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Research paper

Policy measures for sustainable sunflower cropping in EU-MED marginal lands amended by biochar: case study in Tuscany, Italy

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ABSTRACT

The aim of this study is to evaluate economic support measures based on current EU policies affecting the profitability of large-scale deployment of biochar for sunflower cultivation in dry marginal lands in Italy, paving the way to large scale carbon sequestration in the EU Mediterranean region. Two cases were considered: i) straight biochar use and ii) biochar in combination with compost (COMBI: 20% biochar and 80% compost mass fraction), at application rates of 5 and 10 Mg ha^{-1} respectively. Based on realistic estimations of achievable crop-yield performances by biochar and COMBI addition to dry soils, the effect of current policies on the economic viability of biochar deployment and farmers' income has been investigated. Using a cost-model we identified the required levels of support, in the form of (i) area subsidies for crop cultivation, (ii) tradable carbon certificates (credits), and (iii) REDII-compliant biofuel support for Aviation and Maritime, so to make biochar and sunflower cultivation in EU MED dry marginal lands competitive for sustainable crop-based biofuels. Results show that, by employing existing policy instruments, sufficient income can be generated for famers to recover marginal land, sequester large amount of carbon by BECCS at costs (~82 € Mg^{-1} of CO_2) falling at or below the typical range of CCS measures, as well as offer additional environmental and socio-economic positive benefits. The combination of currently operational economic mechanisms from the Common Agricultural Policy, the Climate Policy, and the Renewable Energy Directive II can: i) maintain domestic farming activities, ii) support the implementation of biochar projects at local level, iii) contribute to achieve EU and national biofuel targets without generating ILUC impacts and iv) achieve unprecedent potential for carbon sequestration. However, prior to large-scale deployment, targeted on-site R&D actions aimed at validating biochar effects under local conditions (soil, climate, crops) are recommended, together with training and capacity building activities for local farmers.

1. Introduction

1.1. Biochar: main expected benefits and combination with compost

The term "biochar" [1–4] is used to identify carbonized biomass (charcoal, or char), obtained through pyrolysis or hydrothermal carbonization of lignocellulosic materials, and derived products; sometimes also the solid residue from lignocellulosic biomass gasification, which is mainly ash with some residual carbon, is named as biochar. Among other characteristics, biochar can stand chemical and microbial breakdown, and provide long-term storage of carbon in the soil. In addition to being used as a renewable fuel, char can be employed in several different applications, such as flue gas/liquid stream treatment (as activated charcoal), steel making (metallurgical charcoal), silicon making, or serve as amendment or fertilizer (after upgrading and enrichment) in agriculture. During the last years, the use of biochar in agriculture attracted large interest both in the scientific community and the agricultural sector. The possibility of increasing crop yields, especially in marginal land types, while at the same time improving the sustainability of agriculture and land use is obviously a very attractive combination, as well documented in literature and summarized by Lehmann et al. in Ref. [2]. However, the actual performance of biochar in agriculture depends not only on the characteristics of the biochar itself, but also on the crop type, the soil characteristics, the applied quantities, the local climatic conditions, and several other parameters. The effects of biochar are therefore crop, process, site and soil-specific. A major known effect of biochar relates to the increased soil moisture retention: the addition of a very porous material (typically in the range

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of at least some hundreds g m^{-2} [5]) to the soil promotes water retention, that as a result can be made available to the crop, favoring also the slow release of nutrients and limiting leaching and GHG emissions (as nitrous oxide, N_2O). This specific effect, that also depends on pore dimension distribution and char surface characteristics, can be very useful for arid regions, where water resources are scarce, and their efficient use is of paramount importance for agriculture to avoid loss of organic carbon, while sequestering fixed carbon in the soil.

In addition to the use of pure biochar in soil, the combination of biochar with compost from the Organic Fraction of Municipal Solid Waste is still rarely implemented, although the combined use of these two components is known to be synergistic, offering both short (from compost) and long-term (from biochar) benefits to agriculture. In particular, regarding the use of biochar in co-composting, the following benefits can be expected [6]: (1) faster attainment of compost maturity, (2) compost pH (usually increases it), (3) reduction of nutrient losses (Ca, Mg, N etc.), (4) increase of nitrification, (5) formation of stable humic like substances, (6) immobilisation of heavy metals (reduction of their bioavailability), and (7) reduction of emission of greenhouse gases.

1.2. *Desertification in the Mediterranean basin EU: a major threat to environmental, agricultural and socio-economic sustainability*

The amount of European land that is threatened with desertification is considerable [15,18]. Recently (2017), the EU-funded S2Biom project [7] estimated a total of 18.3 million ha marginal land in Europe by 2030. Out of this, the respective figures for the Mediterranean basin (PT, ES, FR, I, HR, EL, CY) are 8.5 million ha in total, from which 6.8 million ha of land with biophysical restrictions and 1.7 million ha of land released from traditional cropping due to low economic competitiveness.

Recently, the European Court of Auditors [8] carried out a comprehensive analysis of EU and Member States effort to combat desertification due to growing impacts from climate change, finding that the risk of desertification in the EU is not effectively and efficiently addressed. Effects from desertification are expected to be particularly acute in Portugal, Spain, Italy, Greece, Cyprus, Bulgaria and Romania. The analysis was concluded by remarking that there is an urgent need to enhance the EU legal framework for soil, and to quickly implement focused action. This is considered essential to achieve the EU and MS commitment of land degradation neutrality in the EU by 2030.

The term “desertification” consists of several degradation processes, namely [14]: erosion, decline of soil organic matter (SOM, sometimes called also humus), low rainfall patterns, compaction, salinization, landslides, contamination, and biodiversity. Large part of Western Europe is affected by soil degradation problems [11], in particular the EU Mediterranean area [17].

Erosion: A relevant soil-related critical element is represented by the erosion [20,21. Various models have been considered to address the problem of predicting soil erosion: discussing these models is not the scope of the present work, but it is worth to report that a common conclusion is that the Mediterranean area is subject to considerable erosion risk [14,16]. Among these models, PESERA [16] for instance predicts that overall 3.4% of the area (1.6 million ha) is at risk from erosion of more than 10 Mg ha^{-1} y^{-1}, 18% (54 million ha) are at risk of losing soil above 1 Mg ha^{-1} y^{-1}, and 25% of the area (corresponding to 75.5 million ha) is at risk to lose more than 0.5 Mg ha^{-1} y^{-1} of soil. Spain is the country most vulnerable to desertification and in particular soil erosion, followed by Italy and Greece.

Decline of Soil Organic Matter (SOM): Soil Organic Matter (humus) is important for the properties of the soil, texture, porosity, water and plant nutrient retention capacity. Moreover, SOM represents the living layer for microorganisms, as well as has a pH balancing effect for plants, and offers protection to erosion. Finally, and very relevant for this work, it stores carbon in the soil. In Southern Europe 74% of the soil has less than 3.4% of organic matter. In Europe, approximately 45% of soils contains low or very low organic matter content (0–2% organic carbon), and 45% have a medium content (2–6% organic carbon) [19].

Low rainfall patterns: average annual rainfall range in the region varies between 600 and 1200 mm y^{-1}, but in certain areas can be as low as 350 or even 100 mm y^{-1} [9]. Specifically, in Italy, the country under analysis in this paper, rainfall has been decreasing significantly in last decades [10], causing critical abnormalities in the period of emergence (e.g. spring) for many crops, including oil crops (and sunflower which is analyzed here).

Not only the overall lower availability of rainfall is a major critical issue for agricultural activities (that during the last two years in many areas remained below 300 mm y^{-1}) but also the fact that the timing of rainfall does not coincide with the one that major arable, annual crops require water for the critical growth and maturity stages. Unfortunately, the situation is deteriorating also under this point of view: rainfall during this period is dramatically reduced with specific reference to the January to May period [22]. Such low water availability during the first stages of crop growth, combined with land degradation and loss, makes future scenarios for agriculture in the area extremely difficult for the near future.

Due to the increased risks of soil erosion, decline of soil organic matter and reduced annual rainfall the issue of water retention capacity is a key threat to crop cultivation in the Mediterranean. Therefore, the application of biochar can offer an important outlet for future agricultural practices.

1.3. *The case of sunflower crop in Italy*

The Utilised Agricultural Area (UAA) in Europe showed a general decline during the last decades [12,13]. Sunflower, a well-adapted, important oil crop in EU and a typical oil crop for the Mediterranean region and Italy, follows the same declining trend [25].

In addition, the crop heavily suffers by the previously discussed desertification patterns. The sunflower cropped area cultivated in Italy ranged from 110,716 ha in 2016, to 114,446 ha in 2017 and 108,717 ha in 2018. The total seed production, however, was 268,331 Mg in 2016; 243,671 Mg in 2017; and 282,383 Mg in 2018 [23]. The very hot and dry weather conditions in southern and eastern Europe in June had a significant negative impact on crop yields in 2017 in these MED and eastern EU areas, and thus Italy as well [25]. Between 2006 and 2017 the sunflower production was reduced by approx. 20.8%, at national level, while the average specific yield was similar (2.13 Mg ha^{-1} collected seed): thus the lower production was mostly due to a lower area cultivated with sunflower (which in fact was also reduced by approximately 20%). A recent specific yield increase was observed in 2018, which reached 2.58 Mg ha^{-1}, bringing the national average for sunflower seed production to 280,000 Mg.

Referring to the Tuscany region in Italy, various studies and projects examined the impact of climate change on non-irrigated sunflower crop [26]. A significant reduction of sunflower see production was recorded in selected reference farms over the period 1995–2003: for instance, from 2133 Mg in 1995 to less than 1000 Mg yield in 2003 in the same farm. Again, comparing 2006 and 2017 data for Tuscany, the cultivated area was reduced by 28.8%, and the total seed production by 29.4%, i.e. a worst situation than national average. In terms of sunflower average specific yield per ha, it presented an almost negligible reduction from 1.64 to 1.63 Mg ha^{-1}, i.e. 0.0079%. During 2018 preliminary data show a slight improvement of the collected yield, thanks to an average increase in rainfall: despite this, the reduction of the area cultivated with sunflower continued (−24% compared to 2007), suggesting farmers' concerns on this crop. Keeping the other factors (e.g. nutrients and water) unchanged, a 0.5 °C average air temperature increase determines a sunflower yield reduction equal to 4% w/w, while 1 °C increase brings the reduction further down to 11% w/w. Estimates of climate change impact on future sunflower cultivation correspond to an average 20% w/w reduced seed yield [27]. Sunflower is a major oil crop for industrial uses, mainly biofuels and biopolymers, in Italy, which already faces severe negative impacts due to climate change. The crop can also be considered a representative example of the impact of marginalization of dry EU MED areas and therefore has been selected for the analysis in this paper.

1.4. Scope of work

This paper evaluates potential economic interventions based on the integration of existing policies affecting the profitability of biochar addition to dry marginal lands for sunflower cultivation and use for biofuels in the agro-climatically homogeneous Mediterranean region. No clear strategy and economic support for biochar use are in place today. Moreover, so far very large amount of straight biochar have been used in many past pilot tests (20 Mg ha^{-1} and more, as for example reviewed in Ref. [24]), a significant expense for the farmer. The aim is to suggest a set of combined economic mechanisms, based on current agricultural, climate and enegy policies, that could facilitate wider deployment of biochar and compost in the EU Mediterranean arid areas, and illustrate how resources could be leveraged through these measures. This analysis is carried out by modelling the economic impact of biochar and biochar + compost (here named COMBI) addition to arid soils, assuming reasonable crop yield increase, calculating expected economic performances for the farmers and CO_2 sequestration cost under different policy support mechanisms, to identify the feasibility of the different cases.

The work investigates the design of a coordinated and synergistic approach, based on existing energy, agricultural and climate policies, to support the costs associated with biochar and compost addition to the soil through modelling a specific case study. The model tested different incentives and support tools, comparing their effects to current situation (i.e. no support for marginal land). Sunflower was selected as reference crop, while the Tuscany region (central Italy) was considered as reference region for crop yield data and estimations, since it can be considered as representative of typical average (not extreme) Mediterranean conditions. Thus, the work addresses the EU Mediterranean region, taking Italy and sunflower as a representative example.

2. Economic policy mechanisms affecting the implementation of biochar in agriculture and support for biofuels

Three main existing economic policy instruments are included in this study; crop area payments (through the EU Common Agricultural Policy - Pillar II) for sunflower promoting the application of biochar/COMBI, the tradable CO_2 emission allowances (from the EU Climate Policy), and the biofuel support mechanisms established by the EU Energy Policy.

2.1. Common Agricultural Policy (CAP) in Italy

The European Common Agricultural Policy is an extraordinary instrument to drive agriculture towards higher sustainability and rural development [35]: however, it suffers from un-harmonized implementation across Member States (MS), that have generated 118 Rural Development Plans (RDPs) [35], each one with its own strategy and priorities. Italy has a total 23 RDPs, considering both Regional and National ones. Clearly, when dealing with global issues as climate change, desertification, etc, a common strategy above the national dimension would be more appropriate, grouping EU Member States on the base of agroclimatic similarity. The EU MED region (see previous section 1.2) is an area having common problems and critical elements, in particular a full-blown ongoing and well documented desertification effect. A harmonized approach would thus be necessary to face the same challenges.

Within the current CAP in Italy, there are suitable instruments to support biochar deployment. These are included in Priorities 4 and 5:

- Priority 4: to restore, preserve and enhance agricultural and forest ecosystems (biodiversity, water and soil). This priority accounted for 34% of total resources, even more than those assigned to the well-known Priority 2 (to increase the viability and competitiveness of all types of agriculture, promote innovative agricultural technologies and support sustainable forest management), a traditionally key area of EU rural plans.
- Priority 5: to promote the efficient use of resources (water and energy) and support the transition to a low-carbon economy (renewable energy use, greenhouse gas emission reduction, carbon sequestration and storage). This priority covered 7.5% of total financial resources.

The sum of these two priorities over the period 2014–2020 accounts for ~8.5 billion € (7 and 1.5 billion € for priority 4 and 5, respectively) [36]. In addition to the above, measure number 10 of the Rural Development Plans in Italy includes the following:

- Inclusion of number 10 measure in Rural Development Plans (RDPs) is mandatory at National/Regional level.
- Payments (€) are based on the area (ha) subject of intervention.
- Farmers are paid for voluntary actions (one or more Agro-Climatic-Environmental actions, named « Priorità Agro-Climatiche Ambientali, (ACA)») going beyond existing legislative mandatory works.
- Commitments must be maintained by farmers for a period of 5–7 years, or beyond.
- Payments cover reduced earnings and/or higher production costs for the voluntary actions, beyond the baseline (greening).

The 21 Italian Regional and autonomous Provinces RDPs allocated approximately 4.5 billion € to ACA actions. Within the previous RDP (2007–2013), these measures (at the time named measures number 214) accounted to 3 billion € through more than 200,000 contracts on 3 Mha area [36]. The total of resources allocated to the RDP of Tuscany during the period 2007–2013 reached more than 870 M€, 40.09% of which (equal to 349 M€) allocated to Sustainability, and 390 M€ given to the agro-climatic actions and modernization of farms [37]. As regards planning for the 2014–2020 RDP, the total resources increase to 961.7 M€, but agro-climatic actions will receive 49 M€ from the Tuscany RDP [38]. It is worth to note that during the period 2000–2010, Tuscany lost approximately 100000 ha of agricultural land, mainly due to abandonment and urbanization.

2.2. International and EU Climate Policy

The EU Climate Policy addresses the decarbonization of the EU area. During 2016 EU agriculture was responsible for 10% of total EU GHG emissions [44], while transports (including international aviation) for 24%. The most significant actions carried out at EU level to reduce GHG emissions relates to the EU Emissions Trading System (which final goal is to set up an effective international carbon trading market, including aviation), to monitoring the implementation of Member States' emission reduction targets in the sectors outside the EU ETS ('Effort Sharing Decision'), to promote renewable energies and energy efficiency (both targets set at 20% by 2020), to establish new binding targets to limit CO_2 emissions from new cars and vans, and finally to stimulate and promote carbon capture and storage (CCS) technologies, focusing on CO_2 emissions from power stations and other major industrial installations.

At Paris COP21 the very ambitious max 2 °C target (with an even more aspiration of 1.5 °C) was set. The Green Climate Fund (GCF) was established after COP16 in Cancun as an operating entity of the

Financial Mechanism of the Convention under Article 11 [52]. At COP21 in Paris, by decision 1/CP.21, paragraph 58, the COP decided that GCF shall serve the Paris Agreement. - UN negotiators understood the magnitude of the Climate Change problem and made clear statements in support of carbon removal actions, without which the achievement of the climate goals is not possible [45–47]. Unfortunately, global CO_2 emissions are still growing, reaching unprecedent levels [48–51]. There is today a strong agreement on using the potential offered by the agricultural soil as a unique carbon storage opportunity [28], which in turns generate benefits to the agricultural sector and fight the marginalization of the land. The recent IPPC report further emphasized it, as biochar was included for the first time as a promising negative emission technology (NET) in the new IPCC special report published on the 8th of October 2018 [48]. A large set of studies investigated the Mean Retention Time (MRT) of carbon (in the form of biochar) in the soil, as summarized in Ref. [49]. By far, many of studies considered MRTs of well-pyrolyzed biomass between hundred years and millennials (even if some studies also reported decades), thus beyond the transformation of the energy sector that one can reasonably expect during the next century. Thus, biochar can effectively support a smooth transition to a new decarbonize energy system.

It therefore makes sense to consider the use of the EU ETS allowance system to the sequestered CO_2 equivalent to the amount of fixed carbon deployed in the soil through biochar. CO_2 EU emission allowances considerably increased during the last semester, reaching 23.40 € Mg^{-1} of CO_2 on 17.12.2018 [60], and could double by 2021 and quadruple by 2030 compared to April 2018 [59].

2.3. Support schemes for biofuels for transport

As in all EU Member States, biofuel blending obligation quota is governed by the provisions following the Renewable Energy Directive (RED) [39] and Fuel Quality Directive (FQD) [40], then complemented by the so-called ILUC Directive [42]. In order to comply with the 10% EU RES target in the transport sector, Italy introduced, through the legislative decree implementing Directive 2009/28 [41], a quota obligation of biofuel on parties that inject into the grid, for consumption, petrol and diesel from fossil sources. The obliged companies can fulfil their obligation by acquiring, in whole or in part, the equivalent quota or corresponding rights from others, buying the so-called Biofuel Certificates.

It is relevant to point out that a mandatory quota for "advanced biofuels" has been introduced, as well. The concept of "Advanced biofuels" has been introduced by Ministerial Decree: those are biofuels produced from materials listed in Annex 3 of the Decree and include agricultural and industrial wastes (apart from UCOs and animal fats), residues, ligno-cellulosic materials, cellulosic materials and algae.

As mentioned, all biofuels released for consumption in Italy must comply with the sustainability criteria stated by Renewable Energy Directive, RED (2009/28/EC) and FQD Directive (2009/29/CE) and they must be certified by specific certification bodies according to the National Certification Scheme (DM 23 January 2012) or according to voluntary schemes approved by the EU Commission or according to bilateral or multilateral agreements with third countries.

The scheme encourages second and third generation biofuels by providing extra incentives (double counting mechanism – 5 Gcal of biofuels released gives rights to a certificate), as well as biofuels produced from wastes and by-products, such as Used Cooking Oil (UCO).

The new Renewable Energy Directive (REDII), officially released on the 21st of December 2018 [43], will not only continue to promote advanced biofuels (as defined by feedstocks listed in Annex IX Part A), but also introduces the new concept of so-called Low-ILUC impact biofuels, as well as other elements related to the soil (such as measuring and monitoring carbon content in the soil) and agronomic practices (as cover cropping). Low-ILUC risk biofuels will be exempted from being phased out from 2023, to 0% at 2030: feedstocks cultivated on marginal, degraded or contaminated land should fall under this category. REDII also states the possibility to add feedstocks to Annex IX Part A list, but not removing those already present. Moreover, and relevant for the present work, REDII establishes the possibility to adopt a 1.2 multiple counting factor when sustainable biofuels are used in aviation and maritime.

These innovative components in REDII represent an opportunity to produce sustainable biofuels in EU MED marginal lands, and would merit being considered as advanced feedstocks.

3. Material and methods

3.1. Case description

The land cultivated with sunflower in Tuscany was 22,644 ha and 17,942 ha in 2017 and 2018 respectively. The corresponding figure in 2006 was 31,816 ha, which shows the considerable reduction of 29% for 2017 and 44% for 2018, with direct (rural economy) and indirect (such as landscape change, being sunflower a typical crop of this highly touristic region) consequences.

The present work analyzes biochar application to sunflower cultivation in marginal areas of Tuscany (as representative of EU Mediterranean areas), and investigates the effect of a combination of economic policy instruments, to farmers' income. The following policies are considered:

- The EU Common Agricultural Policy as applied in Italy, addressing agriculture. We assumed that support for the deployment of biochar and COMBI in EU Mediterranean dry areas can be generated through the agro-environmental measure, which will be activated to improve the resilience of these agricultural lands, under marginalization and desertification, to climate change.
- The Climate Policy, which supports Carbon sequestration through the ETS certificates. We used this mechanism to provide support for the sequestered CO_2 corresponding to the amount of fixed carbon in the biochar stored in the soil.
- The Renewable Energy Policy (RED/REDII), that provides support to the production of sustainable biofuels. In particular, we could propose to adopt a multiple (double) counting mechanism for the lipids produced on these marginal areas, as already exist for feedstocks included in Annex IX – Part A of RED/REDII. However, current REDII does not recognize a merit for this so called low-ILUC risk biofuels, but only the exemption to phasing out (which is instead due for high ILUC risk feedstocks). It is also important to remark that amending Annex IX Part A list to add new sustainable feedstocks is possible according to REDII.
- These policies are well integrated across the value chain, as each policy instruments targets a different and specific goal, coherent with the scope of each policy. It also ensures risks of carbon double counting is avoided, since:

CAP support focuses on maintaining agricultural activities and improving their environmental performance in areas at risk of marginalization, as well as improving soil resilience to climate change. This component is assumed to cover the costs for deploying biochar and COMBI in the agricultural soil.

ETS support the carbon sequestered and stored in the soil. This component thus covers the amount of CO_2 equivalent to the fixed carbon content in the biochar. The amount of carbon deployed in the soil through the compost is not considered in order to maintain a conservative approach in the analysis.

The RED/REDII component supports the production of sustainable biofuels in these areas (i.e. the carbon emissions avoided using sustainable biofuels originated from feedstocks produced on this low-ILUC land).

CAP support was balanced to secure a farm income comparable to the one achieved through conventional agricultural practices in good agricultural land.

The use of the biofuel in road, aviation and maritime transport was also not considered in this study, so that the results are not restricted to a specific type of transport mode. In fact, REDII adds further support components (1.2 multiple counting) to the use in Aviation and Maritime.

3.2. Crop yields, cultivation practices, cost data, and seed market

Data for sunflower yields and crop production costs derived from actual on-field experience of the University of Florence in Tuscany, to ensure site-related figures [30–32], where seed yields in five (5) selected representative farms in the South of Tuscany ranged between 1.36 Mg ha^{-1} to 2.55 Mg ha^{-1}.

The extreme (i.e. min-max) figures for the following data were considered, referring to both conventional and high-oleic sunflower crops, under three cultivation regimes:

- Typical yield per ha for conventional, minimum tillage and no tillage cultivation
- Total costs per ha for conventional, minimum tillage and no-tillage sunflower
- Minimum and maximum seed selling price for both conventional and high-oleic sunflower

As regards income, the average CAP support available for sunflower cultivation in Italy has been added to farmers' profits derived from seed priced at market value (as derived from Ref. [33]). CAP support regime for sunflower today is composed by different contributions [32,32,34]: a base support (up to 58% of National max), decoupled from the type of crop, a support for Greening (30% of National max), and a coupled support (11% of National max). The result of this work allowed to calculate the range of gross farmers' income in case of conventional agriculture in conventional land. These figures were used as reference case for the analysis.

Possible and reasonable yield reductions (as reported in literature [30], communicated by farmers in Tuscany and discussed with experts from the Agrifood Production and Environmental Sciences DISPAA of the University of Florence [31]) due to crop cultivation in marginal areas were then estimated (up to 29%), and the revised farmers' economic returns under these less favorable conditions were calculated. However, it is worth to mention that the scope of this paper relates to the simulation of different economic options for the farmer, using realistic and reasonable ranges of crop yield under different circumstances (i.e. marginal land and various policy-related incentives). Assessing the exact crop yield variation is a site and crop-specific experimental exercise, that is out of scope for the present work, as discussed also in the conclusions.

Following, the analysis accounted for improved soil resilience by adding biochar or a blend of biochar and compost (COMBI) to the soil, and reasonable expected yields were estimated. Two cases were considered: i) pure biochar and ii) biochar in combination with compost (COMBI: 20% biochar and 80% compost mass fraction), at application rates of 5 and 10 Mg ha^{-1} respectively. On this basis, different crop yield increase compared to ones in marginal land were modelled, differentiating between the case of biochar only or COMBI supplement. Crop yield increase was assumed higher at the lowest conventional yield conditions (i.e. when the product is applied to the most marginal land in the case under study), as here the crop mostly benefit from soil reconstitution through biochar and compost. Costs for biochar production from residues, compost acquisition, and then delivery of the material to the field, were considered and included in modelling: based on the research work currently being carried out within the Horizon 2020 BIO4A project [32], these account to at least 200 € Mg^{-1} and 10 € Mg^{-1} for biochar and compost respectively, and 10 € Mg^{-1} for deployment in the soil.

The model then assumes to provide a variable extra support to the farmer through the Agro-Climatic Environmental measure of CAP (measure nr 10), adjusted to keep the overall farmers' income similar to the case of the conventional agronomic model in conventional land.

Farmers' gross income was then re-calculated, considering revised additional costs and revenues, the first one being related to the production and distribution on soil of pure biochar or COMBI, the second one related to the increased income from higher seed yields.

We also considered two further forms of additional support, from the Climate and form the Energy EU policies: the support from the Emission Trading Scheme (ETS), which valorize the sequestered CO_2 by an allowance system, and the RED/REDII, that could provide a premium for sustainable biofuel production in marginal land (low ILUC) through a possible amendment to feedstock list in Annex IX Part A.

As regards this second component, we thus considered the possibility to provide a double-counting mechanism from RED to these crops cultivated in marginal land after recovery through biochar/COMBI, allocating 50% of this value (calculated on estimated seed yield) to the farmer.

3.3. Model description and modelled scenarios

Options for economic support to biochar deployment were investigated under the light of the considered policies, and following two main assumptions:

- Support to farmers from CAP must be in line with current and possible future EU and MS policies.
- This incentive for biochar or COMBI (biochar + compost) addition to the soil should be limited in time (while the effect of biochar is a long-term one), covering biochar-related additional (i.e. extra) costs only. The amount of added biochar can vary depending on the case of biochar only or biochar + compost (COMBI).

Given the pro-active nature of the proposed agronomic approach, which aims at fighting the loss of soil due to desertification before it takes place (that could be regarded as a kind of "reverse-ILUC measure"), the CAP incentives considered for this work relate to the recovery of agricultural soil and carbon in soil (agriculture), i.e. increasing soil resilience to climate change. The support from the ETS scheme will instead target the carbon sequestration and storage in soil, and valorized according to ETS allowances market value.

In addition, based on the biofuel policy in RED/REDII, a premium for oil crops cultivated in this marginal land was thus assumed and modelled by adopting the same support as proposed by the EC in REDII for Advanced Biofuels in Aviation [43], i.e. by a multiple counting on the vegetable oil. In the present work, this support was however weighted on the typical oil content in sunflower seed (~40% w/w): the premium on oil content is thus equal to an average of ~165% on seed. In order to support both the feedstock and the fuel producers, this premium was equally (i.e. 50%) distributed to these two.

The following Table 1 summarizes the scenarios investigated in the present study.

A scheme detailing the methodology adopted to model sunflower

Table 1
Summary of scenarios investigated in the present study.

0	Ref Case, conventional land
1	Marginal land - reduced yield per ha
2	Marginal land, biochar recovered, CAP support
3	Marginal land, biochar recovered, CAP support, ETS
4	Marginal land, biochar recovered, CAP support, ETS, biofuel premium
5	Marginal land, COMBI recovered, CAP support
6	Marginal land, COMBI recovered, CAP support, ETS
7	Marginal land, COMBI recovered, CAP support, ETS, biofuel premium

Table 2
Methodology and investigated scenarios.

Case nr	0	1	2	3	4	5	6	7
	Ref.Case: SF cultivation in **Conventional land, conventional**, min and no tillage **regime**	Same as 0, but **Marginal Land** with reduced seed yield	Same as 1, adding 5 Mg ha^{-1} **Biochar** + **CAP** support	Same as 1, adding 5 Mg ha^{-1} **Biochar** + **CAP** support + **ETS**	Same as 1, adding 5 Mg ha^{-1} **Biochar, CAP** support + **ETS** + **50% REDII biofuel premium**	Same as 1, adding **COMBI** (2 Mg ha^{-1} biochar + 8 Mg ha^{-1} compost) + **CAP** support	Same as 1, adding **COMBI** 2 Mg ha^{-1} biochar + 8 Mg ha^{-1} compost + **CAP** support + ETS	Same as 1, adding **COMBI** 2 Mg ha^{-1} biochar + 8 Mg ha^{-1} compost + **CAP** support + **ETS** + **50% REDII Biofuel Premium**
Type of land	**Conv**	**Marg**	**Marg**	**Marg**	**Marg**	**Marg**	**Marg**	**Marg**
Scenario Description	Estimation of farmer's gross profit, including CAP contribution for Sunflower (SF) in Italy (Tuscany region)	Calculation of farmers' gross profit, assuming seed yield reduction due to marginal land	Calculation of gross profit estimating % of crop yield increase (vs marginal land case), production & distribution costs of biochar covered by additional CAP support for a determined period	Calculation of gross profit estimating % of crop yield increase (vs marginal land case), production & distribution costs of biochar covered by additional CAP support for a determined period, ETS support for sequestered C	Calculation of gross profit estimating % of crop yield increase (vs marginal land case), production & distribution costs of biochar covered by additional CAP support for a determined period, ETS support for sequestered C, 50% of biofuel multiple counting from REDII	Calculation of gross profit estimating % of crop yield increase (vs marginal land case), production & distribution costs of biochar covered by additional CAP support for a determined period	Calculation of gross profit estimating % of crop yield increase (vs marginal land case), production & distribution costs of biochar covered by additional CAP support for a determined period, ETS support for sequestered C	Calculation of gross profit estimating % of crop yield increase (vs marginal land case), production & distribution costs of biochar covered by additional CAP support for a determined period, ETS support for sequestered C, 50% of biofuel multiple counting from REDII

Table 3
Estimated sunflower seed yields in Tuscany under various cultivation regimes.

Agronomic model	Yield Mg ha^{-1}	Total crop production cost € ha^{-1}
Conventional	2.2–3.0	1058.00
Minimum tillage	1.8–2.4	948.50
No Tillage	1.5–2.2	828.50

cultivation in conventional or marginal land by adding biochar or biochar + compost (COMBI), under possible and suggested (REDII case) incentive scenario based on current policies, is given in the following Table 2.

4. Results and discussion

4.1. Modelling biochar and compost in arid lands: crop yield and farmer's profit in agricultural land in Tuscany

Crop yield and typical production costs were derived from Ref. [53], verified and updated agronomic experts from the University of Florence [31]. These include all necessary agricultural operations per ha, as well as seeds and fertilizers costs.

Depending on the adopted agronomic practices (conventional, minimum or no tillage farming), we assumed the average seed yields in Tuscany given and typical crop production costs as given in Table 3 [29–31].

As regards sunflower seeds market price, both conventional and high oleic-acid seeds were considered. We also assumed that crop production costs and seed yield do not differ in the two cases. The overall ex-works price evolution for conventional sunflower seed is indicated in the following Fig. 1 [54].

Thus, we assumed 300 € Mg^{-1} average selling price for conventional sunflower (and 345 € Mg^{-1} for high-oleic sunflower).

Recently, these prices in the EU increased to 371 € Mg^{-1} [55]. However, in Italy, as reported in Fig. 1, the seed selling price for conventional sunflower was sometimes below the EU average (at December 2016 it was around 315 € Mg^{-1} [56]. It is worth to stress out here that about two-thirds of the oilseeds consumed in the EU each year are produced domestically, but EU imports about half the oilseed meals used annually in animal feed. Import tariffs for oilseeds are set at zero [57].

The support from CAP for crop cultivation in Italy was equal to a total of 329 € ha^{-1}. This figure is composed by 180 € ha^{-1} as base CAP payment, 93 € ha^{-1} for the greening component, and finally 56 € ha^{-1} for the coupled CAP support.

The combination of yield ranges and min-max crop production costs under various agronomic regimes, combined with the economic support from the EU Common Agricultural Policy as indicated above, determines the economic figures shown in Table 4 for the farmer.

The value of production is calculated as the combination of sunflower yield per ha and the seed market value (min or max, as indicated). In the following modelling we will consider only the conventional sunflower case, as it is the most implemented case as of today. Table 4 shows that farm revenues from conventional agriculture are modest and in the best cases they almost correspond to CAP support. Several of the above crop-agricultural management combinations result to income loss, rather than profits. In fact, in case of lower yields (mostly due to climatic conditions), positive margins disappear, and very quickly the balance becomes very low or even negative for the farmer. Thus, the only actual benefit and justification to cultivate sunflower relates to the positive agro-environmental effects in a sustainable crop rotation regime, where the actual income will come from the main crops, i.e. grain and cereals. Sustainable management of agricultural land becomes the main reason for the cultivation of sunflower in Tuscany as well as in many EU MED regions.

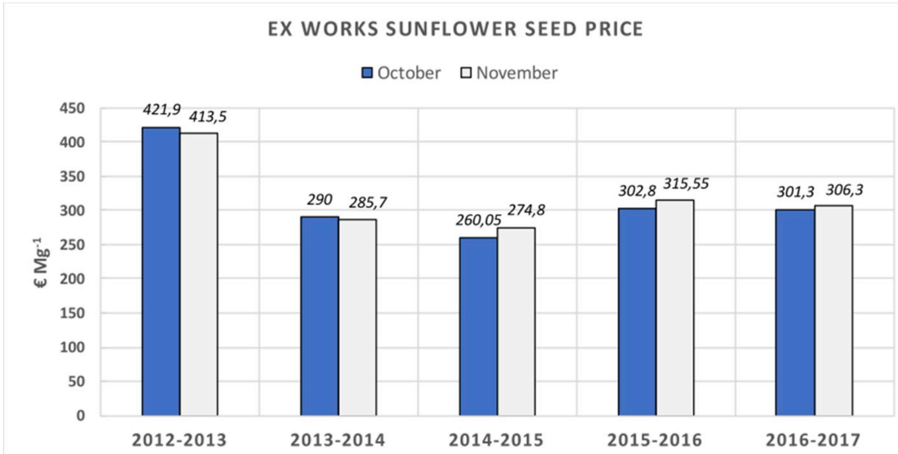

Fig. 1. Seed prices for Sunflower in Italy, 2017 [54] (Ex Works means the buyer is responsible for the whole shipment from door to door. All costs and liabilities are with the buyer).

4.2. Crop yield and gross cultivation profit in marginal land with biochar and biochar + compost (COMBI) addition

Considering the addition of biochar to marginal land, we assumed crop yield increases ranging from 5% w/w to 15% w/w versus marginal land, the first one of the less difficult and the second one for the most degraded marginal land (the effects of soil recovery is in fact expected to be more significant in the most difficult conditions). The crop yield increase ranges are consistent with data reported in literature [58]. Following the same approach, as regards the effects on yields from adding a combination of biochar and compost to the agricultural soil, thanks to the presence of compost (and thus, readily available carbon and nutrients) a higher effect on crop yield was assumed, ranging from 15% w/w to 30% w/w under the same conditions (as shown in the following Fig. 2).

Seed yield ranges corresponding to Fig. 2 are summarized in the following Table 5.

The overall support allocated to each modelled policy scenario is reported in the following Table 6.

As shown Table 6, the CAP contribution to support biochar and COMBI deployment on marginal land was modelled to cover costs and raise – due to the achieved higher seed yield in the recovered soil through COMBI addition – the gross profit at a level similar to those achievable in conventional land and conventional agronomic regime. Thus, the allocation of CAP resources is proportionally reduced as the other forms of support from climate and energy policies enter the calculations (scenarios 3–4 and 6–7), which are the ETS allowances and the Biofuel premium for use in aviation or maritime. The economic support from ETS is estimated equal to the market price at 28.12.2018 [59], i.e. 23.4 € Mg^{-1} of CO_2; the second one is assumed at 50% of the biofuel multiple counting value of 1.2, weighted on the seed yield, and extraction efficiency lipids contained in seeds. Averaging the cases of marine and aviation (jet) fuel production (which lipids-to-fuel process yield considerably varies), the adopted multiplier corresponded to a conservative 130% (on seed market price) in case of biofuel premium. Therefore,

- CAP additional contribution is adjusted to a range, varying from a maximum of 250 € ha^{-1} y^{-1} (scenario 2) to 70 ha^{-1} y^{-1} (scenario 7).
- CAP support is in fact synergistically adapted to complement the ETS and Biofuel premium in the various cases. For instance, in case of Scenario 7 (Table 6), ETS is 120 € ha^{-1} y^{-1} and Biofuel premium ranges from 232.88 € ha^{-1} y^{-1} (min seed yield) to 182.75 € ha^{-1} y^{-1} (max seed yield).

Under these assumptions, economic performances, calculated as expected gross income (i.e. difference between total revenues from production and production costs) for the farmer, were estimated through the application of the model. These are reported in the following Fig. 3, where the various applied economics policies were considered.

Table 4
Gross income for sunflower crop cultivation with and without CAP support.

Value of production	Yield	Income from seed	Gross Profit	Including CAP @ 273 € ha^{-1} (avg)	Adding CAP coupled support @ 56 € ha^{-1}
	Mg ha^{-1}	€ ha^{-1}	€ ha^{-1}	€ ha^{-1}	€ ha^{-1}
Conventional Sunflower (Min 280 € Mg^{-1} - Max 320 € Mg-1)					
Conventional-Min	2,2	616	−442,00	−169,00	−113,00
Conventional-Max	3,0	960	11,50	284,50	340,50
Min.Tillage-Min	1,8	504	−444,50	−171,50	−115,50
Min.Tillage-Max	2,4	768	−180,50	92,50	148,50
No Tillage-Min	1,5	420	−408,50	−135,50	−79,50
No Tillage Max	2,2	704	−124,50	148,50	204,50
High Oleic Sunflower (Min 320 € Mg^{-1} - Max 360 € Mg-1)					
Conventional-Min	2,2	726	−332,00	−59,00	−3,00
Conventional-Max	3,0	1080	22,00	295,00	351,00
Min.Tillage-Min	1,8	594	−354,50	−81,50	−25,50
Min.Tillage-Max	2,4	864	−84,50	188,50	244,50
No Tillage-Min	1,5	495	−333,50	−60,50	−4,50
No Tillage Max	2,2	792	−36,50	236,50	292,50

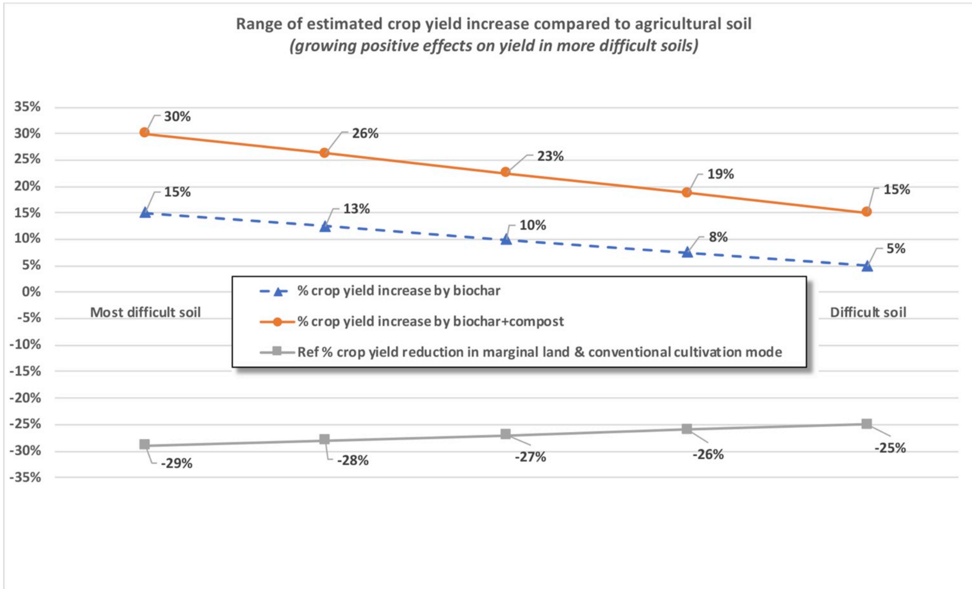

Fig. 2. Estimated range of crop yield increase with biochar and COMBI in marginal land.

The following Table 7 derives from Table 5 and provides and overview of the gross income for each selected case under the different support regimes.

It is important to mention that the present work did not address the production of biochar from agro-residues, as the experience in slow pyrolysis of this feedstock (and the understanding of the derived biochar physical and chemical properties) is at very early stage to make realistic estimations for crop yields. Nevertheless, the conversion of the agricultural residues into biochar and its further reintroduction as biochar or COMBI in the soil is a very attractive option, from agronomic, environmental and social (circular economy) point of views. The use of agroresidues as feedstock for the pyrolysis process would further reduce the biochar and COMBI production cost, and the economics of the proposed approach.

4.3. Discussion

The analysis of conventional farming conditions in Tuscany shows that farmers have little economic gain from the cultivation of sunflower. In the best cases, the actual profit almost equals the CAP support, while in many cases it becomes lower or even uneconomic. If the climatic conditions during the year, or the type of soil, are unfavourable, the cultivation is not economically viable. Thus, either the farmer switches to a different drought-resistant crop, or he abandons farming in such agricultural land types.

In this context, the addition of pure biochar or a combination of biochar and compost (COMBI) to the soil could offer a possible solution both to improve crop competitiveness and to mitigate the impact of climate change. While biochar can help reforming soil structure and improving soil moisture retention capacity (and thus water release to the crop) generating a long-term effect, the combination of biochar and compost (COMBI) could provide both short-term and long-term benefit to the crop, adding readily available carbon and nutrients for crop cultivation in a reformed soil environment. The use of COMBI also helps reduce the required amount of biochar per ha, thus making the costs for soil recovery more affordable for the farmer and the policy support required lower.

The modelling results show that, based on conservative yet realistic assumptions for crop yield increase, the option biochar + compost (COMBI) can be more effective in improving the economic performance of farming in dry marginal land compared to the application of pure biochar only. This could occur with smaller support from CAP (140–70 € ha^{-1} y^{-1}, support maintained over a period of 5 years), as compared to the case of pure biochar only (250–190 € ha^{-1} y^{-1} at an application rate of 5 Mg ha^{-1}), and adjusted to the additional economic support provided by ETS allowances and a premium for low ILUC feedstock for biofuel production. The proposed approach and the amount of applied biochar could also be improved by replicating the operation twice or three times, as it already happens with compost distribution, thus increasing the quantity of biochar or COMBI products distributed over the soil and consequently the long-term storage of carbon.

The proposed system will also stimulate the use of compost in agriculture, a widely available feedstock not yet adequately exploited in several EU countries despite its large potential and the huge volume of unused residues available at farm scale.

Considering that current returns of sunflower cultivation in conventional land range from 150 to 350 € ha^{-1}, the analysis showed that COMBI can achieve these figures (at the highest yield, in case of absence of a REDII premium, or at lower yields, with REDII premium) with a limited support given from CAP and positive effects on crop yields. Adding higher amounts of biochar per ha, or achieving higher yields than those estimated (based on a conservative approach), would

Table 5
Estimated seed yields in conventional and marginal land, at 0 Mg ha^{-1}, 5 Mg ha^{-1} biochar and 10 Mg ha^{-1} 20% w/w biochar + 80% w/w compost (COMBI) application.

	Yield ranges (Mg ha-1)					Reference Scenario
Reference case: conventional land	2,2	2,4	2,6	2,8	3	*0*
Marginal land - 0 Mg ha^{-1} biochar addition	1,6	1,7	1,9	2,1	2,3	*1*
Marginal land - 5 Mg ha^{-1} biochar addition	1,8	1,9	2,1	2,2	2,4	*2,3,4*
Marginal land - 10 Mg ha^{-1} COMBI addition (20% biochar + 80% compost)	2,0	2,2	2,3	2,5	2,6	*5,6,7*

Table 6
Summary of support schemes from the economic policies for the different scenarios.

	Support considered for each scenario	CAP to Sunflower Production	CAP to Biochar or COMBI deployment per year	CAP to Biochar or COMBI deployment over 5 years	ETS	Max premium on seed production from multiple counting	Min premium on seed production from multiple counting
		[€ ha^{-1} y^{-1}]	[€ ha^{-1} y^{-1}]	[€ ha^{-1}]	[€ ha^{-1} y^{-1}]	[€ ha^{-1} y^{-1}]	[€ ha^{-1} y^{-1}]
0	Ref Case, conventional land	330,00	0,00	0,00	0,00	0,00	0,00
1	Marginal land - reduced yield per ha	330,00	0,00	0,00	0,00	0,00	0,00
2	Marginal land, biochar recovered, CAP support	330,00	250,00	1250,00	0,00	0,00	0,00
3	Marginal land, biochar recovered, CAP support, ETS	330,00	190,00	950,00	300,57	0,00	0,00
4	Marginal land, biochar recovered, CAP support, ETS, biofuel premium	330,00	150,00	750,00	300,57	212,63	161,67
5	Marginal land, COMBI recovered, CAP support	330,00	140,00	700,00	0,00	0,00	0,00
6	Marginal land, COMBI recovered, CAP support, ETS	330,00	120,00	600,00	120,23	0,00	0,00
7	Marginal land, COMBI recovered, CAP support, ETS, biofuel premium	330,00	70,00	350,00	120,23	232,88	182,75

obviously modify in a negative or positive direction the results: most likely, given the current growing market forecasts for ETS, the use of biochar in agriculture as a mean for carbon sequestration will be boosted [60], as also reported in the latest IPCC report [61], where biochar and pyrogenic carbon capture and storage are, for the first time, cited and credited as promising negative emission technology. Determining this will however require further and more site and crop-specific investigations.

Regarding the cost associated to C sequestration, this is estimated at ~300 € Mg^{-1} of C, assuming a conservative figure of ≥70% fixed-C content in the biochar, which corresponds to approximately 82 € Mg^{-1} of CO_2. This figure is very consistent with other competing Carbon Capture Sequestration (CCS) options, which costs can be reasonably estimated at a range between very optimistic figures as ~10 US$ Mg^{-1} of CO_2 and well above 100 US$ Mg^{-1} of CO_2 [28,62]. However, while costs for CO_2 sequestrations can be similar, these measures do not offer all the benefits of biochar and COMBI. In fact, CCS (differently from the even more complex CCU) will only generate the cost associated to the collection and sequestration of carbon, without any positive income generation in commercial economic activities. On the contrary, biochar and COMBI deployment on agricultural soil, in addition to a cost associated to production and deployment in the soil (for which the C sequestration potential is huge), will also generate a positive cash flow and additional direct income, in the form of:

- Increased crop yields in marginal land, otherwise of low economic interest.
- Recovery of land unsuitable for cultivation, being abandoned and therefore not generating any income for the farmers (thus, creating also land value, in addition to returns from crop cultivation).
- Promotion and deployment of improved and more sustainable agricultural practices, towards circular economy models and increased resilience of the land to climate change.

These are all benefits that do not occur with CCS measures, despite similar costs.

Summarising, the use of biochar and compost, far from being a single solution to the problem of desertification and carbon storage, can represent a possible and significant component of a wider strategy to fight climate change, and produce biomass feedstocks for renewable energy. Attention must be paid to the way the value chain is planned and implemented as well as to ensure the necessary process controls are adopted. In fact, it is mandatory to ensure that only suitable feedstocks are processed through slow pyrolysis and composting (i.e. lignocellulosic residual biomass, organic fraction of municipal solid waste, digestate from anaerobic digestion of biomass), and that contaminated materials are not introduced in the system. The development of consortia of farmers and producers, owning and operating both the biochar and the compost plants, as well as using and commercializing the products, could be a possible way to guarantee the quality of biochar and COMBI, implementing a truly circular economy system.

5. Conclusions

The work presented in this paper aimed at providing evidence on how existing economic support instruments deriving from EU policies on agriculture, climate and energy could facilitate the use of biochar in marginal agricultural lands in Mediterranean countries, while favouring agriculture and storing carbon. The research analyzed the specific case of sunflower cultivation in Italian marginal land. Key concluding remarks are:

- The marginalization of the land due to desertification is one of the main concerns in the Mediterranean agriculture, and a major reason for land abandonment, well documented over the last decades in many EU Countries.

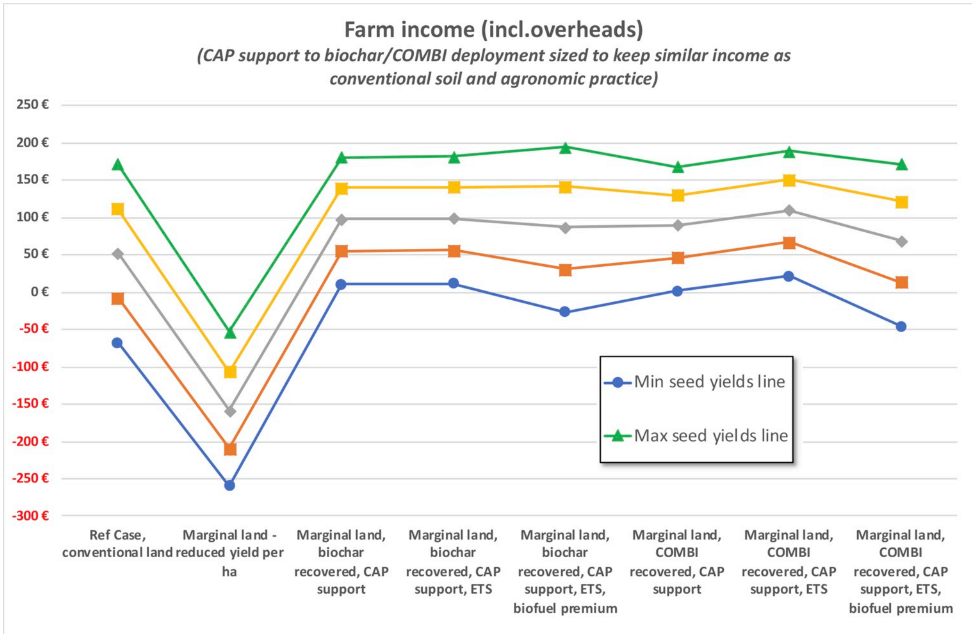

Fig. 3. Estimated farm income for the different modelled scenarios. Calculations based on maximum and minimum seed yield per scenario as reported in Table 5.

Table 7
Biochar and COMBI generated economic performances (€ ha^{-1}) in sunflower cultivation vs conventional and marginal land.

		Min yield				Max yield
0	Ref Case, conventional land	−68 €	−8 €	52 €	112 €	172 €
1	Marginal land - reduced yield per ha	−259 €	−210 €	−159 €	−106 €	−53 €
2	Marginal land, biochar recovered, CAP support	11 €	55 €	98 €	140 €	181 €
3	Marginal land, biochar recovered, CAP support, ETS	11 €	56 €	99 €	141 €	181 €
4	Marginal land, biochar recovered, CAP support, ETS, biofuel premium	−27 €	31 €	87 €	141 €	194 €
5	Marginal land, COMBI recovered, CAP support	1 €	46 €	90 €	130 €	168 €
6	Marginal land, COMBI recovered, CAP support, ETS	21 €	67 €	110 €	150 €	188 €
7	Marginal land, COMBI recovered, CAP support, ETS, biofuel premium	−46 €	13 €	69 €	122 €	171 €

- Given the ongoing desertification effects and the extreme climatic conditions already impacting the region, and considering past and current markets for sunflower as a typical oil crop, the economic viability of oilseed cropping is rapidly decreasing whilst agriculture is becoming less competitive in many sites and conditions. Farmers' income sometimes even hardly reaches the CAP support itself, or stays below (if not becoming negative), as unfavourable weather conditions occur, such as extreme flooding or droughts, occur. The marginalization of the land due to the impacts from the desertification effects is one of the main concerns in the Mediterranean agriculture, and a major reason for land abandonment, well documented over the last decades in many EU Countries.
- The use of biochar and biochar + compost (COMBI) can help mitigate these effects and support sustainable agriculture. Biochar provides long-term benefits to the land by reconstituting the soil matrix, improving porosity, increasing moisture retention and slowing release of fertilizers. The combined use of biochar and COMBI adds further benefits for the short-term, combining readily available carbon and nutrients with the long-term benefits of biochar, stimulating farmers to recover compostable agricultural residues, and citizens to separate and recycle the organic fraction of municipal wastes. This approach also increase soil resilience to climate change, generating a kind of "reverse Land Use Change" effect, since agricultural soil is kept productive or recovered, instead of becoming deserted with a net loss of organic carbon and microbial life
- The amount of marginal land in the EU Mediterranean Countries is significant, being estimated at 8.5 Mha. This means that the potential impact of a biochar-based BECCS (BioEnergy and Carbon Capture and Storage) strategy in the EU MED region is considerable, even at the rather low (2.0–5.0 Mg ha^{-1}) biochar application rate considered in this study. If a theoretical potential in the range of 17–42.5 Million Mg biochar is deployed, with at least 70% w/w fixed carbon, this corresponds to a theoretical potential of 156 Million Mg of sequestered CO_2. This figure roughly amounts to almost 3.5% of total EU-28 GHG emissions (including international aviation and indirect CO_2, excluding LULUCF) in 2015 (equal to 4451.8 Million Mg of CO_{2equiv}), or more than 10% of EU Mediterranean (PT, ES, FR, I, HR, EL, CY) countries only (1471 Million Mg of CO_{2equiv}) [63].
- Large scale deployment of biochar however requires adequate and stable policy support, through various instruments. This paper concluded that several relevant tools already exist and identified some of these within the Common Agricultural Policy, the Energy Policy, and the Climate Change Policy. Moreover, other policies could also apply, *in primis* the Circular Economy policy.
- Through these policy instruments in the selected EU Mediterranean region, farmers could gain sufficient economic returns to continue their activities, developing further or at least protecting the socio-economic status in rural areas.
- Differently to most CCS measures, the C stored in the soil will generate several additional environmental benefits in these critical areas (on top of the economic positive effects related to the continuation of the agricultural production on these soils), adding to the

C-negative benefits those related to the reduction of N_2O emissions and N leaching (still GHG-related benefits), the improvement of the microbial life, etc.
- Finally, the proposed approach would go far beyond the North rim of the EU Mediterranean area, covering also the non-EU Southern rim and other similar regions of the world. Bringing development into these regions would generate a positive integration with other goals of main EU policy, such as those on immigration and international cooperation. These would represent additional benefits from the action.

However, given the high variability of results reported in literature on biochar and COMBI effects, all related to the specific type of soil, local climate, type of cultivated crop, and characteristics of the specific biochar type under investigation, it is essential to demonstrate the impact and the results of these measures under each representative conditions. A small amount of EC budget available under different EU and MS programmes, as CAP, Energy or Climate, could thus be allocated to validate these estimates on a site-specific local basis, to map at EU MED regional scale the potential impact, quantify benefits, and generate harmonized and innovative EU policies able to integrate agriculture, energy and climate into a single complementary policy framework.

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Glossary

BECCS: Bioenergy Carbon Capture and Storage
CAP: Common Agricultural Policy
CCS: Carbon Capture and Storage
CCU: Carbon Capture and Utilization
COMBI: Co-composted biochar and organic matter
EC: European Commission
ETS: Emission Trading Scheme
EU: European Union
FQD: Fuel Quality Directive,
ILUC: Indirect Land Use Change
MED: Mediterranean
MS: Member State
RDP: Rural Development Plan
RED: Renewable Energy Directive,
RES: Renewable Energy Sources
R&D: Research & Development
SOM: Soil Organic Matter
UUA: Utilised Agricultural Area