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IMPLEMENTATION OF GIS TECHNOLOGIES FOR PLANNING THE VALORISATION OF AGRICULTURAL WASTE: THE TANGO-*CIRCULAR* PROJECT

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Abstract. *The volume of waste produced by agricultural activities is constantly rising, due to the continuous increase of crop and livestock production, aimed to cover the nutritional needs of the accreting population of the Planet. According to recent estimations, the total amount of waste produced in the whole EU by the agricultural sector during the period 2010-2016, has been around 18.4 billion tons, which represents an average of 2.6 billion tons/year. This number is slightly exceeding the amount of waste from all other sectors combined. This enormous mass of waste has a significant environmental impact, which needs suitable solutions to reduce the carbon footprint of agriculture, while increasing the economic income for farmers.*

A promising way to reduce agricultural waste, passes through the valorization of agricultural co-products, by-products and residues, as well as other non-organic materials - such as plastics, widely used in crop cultivation and animal production - after the end of their working life. In order to involve farmers to play an active role on this issue, contributing to transform what they currently consider as a "waste" into a new "resource", under the perspective of a circular economy and for a more sustainable agriculture, the Project TANGO-Circular has been financed by the EU Erasmus+ Programme. Aim of this Project is to train farmers and other agricultural

stakeholders to be involved in finding viable solutions to exploit unusable remains of crops or animal farms, so as to enhance their financial input, while simultaneously contribute to reducing the environmental impact of their agro-livestock activities.
With the aim to plan the valorization of agricultural waste, under the TANGO-Circular Project, a Geographical Information System (GIS) has been implemented through an open-access software (Q-GIS). This GIS has been structured into a first part dedicated to the quantification of agricultural waste flows – both organic, coming from agro-industrial activities, and not-organic, such as plastics - and a second part, focused on the spatial distribution of these flows in the study area of the project partners. Through GIS, the areas with high density of agricultural waste have been pointed out, and the suitable location of potential collection centres has been proposed. The maps that have been produced, as well as the GIS database, are always updatable tools, useful also for monitoring and optimizing the sorting and collection of agricultural waste from the farms, their suitable treatments and transport to the collection centers or recycling stations.
The implemented GIS methodology has revealed very useful to support farmers and their associations, as well as all public bodies interested to govern the agricultural waste flows, to individuate possible solutions designed for the valorization of these flows, in the perspective of a circular economy. The sustainability and economic, territorial, environmental and social convenience of each form of valorization designed have been investigated, and criticalities associated with each phase of the process and consequent implementation of appropriate solutions to each problem have been addressed. Finally, further possible solutions, aimed at an increasingly better valorization of these flows, have been proposed as well.

Key words: *Sustainable agriculture, Circular economy, Agricultural waste, Farmers training, GIS technologies.*

1. INTRODUCTION

Renewable energy is a priority in the European society, due to reasons of energy security and climate mitigation. Member states are adapting to the EU Directive 2009/28/EC (Renewable Energy Directive) on the promotion of the use of energy from renewable sources, which defines, within the year 2020, the use of 20% of renewable energy. Renewable energy sources are, however, characterized by a high temporal and spatial variability, so they need to be carefully planned in order to safeguard a suitable supply in the energy system. Biomass plays, among different sources of renewable energy, a central role, since it can store energy feedstock for the required use, compared to other renewable energy sources. Considering different types of biomass residues and by-products, there are several processes that allow transforming biomass into high-energy fuels that are easily transportable. In recent years, the attention has been focused on biomass coming from agricultural co-products, by-products and wastes. Even if this kind of biomass has a limited energy potential, in the framework of a circular economy, its valorization can contribute to an energy-efficient conservation, to the economic and environmental sustainability of agricultural practices and to enhance the preservation of natural resources as well [1, 2]. Mostly in the case of Mediterranean countries, biomass production for energy currently looks primarily to its collection and disposal. Especially the incorporation in the energy system of by-products, co-products and waste from agriculture, forestry and agro-industry, should be carefully evaluated at regional level, so as to avoid unsustainable removal of organic matter from the soil and negative effects on natural ecosystems. Waste biomasses are often diffuse sources of energy, spread over large geographic areas, so they need to be collected and transported to a closer conversion plant. Biomass mapping, as a tool for measuring the amount of waste and by-products, helps to conceive the development of an economically sustainable reuse and recycling supply chain.

Geographical Information System (GIS) technologies are currently employed to optimize the flux of materials and goods. In case of waste management and final disposal localization, they have been proposed in different applications. GIS models have been even proposed to determine the minimum cost/distance efficient collection paths for transporting solid wastes to the final disposal option [3]. The applied models can be used as a decision support tool by municipal authorities, to organize an efficient management of the daily operations for transporting solid wastes and by-products.

The present paper is aimed at mapping agro-industrial waste, biomass and agricultural plastics, aspiring to offer a reference database for policy makers and investors, who need to evaluate a possible use of local biomass for bioenergy purposes, or to be processed in biorefineries. In this way, virtuous supply chains would ultimately start, in the full spirit of implementing the concept of circular economy, with integration between waste management and industrial policies. The relevant results here presented have been obtained in the framework of the Project "*Training A New Generation Of farmers and agricultural entrepreneurs to implement the concept of Circular economy in agriculture* – TANGO-*Circular*", financed by the Erasmus+ Programme [4], A part of this Project is indeed focused on the planning the valorization of agricultural waste through the implementation of GIS technologies. A specifically targeted research has been carried out, in order to define a GIS methodology for mapping the agricultural wastes, since they require, at the end of their lifetime, a suitable management system for the collection, treatment and valorization. The produced maps and the GIS database will be always updatable tools, useful for monitoring and optimizing the collection of agricultural waste from the farms and their transport to collection centers/ recycling stations.

2. MATERIALS AND METHODS

The annual local availability of waste of agro-industrial origin have been estimated in all Countries participating into the TANGO-*Circular* Project, *i.e.*: France, Greece, Italy, Portugal and Spain. According to an appropriate planning hierarchy, agricultural and agro-food co-products, by-products and wastes should be primarily employed to re-balance soil fertility, then valorized as new secondary raw materials used in the same agricultural sector or in different industrial chains (*e.g.*, cosmetics, nutraceuticals, *etc*.). Only at the end of this process, they could be finally conveyed to energy production through co-generation. Estimating the quantities that can be obtained annually is not simple and often subject to great uncertainty. The methodology that has been here applied refers to survey criteria already extensively and suitably expanded and updated by different authors. Among the many variables that affect the actual annual amount of agricultural residual biomass available, there are climatic factors, agricultural crop productivity, the amount of residues actually produced, the amount that can actually be used and the amount already used for other purposes.

The applied methodology estimates the theoretical potential, which represents the maximum amount of biomass potentially available in an area. From the exploitation of agro-food products, the following different types of biomass may be derived:

- Residual biomass from forestry waste;
- Traditional food crops, cereal straw (*e.g.*: wheat, rice, barley, oats) and pruning of fruit tree (*e.g.*: grapes, olives, apple, peach);
- Livestock (*e.g.*: cattle, pigs, sheep and goats) manure;
- Remaining processes of transformation from the agro-food industries (*e.g.*: olive mills, wineries, cheese factories, wheat mills);
- Organic fraction of urban waste

as well as not-organic materials, like:

- Agricultural plastic waste.

At the level of spatial definition, the data used to calculate the quantities of by-products have been estimated at NUTS3 level.

The data obtained were thus collected and collated into a database referred to geographical space (geo-database). This particular database has been then appropriately processed and manipulated with specialized a GIS (Geographic Information System) software. The result of this processing made it possible to graphically assess the geographic distribution of agricultural residual biomass and develop thematic maps.

The analyses performed allowed the calculation of the potential availability of the different types of biomass of interest.

2.1 Forest residues

Biomass residues from forestry are currently restricted to tree parts, which are traditionally or, due to technical and environmental restrictions, not completely harvested (crown material such as twigs and branches, stumps and roots). Moreover, a variable amount of branch material is also produced. For ease of calculation, average values were considered for estimating the amount of residual forest biomass resulting from plant management operations of "European Forest Type". The estimation of the potential biomass arising from managing operations of forested areas has been estimated (in m^3 ha^{-1} $year^{-1}$) based on data and information arising from the Land Use Categories (Code 3: Forest and Seminatural Area – 3.1 Forest) or considering the forest area (expressed in ha). The estimation of the potential biomass arising from managing operations of forested areas has been estimated based on data (expressed in hectares) of forest areas in different countries reported in National Statistic Institutes. Where these data were not present, they were obtained from spatial analysis conducted in GIS, to extrapolate the necessary data. Regarding the level of detail, in some Countries it was not possible to consider NUTS3, so data elaboration was conducted at NUTS2 level. Then, the land surfaces were multiplied by the annual increase in biomass (0.5 cubic meter) that is an average value [5]. Finally, the results were expressed in tons of forest residues.

2.2 Cereal straw and pruning of tree

Many agricultural crops that are currently cultivated produce an important source of biomass as by-product, the *straw*. After harvesting the crop, a large quantity of straw, estimated to have a larger volume than the crop itself, is available in the form of waste. Considering the amount of the total cereal residues harvested has to be left on the field as organic fertilizer and the losses of straw during the harvesting process, the gross calculated quantity of by-products can be roughly reduced by up to 50% [5, 6].

To understand the spatial variability of different crops, the data derived from the agricultural census in each country or data arising from Corine Land Cover (Code 2: *Agricultural Area* – 2.1 *Arable land*) have been used to calculate the spatial availability of straw in the different Countries.

Table 1: Overview of residue yield estimation for all crops

CROP	RESIDUE YIELD (t/ha)
Wheat	3.627
Barley	4.216
Rye	5.625
Oats	3.76
Maize	7.84
Other cereals	3.6

From pruning operation in Mediterranean fruit plantations, it is possible to obtain large quantities of ligneous biomass. Currently, these residues are destroyed by crushing them into the soil or by in-field burning (a practice forbidden by law in many countries). But, such residues, also having other potential industrial uses, can be used as a source of energy, if they are properly collected and valorized for energy purposes. To be used as energy source, they need a transformation by physical or chemical processes into liquid, solid or gaseous biofuels [7-9]. However, at the moment, there are some technical problems during harvesting, that do not allow using such residues as biomass for energy purposes. In case of tree crops, an average of 2.20 t/ha of dry biomass has been estimated, while a specific analysis has been conducted for olive grove (2.16 t/ha) and vineyards (2.15 t/ha), which are the most diffused tree production in the study area (Mediterranean Europe). Also in this case, the data derived from the agricultural census in each country or data arising from Corine Land Cover (Code 2: *Agricultural Area* – 2.2 *Permanent crops* – 2.2.1 *Vineyards*; 2.2.2 *Fruits tree and berry plantations*; 2.2.3 *Olive groves*) have been used to calculate the spatial availability of straw in different Country

2.3 Livestock manure

Using manure for energy production after an anaerobic digestion process, it is possible to avoid negative environmental effects. Converting manure to energy at the farm scale (or small cooperatives) allows to avoid transport of high-moisture content feedstock. In the different study area, considering the currently existing livestock units and the total amount of livestock manure, and assuming as the typical manure production rate per animal per year (Table 2) the values reported in [10], the total manure production has been estimated into tons of dry matter per year.

Table 2: Estimates of dry matter from manure

LIVESTOCK (UNITS)	MANURE PRODUCTION RATE (t d.m./head)	RECOVERABLE (%)
Cattle	1.69	25
Pigs	0.21	85
Sheep & Goats	0.28	10
Poultry	0.01	85

2.4 Remaining processes of transformation from the agro-food industries (*e.g.*, olive mills, wineries, cheese factories, wheat mills)

Concerning the agro-food industry, significant quantities of biomass residues would contribute to the calculation of the energy potential or can be reused in other sectors, mainly as exhausted pomace arising from the olive oil industry and exhausted marc from the alcoholic grapevine/wine industry. The main by-products of the olive oil mill consist in vegetation water and pomace. Exhausted olive pomace is the waste generated from the drying and subsequent extraction of residual oil from the olive pomace. The reuse of vinification residues could anyway find a second life in different areas, *e.g.*: as a substrate for the growth of plants (pomace); these materials, after having contributed to the restoration of the level of organic matter in the soil, could be effectively exploited in different ways, *e.g.*, as added-value components in other industrial sectors (nutraceutical, cosmetic, *etc.*), or in the building sector - as a natural additive - that could be incorporated into clay bricks to increase their mechanical and thermal performance [11].

Assuming an average quantity of by-product (40%), the annual amount of virgin pomace has been calculated, 55% of this quantity being of exhausted pomace, which is reusable. Similarly, the amount of exhausted marc to be reused has been determined considering the annual production of grapes, and the percentage of the total amount of exhausted marc considered in this case is 4.6% of the production of wine grapes.

2.5 Organic fraction of urban waste.

The organic fraction of municipal solid waste (OFMSW), or bio-waste, is composed mainly of food rejects (animal or green waste), depending on the region and custom considered. Considering the population in the different study area and the amount of organic waste per inhabitant equal to 121 kg/year [12], the total amount of municipal organic waste has been calculated at spatial level. Data were expressed in tons.

2.6 Agricultural plastic waste

The use of plastics is an integral part of many agricultural production processes. The applications of plastic material are extremely extensive and beneficial to agricultural production, which is why their use is constantly expanding. For agricultural plastic waste, there is still no integrated management system, and only a fraction of agricultural plastic waste is recycled throughout Europe. There is therefore a lot of agricultural plastic waste ending up in landfills, uncontrolled or not, and scattered in the fields, or incinerated in an uncontrolled way. It is therefore necessary to establish an Integrated Management System, in which the managed quantities of Agricultural Plastic Waste (APW) will be monitored and certified [13]. For each study area, data about the quantities of agricultural plastic waste have been considered for the estimation of quantities at spatial level or, starting from data about the greenhouse cultivation or intensive crop, the quantities of plastic waste have been estimated [14-15].

In Italy data were calculated considering coefficient and crop surface [13]; in the other countries, where data on the amount of plastic used in agriculture was not reported, the value was estimated from data reported in Portugal (Table 3), assuming similar growing conditions in the Mediterranean basin. All data were expressed in tons.

Table 3: Use of plastic material in crop production

Crop	Plastic used (Kg/ha)***
Crops for industry	14,86
Horticutural crops	20,04
Tomato	7,67
Forage	111,16
Pomegranate	0,91
Blueberries	0,02
Citrus Fruit	3,59
Almond	297,12
Nut	7,07
Vineyard	18,30
Grape	773,58
Olive grove*	1272,36

All spatial tasks have been performed using an open-source software (Q-GIS v.3.10), able to calculate the spatial distribution of the agricultural by-products considered. Through the use of GIS data in the form of vector, the information has been integrated to calculate values for the whole spatial area with a geographic reference.

3. RESULTS

The use of GIS for data analysis and processing has the great advantage for visualizing the result in a quick and timely manner, considering the peculiar feature of the GIS systems, that is, the geo-referencing of data. Therefore, by visualizing the maps produced (Fig. 1-6), for different countries and for different types of by-products, it is so possible to have a clear picture of the availability of waste produced in the each study area, presented at NUTS3 level. Only when this level of detail was not available, they have been reported at the regional level (NUTS 2).

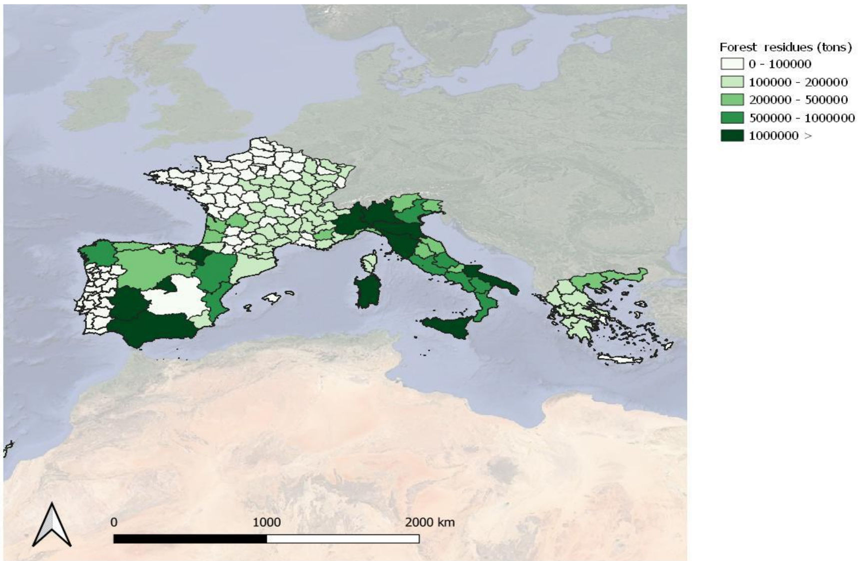

Figure 1: estimation of forest residues in Project Countries

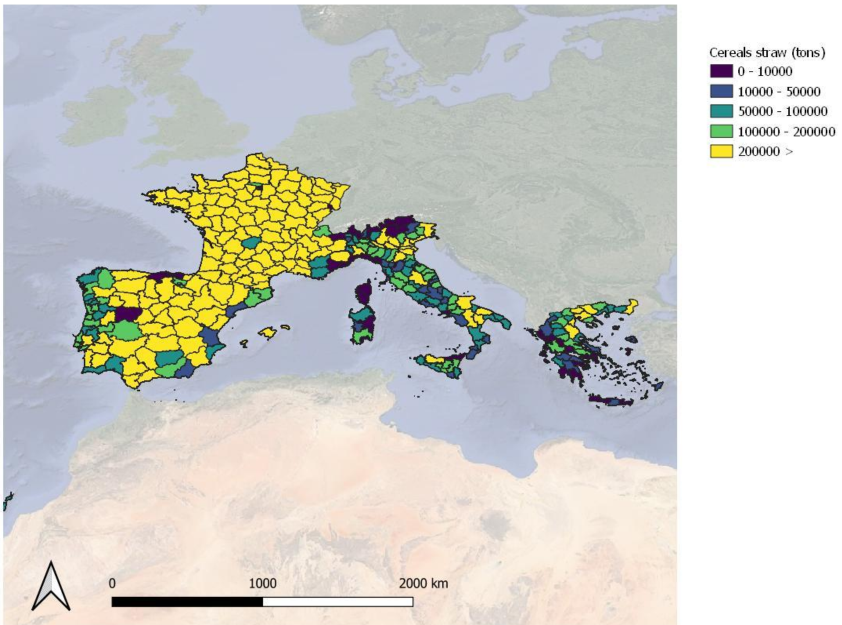

Figure 2: estimation of cereal straw in Project Countries

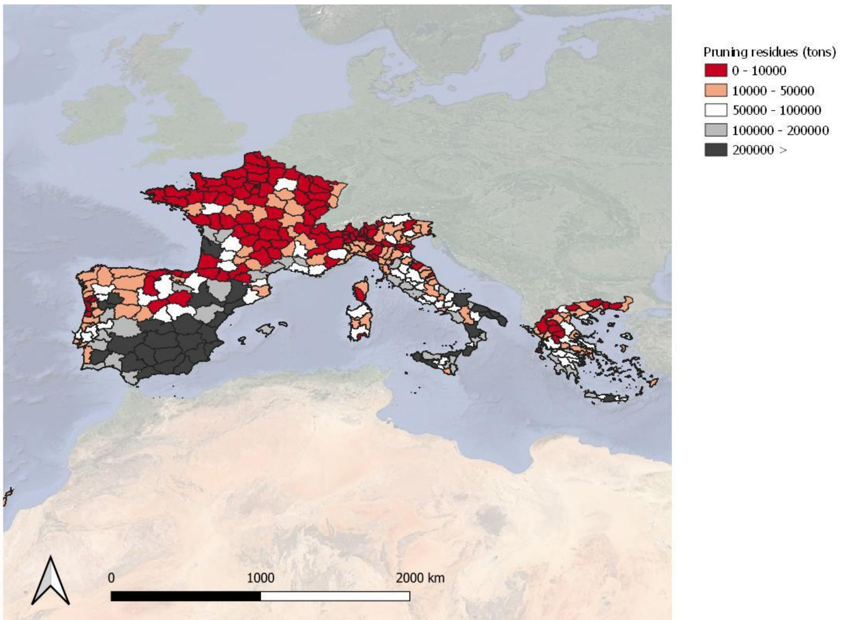

Figure 3: estimation of pruning residues in Project Countries

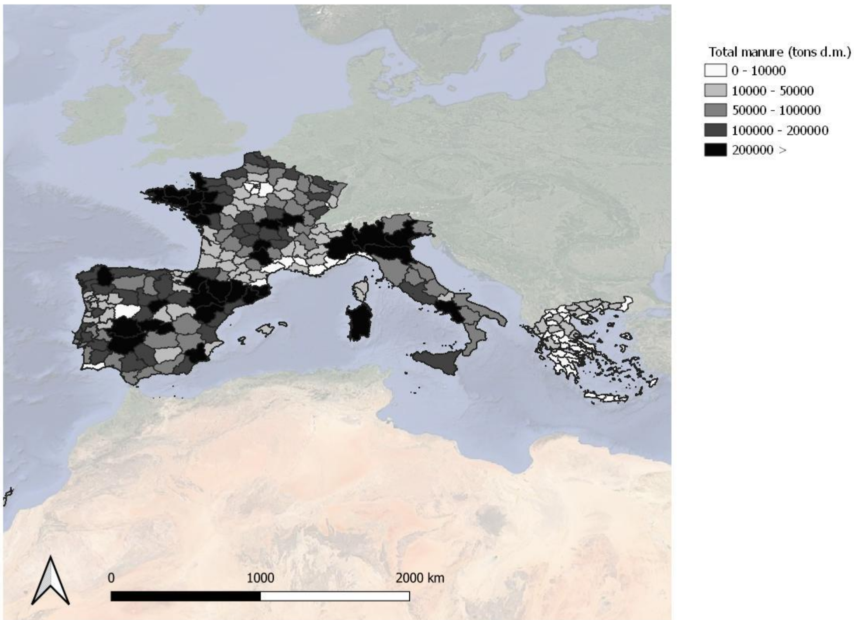

Figure 4: estimation of total manure in Project Countries

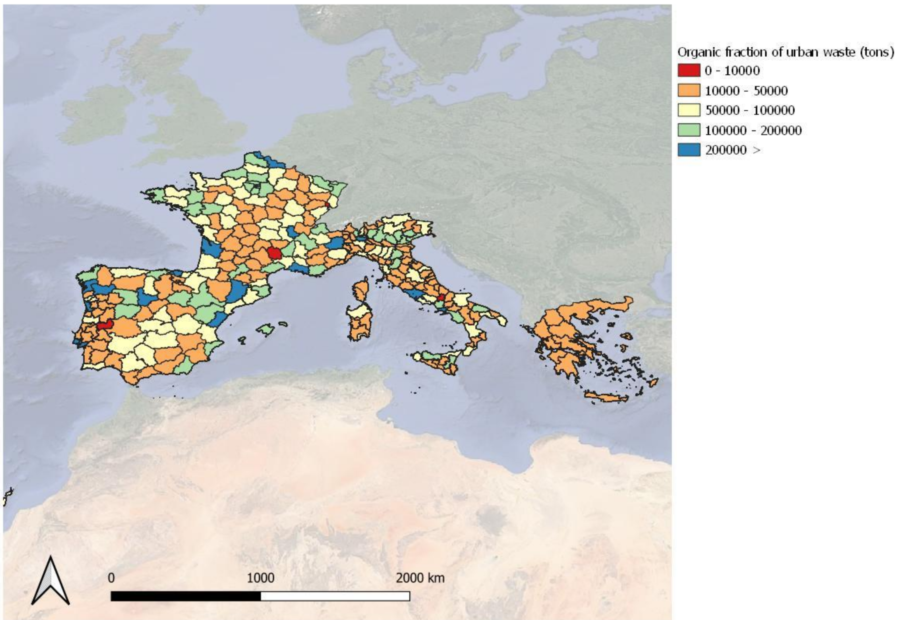

Figure 5: estimation of the organic fraction of urban waste in Project Countries

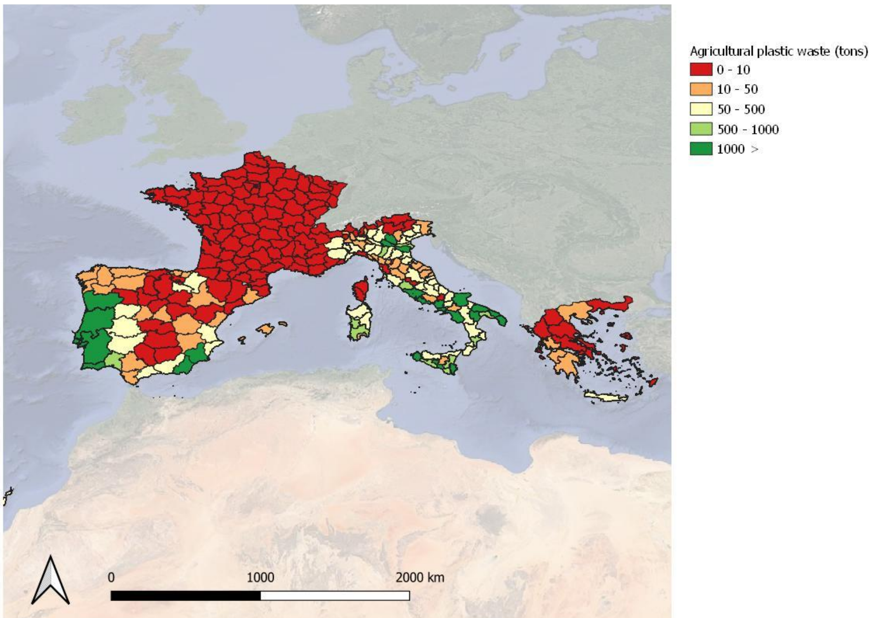

Figure 6: estimation of agricultural plastic waste in Project Countries

4. DISCUSSION AND CONCLUSIONS

From the GIS implemented at a European scale to analyze the agricultural waste production as well as collection and disposal of agricultural by-products in the Countries participating into the Project, it is possible to examine the data introduced in the database, relating to the area in consideration, by querying the system.

The proposed GIS methodology may be improved including an analysis of the road network, in order to optimize the localization of the recycling centres, the optimal distances from them to the principal areas subject to intensive use of agricultural waste and the useful time and the average speed to cover these distances. Also, data regarding the distribution along different seasons of the year could be introduced in this GIS, in order to best fit the material flow towards the recycling centres.

So, this implemented GIS tool enables to localize the main agricultural areas characterized by intensive production with biomass/plastic material; to analyse the specific type of biomass/plastic material in each zone; to study the stream of agricultural waste from the farms to collection areas, in order to optimize the flow of material in the framework of a Circular Economy approach. To achieve this objective, the collaboration of various players is fundamental: from legislators to producers, from environmental protection agencies to the infrastructures for the management of materials, from the personnel responsible for collection and disposal to the citizen and, mostly, from farmers, whose pro-active involvement in sorting, collecting and managing agricultural waste is crucial to reduce the environmental footprint of agriculture, so contributing to implement an eco-sustainable living model.

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