Renewable and Sustainable Energy Reviews 103 (2019) 58–70

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Ongoing and emerging issues for sustainable bioenergy production on marginal lands in the Mediterranean regions

Giuseppe Pulighe[a,*], Guido Bonati[a], Marco Colangeli[b], Maria Michela Morese[b], Lorenzo Traverso[b], Flavio Lupia[a], Cosette Khawaja[c], Rainer Janssen[c], Francesco Fava[d]

[a] CREA Research Centre for Agricultural Policies and Bioeconomy, via Po 14, 00198 Rome, Italy
[b] FAO Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy
[c] WIP Renewable Energies, Sylvensteinstr. 2, D-81369 Munich, Germany
[d] ILRI International Livestock Research Institute, P.O. Box 30709, 00100 Nairobi, Kenya

ARTICLE INFO

Keywords:
Bioenergy crops
Marginal land
Biomass production
GBEP sustainability indicators

ABSTRACT

The cultivation of marginal lands for bioenergy production has recently become a topic of research interest for the agronomic and agricultural economy scientific communities. The growing availability of arable land in the Mediterranean regions, as a consequence of the decline of cereal cropping systems and grain legume, provides ample opportunities for performing successful feedstock production on unmanaged areas. This paper seeks to capture and analyze ongoing and emerging questions concerning bioenergy production on marginal lands in the Mediterranean area in a framework of sustainability indicators. A qualitative methodology was adopted to evaluate the effectiveness of eight critical issues that bio-energy developers, scholars and policymakers should consider in terms of agronomic, techno-economic and methodological practices for growing bioenergy feedstock. The issues investigated on selected case studies are: Greenhouse gas emissions; soil quality; land restoration and phytoremediation capacity; water use and efficiency; biodiversity; land use/cover changes; farmers' willingness and acceptance of new agro-system, and profitability of value chain. Starting from an in-depth analysis of the definition of marginal land from the perspective of ecosystem service cascade, we synthesize how these challenges are nowadays addressed and which are the key bottlenecks, trends and potential directions for guiding future research into bioenergy production in the Mediterranean regions. The findings of this study suggest that dedicated energy crops can be grown on marginal lands with substantial positive effects in terms of sustainability aspects, although more efforts should be carried out through agronomic research especially on water use efficiency and biodiversity conservation, as well as by national and EU institutions and policies for promoting economic opportunities and integration with surrounding agro-ecosystems and farmers' involvement. Developing a site-specific landscape design with the use of Life Cycle Assessment and certification schemes with sustainability indicators is of primary importance for the effective bioenergy production on marginal lands.

1. Introduction

As a resource base for the bioeconomy, agricultural biomass production plays a pivotal role in the production of food and feed, as well as raw materials for a number of end-products in biorefineries [1]. In recent years, several international organizations, governmental institutions, researchers and experts have advocated and promoted the cultivation of biomass for energy purposes (bioenergy) on marginal

Abbreviations: EU, European Union; GBEP, the Global Bioenergy Partnership; MOA, Ministry Of Agriculture; MNRE, the Ministry of New and Renewable Energy; OECD, the Organization for Economic Co-operation and Development; EEA, European Environmental Agency; APEC, the Asia-Pacific Economic Cooperation; CGIAR, the Consultative Group for International Agricultural Research; USDA-NRCS, the United States Department of Agriculture, Natural Resources Conservation Services; FAO, Food and Agriculture Organization of the United Nations; GHG, Greenhouse gas emissions; ISI, the Institute for Scientific Information; KML, Keyhole Markup Language; LCA, Life Cycle Assessment; GPS, Global Positioning System; GIS, Geographic Information System; CAP, Common Agriculture Policy; EPIC, the Environmental Policy Integrated Climate model; SWAT, the Soil & Water Assessment Tool model; DSSAT, the Decision Support System for Agrotechnology Transfer odel; BioMA, the Bio-physical Model Applications Framework model; FACE-IT, a Framework to Advance Climate, Economic, and Impact Investigations with Information Technology; APSIM, the Agricultural Production Systems sIMulator model

* Corresponding author.
E-mail address: giuseppe.pulighe@crea.gov.it (G. Pulighe).

https://doi.org/10.1016/j.rser.2018.12.043
Received 18 May 2018; Received in revised form 18 December 2018; Accepted 19 December 2018

lands, as a compromise for resolving the competing claims on traditional food production on agricultural land, and a viable pathway towards a sustainable and low-carbon society [2–9]. In this sense, governments promoted ambitious policies and development programs designed to foster and adapt dedicated bioenergy crops by increasing their yield, quality, and ability to adapt to the conditions found on marginal lands [10]. Meanwhile, driven by these mandates, the cropland footprint area related to European Union (EU) bioenergy is projected to grow to 14.3 Mha in 2020 [11]. Whereas EU farmers increased rapeseed area to 6.7 Mha in 2017/18 (mainly biodiesel driven) [12] and over 3 million tonnes palm oil feedstock are expected to be imported in 2020, mainly from Malaysia, China and Indonesia [13].

Nonetheless, there is a particular concern for the so called 'food, energy, and environment trilemma' [14] that the production of bioenergy will have on global greenhouse-gas emission, in a post-fossil-fuel world with an increasing demand and competition for land resources [15]. In addition, questions have been raised about the trade-offs between food production and bioenergy (food vs. fuel controversy), in a common debate regarding food security and uncertain availability, access, use, and stability of food to sustain humanity [16]. Furthermore, significant challenges have emerged on the transitions to bioenergy crops in relation to environmental issues such as the impact on land use changes (and indirect land use changes), water resources, biodiversity and habitat conservation [17,18].

A key open issue concerns how to best allocate these crops within traditional agricultural systems, resolving at the field scale the controversies on land use scenarios (land sharing vs. land sparing) [19], but at the same time preserving and enhancing ecosystem services in a framework of new nature-based solutions [20], to turn environmental, social and economic challenges into innovation opportunities. Although this is a global debate, new and smart opportunities and solutions are urgent, especially for the Mediterranean agricultural systems and farmers, considering that the expected effects of climate change to 2050 could result in much lower farm net incomes in Southern regions compared to Northern regions [6,21].

Despite the growing momentum in support of marginal lands for producing biomass in Mediterranean regions, landscape planners, policymakers and decision-makers are still poorly equipped to evaluate and thoughtfully integrate bioenergy crops into sustainable farming projects on drought-prone environments.

Up to now, previous efforts have been driven mainly by prevailing economic analyses and potential feedstock production evaluations covering temperate climates [5,22–24]. In these contexts, a suite of effective indicators and institutional frameworks were developed for assessing and measuring the sustainable production of bioenergy. They are intended to provide stakeholders with a set of analytical tools for policy decision making, management strategies' design and alternative value chains comparative analyses. The most widely known and recognized tools for supporting the decision-making process include indicators proposed by the Global Bioenergy Partnership (GBEP) [2], the Roundtable on Sustainable Biomaterials [25], the Council on Sustainable Biomass Production [26], the International Organization for Standardization Sustainability criteria for bioenergy [27], and the International Sustainability and Carbon Certification [28].

At the same time, the increasing need to account for linkages among dedicated energy crops on under-utilized land, ecosystem services (or disservices) and environmental impacts, has stimulated in recent years a growing number of cross-sectional studies and reviews [5,17,29]. These studies suggest in most cases positive outcomes in terms of biomass potential and input management, biodiversity and ecosystem service provision, while in other studies discrepancies or neutral effects are reported [30–33]. However, the majority of research studies on feedstock production to date have focused on Atlantic and continental environments (e.g., USA, Canada, North and Central Europe). In addition, these studies mainly considered environmental and agronomic aspects, paying too little attention to relevant social and economic perspectives. On the contrary, only few studies have investigated and synthesized the key challenges and issues on sustainable developing feedstock supply chain in traditional cropping systems in Southern Europe, which are mainly based on cereal based rotations, forage and horticultural crops [34]. In fact, the expansion of monoculture plantations in drylands could represent a serious threat specifically for water use and availability, soil erosion and land degradation. In relation to energy crops, recent EU projects such as OPTIMA, FORBIO, SEEMLA, WATBIO, and extensive scientific evidences suggest that 'second-generation' lignocellulosic feedstock production systems (e.g. switchgrass (*Panicum virgatum* L.), *Miscanthus* (*Miscanthus* × *giganteus* Greef et Deuter), cardoon (*Cynara cardunculus* L. var.*altilis*), giant reed (*Arundo donax* L.), and removal of crop residues) are the most promising candidates to be grown on less favorable agricultural lands [35–37]. In summary, skepticism, divergent points of view and controversial debate on second-generation bioenergy crops [38,39] raise many open research questions that shall be addressed concerning the technology-driven transition to a new bio-based energy system.

The purpose of this study is to explore and discuss ongoing and emerging critical questions for supporting realistic lignocellulosic feedstock production on marginal agricultural lands within a framework of science-based and technically-sound sustainability indicators. The study examines in particular the challenges regarding European Mediterranean countries, considering their unique and complex landscape characteristics influenced by topography, soils and surface water conditions [40]. The overall structure of the study is articulated in four sections. The first section investigates the paradigm definitions of marginal land in a vision of context and scale in which they are used. The concept was then contextualized for the bioenergy sector in an ecosystem services perspective. The second section gives an overview of the relevant indicators to evaluate the sustainable bioenergy production. The third section outlines the main challenges and issues for biomass cultivation, with a selection of studies linked with the sustainability indicators relevant for the Mediterranean regions. The final section serves as a platform for setting the context, to share and emphasize strengths, recommendations and strategic suggestions for planners, practitioners and policymakers for better designing and managing of sustainable bioenergy supply chains on marginal lands.

2. The paradigm of marginal lands

The concept and definition of marginal lands have different meanings depending on the reference discipline and context and varies according to the scope and purpose in which is used. The term 'marginal' was originally used under the umbrella of economic theorizing to describe an area, under given conditions, where cost-effective production is not remunerated [41,42]. Table 1 lists a set of available definitions of the concept of marginal land that, over time, was further developed and improved by many international organizations and institutions within their policies, legislations and activities.

For example, OECD defined marginal land as an area with poor agronomic characteristics, and unsuitable for housing and other uses. Similarly, CGIAR emphasized the concept of limitations of land for sustained application of a given use, while USDA-NRCS stressed poor combination of physical and chemical characteristics of the soils for the productivity potential. Remarkably, The World Bank pointed out also the untapped potential of areas (less favored) that are farther from markets (e.g. lack of transport infrastructure), although with crop production potential. In an investigation into degraded land and sustainable bioenergy feedstock production Wiegmann et al. [51] concluded that marginal land, *"……defined as an area where a cost-effective production is not possible"* might supply food, feed or bioenergy feedstock, "…… *but not through a structured, market-based approach"*.

Taken together, these definitions suggest foremost a pertinent role for the physical limitation of the soil capacity for land use productivity and management on a static imaginary. Further meanings may also

Table 1
Overview of marginal land definitions usually reported in the international institutions. The list is not exhaustive, but suggestive of different definitions and visions of marginal land.

Institution	Definition of marginal land	Reference
People's Republic of China, MOA	Winter-followed paddy land and waste land that may be used to cultivate energy crops	[43]
Government of India, MNRE	Degraded or wastelands that are not suited to agriculture, used for non-edible feedstock	[44]
OECD	Land of poor quality with regard to agricultural use, and unsuitable for housing and other uses	[45]
EEA	Low quality land the value of whose production barely covers its cultivation costs	[46]
APEC	Lands characterized by poor climate, poor physical characteristics or difficult cultivation	[47]
CGIAR	Land having limitations which in aggregate are severe for sustained application of a given use. Increased inputs to maintain productivity or benefits will be only marginally justified	[48]
USDA-NRCS	As opposite of prime farmland, marginal land has poor combination of physical and chemical characteristics of the soils for producing food, feed and forage	[49]
World Bank	Interchangeably used with fragile and less favored land (with poor market access), arid and semi-arid regions characterized by frequent moisture stress that limits agricultural production	[50]

MOA: Ministry Of Agriculture; MNRE: The Ministry of New and Renewable Energy; OECD: the Organization for Economic Co-operation and Development; EEA: European Environmental Agency; APEC: The *Asia-Pacific Economic Cooperation; CGIAR:* the Consultative Group for International Agricultural Research; USDA-NRCS: the United States Department of Agriculture, Natural Resources Conservation Services.

refer to terms such as fragile, degraded, contaminated, reclaimed, abandoned, under-utilized, barren and idle lands [52], although may be very rich on biodiversity (e.g. priority species) with key ecosystem processes.

Marginal lands are conceptualized in a vision of anthropogenic use-value attribution of the nature, in line with the concept of ecosystem service proposed by Haines-Young and Potschin [53]. In this cascading approach, biophysical structures generate ecosystem functions and consequent services and values for human well-being. Thus, marginal lands are those that, in a given place, generate ecological functions and services or benefits for humans 'below' certain expectations (for a given use), where the 'degree of intensity' is linked to the opportunity cost of this land [54]. This is clearly a context and temporal scale concept, adaptive and flexible, where the human intentions and activities in these lands are intended to maximize the provision of specific services. Considering all of these evidences and following the framework proposed by Richards et al. [55], in this study the concept of marginal agricultural lands to produce bioenergy have been framed in four main academic disciplines covering geomorphology, agronomy, economy and socio-cultural aspects (Table 2). Within each discipline, a context scale of application and a set of key indicators for a rigorous and objective measurement analysis have been identified.

Table 2 definitions might suggest that starting from limited or degraded geomorphological conditions (e.g. stoniness), marginal lands are located on soil types with low agronomic potential (e.g. water-holding capacity) that are consequently unable to support satisfactory biomass production and profitability for landowners and farmers, and ultimately, the well-being of the local community living in these places.

Therefore, marginality is a cumulative phenomenon derived from the combination of several related factors that can be related to verifiable and observable disadvantages (sometimes transient) or use restrictions. Of course, this is just a general scheme as the anthropogenic pressures and modification of the environment with input materials and technical improvements, energy and labor can change these dynamics and the resulting intended or perceived marginal state. For example, territories with so-called 'heroic' viticulture, characterized by severe limitations for agriculture (steep slope, stoniness) are today conducted by professional and competitive winemakers that produce top wines of excellence for niche markets [60] with high economic returns. Despite the harsh agro-ecological conditions of these environments, these vineyard landscapes have a high level of real estate income and are not seen as marginal lands from a socio-cultural and economic point of view. The human driving forces are able to successfully manage these limiting conditions, moving up the profitability of the 'biomass value-web system' [61] and moving down the line of marginality (with respect opportunity cost). The concept of the biomass value-web takes into account the interlinkages and networks of different value chains in the bioeconomy [62]. As an illustration of these concepts, Fig. 1 presents an overview as a possible pathway for the bioenergy system on marginal lands in the Mediterranean area. The *x-axis* represents the transition of ecosystem functions and services of biomass generation, while the *y-axis* represents the intensity of these transitions modified by human intervention (e.g. payments for biomass, monetary units, private or public goods), explicitly expressed as profitability.

In summary, the potential use of marginal lands for bioenergy feedstock production starts with an implicit assessment that a land unit has an under capacity to maximize profitability in the market (in absence or distance to market) at a breakeven point with production costs [22]. As recently suggested by Spangenberg et al. [63] landscape planning processes for promoting bioenergy could benefit from the reverse application of the cascade model as 'stairways' for generating and allocating ecosystem services. The human demand for service-oriented products is the starting point that lays down the pathway of the supply side management.

Therefore, the residual production capacity of marginal land can be upgraded in the context of bioeconomy sector, where new business models (e.g. biorefineries, processing technology, new ways of recycling, new bio-products) exploit the use of renewable resources and their conversion into value-added products. In this sense new agro technologies can unlock new opportunities, for example using breeding and new genome editing (improved yield, disease resistance) [64] as well as wild germplasm, flex crops (with multiple uses) and orphan crops (important where they are grown), promoting agro-ecological approaches (e.g. use of biochar, digestate, strip tillage) and implementing smart tools for farmers and companies (e.g. big data and smart farming, drones, traceability systems, sensing technologies) [65]. Ultimately, the challenge for the bioenergy production in marginal land is to scale up, in a sustainable way, an economically attractive and flexible biomass 'value-web' [66], by contrast to the narrow value chain that increases services, values and benefits for landowners, stakeholders and local communities.

3. Bioenergy production and sustainability indicators

Sustainability indicators play a pivotal role for monitoring progresses towards the achievement of policy goals, be it the EU-set of policy objectives, the Sustainable Development Goals or any other local, national, regional, and/or global compendium of policy targets. Progress toward sustainable bioenergy systems requires reliable and well-recognized indicators to assess performances of an existing bioenergy value chain at multiple scales. When sustainability indicators results are checked against performance measures (e.g. as set by a given standard or threshold) these can compose the cornerstone of a certification scheme. To date, many organizations, institutions and various

Table 2
Overview of marginal land definitions in the academic field and main measuring indicators. The structure follows the suggestion of Richards et al. [55] regarding the specification of biophysical factors and socioeconomic context contributing to marginality.

Academic discipline	Definition	Context scale	Indicators of marginality	References
Geomorphology	*(Reference to supporting/habitat capacity)* Lands with physical, soil and climate limitations and restrictions, with limited capacity to sustain ecosystem services	Local, regional	Altitude, slope and relief, soil profile, erosion, stoniness, groundwater level, surface water, contaminants, pollution, climate limitations	[56]
Agronomy	*(Reference to production capacity, provisioning, input resources)* Lands poorly suited to cultivation due to inherent edaphic or climatic limitations or because they are in areas affected by erosion or other environmental risks when cultivated	Local	Crop productivity, soil quality, waterholding capacity, evapotranspiration, organic matter, nutrients availability, drainage, salinity, soil texture, pH, compaction	[6]
Economy	*(Reference to economic capacity)* Land where cost-effective production, under given environmental conditions, cultivation techniques, agriculture policies as well as macro-economic and legal conditions is not possible	Local, regional	Costs of production, added value, revenues, cost/benefit analysis, net present value, discounted cash flow, gross margin, profitability, access to market	[41,57]
Socio-cultural	*(Reference to a combination of social and cultural condition)* Land with poor quality of life, or where quality of life indicators are below the reference average. Linked with deprivation and disadvantage concepts	Local, regional, national	Health, education, income, accessibility, personal motivations, leisure and social interactions, crimes, livelihoods, population density, aesthetic, recreation	[58,59]

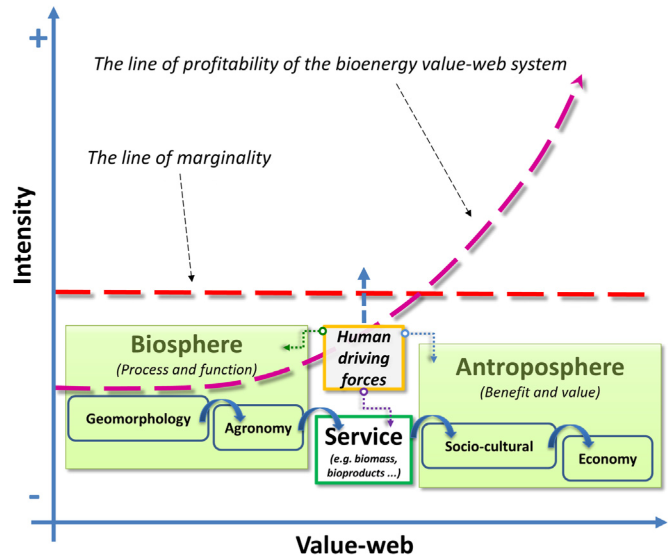

Fig. 1. Schematic framework of the bioenergy system in the vision of the ecosystem service cascade, as illustrated by Haines-Young and Potschin [53]. The line of marginality is flexible, where human driving forces (e.g. planning, management, investments) mediate the breakeven point with the value-web system (e.g. economic return), on the base of societal needs and expectations.

international initiatives have attempted to promote the production of biomass for bioenergy in a coherent and sustainable way. A recent literature review on the subject was presented by Fritsche and Iriarte [67] that presented an overview of sustainability initiatives and efforts related to requirements, criteria and indicators for biomass used for bioenergy. Among these, this study adopted the indicators proposed by GBEP and published by the Food and Agriculture Organization of the United Nations (FAO) in 2011 [2] (Table 3) to promote and provide a mechanism for Partners (mainly national governments and international organizations) for the sustainable development and use of bioenergy. The indicators are intended to provide information about the environmental, social and economic aspects of the bioenergy sector, to monitor impacts and trends, and to guide policymakers towards policies that foster sustainable development.

In the specific case of assessment of sustainability to be performed on Mediterranean marginal lands, a strength of the GBEP indicators is that they are explicit with regard to the specific purpose and framework of the analysis [68]. Furthermore, these indicators present the pathway for assessing the sustainability of modern bioenergy production with a scientifically sound manner, applicable and adaptable in a broad range of contexts and scales. In fact, the indicators are inter-related and transdisciplinary, practical to implement, sufficiently sensitive and easily recognizable for all relevant stakeholders [69], including non-scientific communities and civil society.

Applied to all types of biofuels (e.g. liquid, solid, and gaseous for electricity, heat and transport), and "…… *measured over time, they will show progress towards or away from a targeted sustainable development path* [2]". The GBEP indicators are mainly designed and selected for ex-post assessment of a country's bioenergy sector, thus aggregating performances of individual operators into an average national value. The indicators were selected to be "…… *value-neutral and do not feature directions, thresholds or limits and do not constitute a standard* [2]".

Each indicator was presented with three parts: 1) the name; 2) short description; 3) methodology sheet. The first part of the methodology sheet describes how the indicator relates to relevant themes of sustainability and how the indicator contributes towards assessing sustainability at the national level. The second part describe the methodology in a scientific way, for collecting and analyzing the data needed to evaluate the indicator, as well as for making relevant comparisons to

Table 3
Overview of 24 sustainability indicators developed by GBEP [2].

Pillars		
GBEP's work on sustainability indicators was developed under the following three pillars, noting interlinkages between them:		
Environmental	**Social**	**Economic**
Themes		
GBEP considers the following themes relevant, and these guided the development of indicators under these pillars:		
Greenhouse gas emissions (GHG), Productive capacity of the land and ecosystems, Air quality, Water availability, use efficiency and quality, Biological diversity, Land-use change, including indirect effects	Price and supply of a national food basket, Access to land, water and other natural resources, Labor conditions, Rural and social development, Access to energy, Human health and safety	Resource availability and use efficiencies in bioenergy production, conversion, distribution and end-use, Economic development, Economic viability and competitiveness of bioenergy, Access to technology and technological capabilities, Energy security/Diversification of sources and supply, Energy security/Infrastructure and logistics for distribution and use
Indicators		
1. Lifecycle GHG emissions	9. Allocation and tenure of land for new bioenergy production	17. Productivity
2. Soil quality	10. Price and supply of a national food basket	18. Net energy balance
3. Harvest levels of wood resources	11. Change in income	19. Gross value added
4. Emissions of non-GHG air pollutants, including air toxics	12. Jobs in the bioenergy sector	20. Change in the consumption of fossil fuels and traditional use of biomass
5. Water use and efficiency	13. Change in unpaid time spent by women and children collecting biomass	21. Training and requalification of the workforce
6. Water quality	14. Bioenergy used to expand access to modern energy services	22. Energy diversity
7. Biological diversity in the landscape	15. Change in mortality and burden of disease attributable to indoor smoke	23. Infrastructure and logistics for distribution of bioenergy
8. Land use and land-use change related to bioenergy feedstock production	16. Incidence of occupational injury, illness and fatalities	24. Capacity and flexibility of use of bioenergy

other energy options or agricultural systems. In addition, potential limitations and bottlenecks in the methodology are provided, as well as possible ways to reduce uncertainties. The third part describe detailed data requirements, data sources, strategies for data gap filling, and a link with other international processes that provide similar measurements and procedures. Finally, useful references to collect data and information (i.e. scientific literature, international reports and electronic sources) are provided.

In the case of sustainability assessment on Mediterranean lands, the GBEP indicators require ad-hoc adaptation to describe sub-national features of the studied value chain. In fact, the case of bioenergy feedstock production on Mediterranean marginal lands, brings about aspects that are not directly but only indirectly captured by the GBEP indicators, while some indicators are clearly irrelevant to the context of Mediterranean countries. Moreover, indicators of sustainability can be useful also as a predictive tool, thus as an aid to make future projections of sustainability characteristics of a given value chain that at present is not established, in a scenario where such value chain exists. The need for developing new methodologies and tools for assessing the impacts of bioenergy at local (regional or sub-regional) and site-specific (municipality) level on under-utilized and marginal lands, encouraged FAO to develop a user-friendly and tailored set of sustainability indicators based on the GBEP ones but specifically made for their use on local, ex-ante context of marginality.

4. Challenges and issues for bioenergy production in Mediterranean regions

This study carried out an analysis of recent studies that deeply analyze and discuss the relevant indicators for bioenergy production in the Mediterranean regions to understand to what extent they have been used by the research community to measure impacts and effects of feedstock production on marginal lands. The indicators analyzed are linked to the conceptual framework for indicators of marginality reported in Table 2 and partially with the GBEP indicators in Table 3. The ISI Web of Science and Google Scholar were used to search and collect relevant papers published in English in peer-reviewed journals. Original papers published in the period 2014–2017 were selected to capture recent progress, following the advanced search for the individual terms 'GHG emission', 'carbon sequestration', 'phytoremediation', 'biodiversity', 'water use efficiency', 'land use', 'profitability', 'farmers willingness', using the connectors (AND, OR, AND NOT) for 'feedstock production' and 'bioenergy' on titles, abstracts or keywords. The great amount of publications was filtered out, focusing in particularly on studies on a farm and landscape scale, prioritizing empirical and original analysis addressing bioenergy production. The choice of the research papers was led by the following criteria:

- indicators, data used, methodology and main findings are clearly described and justified;
- different dedicated energy crops suitable for marginal lands were analyzed;
- case studies representative of the broad EU Mediterranean regions was presented.

The literature review was categorized, and eight seminal studies were selected as the most relevant to illustrate our key discussion elements, organized around key indicators. Overall, the aim was to create a qualitative and exhaustive picture of the topic based on non-idiosyncratic judgments, rather than to perform a formal, systematic review. The work reports a range of research approaches, crops, and spatial scales, representative for scientific advances on marginal land across EU Mediterranean countries (Fig. 2). The analysis of the selected papers begins by highlighting the main impacts and challenges associated with the biomass cultivation in marginal lands from an ex-post perspective to frame the usefulness in using these indicators in a science-based manner. Then an evaluation was performed by extracting quantitative results and reporting on key questions with a discussion and comparison along comparable studies, to flag up key insights and outstanding issues for sustainable bioenergy feedstock production.

Table 4 reports for each paper the key findings, while the final key insights summarize the lessons learned, aiming at comparable information for translating the results into operational implementation. Our analysis identified perennial grasses and annual crops as targeted bioenergy feedstock, considering the main results of the research projects underlined in the introduction (e.g. SEEMLA, OPTIMA) that

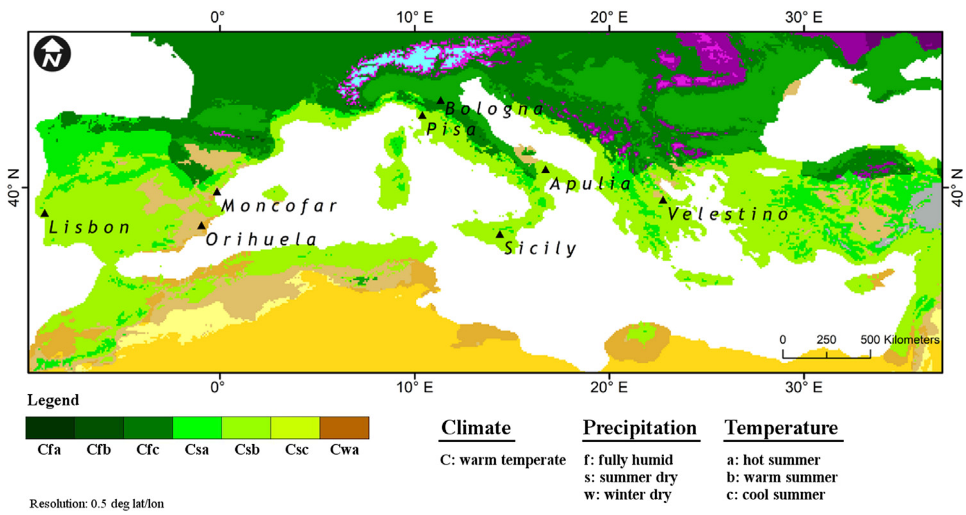

Fig. 2. The climate of the countries adjacent to the Mediterranean Sea. The Mediterranean climate is warm temperate with dry and warm/hot summer (Csa, Csb), based on Köppen-Geiger climate classification [74]. Labels on the map indicate the test sites location of the selected seminal studies analyzed. Map created using the KML file of Köppen-Geiger map freely available at: http://koeppen-geiger.vu-wien.ac.at/.

suggest their adaptability and low environmental impact due to lower amounts of input demands [70]. Although various tree species (e.g. Eucalyptus spp.) and row crops (e.g. maize) are cultivated on marginal land for bioenergy (despite potential environmental drawbacks), their actual adoption depends on local factors or by the public support system with incentive mechanism to meet EU's energy targets as in the case of biogas [71], hence were considered not relevant and therefore excluded from the evaluation. It is widely recognized that biomass yields are affected by management strategies (e.g. fertilization, irrigation) as well as site specific conditions (e.g. weather, soil); consequently, landscape design for bioenergy networks in marginal lands could benefit from a local and context-specific view which considers the variability of sustainability indicators. See Dale et al. [72] and Negri and Ssegane [73] for more details and further explanations on integrating bioenergy production into sustainable landscape designs.

4.1. Impacts on GHG emissions

Bioenergy feedstock production and use of marginal soils in the Mediterranean region could reduce GHG emissions and promote fossil energy savings, and may represent a cost-effective way to counterbalance land use competition, food production and environmental preservation [36]. A recent systematic literature review that analyzes more than one hundred case studies [83] found a clear GHG emissions reduction and a positive energy balance using second generation feedstock for bioethanol production. Using a cradle-to-plant gate Life Cycle Assessment (LCA), Bosco et al. [75] analyzed GHG emissions, energy balance and impacts on air, soil and water of two giant reed systems cultivated in a marginal and fertile soil in Pisa, Italy. In this study the functional unit is taken as 1 ha and 1 t of dry biomass, considering the cultivation phase and biomass transport to the plant gate. The inputs considered include rhizomes nursery, fertilizer, herbicide and diesel consumption for farm tractors. The impact assessment was performed using the GaBi LCA software package [84] and EcoInvent database [85].

Total GHG emission in both systems overcome 2500 kg CO_2eq ha^{-1} y^{-1}, but the more interesting finding is that soil carbon sequestration (calculated as the difference between plots a the establishment year and at the end of growth) was more than twice the total GHG emitted, which are -6464 and -5757 CO_2eq ha^{-1} y^{-1} for fertile and marginal soil, respectively. In fact, the quantification of long-term soil organic carbon changes on the GHG balance is a key element of the cited study and confirmed that giant reed is a carbon negative crop, or a net GHG sink, since they sequestered more CO_2 than the GHG emitted. Recent research in the Mediterranean regions are consistent with these data [86,87], further supporting the ability of the giant reed to mitigate GHG emissions and improve carbon sequestration. Notably, emissions directly related to fertilizer use exceed half of the total emissions, posing a challenge for further investigation on long-term nutrient cycles and management. Priorities for future research should perform LCA approach with different energy cropping systems, using site-specific data derived from field experiment with standardized greenhouse gas accounting procedure. One interesting example was carried out in the OPTIMISC project where a LCA was performed to identify the environmental performance of the *Miscanthus*-based value chains in different climates and on marginal land [88].

4.2. Impacts on soil quality

Perennial rhizomatous crops have great potential to maintain and improve soil quality on land used for biomass production through soil organic carbon accumulation, increasing nutrients availability, and more generally enhancing soil structure, water retention, pH and soil microbial community [36,89,90]. Furthermore, at landscape level these factors are inextricably interlinked and proximate drivers of soil amelioration, helping to prevent soil compaction, erosion and soil degradation in the long-term. Nine years after conversion from annual crop systems (maize and wheat), Gioacchini et al. [76] argue that *Miscanthus* and giant reed were able to significantly increase the amount of carbon accumulation in the soil profile in an experimental farm in Bologna, Italy. Authors assessed the carbon distribution within soil aggregates fractions (macro and micro, silt and clay) in the upper (0–0.15 m), intermediate (0.15–0.30 m) and lowest layer (0.30–0.60 m). The percentage of carbon derived from perennial crops was calculated by using mass spectrometry and the isotope mass balance equation to discriminate the proportion of carbon resulting from the cultivation of cereals.

These findings confirmed that no tillage management promoted the stabilization of the soil and carbon accumulation, approximately 60% more than cereal crops, although differences occurred between *Miscanthus* and giant reed due to their vertical root biomass in the soil. In the same vein, Monti and Zegada-Lizarau [91] documented an accumulation of organic carbon in the whole soil profile on long-term giant reed plantation, thanks to its homogeneous root apparate. A complete soil organic carbon budget with LCA approach, including GHG balance as highlighted in the previous section, is the appropriate approach to depict these impacts.

Creating an inventory of the impacts of long-term soil management for different energy crops systems could be an important step to improve bioenergy management practices, also considering different soil types and interactions with agronomic management (e.g. tillage and agrochemicals) to evaluate runoff, erosion and nutrient leaching.

Table 4
Overview of selected case studies, related indicators, type of biomass, data sources and findings. The key insights are intended as guidance for policymakers and planners for translating the research knowledge into planning and application contexts.

Location	Indicator	Type of biomass	Data source	Findings	Key insights	References
Pisa, Italy	GHG emissions	*Arundo donax* L.	LCA evaluation using primary data for fertile and marginal soil; field operations (fertilizers, pesticide, water, diesel consumption)	The annualized soil carbon gain sequestration was − 6464 kg CO_2eq ha^{-1} in fertile soils (12th year of growth) and − 5757 kg CO_2eq ha^{-1} in marginal soils (5th year of growth)	The net GHG balance for both systems was negative, and confirmed that in the cultivation phase giant reed is a carbon negative crop, or a net GHG sink	[75]
Bologna, Italy	Soil quality	*Miscanthus, Arundo donax* L.	Total C, total N, ^{13}C isotopic analysis on soil samples	In the lowest soil layer, *Miscanthus* and giant reed stored 44 and 35 Mg C ha^{-1}, respectively, while much lower values are stored under annual crops	Perennial crops can represent a promising and sustainable solution not only for energy production but also to restore soil fertility and to increase the C sink potential compared to the annual crops	[76]
Lisbon, Portugal	Land restoration and phytoremediation	*Miscanthus, Arundo donax* L.	Metal concentration (Zn, Cr, Pb) determined by atomic absorption spectrometry	Heavy metal concentration occurs mainly in the hypogeal system, up to 34 mg Pb kg^{-1} dry weight for giant reed, 197 mg Zn kg^{-1} dry weight for *Miscanthus*, and 34 mg Cr kg^{-1} dry weight for giant reed.	Perennial crops showed to be well suited for phytostabilization of heavy metal contamination as these grasses prevented the leaching of heavy metal and groundwater contamination	[77]
Moncofar; Orihuela, Spain	Water use efficiency	*Pancum virgatum* L.	LCA evaluation using weather data, experimental data on the field operations (fertilizers, pesticide, water, electricity, diesel consumption)	Blue water consumption depends on site variability. In Moncofar (Med. climate) blue water consumption is 309 $m^3 t^{-1}$ in the fourth year, namely 3500 m^3 ha^{-1} y^{-1}	Switchgrass could be eligible for electricity production in accordance with the sustainability requirements for GHG saving and water use	[78]
Velestino, Greece	Biodiversity	*Cynara cardunculus* L.	Carabid beetles samples, soil temperature, soil samples for laboratory analysis, weather data, GPS,	Carabid beetle communities, with six species recorded, are positively correlated with the soil organic matter and nitrogen, and are an adequate biodiversity indicator for the Mediterranean area studied	Cardoon favors biodiversity, creating ideal habitats for herbaceous plants and carabids, as indicators of environmental conditions	[79]
River Basin Districts, Spain	Land use	*Arundo donax* L.	Soil database, water electrical conductivity measurements, GIS data, Corine Land Cover 2006, geostatistical analyses	The irrigated and saline agricultural area suitable for biomass production amounted up to 34,412 ha	The use of saline and saline-prone agricultural areas for biomass production avoids competition with agro-food land uses	[80]
Apulia region, Italy	Farmers' willingness and acceptance	Cereal straw	Farmers' questionnaire, local experts, agricultural census, econometric modeling, statistical software	Results show that more than half of respondents would be willing to supply cereal straw for energy purposes	In a new agro-energy industry, farmers will simply re-shape their economic expectations regarding price of the resource they are going to sell	[81]
Sicily region, Italy	Profitability of value chain	*Arundo donax* L.	Structural data and production process (farming operations, inputs required, workload, sales price)	Woodchip production showed the highest net present value and annual gross margin respect to annual crops	Results showed the highest profitability of giant reed respect to other crops with current market prices in the Mediterranean area	[82]

Further open research questions can be raised concerning the use of digestate, animal slurry, biochar or food waste to replace synthetic fertilizers (e.g. in biogas production systems), as well as the evaluation of the effects of rapid residue decomposition and mineralization on drought-prone environments in the Mediterranean regions.

4.3. Impacts on land restoration

The cultivation of lignocellulosic crops is a cost-effective technology that can be effectively used to improve the soil properties of contaminated land with toxic heavy metals and organic pollutants through the process of phytostabilization [92,93]. Moreover, phytoextraction helps to reducing heavy metal leaching into groundwater. Reporting on 2-year pot experiment carried out in Lisbon, Barbosa et al. [77] tested the adaptability and phytoremediation capacity of giant reed and *Miscanthus* spp. on contaminated soil (under the exposure of 450 and 900 mg kg^{-1} dry matter for Zn and Pb; 300 and 600 mg kg^{-1} dry matter for Cr), showing their suitability for phytoextraction and accumulation. In particular, the results confirms that bioaccumulation occurs mainlyin the hypogeal part (i.e. rhizomes and roots), especially Pb and Cr, while Zn is easily transported and accumulated in the aerial fraction. Furthermore, contamination levels did not significantly affect the biomass production if within a certain concentration. Although authors argument that these grasses have a slow removal capacity, these findings have important implications for developing operational protocols regarding the harvesting and removal of above-ground and below-ground biomass in the field.

These findings are encouraging considering that up to now only few sources have reported on phytoremediation using second generation perennial crops on marginal land in Mediterranean countries. Similarly, Fiorentino et al. [94] set up a 2-year open-air experiment aimed at assessing the giant reed potential for phytoextraction and soil fertility restoration, confirming the ability of this crop to grow on polluted soils. Overall, these studies outline a critical role for long-term studies to explain the dynamics of absorption and translocation on different pedoclimatic conditions and therefore the quality of biomass for industrial processing.

4.4. Impacts on water use efficiency

Water availability, use, and efficiency are probably the major limiting factors for feedstock production in the semi-arid Mediterranean area, but at the same time a challenging opportunity to accommodate dedicated energy crops with phenotypic plasticity in terms of drought tolerance, water demand and evapotranspiration rate in drought-prone areas [95]. Yet, bioenergy production has interlinkages on the land-water-energy-food nexus [96], thus, performing a water accounting system is crucial to contain overexploitation of water resources. In a recent LCA study carried out in Spain, Escobar et al. [78] investigated whether switchgrass production fulfils the sustainability criteria, reporting on the impacts of freshwater consumption taking into account both green and blue water (surface and ground water). In the study sites only ground water has been used for irrigation (blue water), while rainfall consumption (green water) has been estimated using the crop evapotranspiration and the Penman-Monteith equation. Overall, blue water consumption is 309 m^3/ton and 3500 m^3/year in the fourth year in Moncofar (Mediterranean climate), while in Orihuela (semi-desert climate, sandy soil) blue water consumption is very high, 963 m^3/ton and 18,444 m^3/year. Switchgrass could be eligible for bioenergy production, but site-specific evaluation is crucial to fulfil sustainability criteria and ensure competitiveness relative to fossil fuels. In the same vein, Giannoulis et al. [97] investigating the response of switchgrass under different agronomic management regimes in Greece, argues that biomass productivity was significantly affected by water availability, fertilization level and soil-climatic conditions.

Water consumption and water efficiency strongly depend on site location and soil water holding capacity, confirming that agronomic management (i.e. irrigation inputs) play a key role in measuring efficiency and performances of bioenergy crops on dry environments. This view is supported by Núñez et al. [98] who concluded that in Spain energy crop rotations (e.g. barley, rapeseed, maize) were most suitable in basins in the northeast, whereas freshwater consumption in the southeast were associated with the greatest environmental impacts. Similarly, Berger et al. [99] highlighted that irrigation of sunflower seed in Spain causes 50% of the impacts resulting from biodiesel, while Fokaides et al. [100] showed that in Cyprus limited water resources of the island are unavailable for irrigate energy crops, whereas there are eligible non-irrigated areas that could potentially be cultivated with indigenous energy crops. Collectively, these studies outline a critical role for water availability at local or watershed level, and consequently the need to deeply evaluate the most resilient crops and cultivars, integrated rotations and agronomic management prior to the bioenergy crop establishment. For example, many recent studies promoted the use of *Cardueae* species as multi-purpose and versatile crops with high water use efficiency that maximize biomass growth during the rainy seasons [101–105].

On the other hand, the inclusion of dedicated bioenergy crops on land reclamation consortia equipped for irrigation (see for example Fig. 3) could open up the opportunity for context-specific landscape design where bioenergy feedstock can be grown on marginal soils (i.e. land capability classes III-IV) so to mitigate competition with food production. The juxtaposition into the best capability classes not strictly marginal (i.e. intercropping, buffer zone, crop displacement) is another option, depending on financial analyses that consider profitability or return on investment, as well as favorable market conditions or policy incentives (cross-compliance with EU Common Agriculture Policy (CAP) support).

4.5. Impacts on biodiversity, ecosystem services and disservices

A number of cross-sectional studies suggest that second generation crops positively impact biodiversity and many ecosystem services if compared to first generation ones in bioenergy landscapes [30,33]. The benefits might contribute to landscape heterogeneity and connectivity with natural habitats, buffer zones around vulnerable areas and protection of riparian areas as well. Investigating the species richness in the low input cardoon plots in Velestino, Greece, Solomou et al. [79] found that carabid beetle communities and abundance of herbaceous plants were positively correlated with the soil organic matter and nitrogen and

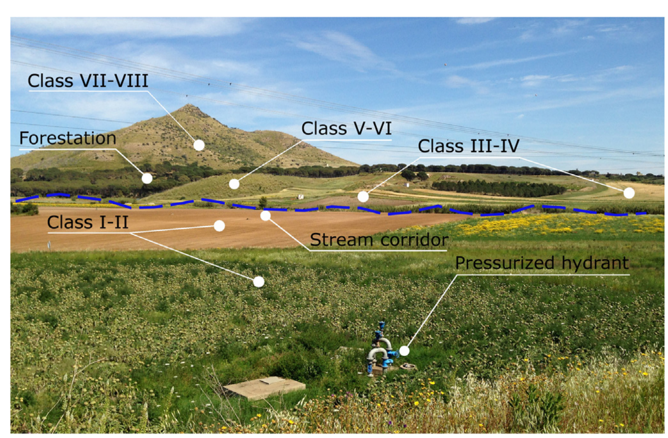

Fig. 3. An example of Mediterranean landscape and soil catena within a Land Reclamation and Irrigation Consortia in Sardinia, Italy. The toposequence of land capability classes, from summit to footslope, shows the increasing soil depth down the slope that affects the suitability for supporting vegetation cover. In the foreground, artichoke cultivation at the end of the growing cycle in spring. Photo credit: Giuseppe Pulighe.

concluded that carabid species richness and plant species diversity was an adequate biodiversity indicator in the study area. The carabid species were sampled by using pitfall traps while herbaceous plants were randomly selected in plots. In addition, soil temperature, soil samples for laboratory analysis, weather data, GPS measurements and statistical analyses were performed to account for correlations between variables as well. Regarding biodiversity on perennial crops, Cattaneo et al. [106] reported increased soil biochemical activity and microbial diversity under *Miscanthus* and giant reed in South European soils, positively correlated with soil carbon and nitrogen contents.

However, although many scholars have recently emphasized the role of different bioenergy crops in supporting biodiversity [33,107], it should not be overlooked that the length of most of these studies was temporarily limited, especially to perennial crops. To extend the positive effects on biodiversity as a win-win scenario for the Mediterranean regions it is advisable to consider long-term effects of direct and indirect land use changes on biodiversity and habitat loss, even if the comparison with first generation crops would seem to be understood. As stated in the introduction, it is assumed that the expansion of bioenergy crops will take place only on marginal lands or under-utilized arable land, avoiding expansion into pastures, permanent meadows, riparian ecosystems, and protected and fragile areas, in compliance with the EU Renewable Energy Directive and certification schemes [8]. According to the ecosystem service cascade model, bioenergy production implies dynamic flows (e.g. nitrogen, phosphorous, GHG and non-GHG emissions, other chemicals) into the soil, water, and air, thus the magnitude of measured impacts on biodiversity and related ecosystem services or disservices (e.g. nutrient leaching, increasing evapotranspiration, loss of habitat) depends on how bioenergy landscapes are established and managed [108].

In summary, further research should be undertaken to investigate the linkage between bioenergy production and biodiversity at different hierarchical levels (i.e. landscape, ecosystem, species, genetic) [109], including compositional, structural and functional components (e.g. richness and abundance, heterogeneity and connectivity, dispersion, disturbance, colonization, population dynamics). Research priority-setting in the Mediterranean area should be toward small mammals, birds, insects and soil biota, since there is a lack of investigations in comparison with the United States and Northern Europe.

4.6. Impacts on land use and land use change

Growing bioenergy crops on marginal or under-utilized land has significant potential to avoid competition with food production and reduce direct and indirect land use changes of the most productive soils [6110]. A recent study by Allen et al. [111] estimated that about 1.35 Mha are available for growing energy crops in the EU, of which 0.2 Mha is fallow land and 0.05 Mha are represented by suitable contaminated sites. In a study aimed at determining surplus saline land in Spain, Sánchez et al. [80] found that about 34,412 ha are available for biomass production using giant reed, with a potential production of lignocellulosic biomass of 597,338 t/dry matter/year. The study was carried out using Geographic Information System (GIS) analysis based on a soil database, agro-climatic data, electrical conductivity measurements, irrigation water requirements, Corine Land Cover 2006, and geostatistical analyses. Regarding land use implications, the authors of the study suggested that the cultivation of bioenergy crops on saline soils would contribute to decreasing the abandonment of agricultural land and its progressive degradation, avoiding competition with food production and water resources. Similarly, Pulighe et al. [37] used GIS-based techniques, remotely sensed data and a multi-criteria decision-making approach to assess the land suitability for growing energy crops on marginal and polluted areas in Sardinia, Italy, finding that about 1000 ha are available on the most polluted soils with heavy metals, and a further 5700 ha in the surrounding area equipped for irrigation. Some of the issues emerging from these studies relate specifically to the scale, spatial data and methodologies followed for mapping the potential areas [112], but also the future need to disaggregate the results by groups of crops, and to consider the effects of land use transitions in conjunction with GHG emissions, water use, water quality, soil organic carbon and biodiversity. Especially in EU agricultural landscape context, scenarios of land use management for integrating energy crops and food crops (e.g. catch crops after harvest of the main crop) into agroecosystems need to consider sustainability aspects [113].

4.7. Farmers' willingness and acceptance

To date, several studies have attempted to evaluate farmers' and landholders' willingness to grow and supply dedicated bioenergy feedstock in marginal lands, showing that attitudes and perceptions are affected by concerns about environmental impacts, sociocultural factors and rental disamenities [114–118]. In general, growing bioenergy crops is perceived as an uncertain and risky investment option due to the long establishment period. A recent study by Giannocaro et al. [81] in Apulia region, Italy, found that more than half (57%) of the farmers are willing to sell straw to the bioenergy feedstock market (they prefer a one to three-year contract with an average of 15.15 € ha^{-1}, straw in swath), but at the same time the authors outline that about one-third (31%) would not trade biomass on feedstock market. The research used farmers' stated preferences and an econometric regression to investigate the price that farmers demand for cereal straw. In summary, the current straw uses and agronomic practices (i.e. on-field burning), sale to market and soil incorporation under EU CAP determine a 'break-even point' price for farmers preferences higher than the price paid by the established (i.e. traditional) local straw market.

Although financial and economic returns are important drivers in decision making, interestingly Convery et al. [119] highlighted that a 'follow the leader' mentality is an important factor that oriented farmers choices, where the farming community showed a much higher willingness to adopt new farming practices whether a successful farmer adopt new approaches and technologies. However, it is important to bear in mind that farmers and landowners are substantially unfamiliar with new bioenergy crops (e.g. variability in yields, crop failure risk, market price) and their uncertain market. Much of the available literature on farmers' willingness to grow alternative bioenergy crops suggests a pertinent role of governments, institutions and big enterprises for encouraging targeted support policies (e.g. monetary incentives, feed-in tariffs, tax credits and subsidized crop insurance) avoiding market distortions [81] and conflicting goals. A recent study [120] used game theory modeling to resolve the so called 'Chicken and Egg' situations regarding the amount of monetary incentives for promoting the farmers' participation in switchgrass production in an unknown potential biofuel market in the US. The study shows that farmers' risk-taking attitudes become more favorable when cost of biomass production decreases or with flexible personalized incentive mechanism in the emerging bioenergy industry.

One interesting example in this sense is the pricing agreement between the Italian Agricultural Entrepreneurs Association (Coldiretti) and the biorefinery at Porto Torres (Sardinia) for the supply chain of thistle (*Cynara cardunculus L.* var. *Altilis)* seeds and raw material cultivated in marginal land in a radius of 70 km from the plant [121]. The agreement should guarantee farmers a fixed price over a three-year period for the supply of seeds and biomass, for with price adjustment mechanisms starting from the fourth year onwards. Further work needs to be done among local stakeholders about farmers' concerns and risk perceptions toward dedicated energy crops, taking into account peculiar cropping pattern of the Mediterranean marginal areas that is cereal-agropastoral system oriented (strongly financially supported by the CAP in EU countries).

4.8. Impacts on profitability

Ultimately, given the role of farmers' willingness to grow dedicated energy crops discussed above, the key question to be explored is whether farmers get marginal profits growing bioenergy crops on underutilized land as well. Recent studies suggest that the introduction of dedicated energy crops on marginal cropping systems could have a positive economic impact for farmers [122,123], partially replacing cereal crops without jeopardizing durum wheat trade balances [124]. In an economic feasibility study evaluating giant reed production as an energy crop in Sicily, Testa et al. [82] reported that woodchip and silage production with this crop shows the highest profitability (up to 617 € ha^{-1}), especially with respect to annual crops such as melon (310 € ha^{-1}) and tomato (280 € ha^{-1}). Testa and colleagues performed a financial analysis through a discounted cash flow method, collecting techno-economic data from interviews with farmers, biomass markets, and literature. In contrast to other crops, the highest profitability was attributable both to the current market prices (up to 50 € Mg^{-1} dry matter for woodchip production) and lower production costs. Similarly, the economic performance of giant reed as silage biomass feedstock for biogas plants in Sicily was undertaken by Sgroi et al. [125], who concluded that this perennial plant is an effective alternative energy crop in Mediterranean areas respect to other crops (i.e. maize and sorghum), given the current market conditions.

According to Soldatos [54] who examined the profitability of perennial grasses in marginal lands of South Europe, giant reed seems the most profitable and suitable crop. In contrast with perennial grasses, agro-forestry species such as black locust (*Robinia pseudoacacia* L.), poplar (*Populus* spp.) and eucalyptus (*Eucalyptus* spp.) cultivated as 'short rotation coppice', giant reed seems to give mixed opportunities to guarantee a positive profit for farmers in Southern Europe with respect to more secure options such as wheat [126,127]. This essentially depends on the sale prices of biomass need to achieve the break-even point in the future market. As recently stressed by Giannoulis et al. [128] farmers' income from switchgrass production in Greece largely depends on site location (especially soil type and water availability), that ultimately affects production costs and agronomic management. Thus, the verification of the profitability in the marginal land should be accurately verified based upon these preconditions.

However, despite encouraging results of most former studies, the cultivation of energy crops still remains uncertain and less attractive without incentive mechanisms, tax credits and exemptions or long-term pricing schemes as stressed in the previous section. Thus far, a broad range of policies provided direct and indirect support for energy from renewable sources in EU countries, essentially divided into 'regulatory policies' and 'fiscal incentives and public financing' [129]. Among these, the most important comprises premium tariffs, feed-in tariffs, and tender schemes. Generally, the amount of financial support decreases with increasing power plant capacity. In light of the aforementioned, in the future support schemes (e.g. CAP supports) and business models for mobilizing financing and attracting investors should be more aligned with GHG emissions, ecosystem services and sustainability indicators, avoiding criticism raised for the biogas sector in the EU regarding trade-offs on land use pressure for biomass production, market distortions and environmental impacts [130,131].

4.9. Practical implications of this study

Overall, this study strengthens the idea that energy crops can be successfully grown on marginal lands providing substantial benefits in terms of environmental impacts and socio-economic issues and supporting ecosystem services compared to intensive monocropping systems. Regarding the bibliography analyzed it clearly emerges that a full landscape design analysis with field research data is needed prior to cultivating a specific crop at a specific location, considering the complex and fragile landscape of the Mediterranean ecoregion. Main challenges include environmental risks associated with the agronomic practices (e.g. soil management, irrigation practices, biodiversity, GHG emissions, land use competition with food), as well as uncertainty about economic sustainability and integration with surrounding agro-ecosystems and farmers' needs.

Regarding the agronomic management, more research is especially needed to raise the ambition on water use and efficiency, with tailored applications for energy crops in terms of resilience or adaptability to future climate scenarios. It is important to note that detailed information about evapotranspiration rate, life-cycle water requirements, drought tolerance, as well as water stewardship strategies (technologies, methods, scheduling, watershed delivery) for second generation energy crops have been barely investigated and is scarce. On the other hand, the application of irrigation practices coming from traditional crops is risky (e.g. could encourage the growth and spread of unknown disease, weeds and pests) and is probably inefficient.

The use of certification schemes, analytical tools and context-specific measurable indicators such as those developed by the GBEP can inform farmers, industry representatives and stakeholders on how to achieve sustainability goals for ex-post assessment or for ex-ante suitability evaluation. To unlock the opportunities and ambitions for bioenergy production in the marginal lands, further work needs to be carried out to resolve uncertain and controversy points for aforementioned agronomic practices and socio-economic aspects. As suggested by Whitaker et al. [132], spatially explicit ecosystem process-based modeling integrated with land-use management analyses can positively inform about impacts and challenges of bioenergy systems. In addition to LCA methodology, model's application can be run on single solutions (e.g. EPIC, SWAT, DSSAT, DayCent, CropSyst), or within modeling frameworks platforms (e.g. BioMA, FACE-IT, APSIM) [133] for analyzing, parametrizing and finding solutions regarding agronomic practices, agro-chemicals, pest diseases, water use, crop growth and products quality.

5. Conclusions

The use of marginal lands for addressing the growing demand of renewable feedstock resources for bioenergy production raises several poorly addressed research questions with regards the sustainability issues of agro-bioenergy systems. In this study we analyze the concept of marginal land from the perspective of ecosystem service cascade model, fostering the use of tailored sustainability indicators developed by The Global Bioenergy Partnership for bioenergy production in the EU Mediterranean basin. The main emerging challenges regarding the cultivation of energy crops were framed by eight selected case studies, through an in-depth analysis and discussion of key insights of quantitative results related to the sustainability indicators.

Bioenergy production is a long-term and relative complex technology with complexities of fragmented regulations and markets. Looking to the coming years more should be done by national and EU institutions to reinforce and better guide the development of the bioenergy sector in Mediterranean regions with clear benefits for sustainable development in rural territories. For instance, coherent agricultural, energy and environmentalpolicies should affect the economic attractiveness of bioenergy production engaging investors on long-term energy strategies for viable markets, connecting fiscal incentives, feedstock prices, grant programs and CAP with the compliance of environmental and social criteria, avoiding detrimental land use changes, land grabbing or intensive cultivation. For example, under the future CAP reform post-2020 direct support schemes could be expanded including bioenergy under the Pillar I with direct payments for specific crops most suited on marginal lands. Furthermore, under the 'greening measures' and 'agri-environment schemes', bioenergy crops (e.g. perennial) can be inserted under agricultural practices and management commitments beneficial to the climate and the environment care since could have a significant impact on marginal land (e.g. carbon

sequestration, water quality, biodiversity). In addition, under the Pillar II, Rural Development Programmes could support the web value chain (i.e. farmers, processors and investors) with tailored initiatives including technical support, business models and financial guidance for making bioenergy projects bankable, in the purpose of removing market uptake barriers.

Arguably, the challenge for investors and stakeholders is to reverse the conventional approach, moving beyond biomass value chain legacy, linking sustainable bioenergy production in the framework of biorefinery systems by fully exploiting the global value of bioenergy crops and raw materials into commercially competitive and sustainable products.

Acknowledgments

This work was performed in the context of the FORBIO Project (www.forbio-project.eu) for measuring the impacts of the advanced bioenergy value chains studied in such project.

Fundings

The FORBIO project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 691846. This paper reflects only the author's view and the INEA is not responsible for any use that may be made of the information it contains.

References

[1] Espinoza Pérez AT, Camargo M, Narváez Rincón PC, Alfaro Marchant M. Key challenges and requirements for sustainable and industrialized biorefinery supply chain design and management: a bibliographic analysis. Renew Sustain Energy Rev 2017;69:350–9. https://doi.org/10.1016/j.rser.2016.11.084.
[2] The Global Bioenergy Partnership. (GBEP); 2018. ⟨http://www.globalbioenergy.org⟩.
[3] Lewandowski I. Securing a sustainable biomass supply in a growing bioeconomy. Glob Food Sec 2015;6:34–42. https://doi.org/10.1016/j.gfs.2015.10.001.
[4] Dale VH, Kline KL, Buford MA, Volk TA, Tattersall Smith C, Stupak I. Incorporating bioenergy into sustainable landscape designs. Renew Sustain Energy Rev 2016;56:1158–71. https://doi.org/10.1016/j.rser.2015.12.038.
[5] Blanco-Canqui H. Growing dedicated energy crops on marginal lands and ecosystem services. Soil Sci Soc Am J 2016;80:845. https://doi.org/10.2136/sssaj2016.03.0080.
[6] Gelfand I, Sahajpal R, Zhang X, Izaurralde RC, Gross KL, Robertson GP. Sustainable bioenergy production from marginal lands in the US Midwest. Nature 2013;493:514–7. https://doi.org/10.1038/nature11811.
[7] Chum H, Faaij A, Moreira J, Berndes G, Dhamija P, Dong H, Gabrielle B, Eng A Goss, Lucht MM W, Cerutti O Masera, McIntyre T, Minowa T, Bioenergy KP. Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, Zwickel T, Eickemeier P, Hansen G, Schlömer S, von Stechow C, editors. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2011.
[8] European Commission. Proposal for a directive of the european parliament and of the council on the promotion of the use of energy from renewable sources (recast). COM/2016/0767 final/2 - 2016/0382 (COD); 2017.
[9] JRC, EEA, CENER, CIEMAT. Sustainable bioenergy cropping systems for the Mediterranean. Proc. Expert Consult. 9–10 Febr. 2006, Madrid; 2006, p. 149.
[10] The White House. National bioeconomy blueprint. Washington, DC; 2012.
[11] De Schutter L, Giljum S. A calculation of the EU bioenergy land footprint. Discussion paper on land use related to EU bioenergy targets for 2020 and an outlook for 2030. Vienna; 2014.
[12] Krautgartner R, Audran X, Rehder LE, Boshnakova M, Dobrescu M, Rossetti A, et al. EU-28 oilseeds market update. GAIN report number: AU1706. USDA Foreign Agric Serv; 2017.
[13] Flach B, Lieberz S, Rossetti A. EU-28 biofuels annual report. Gain report number: NL7015. 2017.
[14] Tilman D, Socolow R, Foley JA, Hill J, Larson E, Lynd L, et al. Beneficial biofuels—the food, energy, and environment trilemma. Science (80-) 2009;325:270–1. https://doi.org/10.1126/science.1177970.
[15] Bosch R, van de Pol M, Philp J. Policy: define biomass sustainability. Nature 2015;523:526–7. https://doi.org/10.1038/523526a.
[16] Pretty J, Sutherland WJ, Ashby J, Auburn J, Baulcombe D, Bell M, et al. The top 100 questions of importance to the future of global agriculture. Int J Agric Sustain 2010;8:219–36. https://doi.org/10.3763/ijas.2010.0534.
[17] Holland RA, Eigenbrod F, Muggeridge A, Brown G, Clarke D, Taylor G. A synthesis of the ecosystem services impact of second generation bioenergy production. Renew Sustain Energy Rev 2015;46:30–40.
[18] Milner S, Holland RA, Lovett A, Sunnenberg G, Hastings A, Smith P, et al. Potential impacts on ecosystem services of land use transitions to second-generation bioenergy crops in GB. GCB Bioenergy 2015:317–33. https://doi.org/10.1111/gcbb.12263.
[19] Anderson-Teixeira KJ, Duval BD, Long SP, DeLucia EH. Biofuels on the landscape: is "land sharing" preferable to "land sparing"? Ecol Appl 2012;22:2035–48. https://doi.org/10.1890/12-0711.1.
[20] Nesshöver C, Assmuth T, Irvine KN, Rusch GM, Waylen KA, Delbaere B, et al. The science, policy and practice of nature-based solutions: an interdisciplinary perspective. Sci Total Environ 2016;579:1215–27. https://doi.org/10.1016/j.scitotenv.2016.11.106.
[21] Wolf J, Kanellopoulos A, Kros J, Webber H, Zhao G, Britz W, et al. Combined analysis of climate, technological and price changes on future arable farming systems in Europe. Agric Syst 2015;140:56–73. https://doi.org/10.1016/j.agsy.2015.08.010.
[22] Stoof CR, Richards BK, Woodbury PB, Fabio ES, Brumbach AR, Cherney J, et al. Untapped potential: opportunities and challenges for sustainable bioenergy production from marginal lands in the Northeast USA. BioEnergy Res 2015;8:482–501. https://doi.org/10.1007/s12155-014-9515-8.
[23] Emery I, Mueller S, Qin Z, Dunn JB. Evaluating the potential of marginal land for cellulosic feedstock production and carbon sequestration in the United States. Environ Sci Technol 2017;51:733–41. https://doi.org/10.1021/acs.est.6b04189.
[24] Smeets EMW, Lewandowski IM, Faaij APC. The economical and environmental performance of miscanthus and switchgrass production and supply chains in a European setting. Renew Sustain Energy Rev 2009;13:1230–45. https://doi.org/10.1016/j.rser.2008.09.006.
[25] Roundtable on sustainable biofuels. n.d. ⟨http://rsb.org/⟩. [Accessed 30 October 2017].
[26] Council on sustainable biomass production - ⟨http://www.merid.org/Content/Projects/Council_on_Sustainable_Biomass_Production.aspx⟩. n.d..
[27] ISO sustainability criteria for bioenergy - ⟨https://www.iso.org/standard/52528.html⟩. n.d..
[28] International sustainability and carbon certification - ⟨http://www.iscc-system.org/en/⟩. n.d..
[29] Anuar MR, Abdullah AZ. Challenges in biodiesel industry with regards to feedstock, environmental, social and sustainability issues: a critical review. Renew Sustain Energy Rev 2016;58:208–23. https://doi.org/10.1016/j.rser.2015.12.296.
[30] Immerzeel DJ, Verweij PA, van der Hilst F, Faaij APC. Biodiversity impacts of bioenergy crop production: a state-of-the-art review. GCB Bioenergy 2014;6:183–209. https://doi.org/10.1111/gcbb.12067.
[31] Pedroli B, Elbersen B, Frederiksen P, Grandin U, Heikkilä R, Krogh PH, et al. Is energy cropping in Europe compatible with biodiversity? - opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. Biomass Bioenergy 2013;55:73–86. https://doi.org/10.1016/j.biombioe.2012.09.054.
[32] Gasparatos A, Doll CNH, Esteban M, Ahmed A, Olang TA. Renewable energy and biodiversity: implications for transitioning to a green economy. Renew Sustain Energy Rev 2017;70:161–84. https://doi.org/10.1016/j.rser.2016.08.030.
[33] Werling BP, Dickson TL, Isaacs R, Gaines H, Gratton C, Gross KL, et al. Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proc Natl Acad Sci 2014;111:1652–7. https://doi.org/10.1073/pnas.1309492111.
[34] Solinas S, Fazio S, Seddaiu G, Roggero PP, Deligios PA, Doro L, et al. Environmental consequences of the conversion from traditional to energy cropping systems in a Mediterranean area. Eur J Agron 2015;70:124–35. https://doi.org/10.1016/j.eja.2015.07.008.
[35] Cosentino SL, Scordia D, Sanzone E, Testa G, Copani V. Response of giant reed (Arundo donax L.) to nitrogen fertilization and soil water availability in semi-arid Mediterranean environment. Eur J Agron 2014;60:22–32. https://doi.org/10.1016/j.eja.2014.07.003.
[36] Fernando AL, Costa J, Barbosa B, Monti A, Rettenmaier N. Environmental impact assessment of perennial crops cultivation on marginal soils in the Mediterranean Region. Biomass Bioenergy 2017. https://doi.org/10.1016/j.biombioe.2017.04.005.
[37] Pulighe G, Bonati G, Fabiani S, Barsali T, Lupia F, Vanino S, et al. Assessment of the agronomic feasibility of bioenergy crop cultivation on marginal and polluted land: a GIS-based suitability study from the Sulcis Area, Italy. Energies 2016;9:895. https://doi.org/10.3390/en9110895.
[38] Kuchler M. Sweet dreams (are made of cellulose): sociotechnical imaginaries of second-generation bioenergy in the global debate. Ecol Econ 2014;107:431–7. https://doi.org/10.1016/j.ecolecon.2014.09.014.
[39] Burnham M, Eaton W, Selfa T, Hinrichs C, Feldpausch-Parker A. The politics of imaginaries and bioenergy sub-niches in the emerging Northeast U.S. bioenergy economy. Geoforum 2017;82:66–76. https://doi.org/10.1016/j.geoforum.2017.03.022.
[40] García-Ruiz JM, Nadal-Romero E, Lana-Renault N, Beguería S. Erosion in Mediterranean landscapes: changes and future challenges. Geomorphology 2013;198:20–36. https://doi.org/10.1016/j.geomorph.2013.05.023.
[41] Peterson GM, Galbraith JK. The concept of marginal land. Am J Agric Econ 1932;14:295–310.
[42] Baldock D, Beaufoy G, Brouwer F, Godeschalk F. Farming at the margins: Abandonment of redeployment of agricultural land in Europe. London. London/The Hague: Institute for European Environmental Policy (IEEP)/Agricultural Economics Research Institute (LEI-DLO); 1996.
[43] Tang Y, Xie J-S, Geng S. Marginal land-based biomass energy production in China.

J Integr Plant Biol 2010;52:112–21. https://doi.org/10.1111/j.1744-7909.2010.00903.x.
[44] Government of India. National policy on biofuels. Minist New Renew Energy; 2008. p. 1–18.
[45] OECD. The organisation for economic co-operation and development - marginal land definition. 2001 n.d. 〈https://stats.oecd.org/glossary/detail.asp?ID=1591〉. [Accessed 21 July 2017].
[46] EEA. European environment agency - marginal land definition n.d. 〈http://www.eionet.europa.eu/gemet/en/concept/5023〉. [Accessed 21 July 2017].
[47] Milbrandt A, Overend R. Assessment of biomass resources from marginal lands in APEC economies. 35 Heng Mui Keng Terrace Singapore 119616: APEC Secretariat; 2009.
[48] CGIAR Technical Advisory Committee. CGIAR research priorities for marginal lands. Washington, DC, USA; 2000.
[49] United States Department of Agriculture-Natural Resources Conservation Services (USDA-NRCS). National soil survey handbook 430-VI. 2010.
[50] The World Bank. World development report 2003. Sustainable development in a dynamic world transforming institutions, growth, and quality of life. Washington, DC 20433; 2003.
[51] Wiegmann K, Hennenberg KJ, Fritsche UR. Degraded land and sustainable bioenergy feedstock production. in: Proceedings of the joint international workshop on high nature value criteria and potential for sustainable use of degraded lands; 2008. p. 1–12.
[52] Dale V, Kline K, Wiens J, Fargione J. Biofuels: implications for land use and biodiversity. Biofuels Sustain Rep 2010:1–13.
[53] Haines-Young R, Potschin M. The links between biodiversity, ecosystem services and human well-being. In: Raffaelli D, Frid C, editors. Ecosyst. Ecol. a new Synth. Cambridge University Press; 2010. p. 30.
[54] Soldatos P. Economic aspects of bioenergy production from perennial grasses in marginal lands of South Europe. Bioenergy Res 2015;8:1562–73. https://doi.org/10.1007/s12155-015-9678-y.
[55] Richards BK, Stoof CR, Cary IJ, Woodbury PB. Reporting on marginal lands for bioenergy feedstock production: a modest proposal. Bioenergy Res 2014;7:1060–2. https://doi.org/10.1007/s12155-014-9408-x.
[56] Kang S, Post WM, Nichols JA, Wang D, West TO, Bandaru V, et al. Marginal lands: concept, assessment and management. J Agric Sci 2013;5:129–39. https://doi.org/10.5539/jas.v5n5p129.
[57] Barbier EB, Bugas JS. Structural change, marginal land and economic development in Latin America and the Caribbean. Lat Am Econ Rev 2014;23:1–29. https://doi.org/10.1007/s40503-014-0003-5.
[58] Perlman J. Marginality: from myth to reality in the favelas of Rio de Janeiro, 1969–2002. Presented at staying poor: chronic poverty and development policy, institute for development policy and management, university of Manchester, 7-9 april 2003. Manchester, UK: CPRC; 2003.
[59] Preissel S, Zander P, Knierim A. Sustaining farming on marginal land: farmers' convictions, motivations and strategies in Northeastern Germany. Sociol Rural 2017. https://doi.org/10.1111/soru.12168.
[60] Costantini EAC, Lorenzetti R, Malorgio G. A multivariate approach for the study of environmental drivers of wine economic structure. Land Use Policy 2016;57:53–63. https://doi.org/10.1016/j.landusepol.2016.05.015.
[61] Virchow D, Denich M, Kuhn A, B T. The biomass-based value web as a novel perspective on the increasingly complex African agro-food sector. In: Proceedings of the Tropentag – Int. Conf. Res. Food Secur. Nat. Resour. Manag. Rural Dev. Sept. 17–19, Prague; 2014.
[62] Scheiterle L, Ulmer A, Birner R, Pyka A. From commodity-based value chains to biomass-based value webs: the case of sugarcane in Brazil's bioeconomy. J Clean Prod 2016. https://doi.org/10.1016/j.jclepro.2017.05.150.
[63] Spangenberg JH, von Haaren C, Settele J. The ecosystem service cascade: further developing the metaphor. integrating societal processes to accommodate social processes and planning, and the case of bioenergy. Ecol Econ 2014;104:22–32. https://doi.org/10.1016/j.ecolecon.2014.04.025.
[64] Arora L, Narula A. Gene editing and crop improvement using CRISPR-Cas9 system. Front Plant Sci 2017;8. https://doi.org/10.3389/fpls.2017.01932.
[65] Wolfert S, Ge L, Verdouw C, Bogaardt MJ. Big data in smart farming – a review. Agric Syst 2017;153:69–80. https://doi.org/10.1016/j.agsy.2017.01.023.
[66] Borras SM, Franco JC, Isakson SR, Levidow L, Vervest P. The rise of flex crops and commodities: implications for research. J Peasant Stud 2016;43:93–115. https://doi.org/10.1080/03066150.2015.1036417.
[67] Fritsche UR, Iriarte L. Sustainability criteria and indicators for the bio-based economy in Europe: state of discussion and way forward. Energies 2014;7:6825–36. https://doi.org/10.3390/en7116825.
[68] Dale VH, Efroymson RA, Kline KL, Davitt MS. A framework for selecting indicators of bioenergy sustainability. Biofuels, Bioprod Bioref 2015;9:435–46. https://doi.org/10.1002/bbb.1562.
[69] Dale VH, Efroymson RA, Kline KL, Langholtz MH, Leiby PN, Oladosu GA, et al. Indicators for assessing socioeconomic sustainability of bioenergy systems: a short list of practical measures. Ecol Indic 2013;26:87–102. https://doi.org/10.1016/j.ecolind.2012.10.014.
[70] Alexopoulou E, Zanetti F, Scordia D, Zegada-Lizarazu W, Christou M, Testa G, et al. Long-term yields of switchgrass, giant reed, and Miscanthus in the Mediterranean Basin. BioEnergy Res 2015;8:1492–9. https://doi.org/10.1007/s12155-015-9687-x.
[71] Bartolini F, Gava O, Brunori G. Biogas and EU's 2020 targets: Evidence from a regional case study in Italy. Energy Policy 2017;109:510–9. https://doi.org/10.1016/j.enpol.2017.07.039.
[72] Dale VH, Kline KL, Buford MA, Volk TA, Tattersall Smith C, Stupak I. Incorporating bioenergy into sustainable landscape designs. Renew Sustain Energy Rev 2016;56:1158–71. https://doi.org/10.1016/j.rser.2015.12.038.
[73] Negri MC, Ssegane H. Incorporating bioenergy in sustainable landscape designs. Workshop two: agricultural landscapes. Held at Argonne National Laboratory June 24–26; 2014.
[74] Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. World map of the Köppen-Geiger climate classification updated. Meteorol Z 2006;15:259–63. https://doi.org/10.1127/0941-2948/2006/0130.
[75] Bosco S, Nassi o Di Nasso N, Roncucci N, Mazzoncini M, Bonari E. Environmental performances of giant reed (Arundo donax L.) cultivated in fertile and marginal lands: a case study in the Mediterranean. Eur J Agron 2016;78:20–31. https://doi.org/10.1016/j.eja.2016.04.006.
[76] Gioacchini P, Cattaneo F, Barbanti L, Montecchio D, Ciavatta C, Marzadori C. Carbon sequestration and distribution in soil aggregate fractions under Miscanthus and giant reed in the Mediterranean area. Soil Tillage Res 2016;163:235–42. https://doi.org/10.1016/j.still.2016.06.009.
[77] Barbosa B, Boléo S, Sidella S, Costa J, Duarte MP, Mendes B, et al. Phytoremediation of heavy metal-contaminated soils using the perennial energy crops Miscanthus spp. and Arundo donax L. BioEnergy Res 2015;8:1500–11. https://doi.org/10.1007/s12155-015-9688-9.
[78] Escobar N, Ramírez-Sanz C, Chueca P, Moltó E, Sanjuán N. Multiyear life cycle assessment of switchgrass (Panicum virgatum L.) production in the Mediterranean region of Spain: a comparative case study. Biomass Bioenergy 2017;107:74–85. https://doi.org/10.1016/j.biombioe.2017.09.008.
[79] Solomou AD, Skoufogianni E, Danalatos NG. Herbaceous plant and carabid beetle communities in relation to environmental factors in a Mediterranean bioenergy crop. Agric Sci Res J 2014;5:42–9.
[80] Sánchez J, Curt MD, Fernández J. Approach to the potential production of giant reed in surplus saline lands of Spain. GCB Bioenergy 2016:105–18. https://doi.org/10.1111/gcbb.12329.
[81] Giannoccaro G, de Gennaro BC, De Meo E, Prosperi M. Assessing farmers' willingness to supply biomass as energy feedstock: cereal straw in Apulia (Italy). Energy Econ 2017;61:179–85. https://doi.org/10.1016/j.eneco.2016.11.009.
[82] Testa R, Foderà M, Maria A, Trapani D, Tudisca S, Sgroi F. Giant reed as energy crop for Southern Italy: an economic feasibility study. Renew Sustain Energy Rev 2016;58:558–64.
[83] Morales M, Quintero J, Conejeros R, Aroca G. Life cycle assessment of lignocellulosic bioethanol: environmental impacts and energy balance. Renew Sustain Energy Rev 2015;42:1349–61. https://doi.org/10.1016/j.rser.2014.10.097.
[84] GaBi LCA software 2018. 〈http://www.gabi-software. com/america/index/〉. [Accessed 30 October 2017].
[85] The ecoinvent Database 2018. 〈http://www.ecoinvent.org/database/database.html〉. [Accessed 30 October 2017].
[86] Fagnano M, Impagliazzo A, Mori M, Fiorentino N. Agronomic and environmental impacts of giant reed (Arundo donax L.): results from a long-term field experiment in hilly areas subject to soil erosion. Bioenergy Res 2015;8:415–22. https://doi.org/10.1007/s12155-014-9532-7.
[87] Forte A, Zucaro A, Fagnano M, Bastianoni S, Basosi R, Fierro A. LCA of Arundo donax L. lignocellulosic feedstock production under Mediterranean conditions. Biomass Bioenergy 2015;73:32–47. https://doi.org/10.1016/j.biombioe.2014.12.005.
[88] Wagner M, Kiesel A, Hastings A, Iqbal Y, Lewandowski I. Novel miscanthus germplasm-based value chains: a life cycle assessment. Front Plant Sci 2017:8. https://doi.org/10.3389/fpls.2017.00990.
[89] Agostini F, Gregory AS, Richter GM. Carbon sequestration by perennial energy crops: is the jury still out? Bioenergy Res 2015;8:1057–80. https://doi.org/10.1007/s12155-014-9571-0.
[90] Dondini M, Van Groenigen K-J, Del Galdo I, Jones MB. Carbon sequestration under Miscanthus: a study of 13C distribution in soil aggregates. GCB Bioenergy 2009;1:321–30. https://doi.org/10.1111/j.1757-1707.2009.01025.x.
[91] Monti A, Zegada-Lizarazu W. Sixteen-year biomass yield and soil carbon storage of giant reed (Arundo donax L.) grown under variable nitrogen fertilization rates. Bioenergy Res 2016;9:248–56. https://doi.org/10.1007/s12155-015-9685-z.
[92] Pavel P-B, Puschenreiter M, Wenzel WW, Diacu E, Barbu CH. Aided phytostabilization using Miscanthus sinensis × giganteus on heavy metal-contaminated soils. Sci Total Environ 2014;479–480:125–31. https://doi.org/10.1016/j.scitotenv.2014.01.097.
[93] Nsanganwimana F, Pourrut B, Waterlot C, Louvel B, Bidar G, Labidi S, et al. Metal accumulation and shoot yield of Miscanthus × giganteus growing in contaminated agricultural soils: insights into agronomic practices. Agric Ecosyst Environ 2015;213:61–71. https://doi.org/10.1016/j.agee.2015.07.023.
[94] Fiorentino N, Ventorino V, Rocco C, Cenvinzo V, Agrelli D, Gioia L, et al. Giant reed growth and effects on soil biological fertility in assisted phytoremediation of an industrial polluted soil. Sci Total Environ 2017;575:1375–83. https://doi.org/10.1016/j.scitotenv.2016.09.220.
[95] Triana F, Nassi o Di Nasso N, Ragaglini G, Roncucci N, Bonari E. Evapotranspiration, crop coefficient and water use efficiency of giant reed (Arundo donax L.) and miscanthus (Miscanthus × giganteus Greef et Deu.) in a Mediterranean environment. GCB Bioenergy 2015;7:811–9. https://doi.org/10.1111/gcbb.12172.
[96] Rulli MC, Bellomi D, Cazzoli A, De Carolis G, D'Odorico P. The water-land-food nexus of first-generation biofuels. Sci Rep 2016;6:22521. https://doi.org/10.1038/srep22521.
[97] Giannoulis KD, Karyotis T, Sakellariou-Makrantonaki M, Bastiaans L, Struik PC, Danalatos NG. Switchgrass biomass partitioning and growth characteristics under

different management practices. NJAS - Wagening J Life Sci 2016;78:61–7. https://doi.org/10.1016/j.njas.2016.03.011.
[98] Núñez M, Pfister S, Antón A, Muñoz P, Hellweg S, Koehler A, et al. Assessing the environmental impact of water consumption by energy crops grown in Spain. J Ind Ecol 2013;17:90–102. https://doi.org/10.1111/j.1530-9290.2011.00449.x.
[99] Berger M, Pfister S, Bach V, Finkbeiner M. Saving the planet's climate or water resources? The trade-Off between carbon and water footprints of European biofuels. Sustainability 2015;7:6665–83. https://doi.org/10.3390/su7066665.
[100] Fokaides PA, Tofas L, Polycarpou P, Kylili A. Sustainability aspects of energy crops in arid isolated island states: the case of Cyprus. Land Use Policy 2015;49:264–72. https://doi.org/10.1016/j.landusepol.2015.08.010.
[101] Rana G, Ferrara RM, Vitale D, D'Andrea L, Palumbo AD. Carbon assimilation and water use efficiency of a perennial bioenergy crop (Cynara cardunculus L.) in Mediterranean environment. Agric For Meteorol 2016;217:137–50. https://doi.org/10.1016/j.agrformet.2015.11.025.
[102] Ledda L, Deligios PA, Farci R, Sulas L. Biomass supply for energetic purposes from some Cardueae species grown in Mediterranean farming systems. Ind Crops Prod 2013;47:218–26. https://doi.org/10.1016/j.indcrop.2013.03.013.
[103] Deligios PA, Sulas L, Spissu E, Re GA, Farci R, Ledda L. Effect of input management on yield and energy balance of cardoon crop systems in Mediterranean environment. Eur J Agron 2017;82:173–81. https://doi.org/10.1016/j.eja.2016.10.016.
[104] Gominho J, Curt MD, Lourenço A, Fernández J, Pereira H. Cynara cardunculus L. as a biomass and multi-purpose crop: a review of 30 years of research. Biomass Bioenergy 2018. https://doi.org/10.1016/j.biombioe.2018.01.001.
[105] Pesce GR, Negri M, Bacenetti J, Mauromicale G. The biomethane, silage and biomass yield obtainable from three accessions of Cynara cardunculus. Ind Crops Prod 2017;103:233–9. https://doi.org/10.1016/j.indcrop.2017.04.003.
[106] Cattaneo F, Di Gennaro P, Barbanti L, Giovannini C, Labra M, Moreno B, et al. Perennial energy cropping systems affect soil enzyme activities and bacterial community structure in a South European agricultural area. Appl Soil Ecol 2014;84:213–22. https://doi.org/10.1016/j.apsoil.2014.08.003.
[107] Graham JB, Nassauer JI, Currie WS, Ssegane H, Negri MC. Assessing wild bees in perennial bioenergy landscapes: effects of bioenergy crop composition, landscape configuration, and bioenergy crop area. Landsc Ecol 2017;32:1023–37. https://doi.org/10.1007/s10980-017-0506-y.
[108] Dale VH, Kline KL, Richard TL, Karlen DL, Belden WW. Bridging biofuel sustainability indicators and ecosystem services through stakeholder engagement. Biomass Bioenergy 2017. https://doi.org/10.1016/j.biombioe.2017.09.016.
[109] Noss RF. Indicators for monitoring biodiversity: a hierarchical approach. Conserv Biol 1990;4:355–64. https://doi.org/10.1111/j.1523-1739.1990.tb00309.x.
[110] Valentine J, Clifton-Brown J, Hastings A, Robson P, Allison G, Smith P. Food vs. fuel: the use of land for lignocellulosic "next generation" energy crops that minimize competition with primary food production. GCB Bioenergy 2012;4:1–19. https://doi.org/10.1111/j.1757-1707.2011.01111.x.
[111] Allen B, Kretschmer B, Baldock D, Menadue H, Nanni S, Tucker G. Space for Energy Crops - Assessing the Potential Contribution to Europe's Energy Future. London: Institute for European Environmental Policy (IEEP); 2014.
[112] Lewis S, Kelly M. Mapping the potential for biofuel production on marginal lands: differences in definitions, data and models across scales. ISPRS Int J Geo-Inf 2014;3:430–59. https://doi.org/10.3390/ijgi3020430.
[113] Dauber J, Miyake S. To integrate or to segregate food crop and energy crop cultivation at the landscape scale? perspectives on biodiversity conservation in agriculture in Europe. Energy Sustain Soc 2016;6:25. https://doi.org/10.1186/s13705-016-0089-5.
[114] Swinton SM, Tanner S, Barham BL, Mooney DF, Skevas T. How willing are landowners to supply land for bioenergy crops in the Northern Great Lakes Region? GCB Bioenergy 2017;9:414–28. https://doi.org/10.1111/gcbb.12336.
[115] Skevas T, Hayden NJ, Swinton SM, Lupi F. Landowner willingness to supply marginal land for bioenergy production. Land Use Policy 2016;50:507–17. https://doi.org/10.1016/j.landusepol.2015.09.027.
[116] Perrin RK, Fulginiti LE, Alhassan M. Biomass from marginal cropland: willingness of North Central US farmers to produce switchgrass on their least productive fields. Biofuels, Bioprod Bioref 2017;11:281–94. https://doi.org/10.1002/bbb.1741.
[117] Caldas MM, Bergtold JS, Peterson JM, Graves RW, Earnhart D, Gong S, et al. Factors affecting farmers' willingness to grow alternative biofuel feedstocks across Kansas. Biomass Bioenergy 2014;66:223–31. https://doi.org/10.1016/j.biombioe.2014.04.009.
[118] Galik CS. Exploring the determinants of emerging bioenergy market participation. Renew Sustain Energy Rev 2015;47:107–16. https://doi.org/10.1016/j.rser.2015.03.005.
[119] Convery I, Robson D, Ottitsch A, Long M. The willingness of farmers to engage with bioenergy and woody biomass production: a regional case study from Cumbria. Energy Policy 2012;40:293–300. https://doi.org/10.1016/j.enpol.2011.10.009.
[120] Luo Y, Miller SA. Using game theory to resolve the "chicken and egg" situation in promoting cellulosic bioenergy development. Ecol Econ 2017;135:29–41. https://doi.org/10.1016/j.ecolecon.2016.12.013.
[121] Yazan DM, Mandras G, Garau G. Environmental and economic sustainability of integrated production in bio-refineries: the thistle case in Sardinia. Renew Energy 2017;102:349–60. https://doi.org/10.1016/j.renene.2016.10.055.
[122] Torres CM, Ríos SD, Torras C, Salvadó J, Mateo-Sanz JM, Jiménez L. Sustainability analysis of biodiesel production from Cynara cardunculus crop. Fuel 2013;111:535–42. https://doi.org/10.1016/j.fuel.2013.04.021.
[123] Bonfante A, Impagliazzo A, Fiorentino N, Langella G, Mori M, Fagnano M. Supporting local farming communities and crop production resilience to climate change through giant reed (Arundo donax L.) cultivation: an Italian case study. Sci Total Environ 2017;601–602:603–13. https://doi.org/10.1016/j.scitotenv.2017.05.214.
[124] Mantziaris S, Iliopoulos C, Theodorakopoulou I, Petropoulou E. Perennial energy crops vs. durum wheat in low input lands: economic analysis of a Greek case study. Renew Sustain Energy Rev 2017;80:789–800. https://doi.org/10.1016/j.rser.2017.05.263.
[125] Sgroi F, Di Trapani AM, Foderà M, Testa R, Tudisca S. Economic performance of biogas plants using giant reed silage biomass feedstock. Ecol Eng 2015;81:481–7. https://doi.org/10.1016/j.ecoleng.2015.04.068.
[126] Gasol CM, Brun F, Mosso A, Rieradevall J, Gabarrell X. Economic assessment and comparison of acacia energy crop with annual traditional crops in Southern Europe. Energy Policy 2010;38:592–7. https://doi.org/10.1016/j.enpol.2009.10.011.
[127] Testa R, Di Trapani AM, Foderà M, Sgroi F, Tudisca S. Economic evaluation of introduction of poplar as biomass crop in Italy. Renew Sustain Energy Rev 2014;38:775–80. https://doi.org/10.1016/j.rser.2014.07.054.
[128] Giannoulis KD, Vlontzos G, Karyotis T, Bartzialis D, Danalatos NG. Assessing the efficiency of switchgrass different cultural practices for pellet production. Land Use Policy 2014;41:506–13. https://doi.org/10.1016/j.landusepol.2014.04.004.
[129] REN21. Renewables 2017: global status report. Vol. 72. 2017. https://doi.org/10.1016/j.rser.2016.09.082.
[130] Massaro V, Digiesi S, Mossa G, Ranieri L. The sustainability of anaerobic digestion plants: a win-win strategy for public and private bodies. J Clean Prod 2015;104:445–59. https://doi.org/10.1016/j.jclepro.2015.05.021.
[131] Chinese D, Patrizio P, Nardin G. Effects of changes in Italian bioenergy promotion schemes for agricultural biogas projects: insights from a regional optimization model. Energy Policy 2014;75:189–205. https://doi.org/10.1016/j.enpol.2014.09.014.
[132] Whitaker J, Field JL, Bernacchi CJ, Cerri CEP, Ceulemans R, Davies CA, et al. Consensus, uncertainties and challenges for perennial bioenergy crops and land use. GCB Bioenergy 2017. https://doi.org/10.1111/gcbb.12488.
[133] Jones JW, Antle JM, Basso B, Boote KJ, Conant RT, Foster I, et al. Toward a new generation of agricultural system data, models, and knowledge products: state of agricultural systems science. Agric Syst 2017;155:269–88. https://doi.org/10.1016/j.agsy.2016.09.021.