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Using GIS Technologies for designing agro-energy districts

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Abstract

The current energy guidelines requested by the European Community encourage the use of renewable resources as an alternative to traditional fossil fuels. By supporting sustainable development, energy needs can be met through the transformation of agro-forestry biomass into biofuels. Therefore, the requirement to establish sustainable production and consumption chains at local level emerges. Accurate planning becomes crucial to ensure the establishment of agro-energy districts. Such process requires a careful analysis of potential energy resources that can be obtained in each territorial area. It should be remembered that the primary sector in Europe (and more specifically in Italy) has suffered a severe decline in recent decades, e.g. loss of employment and increase of abandoned rural areas. By re-establishing rural landscape and promoting multifunctional agriculture, agro-energy districts arise as competitive and sustainable realities for agricultural contexts.

The purpose of the present work is to highlight how GIS technologies are useful tools for identifying which rural areas, based on for example typical crops or contextual particularities, may become efficient agro-energy districts. Furthermore, by using GIS technologies the results highlighted a quantitative evaluation of biomass based on the agro-energy supply and demand of potential districts. Guaranteeing the correct knowledge and use of these tools, it is essential that economic, political and local actors are regarded as essential interacting components in innovative and efficient systems. In this sense, the present work also reflects on the educational impact of using GIS technologies as political decision-makers and planners must be able of enhancing local contexts with these tools with the aim of offering suitable opportunities and strategies for the sustainable development of agro-energy districts.

Keywords: Agro-Energy Districts, GIS, Rural Contexts, Spatial Planning, Sustainable Development

1. Introduction

The European Community has extensively encouraged the inclusion of significant shares of energy produced from renewable sources in national and regional energy balances (Pozzo, 2009). The current energy guidelines required encourage the use of renewable resources more than traditional fossil fuels (Best, 2003; Colantoni et al., 2016). By supporting sustainable development, energy needs can be met by transforming agroforestry biomass into biofuel. From the standpoint of eco-systemic and energy sustainability, the calculation of how much biomass a territory can offer is relevant for elaborating future strategies and possibilities (Masera et al., 2006; Emer et al., 2011; Colantoni et al., 2016; Zambon et al., 2015, 2017a).

In Italy, the awareness of the role of bioenergy was reached only at the end of the 1990s, after the Rio Conference on Climate Change in 1990 and the Kyoto Protocol in 1997. In the "National Renewable Energy Program for Biomass" (1998), the integrated approach to energy issues took on importance to (i) preserve the environment; (ii) improve the efficiency of energy sources; (iii) avoid waste; (iv) reduce the use of fossil fuels; and (v) rationalize the use of resources through the agreement between Public Administration and stakeholders in carrying out sectoral and territorial actions. Through the implementation tool "National Program for the Valorization of Agricultural and Forestry Biomasses" (1999), the actions focused on the sustainable development of agro-energy supply chains and the involvement of local administrations and agricultural and industrial entrepreneurs in pilot projects at regional or interregional scale. However, the process of transferring energy powers to the regions did not develop a National Plan that sets out guidelines, rules and objectives, resulting in several conflicts of competence, technical-administrative and financial barriers.

The work was carried out based on this background with the aim of defining and planning agro-energy districts. The main objective was to identify suitable areas for designing an agro-energy district and to count the existing biomass quantity. The estimation of the latent installed power derived from biomass (e.g. agricultural waste, forest wood and energy crops) made it possible to reflect on the degree of sustainability at local scale (Masera et al., 2006; Emer et al., 2011; Colantoni et al., 2016; Zambon et al., 2017a). The goal is to identify the contexts in which to set up an agro-energy district, or "networks of producers and transformers, also differentiated by type of energy produced, able to ensure energy quotas for a territory, through a system of distributed generation and such as to maximize the multifunctionality of agricultural enterprises in their various aspects" (Gaviglio et al., 2009, p. 171).

The study area is the Italian context. Corresponding to other European countries, the Italian rural landscape, typical for its peculiar crops and agricultural practices, has undergone intense changes in recent decades in the use of land for urban or speculative uses, leading to a loss of rural employment and, at times, to a consequent reforestation due to the abandonment of agricultural land (Bonet, 2004; Godone, 2014; Sitzia, 2010; Sluiter and de Jong, 2007; Leal Filho et al., 2017). With the aim of consolidating realities definable as "agro-energy districts", the present work is aimed at using GIS technologies to (i) identify the current state of a given area that presents the basic characteristics to undertake a circular economy (Zambon et al., 2017a). These areas may consist of different local realities, e.g. few municipalities which have a common cultivation within them. Consequently, during the analysis, it is necessary to verify whether the characteristics of the agricultural and productive system can be defined as a local or regional vocation (Gaviglio et al., 2009). From the production phase to the collection of crop products, very often the agricultural waste produced cannot be sustainably used. For this reason, their re-use for energy purposes corresponds to energy production at local and/or district level based on a kind of circular economy (Monarca et al., 2011; Delfanti et al., 2016).

The current decline of the Italian agricultural sector caused the abandonment of several agricultural areas (Bonet, 2004; Godone, 2014; Sitzia, 2010; Sluiter and de Jong, 2007). Understanding and studying this phenomenon is essential before promoting a new local economy. GIS technologies therefore shed light on territorial difficulties and limitations. For instance, the problematic achievement of a certain economic activity may be linked to the complex locations, which compromise the safety of the operators working there. This aspect is often neglected and rarely integrated into the themes of agro-energy districts and circular economy (Zambon et al., 2017a). At this point, GIS technologies highlighted the contexts that can be included and become an agro-energy district, providing useful strategies and tools for planning and managing biomass at numerous territorial scales.

2. Methodology

In order to plan an agro-energy district, the existing crops that can be used as energy biomass first need to be identified (Colantoni et al., 2016). However, such quantification refers to a rough approximation (Masera et al., 2006; Emer et al., 2011). Avoiding many estimates, GIS technologies can be applied to measure how much biomass a territory can produce and offer (Emer et al., 2011; Sacchelli et al., 2013; Zambon et al., 2017a). However, the available databases show limitations. For instance, the Corine Land Cover is used for specific crops e.g. olive or vine, but not for orchards which include different rural crops. Furthermore, vegetation maps are also vital since they classify the biodiversity of flora in a given spatial context. Precision farming has recently made its contribution. However, the distribution of woody biomass is difficult to detect by distinguishing each type of crop (Franco, 1997). Considering this limit, the study area focused on 10 municipalities in the region of Sicily (Italy), since they are part of the national association of hazelnuts, which are a characteristic crop in Sicily because they are well adapted to the Nebrodi Mountains (Gianguzzi and Papini, 2016). Nevertheless, they are situated in remote areas with variable density, on steep slopes and on uneven terrain, hard to reach safely. In fact, many hazelnut orchards appear as forests. However, hazelnuts are one of the most cultivated crops in the Mediterranean context because they have a significant nutritional and economic value (FAO, 2010; Aydinoglu, 2010). Given their profitability, hazelnuts are usually grown on inadequate land without appropriate land use policies (Godone et al., 2014; Reis and Yomralioglu, 2006). For instance, Turkey imposed specific rules on hazelnut cultivation in certain areas (e.g. maximum altitude of 750 m) (www.turkstat.gov.tr). According to these government regulations, potential areas can be mapped with specific criteria using GIS technology (Sarıoğlu et al., 2013). Consequently, their identification can be useful for examining landscape changes, providing greater support to national and international institutions in the assessment of rural agriculture policies and their socio-economic and landscape consequences (Martinez-Casasnovas et al., 2010; Van Berkel and Verburg, 2011; Westhoek et al., 2006; Manos et al., 2014).

The identification of hazelnuts was run through an advanced computer program, GIS technology (Geographical Information Systems), offering advantages in terms of data management and acquisition, analysis of maps and satellite images (Aydinoglu, 2010; Official Gazette, 2009). The GIS program is a suitable tool for the processing, analyzing and collecting of spatial information (Reis and Yomralioglu, 2006; Lioubimtseva and Defourny, 1999; Longley, 2001), revealing data for example on altitude, appearance, slope, soil proprieties, environmental circumstances and topographical variations (Aydinoglu, 2010; Sarıoğlu et al, 2013; Bolca et al., 2011). Therefore, GIS can fully monitor land-use changes, forest cover, soil degradation and other ecological issues (Mundia and Aniya, 2005; Yuan et al., 2005; Zambon et al., 2017b). GIS techniques were used to overlay different maps such as vegetation maps of Sicily; Corine Land Cover (CLC) and other geo-spatial statistics, e.g. Digital Terrain Model (DMT) and road networks. GIS tools and elaborations were used to recognize where hazelnuts are located and where mechanization processes are used, focusing on some morphological and spatial characteristics of the study case assumed. In addition to the Sicilian context, the entire province of Viterbo was also observed, which is also recognized for its strong vocation to growing hazelnuts (Boubaker et al., 2015; Cecchini et al., 2013; Piacentini et al., 2015). Thanks to the climatic conditions, hazelnuts thrive in the Mediterranean basin, particularly like the one with the geographical and geological aspects of the study area of Sicily and Viterbo (Marzocchi et al., 1993; De Vecchis, 2007; Cecchini et al., 2013; Fea et al., 2015; Zambon et al., 2017a). The Viterbo area is much larger because the entire province has a territorial structure that is like the Sicilian intermunicipal context considered, in which hazelnuts grow in an ideal manner. In fact, the two contexts analyzed have a similar territorial structure (among the hilly and mountainous landscape) that define the ideal climate for the growing of hazelnuts.

3. Results

52% of the hazels present in Sicily are situated in the study area, which covers about 4970 hectares. Through GIS elaboration, the comparison between the two key maps (vegetation map of Sicily and CLC) highlighted the accuracy of the first map. In fact, 63% of the hazelnuts in the CLC are identified as “orchards” (code 222 in the CLC) and 22% of them as “deciduous forests” (in code ‘3’ for woodlands) (Figure 1a). However, many hazelnut orchards appear abandoned and concentrated as woodlands. The GIS analysis exposed some common features of hazelnut orchards (Figure 1b). Hazelnuts prefer high altitudes between 500 and 1000 meters above sea level. Furthermore, some maps were produced by means of specific GIS tools for the Digital Terrain Model, slope (classified in percentage terms), appearance and curvature. Unclear contexts (e.g. with higher degrees of slope or altitude) were evaluated in a parallel survey, even if the vegetation map of Sicily established hazel plants. The highest degree of correctness of the vegetation map of Sicily was confirmed. The results showed which areas have a steep slope (>30%) and high altitude (higher than 1000 meters). Such contexts should be avoided for mechanized harvesting as they present greater risks to workers when they collect the hazelnuts. With all the data processed, an integrated map was prepared pointing out three kinds of circumstances (Figure 1c): (i) optimal areas for hazelnut production and cultivation, with minimal risks for operators, minimum slopes, ideal altitudes and easy mobility for the machines that have to reach these areas; (ii) good and favorable places; and (iii) unsuitable contexts for hazelnut production and cultivation due to increased risks for operators, high altitude (>1000 m) and slopes (>30%), discontinuous oad system with steep slopes. Acceptable areas for a potential agro-energy district are located mainly in the northern part of the study context, covering a surface area of about 4600 hectares of hazelnut orchards (Figure 1d).

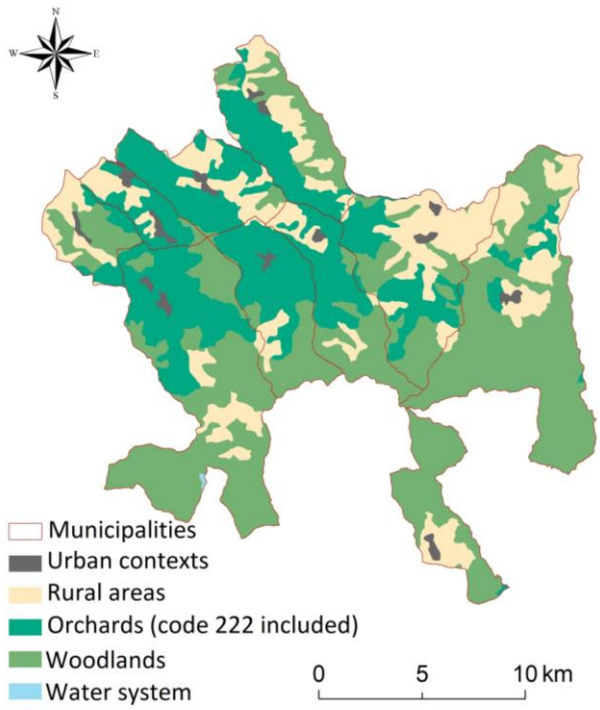
Integrating this data with those of INAIL on accidents at work from 2012 to 2017, the province of Messina, which is particularly suitable for hazelnut crops, showed a steep increase in accidents at work in September (ninth month) linked to agricultural practices to harvest hazelnuts (Figure 2).

Regarding the context of Viterbo (Figure 3), however, there is no vegetation map even if the Corine Land Cover realistically expresses where the hazelnut orchards are concentrated, but also olive trees and vineyards (two typical and well-established crops in the province of Viterbo).

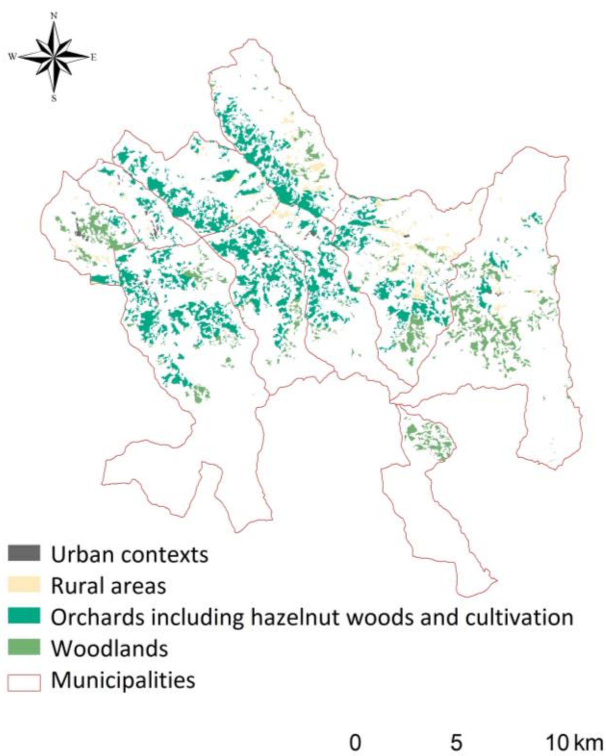
Thanks to the gentler slopes and a less complex territorial morphology than that of Sicily, the Viterbo background meets every prerequisite in terms of safety at work, confirming the fact that the entire territorial context can be included in an agro-energy district. Covering an area of 33720 hectares, its southern area (more compact and therefore ideal for logistical reasons to establish an agro-energy district), can guarantee about 62 tons of biomass.

These harvests are especially concentrated in the southern area of the province of Viterbo. Nevertheless, there is no real agro-energy district despite the numerous studies carried out.

(a) CLC for each land-use Class



(b) Hazels in the vegetation map of Sicily on CLC



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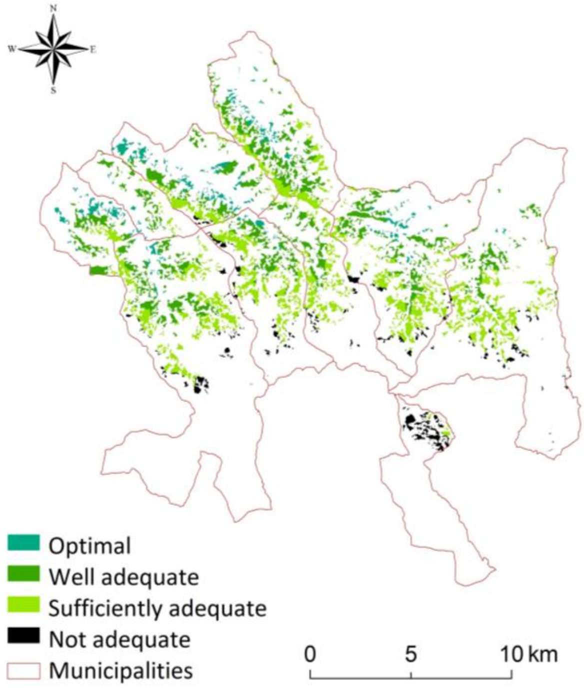
(c) Degree of suitability of contexts



(d) Potential areas for the agro-energy district

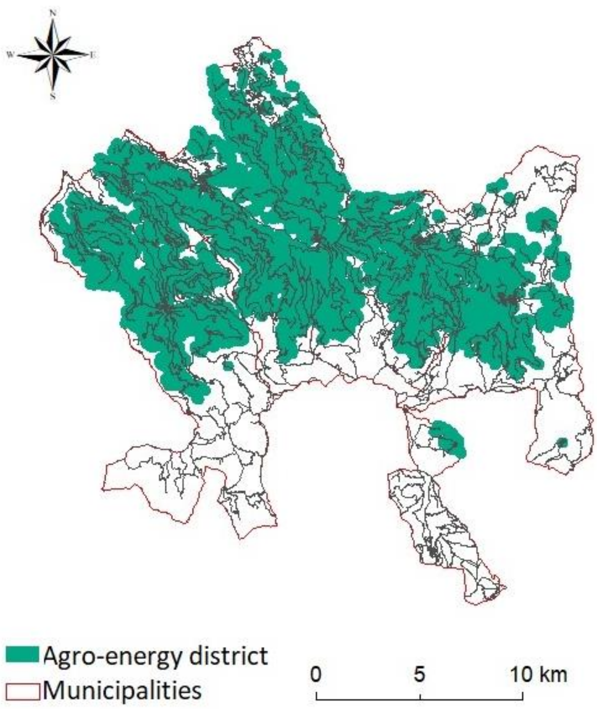


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Figure 1. Results from GIS elaborations for the Sicilian context of study. Source: Author’s elaboration.

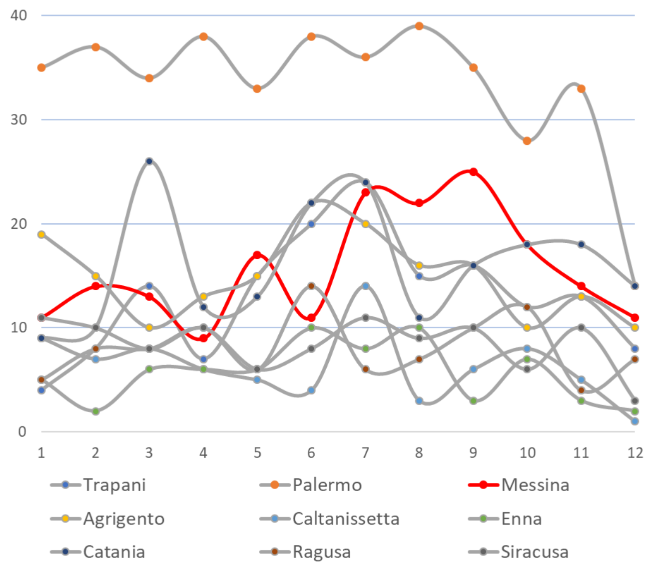
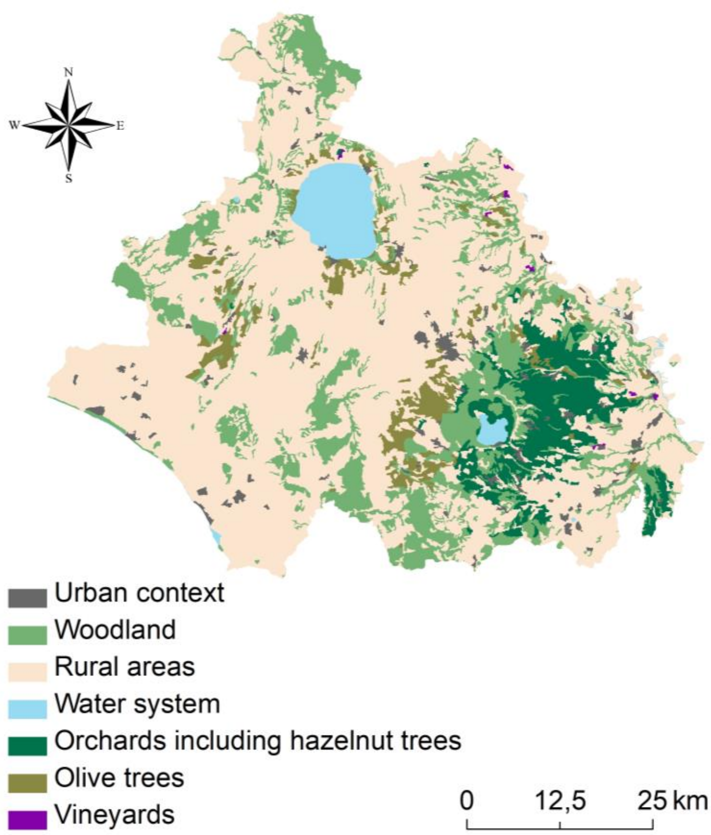


Figure 2. Work-related accidents for each province in Sicily region (abscissa: month, ordinates: number of accidents). Source: Author's elaboration on INAIL data (2002-2017).

(a) CLC for each land-use class



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(b) Potential areas for the agro-energy district

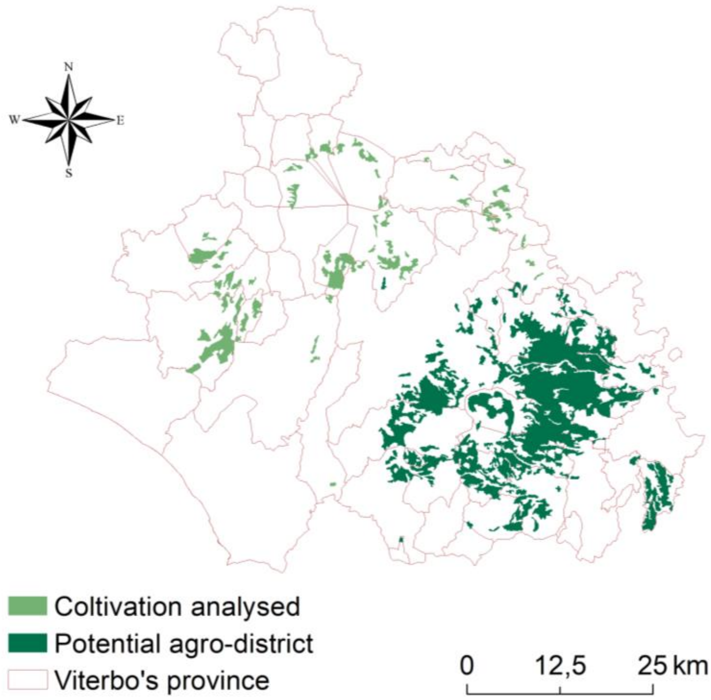

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Figure 3. Results from GIS elaborations for the province of Viterbo. Source: Author's elaboration.

4. Conclusions

The current energy commitment supported by the European Commission offers strategies and actions, e.g. reducing energy demand, using efficient technologies and raising awareness of policy makers towards sustainable practices. Among these issues, agroforestry biomass is definable as alternative proposals to ensure the supply and diversification of the energy mix, availability, sustainable development, economic competitiveness and the fight against climate change (Monarca et al., 2008; Colantoni et al., 2016).

The educational and didactic aspects that can be dealt with in this work are evident because through GIS technologies the analysis of a typical cultivation based on a territorial context can be carried out; moreover, the analysis can also allow a comparison between two areas (in Sicily and the Lazio regions) that are very similar because they have the same topological and geographical characteristics but also the presence of a specific cultivation that allows local farmers an increase in their income.

Thanks to GIS technologies, the present paper identified rural areas with high potential in economic and energy terms for sustainable development, an innovative reality based on circular economics and then agro-energy districts (Zambon et al., 2018). The role of GIS applications in the field of educational processes linked to territorial development are fundamental today in the Italian context, which, thanks to its biodiversity and latent local traditions, can be a driving force for economic, social and even sustainable development. Moreover, sustainable education does not rely exclusively on the concept of environmental respect, but also on the sustainability that such cultivation will remain over time. Indeed, the analysis suggested how to optimize agricultural mechanization systems limiting job-related risks for operators (Zambon et al., 2017). Currently, traditional and manual mechanical methods are still used in Sicily, making hazelnut harvesting expensive with high labor costs and long hours of work, while in the Viterbo area, mechanization is more advanced and geared to the safety of the operators. The importance of identifying suitable instruments in irregular soils and steep slopes (from 24 to 35%) is perceptible, such as with a self-propelled prototype that can be easily transported in areas with uneven or no roads and other difficult conditions (Monarca et al., 2016).

In a perspective of sustainable development based on the concepts of circular economy, the district in the Sicily project will ensure a biomass of 8.5 tons available over a surface area of 4600 hectares of hazelnuts; while, in the southern context, the province of Viterbo (thanks to the residues of hazelnuts, olive trees and vineyards) can guarantee more than 60 tons of biomass (Abenavoli et al., 2016). The use of biomass for energy purposes points to the need for more environmentally friendly and more energy-saving behavior (Colantoni et al., 2016). The development of efficient projects for the energy valorization of biomass tends to involve different actors (e.g. agricultural, industrial and service company producers) and to be characterized by a complex process (Manos et al., 2014). In fact, the organization of agro-energy districts often fails to well define consortia or business associations between the different actors useful for the supply, the first processing of biomass, the management of plants and the distribution of energy. Finally, a network of territorial relations must be set up with an appropriate division of tasks regarding the programming and coordination of financial support measures at local, regional and/or district level, improving the effectiveness of all the instruments that can be used for planning and developing the agro-energy supply chain. These interventions must be adequately supported by communication and technical assistance actions for all the stakeholders who are part of the agro-energy system. Ensuring the correct knowledge and use of GIS tools is indispensable for economic, political and local actors since they must be constantly updated and skilled in using GIS technologies for the management of their territory. The educational impact of using these tools is decisive, for example, in managing changes in land use and impacts on ecosystem systems. Moreover, the educational influence of GIS technologies can guarantee accurate opportunities and strategies for spatial planning, conscious management of resources (Privitera and Privitera, 2018; Pesaresi and Pavia, 2018; Presti, 2018), and sustainable development of agro-energy districts.

The territories analyzed have a high socio-economic potential, which makes it possible to encourage the cultivation of hazelnuts in the most suitable areas (guaranteeing a typical and local economy and also the safety of its workers), as well as to promote other forms of economic activity, e.g. sustainable tourism and the consumption of typical and local products. Thanks to the planning and territorial analysis through the GIS programs, the examination of which territories can be suitably cultivated is the first step to establishing virtuous local realities.

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