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TRADE-OFF BETWEEN CARBON STORAGE AND BIOMASS-BASED ENERGY SOURCES ECOSYSTEM SERVICES, THE CASE STUDY FROM THE PROVINCE OF ROVIGO (ITALY)

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ABSTRACT – Biomass Based Energy Sources (BBES) are an Ecosystem Service (ES) which can contribute to achieve EU 2020 targets and to ensure energy security. Their effects on other ESs can be different according to biomass typologies, as energy crops and residuals. In order to plan a Greenhouse Gasses (GHGs) efficient supply chain and to maintain ES of carbon storage, as well as other related ESs, effect of feedstock chain on Soil Organic Carbon (SOC) should be considered. An ESs approach, based on the cascade model, takes into consideration biological interdependencies and management options to assess trade-offs. This study aims to describe and map trade-off between BBES and carbon storage services in Province of Rovigo (Veneto Region, Italy), a mainly intensive cultivated area. Results show that the trade-offs between the two ESs is potentially high in large part of the territory (75%), while just 25% expresses low possibility of conflict. Possible management options are discussed in order to minimize trade-off between energy provision and climate change mitigation. This study highlights that ESs approach can provide a suitable tool for decision makers, with respect to biomass feedstock chain, whose effects on ecosystems are often underestimated.

KEYWORDS: BIOMASS BASED ENERGY SOURCES, ECOSYSTEM SERVICES, CARBON STORAGE, SOIL ORGANIC CARBON, TRADE-OFF, CROP RESIDUES, ENERGY CROPS

INTRODUCTION

Overall the scientific debate on an approach based on the Ecosystem Services (ESs) has brought a new perspective in managing problems which concern several fields as natural resources management, conservation, local economies and other public field, with the goal of harmonizing environmental issues and human development. The management of the complex interactions among different ESs is a central issue in ESs approach framework (Burkhard et al., 2012). A holistic view requires the description of how services respond to different human induced pressures and how they depend from each other, in order to properly assess public decisions.
Among the issues which affect decision making, the demand of renewable energy is one of the most urgent in order to guarantee energy security, independence from fossil sources and to achieve the 20-20-20 European targets (EU, 2009). In 2011 the Common International Classification of Ecosystem Services (CICES, Haines-Young & Potschin, 2011) has classified Biomass-Based Energy Sources (BBES) as provisioning service, as a possible contribution that ecosystems make to human well-being.
BBES exploitation can affect the provisioning of other ESs, causing their loss or altering their quality since other ESs are depending on same ecosystem functions on which BBES are based, or by others related to them. In fact, considering the cascade approach (Haines-Young & Potschin, 2010), biophysical structures and processes can deliver several ecosystem functions, which ESs provision depends on. The challenge of how to obtain energy from biomass without threatening other ESs is critical for the future development of

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this renewable energy sources in line with the maintenance of the provisioning of other ESs. There is an urgency to face such critical issue, as BBES have been appointed as one of the great potential to achieve National targets of energy from Renewable Energy Sources, as the case of Italy (MISE, 2010).
The aim of this study is to evaluate the possible trade-off between BBES feedstock and the ES of climate regulation related to Carbon Storage provided by agro-ecosystems for the case study of Rovigo Province. The authors calculate and map the capacity of agro-ecosystems to provide Carbon Storage service, in order to investigate the relations between concurring feedstock provision for BBES, as case study example on interactions between ESs. Results of trade-offs has been described in order to explore management solutions that minimize the negative effects between ESs, intervening to mitigate or eliminate impacts that affect ecosystem functions.

MATERIALS AND METHODS

The theoretical framework of ESs is based on the understanding of ecological functioning of ecosystems, and their relationship with the socio-cultural context in which ESs are estimated and benefited. According to the cascade model, proposed by Haines-Young & Postchin (2010), ESs represent the link between ecological functions, depending in turn by several biophysical structures, and socio-cultural context (Haines-Young et al., 2012). ESs depend on ecosystem functions; each ecosystem delivers several functions at once and each function can provides one or more ESs. Consequently, different ESs are biologically related with each other rather than mutually independent, and their relationships can be complex (Bennet et al., 2009). Thus, some ESs appear together repeatedly, producing bundles of ESs (Raudsepp-Hearne et al., 2010).
Because of their complex interactions, the exploitation of an ES can results in change of other ESs status. That happens because two or more ESs derive from the same ecological function, or from more ecological functions which are related to a common driver (Bennet et al., 2009).
The present study focuses on the interrelations between Biomass-Based Energy Sources (BBES) with the ES of carbon storage, from the perspective of biological interdependencies between functions providing the two ESs. The mapping of the trade-off has been developed for the case study of the Province of Rovigo. The present research considers biomass produced by agro-ecosystem. Those ecosystems are exploited to obtain a surplus production of biomass, based on ecosystem functioning of primary production.
According to the cascade approach (HainesYoung & Postchin, 2010), the functions providing several ESs have been related to study reciprocal behavior about the capacity to provide ESs. Primary productivity has been analyzed with respect to soil functionality in relation to carbon stocks regulating services, focusing on mechanisms of interaction and potential trade-offs between the two ESs.

Case study area: agro-ecosystems of the Province of Rovigo, Italy

The Province of Rovigo is a largely anthropogenic area of 1.789 Km^2 in North-East of Italy (Fig. 1b), as part of the Veneto Region (Fig. 1a). In fact, 75% of its territory is covered by agricultural areas, mainly exploited with intensive management; 61% of its agricultural land is dedicated to cereal crops, mainly maize (Zea Mays L.). As a manly rural area, a high potential of bio-energy from agriculture productions is present, which led to the increase in construction and the request for permit issuing of biogas plants. Anyway, BBES exploitation can results in several conflicts with other ecosystem services, which in current management system are not yet being considered.

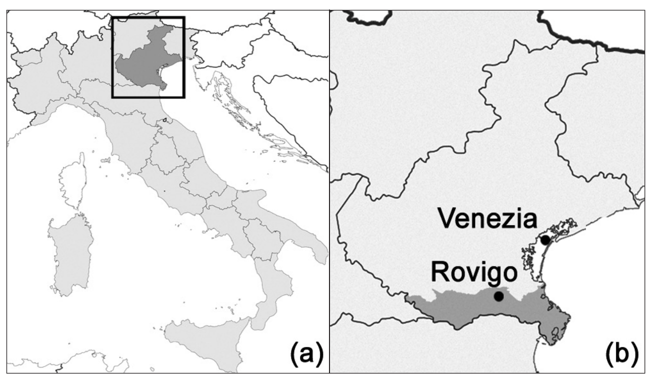

Figure 1. The Province of Rovigo (in grey in 1b), within Veneto Region (in grey in 1a), Italy.

RESULTS AND DISCUSSION

ES of BBES derives from ecological function of primary production, on which the quantification of BBES is based. Primary production is related to soil productive capacity, and therefore to its physical, chemical and biological characteristics. It can be reduced as consequence of a decrease of soil quality (Grigal, 2000).

BBES energy crops potential (Fig. 2) has been obtained by multiplying average yield of each crop type for the relative area, according to the Land Use map (Veneto Region, 2008) at a scale of 1:20.000. Average yield for each crop type has been calculated by considering ISTAT agriculture database (Istituto Nazionale di Statistica , Agricoltura e Zootecnia: http://agri.istat.it/) for the period 2006-2013. When land use category were not clearly specified (e.g. arable lands), the average composition of macro-category has been applied. Uncultivated crops and arboriculture areas have not been considered.

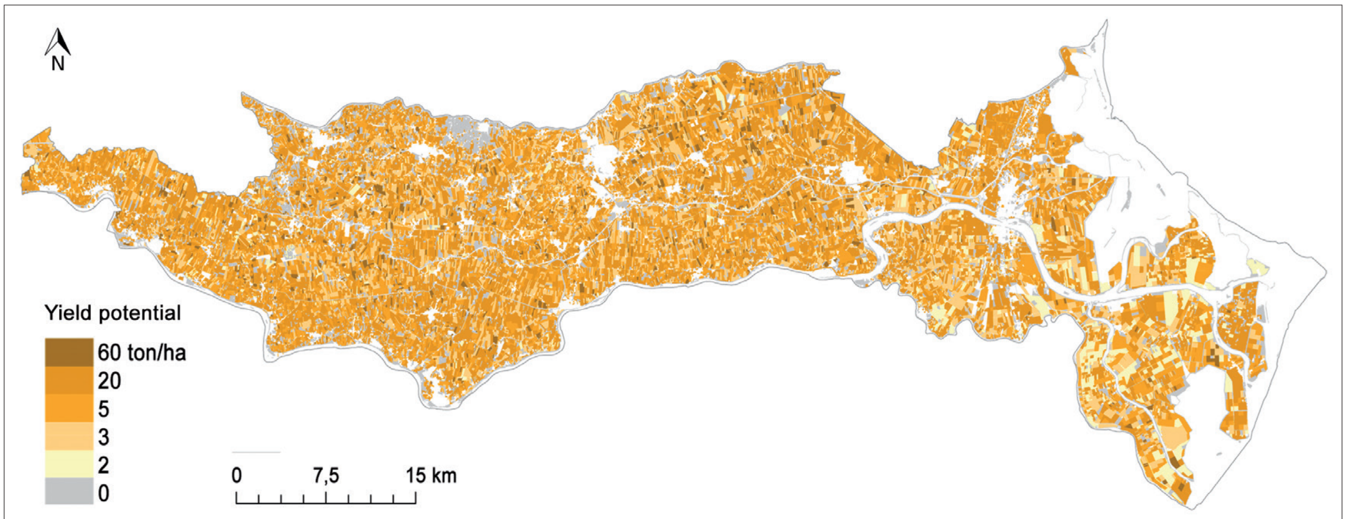

Figure 2. Map of the capacity to provide Biomass Based Energy Sources from potential energy crops for the Province of Rovigo.

For the calculation of BBES residues crops potential, both agricultural and industrial residues have been considered. Agricultural residues include crop residues (e.g. corn stover) and orchards pruning wood. Specific crop residues and pruning yields have been calculated for each cultivation according to ENEA (2010), applying the average crop yield obtained as described above. Results of BBES calculation for the Province of Rovigo are contained in Tab.1.

Carbon storage, as well as other ESs as soil protection and soil regeneration, affects and depends on the function of primary production through maintaining soil quality and receiving biomass to humificate (Lal 2004b; Blanco-Canqui, 2010; Janowiak & Webster, 2010), resulting in a bidirectional interaction. Trade-off between BBES and Carbon Storage depends on interactions between the two ecological functions which support their provision in agro-ecosystems: primary production and Soil Organic Carbon (SOC) accumulation. Different models, such as InVEST (http://www.naturalcapitalproject.org/InVEST.html) estimate the amount of carbon stored in ecosystems, adding carbon values of different pools, as aboveground living biomass, belowground living biomass, soil, and dead organic matter (Tallis et al., 2010).

According to Watson et al. (2000), current carbon stocks in middle and high latitude croplands are much larger in soils rather than in vegetation. Moreover, in agro-ecosystems, carbon stored in living biomass is destined to agricultural production, while dead organic matter is represented by agricultural residues, which can be harvested or retained *in situ*. Thus, soil carbon results to be the only significant carbon pool to be considered in agro-ecosystems analysis.

Therefore, SOC is the most suitable indicator to estimate Carbon Storage service of agro-ecosystems. SOC plays a key role in maintaining soil quality and therefore soil fertility, as well as to store carbon in soil (Lal, 2004a; Lal, 2004b). According to Sparling et al., (2006) crop yield and other ESs are enhanced in soil with high SOC levels, and, the main driver of SOC loss is the land-use change (Brandao et al., 2011). For the case of Rovigo Province, the capacity of providing Ecosystem service of Carbon Storage of agro-ecosystems has been estimated according to the SOC contained in soil (Fig. 3). SOC is expressed as percentage in the first 30 cm of soil. This indicator is generally less than 5% in lowlands soils, while high percentages are reached in the mountain zones of the region, where conditions of high naturalness are maintained.

To evaluate the trade-off between the BBES and Carbon Storage, it is necessary to understand the relative bio-physical interdependences between the two ESs. Relationships between SOC and soil quality and fertility, soil erosion, water cycle and microbial life have been considered.

Table 1. Calculation of BBES Potential (P) from dedicated crops and from agricultural residues in the Province of Rovigo, with the percentage of potentials from the areas of probability of trade-off (Pr1, Pr2, Pr3, Pr4), and the calculation of P from residues under the scenario of controlled trade-off with BBES.

	Surface	P from energy crops	P from residues**	P from Pr1 area	P from Pr2 area	P from Pr3 area	P from Pr4 area	P from residues if tradeoff is controlled ***
	ha	ton	ton	%	%	%	%	ton
Maize	185.420,3	3.521.329,3	939.357,8	26,1	46,8	26,9	0,2	234.839,5
Soy	62.276,9	237.897,8	0,0	20,9	48,3	30,8	0,1	0,0
Cereals *	60.580,1	397.405,3	239.018,7	28,7	44,1	27,1	0,1	59.755,0
Sugar Beet **	8.190,7	510.607,6	214.439,6	28,9	38,4	32,7	0,0	111.049,0
Oilseed rape and forage	17.585,6	56.161,3	0,0	6,6	79,4	14,0	0,0	0,0
Sunflower	1.943,9	5.753,8	0,0	20,3	47,6	31,7	0,4	0,0
Rice paddies **	4.709,7	26.892,4	18.153,6	3,4	93,9	2,7	0,0	18.153,6
Vineyards **	789,9	0,0	3.265,6	44,5	41,2	14,3	0,0	3.265,6
Orchards	5.695,6	0,0	11.232,3	39,3	40,0	20,7	0,0	11.232,3
Others (not used for BBES)	37.149,4	0,0	0,0	26,3	59,2	14,5	0,0	0,0
TOT	**384.342,1**	**4.756.047,6**	**1.425.467,6**					**438.295,0**

* Cereal crops including durum and common wheat, barley, grain sorghum
** Residues from cultivation and from industrial process
*** Hypothesis of 25% of harvested residues for maize, cereals, sugar beet and rice paddies harvested residues

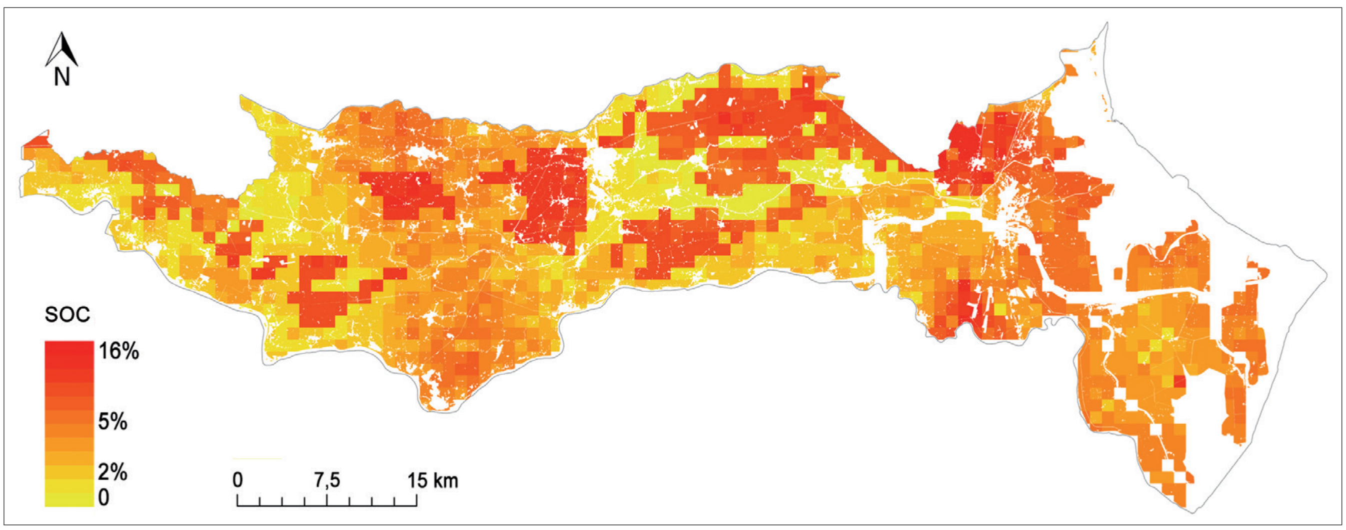

Figure 3. Map of the capacity to provide Ecosystem service of Carbon Storage of agro-ecosystems, estimated according to the percentage of SOC in the first 30 cm of soil.

SOC affects soil quality and soil fertility. SOC is both source and sink of main plant nutrient; it regulates their availability, favors build-up of salts in root zones and buffer fluctuation in soil pH; therefore, its loss causes soil degradation and nutrient depletion (Lal 2004a). Soil quality and fertility heavily affect primary production, on which BBES depends. In the Province of Rovigo, zones with higher SOC levels are the most productive ones. Soil erosion affects SOC levels causing removal of upper horizon, which is rich in organic matter (Grigal 2000), and it is related to topography and climate conditions (Lal 2004a). In turn, SOC avoids erosion phenomena by increasing bulk density, improving soil structure and avoiding crusting and compaction (Lal 2004a). Erosion processes decrease primary production by the loss of upper soil horizon, suitable for plant growth. The study area is a completely plain land, with weak winds, where erosion processes are not likely to occur. Thus, this interaction has not been considered in trade-off evaluation.

SOC also affects water cycle, directly influencing primary productivity. It promotes soil water absorption capacity, leading to an increase of water availability for plants, as well as promoting water infiltration rather than runoff (Rawls et al., 2003; Lal 2004a). Even if water availability is high in the study area, the role of SOC in water cycle promises to become more important in the future, according to general projection about climate change (IPCC, 2013).

Finally, SOC supports microbial life by providing trophic resources to microbial community. The latter regulates plant productivity through mineralization of nutrients (Van der Heijden et al., 2008). This aspect can be an important support in intensive agricultural zones, as that of Province of Rovigo, where the use of fertilizers to maximize the yields causes severe ecological effects.

The biological interdependencies described above highlight that both Carbon Storage and BBES services compete for areas with high SOC levels, in order to maximize their provision.

As final results the map of trade-offs between the two ESs has been drawn from the hypotheses as explained above (Fig. 4). From the analysis, as general assumption, agricultural areas with high SOC levels are at greater risk of trade-off, since good SOC level enhance their fertility (i.e. potential for primary production) at the cost of soil carbon loss. Conversely, growing annual energy crops in areas where ES of Carbon Storage is lower can mitigate trade-off with BBES.

Absence of trade-off probability in areas classified as non-agricultural zones is due to a lack of BBES potential and not to the absence of Carbon Storage service. SOC contained in these soils can be subjected to trade-offs with other ESs and affected by other drivers (e.g. land use change). SOC in agricultural areas suffers of trade-off due to the presence of BBES potential. The severity of this probability is classified from low to very high according to SOC levels (Tab. 2; Fig. 4).

Table 2. Trade-off between BBES and Carbon Storage, class of possibility levels and distribution of surface per class of trade-off for the Province of Rovigo.

Class	**Trade-off**	**level of SOC in first 30cm of soil**	**surface**	**surface**
type	**level**	**%**	**ha**	**%**
class 1	low	< 1	95308,14	24,80
class 2	moderate	1<SOC<2	190572,41	49,58
class 3	high	2<SOC<5	98064,96	25,52
class 4	really high	>5	396,55	0,10
TOT			**384342,06**	**100,00**

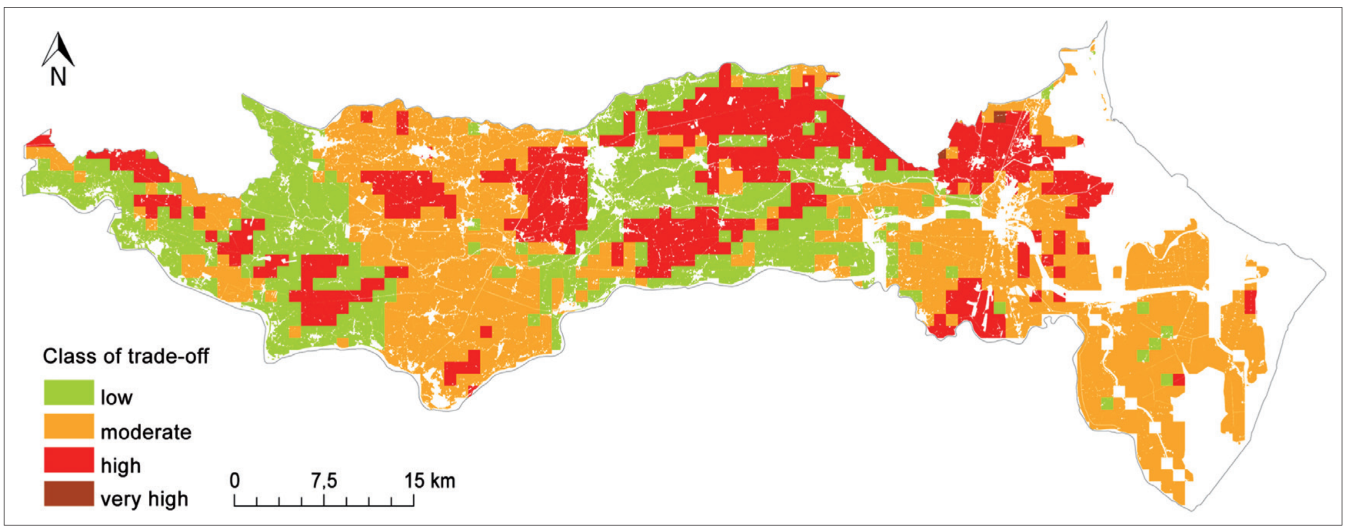

Figure 4. Map of trade-off between Biomass Based Energy Sources from potential energy crops and Carbon Storage according to 4 classes of probability.

For the case study of the Province of Rovigo, results show that only 25% of agricultural land has low probability to suffer conflict between BBES and Carbon Storage, while almost 75% is at moderate and high probability to suffer for a trade-off with BBES. The almost total lack of really high probability zones is due to a nearly total absence of soil with more than 5% of SOC content.

In Table 1, crop areas surfaces and related BBES potential are given for each crop type. Moreover, crop areas distributions are specified for each category of trade-off probability.

Concerning the distribution of different crop types in the four different trade-off probability areas, maize crops percentages (unlike others) are divided according to overall distribution. In fact, maize has the greatest impact on the overall distribution, due to the fact that it is the prevalent crop type in the Province, leading to a decrease of SOC levels, if considered as potential annual crop (Brandao et al., 2011).

In comparison to the total distribution, the distributions percentage of vineyards and orchards are higher in low probability zones, while rice paddies and oilseed rape and forage are concentrated in moderate probability areas. Soy distribution is higher in high trade-off probability zones; its cultivation in these areas is likely performed to exploit its capacity to improve N levels in soil, previously lost because of intensive management practices.

With respect to BBES from agricultural residues, trade-off with SOC is due to their role in soil regeneration and soil quality maintenance. In fact an excessive residues uptake can reduce N and P levels and availability, cation exchange capacity and soil micro-aggregates (Blanco-Canqui and Lal, 2009b), with negative effects on primary production. Trade-off with residues has not been mapped, as they depend on management decisions, as discussed in the next section.

The probability of trade-off between BBES and Carbon Storage Ecosystem Services exists, and it is distributed in different ways on the territory (Fig. 4), affecting almost the 75% of production of BBES from potential energy crops (as maize, or other cereals) on the entire Province of Rovigo. This can be avoided or mitigated by considering proper management options.

Among energy crops, annual and perennial ones impact in different manner on soil functionality (Blanco-Canqui, 2010). Annual crops affect SOC levels, both during vegetation time and after dismission (Brandao et al., 2011), while the latter can increase SOC level. For example, Brandao et al. (2011) show that miscanthus (Miscanthus x giganteus) has good performance in term of soil quality, as it sequesters carbon at high rate in soil, which has been quantified in 0.62 tons C ha^{-1} (Dowson & Smith 2007).

Possible managed scenario would foresee cultivation of annual crops only in zones with low SOC level, where the trade-off probability is low. However, this solution would require the addition of organic matter (such as manure or other soil amendments), resulting in increased effects on other ESs (e.g. water quality) which should be evaluated. The fact of destining other areas to perennial crop would guarantee maintenance or increase of SOC levels. Anyway, cultivation of new crops for energy purposes may lead to severe consequences on land cover change and landscape patterns, (Dale et al., 2011) and on other related services as biological control (Landis et al., 2008).

Since the aim of this study is to evaluate only possible trade-off with Carbon Storage, the map of BBES potential has been draw according to assumption that all arable land might be available for energy production, without considering conflict with ES of food production.

This trade-off occurs when BBES and food production compete for arable land or just for the final use of crops production (i.e. when food crop is exploitable also for energy purposes, as for maize).

Conflict between food and energy production is one of the main issue on the debate concerning bio-energy development production; it involves socio-economic aspects as food and energy security and food prices (Johansson & Azar 2007; Koh & Ghazoul 2008; Ajanovic, 2011; Nonhebel & Kastner 2011). A BBES supply chain analysis should be planned in order to avoid or, at least, mitigate this conflict. Johannson & Azar (2007) suggest the use of less productive land to establish energy crops, as to avoid food-fuel competition, beside other trade-offs. The use of abandoned arable land (i.e. land previously used for agriculture or pasture, and not converted to urban or forested areas after abandonment) could allow both recovery of these areas and avoid competition with food production. According to Field et al. (2010) the use of abandoned land for energy crops could provide about the 5% of world primary energy consumption. In the case of Province of Rovigo, the use of abandoned arable land can solve only partially the trade-offs, as it constitutes around the 10% of agricultural areas, and it is located for almost the 50% of its extension within areas of moderate probability of trade-off with SOC.

The use of BBES from residues may be an effective option to avoid this competition. Food crops can provide residues deriving from agricultural activities and related food transformation industry, which could provide economic support for farmers resulting in synergies with maintaining food production. However, high harvesting costs and other logistic restrictions due to their low density distribution on territory should be considered in order to plan an efficient supply chain for BBES.

On the contrary, the trade-off between BBES produced from agricultural residues and carbon storage is mediated by management options, which influence biological interdependences.

With respect to residues, their removal affects SOC levels as well as soil stability, leading to a loss of Carbon Storage

service and a decrease in time of primary production, whose magnitude changes according to the different soil texture and mineralogy (Blanco-Canqui & Lal, 2009a).
However, a sustainable residuals uptake threshold can be identified in order to maintain soil functionality. In agro-ecosystems, Blanco-Canqui & Lal (2009b) determine that only 25% of residues should be removed in order to guarantee a good level of nutrients and SOC, also in flat soils. This threshold allows maintenance of SOC levels. Tab.1 shows scenarios at 100% and 25% of residual uptake.
In comparison with energy crop potential, a supply chain based only on residual exploitation (100% uptake scenario) would foresee a decrease of 70% of biomass from crops residues, even if the overall BBES potential decrease would be less severe because of the presence of woody biomass (i.e. prunings), which has a higher calorific value than the herbaceous ones. Limited agricultural residual uptake (25% uptake scenario) would further decrease this potential.
Besides the discussion of the availability and feasibility of different sources to provide BBES, an important question which deserves attention consists in the capacity and the technology of conversion of those different sources to produce energy. This study provides a clear characterization of different potential sources that can be available for energy transformation. Further discussion should be drawn on the capacity of the energy infrastructures of the Province of Rovigo to effectively transform those sources. Main concerns that should be further investigated regard the capacity to structure the supply chains on available BBES sources, considering infrastructures, existing and planned plants, and the organization of the network of BBES providers, as well as other issues concerning bio-energy plants, such as emissions, social acceptability, and economic paybacks.

Conclusions

ESs based approach evaluates and quantifies BBES feedstock and their effects on other ESs, as in case of Carbon Storage in Province of Rovigo, considering the interrelationship occurring between the ecological functions which provide them: primary productivity and SOC accumulation, respectively.
In synthesis, energy crops provide good energy performances at the cost of trade-off with Carbon Storage service. In order to maintain both services at good levels and mitigate trade-off, dedicated crops should be avoided in areas with high SOC levels. Perennial crops cause less potential conflicts with other soil-related services, and synergy with Carbon Storage service. Anyway they can lead to severe trade-offs with food production and water services. Exploitation of agricultural residues can avoid trade-off between the two ESs discussed in this study, especially if proper management options are performed. On the other hand, their low density availability requires a wide supply range, which leads to high economic and time costs due to the harvest and transport. In addition, their total remove would compromise other essential ESs for the agro-ecosystem.
The identification of a minimum sustainable threshold for each ES involved in trade-off with BBES would allow managing efficiently the issues related to the BBES supply chain, considering trade-offs and synergies with other ESs. It is therefore necessary to extend future researches to other ESs related to BBES, with the aim to obtain a comprehensive view.
Although BBES supply chain is the most critical stage of bioenergy system, it is not subjected to a proper assessment of cumulative impacts between ESs, such as Carbon Storage. The evaluation can be included to inform decision making and to revise bioenergy potentials of different territories, according to the territory carbon storage capacity and their capacity to achieve renewable energy sources targets by 2020.

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