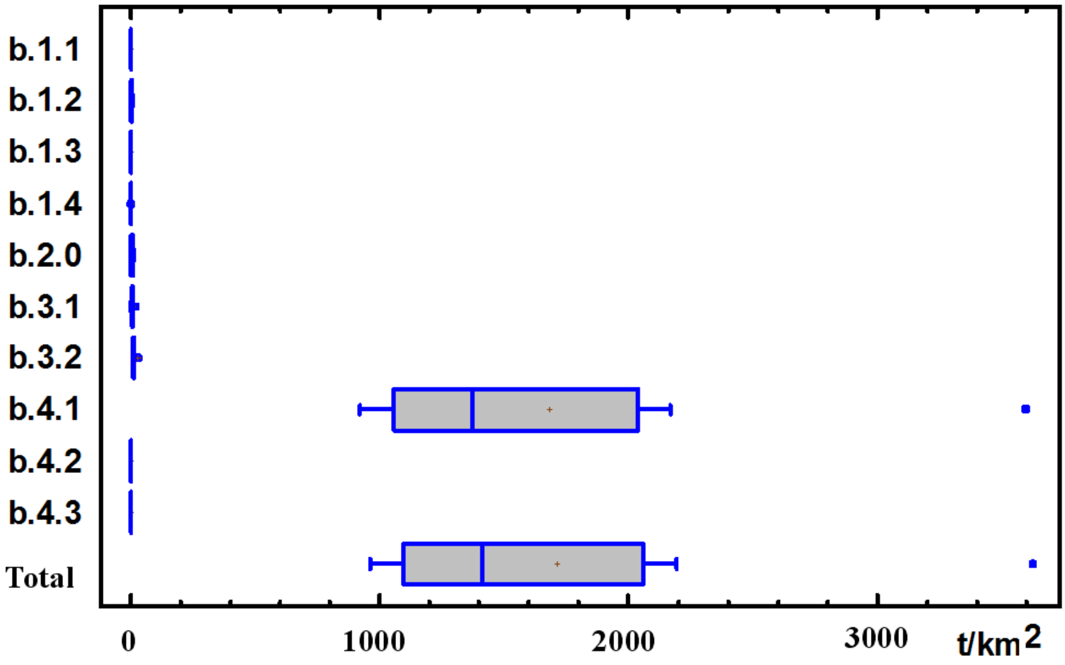

Figure 57. Box-and-Whisker chart for potential distribution in class 4 (of 6 clusters)

Fifth class represents a region dominated by straw and isolates' regions typical for agriculture: central and western France, the valley of the Po Plain, Lower Silesia, Lower Danube regions. It consists 89 NUTS-3 with relatively high biomass potential (174 t/km^2). Due to the study of the structure of biomass, this class is very important because it defines typical croping regions, with a small share of forest residues and biodegradable municipal waste. In these regions, the most important renewable energy source is straw (130 t/km$_2$), which in Europe is the largest potential of biomass.

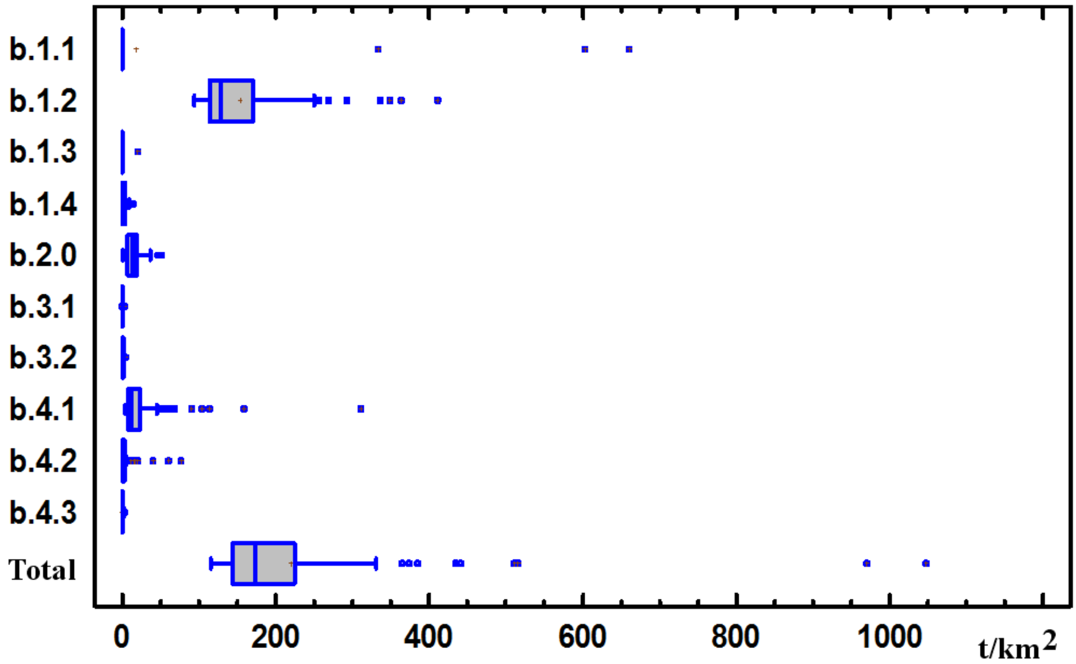

Figure 58. Box-and-Whisker chart for potential distribution in class 5 (of six clusters)

Sixth class is the class of biodegradable municipal waste dominance. Their average density in these regions amounts at 257 t/km^2. This class comprises 107 NUTS-3 of an urban typically, but not quite as tight as in the agglomerations of fourth class. A characteristic feature of this class is its lack of presence in Southern Europe. This is due to the lack of small NUTS-3 presence there, involving only urban areas. Therefore, the NUTS-3 included in this class is most common in Germany, where all administrative units are smaller in size compared to the rest of Europe.

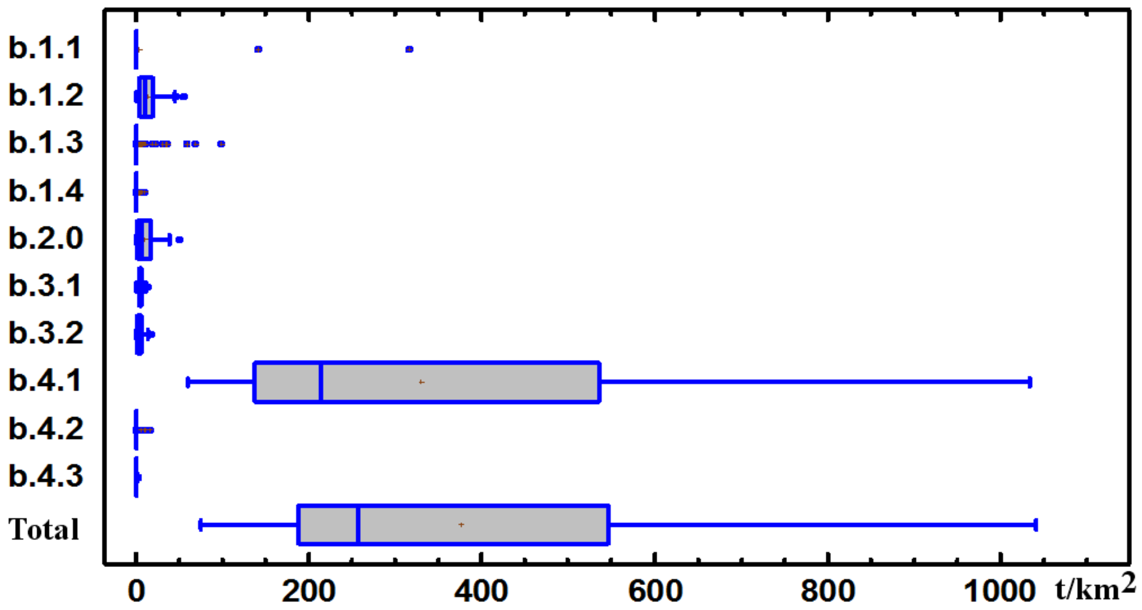

Figure 59. Box-and-Whisker chart for potential distribution in class 6 (of six clusters)

Summing up the results obtained with the cluster analysis it can be concluded that on the basis of the research, considered from the point of view of pure data analysis, the class structure is weak. However, after deeper analysis of the data structure (HINoV), selecting the optimal number of classes (Silhouette index) and a classification method, the structure has become possible to read and interpret. If one adds to this expert knowledge, one can be convinced that the use of cluster analysis with the data is justified. Through cluster analysis:

- six clusters with similar structure of biomass potential was obtained,
- a large number of primary data (ten separate maps for different types of biomass), up to six basic categories was reduced,
- difficult for interpretation areas were classified, separation of three clusters with dominance of: straw, biomass from forestry and municipal biodegradable waste.

Spatial analysis showed a high potential of geographic diversity and the presence of NUTS-3 with very specific characteristics, clearly outlying from the general population. This situation is especially evident in the case of urban NUTS units in which they have a dominant share of biodegradable municipal waste. This global diversity in the potential, with presence of local extremes determines that Europe is an area of highly heterogenneity in terms of the modelled biomass potentials. This is confirmed by statistical analysis sets gained in spatial analysis. All estimates obtained are characterised by a distribution deviating from the Gaussian distribution, showing positive skewness.

7. SUMMARISED FEEDSTOCK POTENTIAL

Spatial analysis was performed for the EU-27 + Switzerland. The estimates were carried out for the third level of territorial units (NUTS-3 Nomenclature of Territorial Units for Statistics), distinguished for statistical purposes by the European Statistical Office (Eurostat) - NUTS, 2003, 2011. Switzerland was included in the analysis primarily to maintain consistency of geographical study.

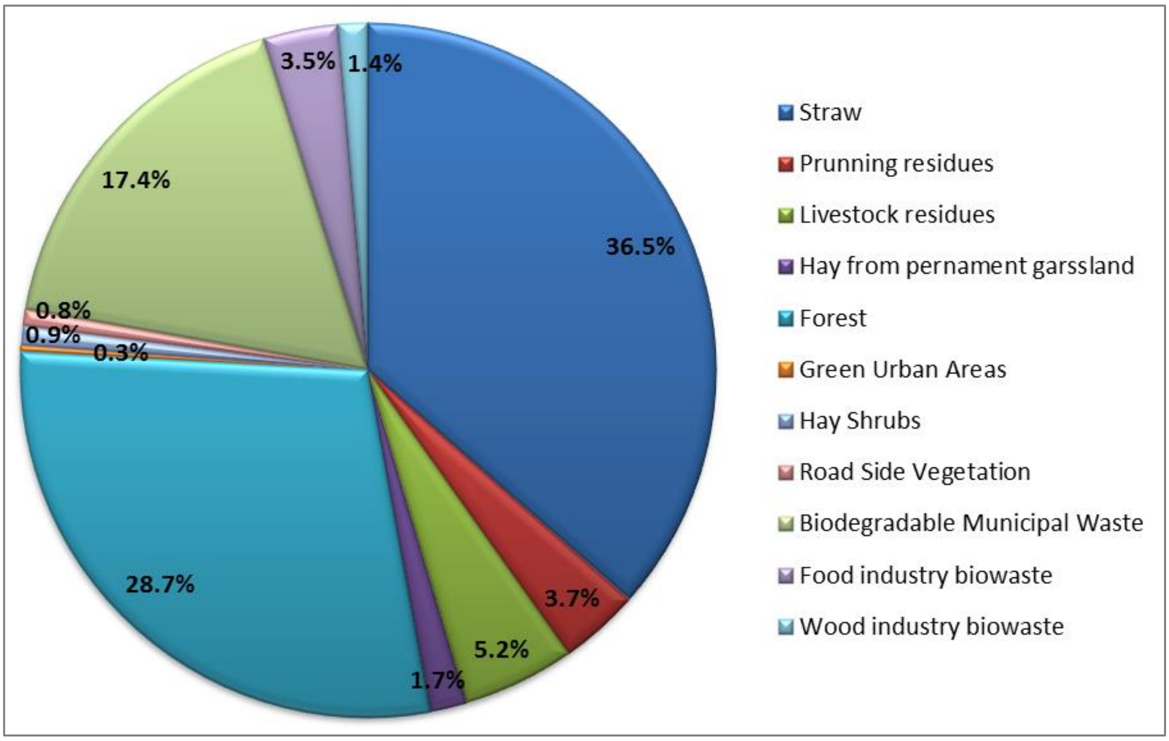

Figure 60.Partition of biomass resources in kt bioenergy production

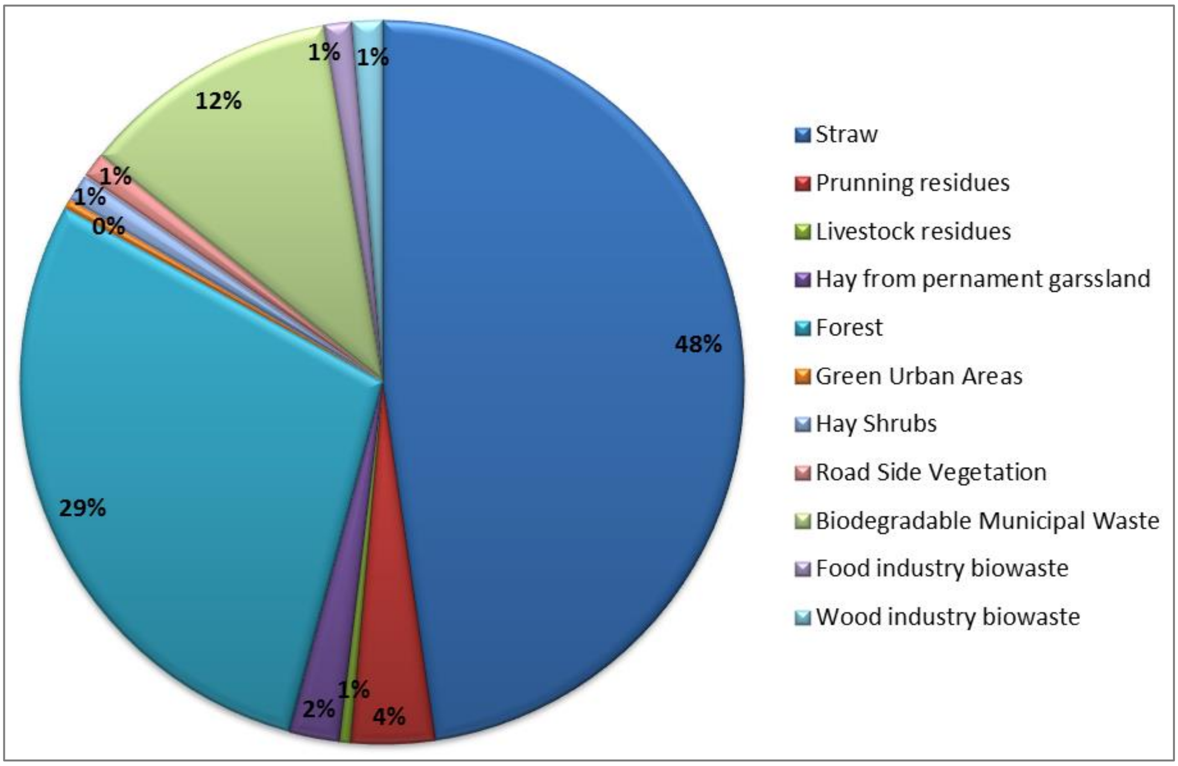

Figure 61. Partition of biomass resources in PJ bioenergy production

A comparison of the assessed energy potential for Europe shows a dominance of three types of biomass. The most notable is straw. This represents 36.5 percent of the total mass (Figure 60). This percentage increases when comparing the results converted into energy. This is due to the high-energy content of straw and relatively low humidity at the time of acquisition (ca. 15%). The second most important potential is forestry biomass residue (29 % of the total mass and energy). The third assortments is biodegradable municipal waste (17,4% of the total mass and 12 % of energy). All other biomass resources (excluding straw, forestry and biodegradable municipal waste) are estimated at a 17.4 % share in the mass structure and in the energy structure of 11.9%. Therefore, the individual ranges cannot be regarded as a strategic resource in the pan-European energy policy. They may however, as it was shown in a study be an important source of the biomass in some regions.

Estimates into the technical potential, allow an approximate evaluation of global and regional sourcing possibilities of biomass for energy. However, there are other limitations in the acquisition and use of these resources. This applies mainly to the straw, which is one of the most promising resources. In some regions, problems in the immediate acquisition can be found. For example, the Lublin region that is rich in straw (eastern Poland) has highly fragmented farms. The farms may often have no more than 1 ha, which definitely makes it difficult to prepare straw for transportation (baling) in addition to its subsequent logistics. As a contrast to straw, the best situation in collecting biomass can be identified for biodegradable municipal waste. EU policy places great emphasis on sustainable waste management, which enforces segregation and proper disposal. In addition, metropolitan areas and cities are a natural focus of these resources, and greatly allow the facilitation of logistics for transport, storage and utilisation for energy purposes. The energy use of biodegradable municipal waste does not compete with its other use, so the theoretical potential of this type of biomass is close to its technical potential. This cannot be said about by-products from agriculture and forestry, which have a number of alternative uses.

Animal residues are a very valuable fertiliser, which should find their primary use in soil conservation. Part of manure can be used for energy production, where the residues are generated by large farms as a surplus. However, this can only be conducted by first considering where due to environmental considerations it would be an arduousness task to collect.

The results of the technical straw potential obtained in the Bioboost project are comparable to other previous research (Figure 62). In the case of straw, only the results obtained by Nordenstaaf and Thonqvist (2008) significantly differ from other.

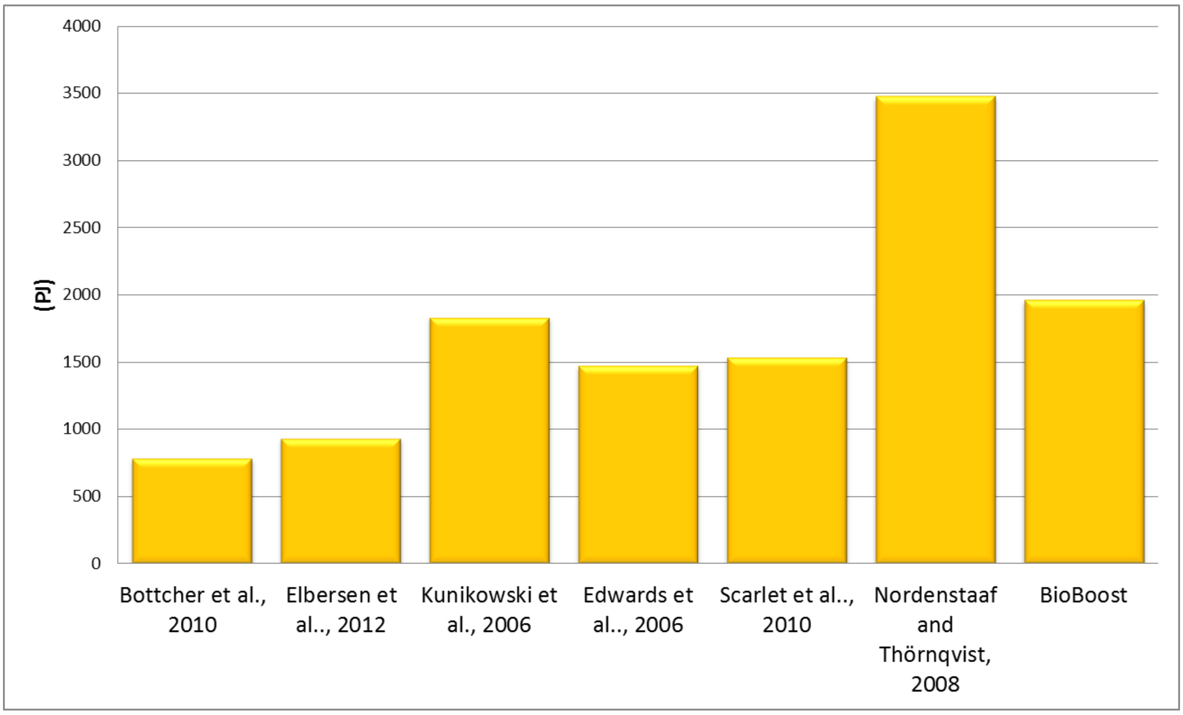

Figure 62 The total technical straw potential in EU-27+CH by different authors

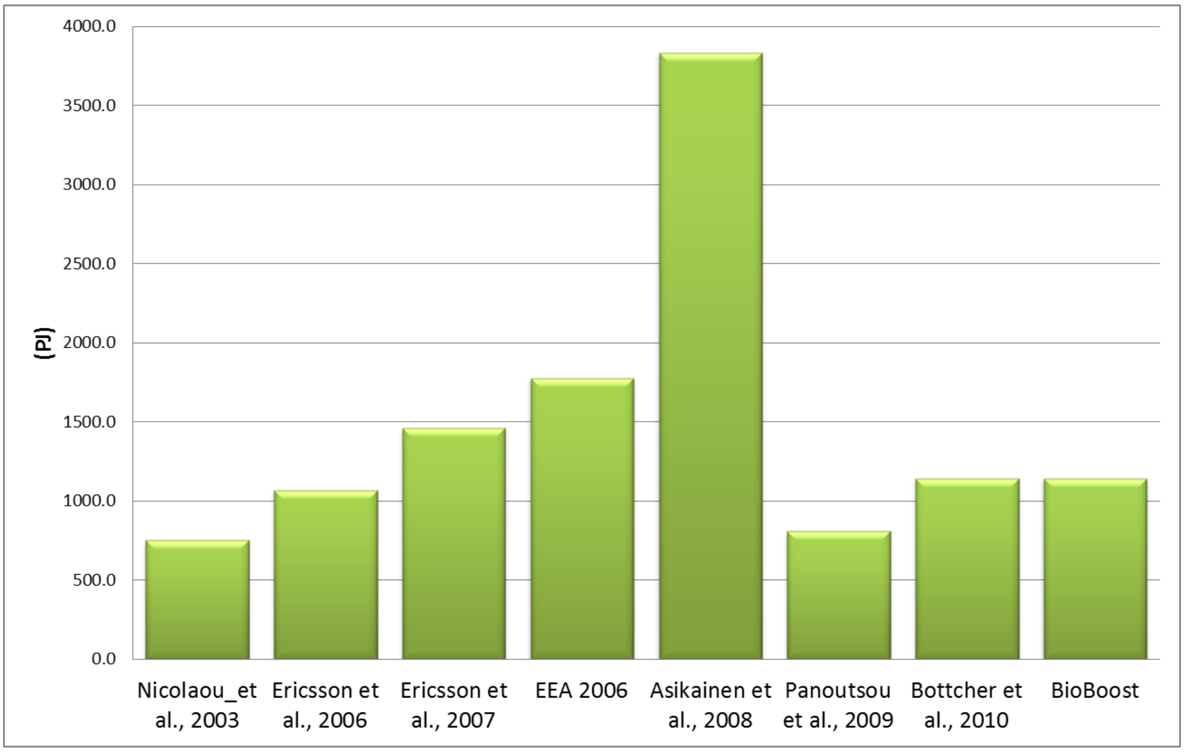

Figure 63 The total technical forest residues potential in EU-27+CH by different authors

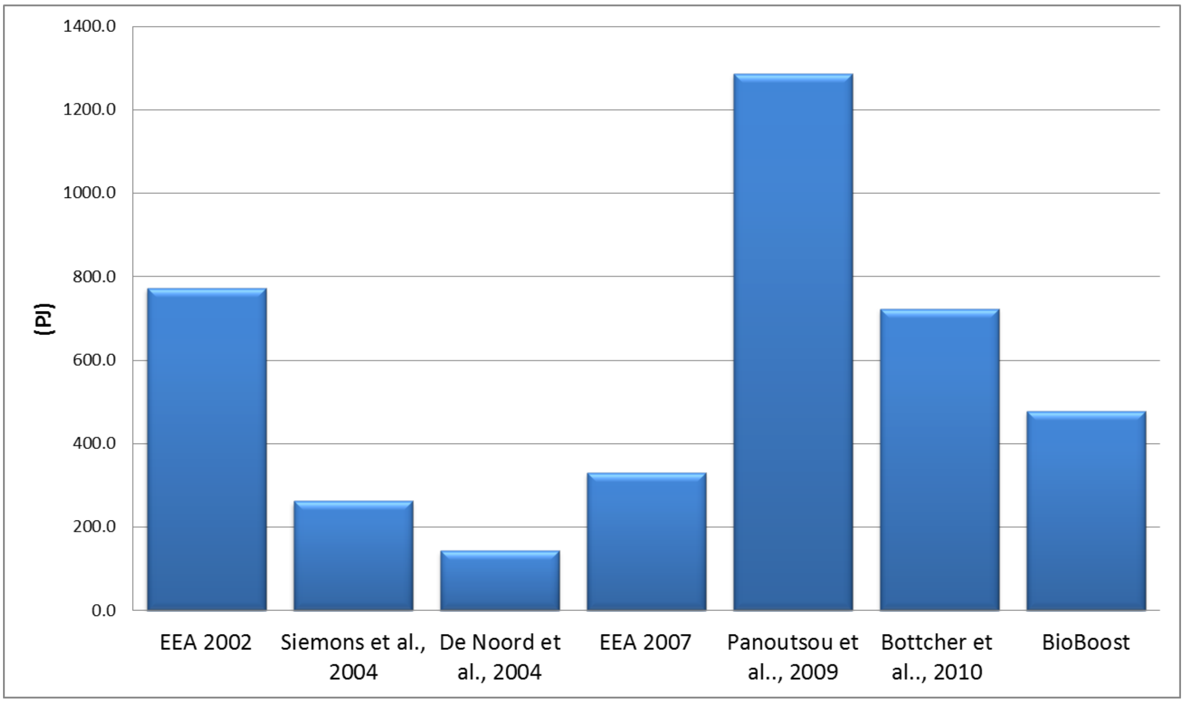

Figure 64. The total technical biodegradable municipal waste potential in EU-27+CH by different authors

The maps below show the total biomass resources and their energy in the NUTS-3. The list of the potential can be a valuable indication to support the development of local decision-makers. These maps, due to differences in the surface NUTS-3 do not reflect the actual spatial distribution of biomass resources. These relationships were visualised on maps showing the 'density' of resources, which was presented as values normalised by the surface potential of the region. In this way, these maps allow the regionalisation of the biomass potential.

The most prosperous biomass regions include:

In France: Pays de la Loire, central region Ile-de-France, Picardy, Champagne,

In Germany: Nordrhein-Westfalen, Niedersachsen, Sachsen-Anhalt,

In Great Britain: East Midlands, East Anglia, South East

Hungary and W-Slovakia

In Italy: Lombardy and Veneto (in the valley of the river Po),

In addition: NE Austria, In-Slovakia, Hungary, Surrounding all larger agglomerations.

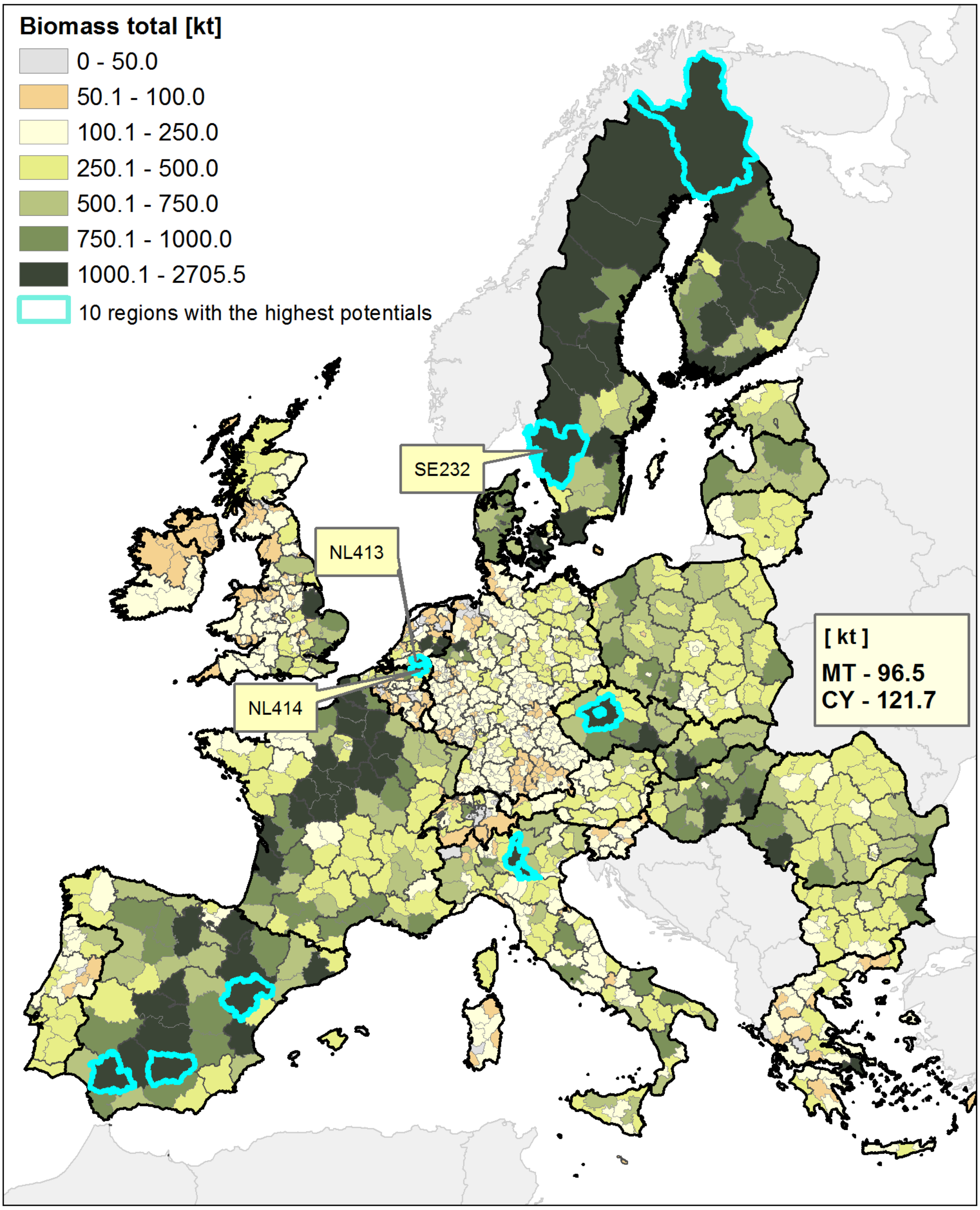

Figure 65. Summarised biomass potentials in NUTS-3

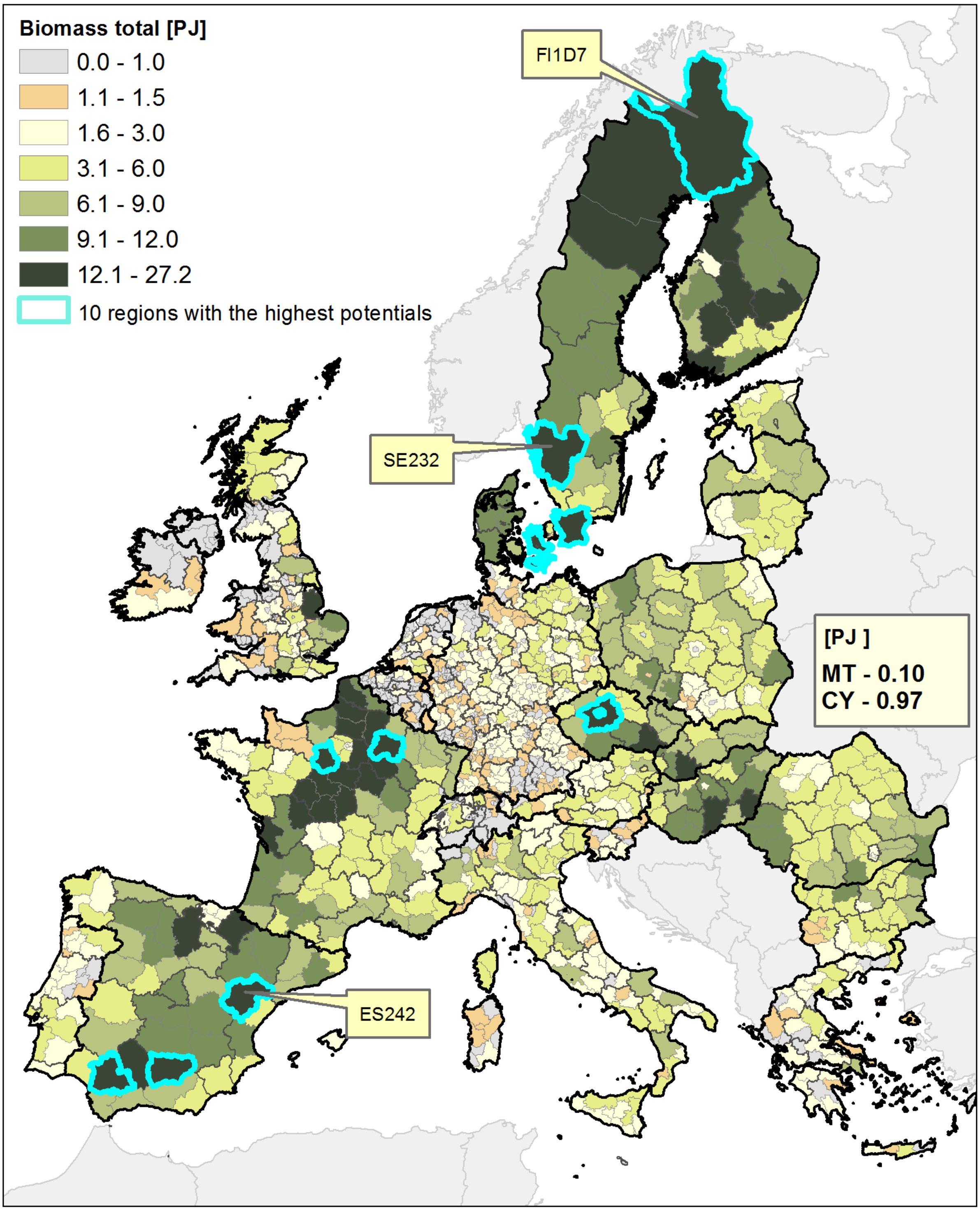

Figure 66. Summarised energy potentials in NUTS-3

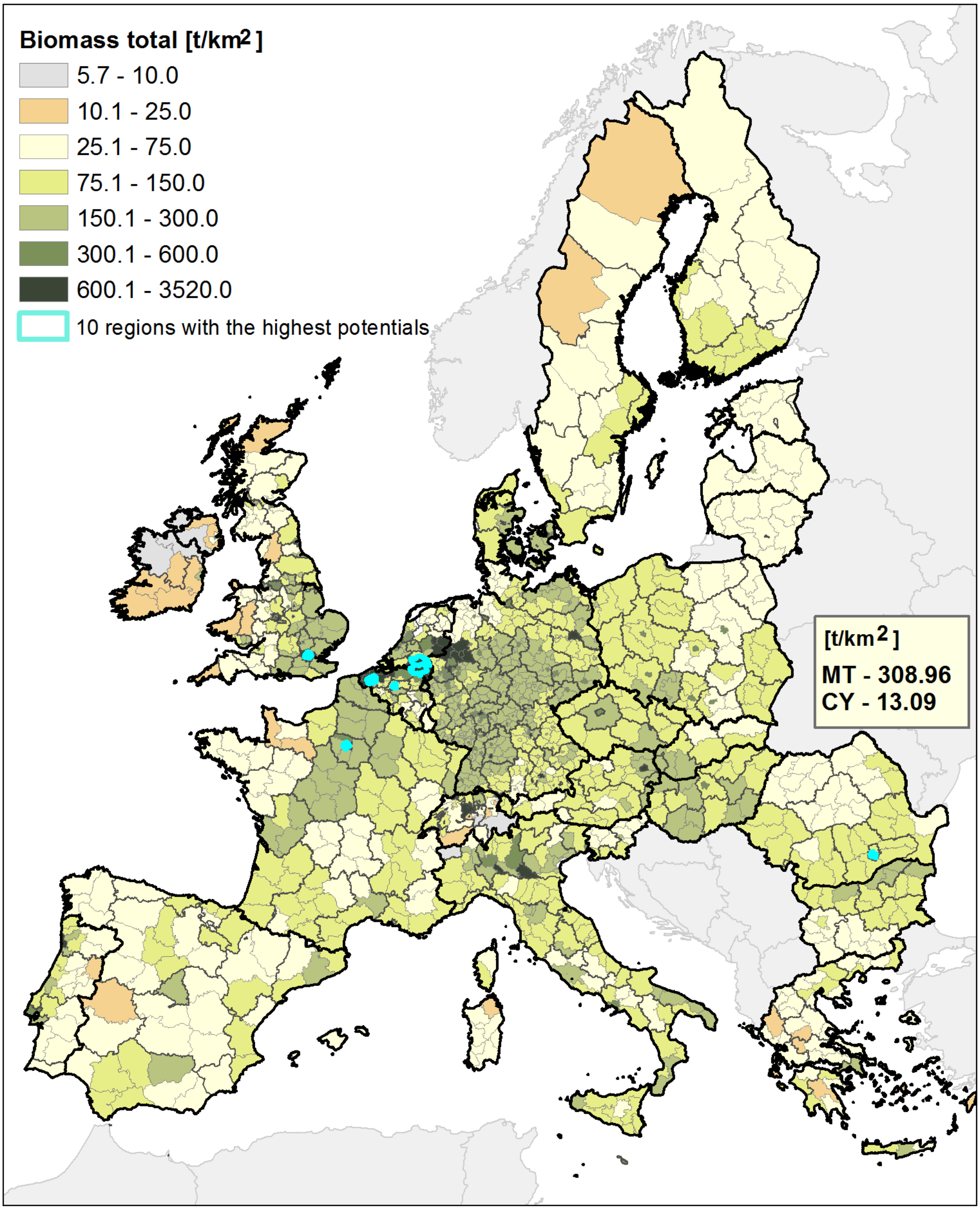

Figure 67. Summarised biomass potentials (density) in NUTS-3

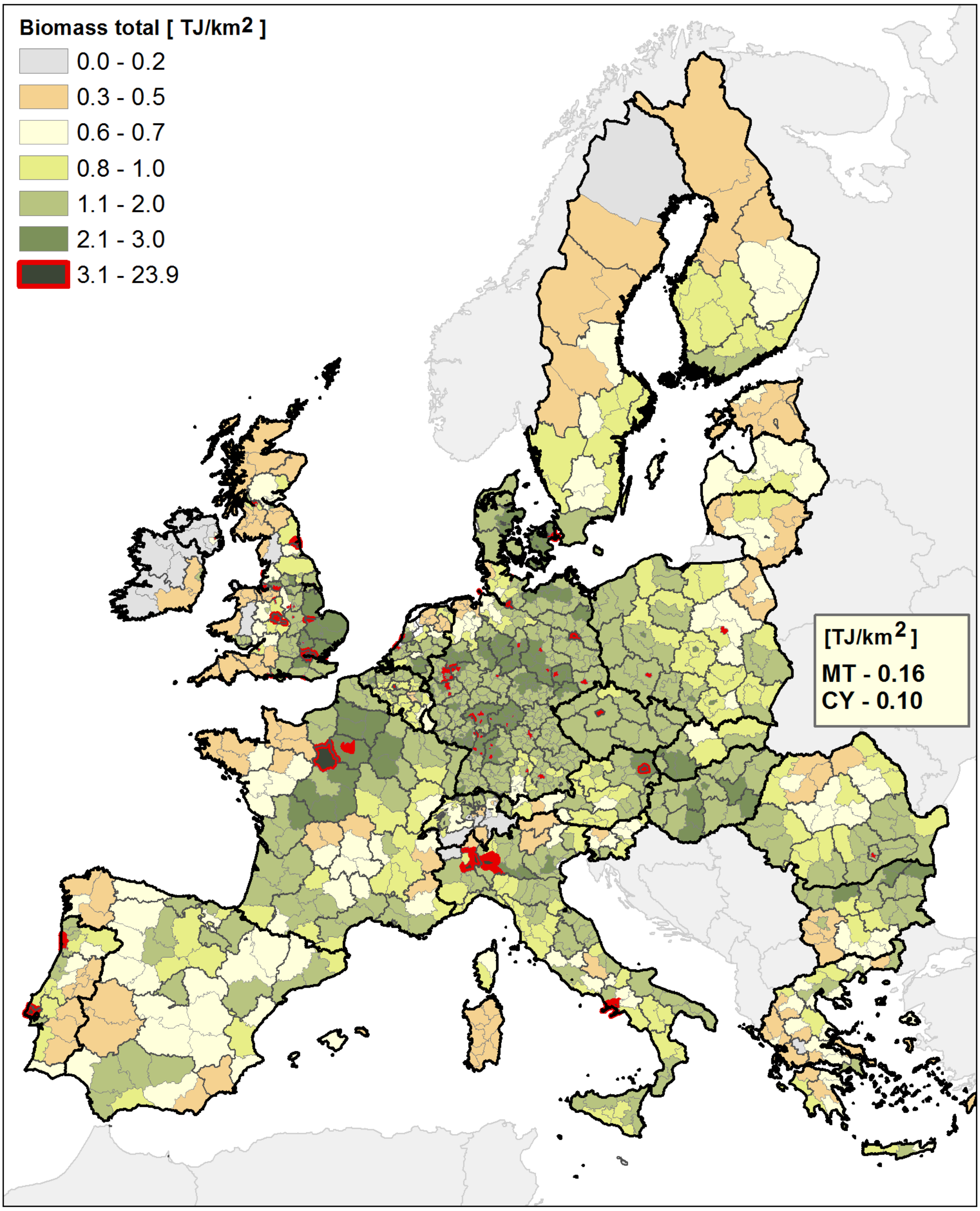

Figure 68. Summarised energy potentials (density) in NUTS-3

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A. List of abbreviations

BEE – Biomass Energy Europe

BETHY/DLR - Biosphere Energy Transfer Model

BIOBIB - A Database for biofuels

BIOBOOST –Biomass based energy intermediates boosting biofuel production

Biomass Future - Biomass role in achieving the Climate Change & Renewables EU policy targets. Demand and Supply dynamics under the perspective of stakeholders

CLC –Corine Land Cover

DEM –Digital Elevation Model

EEA – European Environmental Agency

ESRI – Environmental Systems Research Institute, Inc., in Redlands, California

EUROSTAT – Statistical Office of the European Communities,

GIS – Geographical Information System

JRC –Joint Research Centre

NPP - Net Primary Productivity

NUTS- Nomenclature of territorial units for statistics,

OECD - Organisation for Economic Co-operation and Development

RENEW- Renewable fuels for advanced powertrains

TBFR- Temperate and Boreal Forest Resource Assessment

LHV – Lower heating value

B. Units

J = joule

t = tonne

ha = hectare

$dam^3 = 1000\ m^3$

$cum = 1000\ m^3$

toe = tonnes of oil equivalent (40.61 GJ)

C. Calorific value of biomass

Biomass	LHV dry* [GJ*t-1]	LHV ar** [GJ*t-1]	Moisture (%)	Source
Composted cattle manure	11.2 – 14.1	0.3-0.9	80	ECN Phillis
Composted pig manure	13.4	1.2	77	ECN Phillis
Straw	18.1 (daf)[1]	13.1	15	ECN Phillis. RENEW (2008)
Hay	16.2	13.4	15	ECN Phillis
Pruning residues	18.5	9.9	40	ECN Phillis. Voivonas et al., 2001
Forest residues	20.0	10.0	50	BEE (2010)
Green urban areas	17.6	14.8	15	ECN Phillis
Road side vegetation	17.6	14.8	15	ECN Phillis
Biodegradable municipal waste	15.9	6.7	50	ECN Phyllis 2. BIOBIB
Bio-waste of wood industry	20.0	7.2	57	ECN Phyllis 2. RENEW (2008)
Bio-waste of food industry /processing olives	20.6	5.6	65	ECN Phyllis 2. Mohro i Timm. 2007
Bio-waste of food industry /processing grapes/	20.5	2.2	80	ECN Phyllis 2. Mohro and Timm. 2007

* LHV dry - energy value for dry matter
** LHV ar -energy value for a specific humidity.
[1] daf –dry matter. excluding the fraction of ash

D. Prefixes for units in the SI system

10^{18} exa E
10^{15} peta P
10^{12} tera T
10^{9} giga G
10^{6} mega M
10^{3} kilo k

E. Country code identification

EU-27: AT, BE, BG, CY, CZ, DE, DK, EE, EL (GR), ES, FI, FR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK, UK,
EU-25: AT, BE, CY, CZ, DE, DK, EE, EL (GR), ES, FI, FR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, SE, SI, SK, UK,
EU-15: AT, BE, DE, DK, EL(GR), ES, FI, FR, IE, IT, LU, NL, PT, SE, UK,

AT	Austria	**ES**	Spain	**NL**	Netherlands
BE	Belgium	**FI**	Finland	**NO**	Norway
BG	Bulgaria	**FR**	France	**PL**	Poland
CH	Switzerland	**HU**	Hungary	**PT**	Portugal
CY	Cyprus	**IE**	Ireland	**RO**	Romania
CZ	Czech Republic	**IT**	Italy	**SE**	Sweden
DE	Germany	**LT**	Lithuania	**SI**	Slovenia
DK	Denmark	**LU**	Luxemburg	**SK**	Slovakia
EE	Estonia	**LV**	Latvia	**TR**	Turkey
EL	Greece	**MT**	Malta	**UK**	Great Britain

Review report