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Received: 9 July 2019; Accepted: 9 August 2019; Published: 14 August 2019

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Abstract: This study deals with approaches for a social-ecological friendly European bioeconomy based on biomass from industrial crops cultivated on marginal agricultural land. The selected crops to be investigated are: Biomass sorghum, camelina, cardoon, castor, crambe, Ethiopian mustard, giant reed, hemp, lupin, miscanthus, pennycress, poplar, reed canary grass, safflower, Siberian elm, switchgrass, tall wheatgrass, wild sugarcane, and willow. The research question focused on the overall crop growth suitability under low-input management. The study assessed: (i) How the growth suitability of industrial crops can be defined under the given natural constraints of European marginal agricultural lands; and (ii) which agricultural practices are required for marginal agricultural land low-input systems (MALLIS). For the growth-suitability analysis, available thresholds and growth requirements of the selected industrial crops were defined. The marginal agricultural land was categorized according to the agro-ecological zone (AEZ) concept in combination with the marginality constraints, so-called 'marginal agro-ecological zones' (M-AEZ). It was found that both large marginal agricultural areas and numerous agricultural practices are available for industrial crop cultivation on European marginal agricultural lands. These results help to further describe the suitability of industrial crops for the development of social-ecologically friendly MALLIS in Europe.

Keywords: bioeconomy; bio-based industry; biomass; bioenergy; industrial crop; perennial crop; low-input agriculture; marginal land; MALLIS; sustainable agriculture

1. Introduction

In the targeted 'ideal' bioeconomy, the production of biomass will take social, ecological, and health aspects into account [1] to help achieve the sustainable development goals 2015–2030. From the bioeconomy's ambitions and definitions, conclusions can be drawn that the growth of the bioeconomy demands both a reduction of waste and losses and an adequate supply of sustainably grown biomass [2]. However, an increasing biomass production also carries a higher risk of social-ecological threats, such as increased use of fertilizers and pesticides, negative impacts from land-use changes and additional pressure on water resources [3–5]. The EU Horizon 2020 project MAGIC (Grant agreement ID: 727698) was established with the ambition of supporting the mitigation of these risks. This study deals with the basic findings of the 'Low-input agricultural practices for industrial crops on marginal land'.

Low-input agriculture (Figure 1) generally provides a number of promising practices that can help improve the social-ecological sustainability of biomass production while maintaining economic feasibility [6]. Here, a key parameter is the ratio between on- and off-farm inputs. According to Biala et al. (2007) [6], in low-input agriculture, the use of on-farm inputs should be maximized and off-farm inputs minimized. Currently, there are four concrete and real farming system types which follow these low-input agriculture principles (taken from Reference [7]): (i) Integrated farming, (ii) organic farming, (iii) precision farming, and (iv) conservation farming.

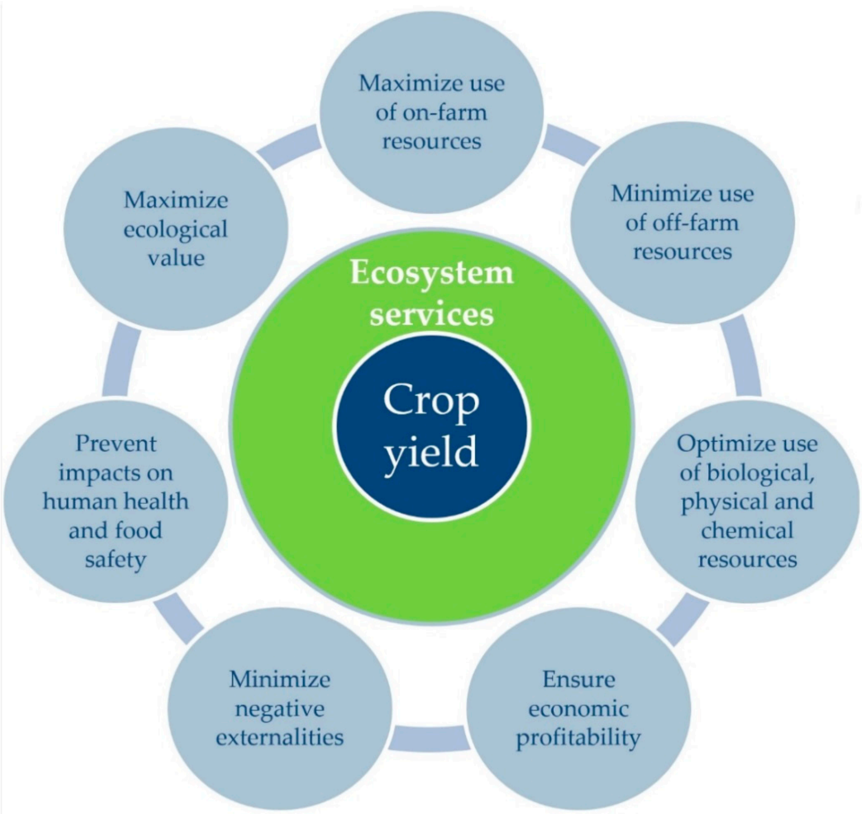

Figure 1. Principles of low-input agriculture (Source: This study).

For each of these farming systems, crop selection was found to be highly relevant for efficient use of resources during their cultivation [8–11]. The resource use efficiency becomes even more relevant for industrial crop cultivation on marginal agricultural lands (Figure 2). This is because both the yield potential and the resilience of the agro-ecosystems (their robustness against cropping failures) may be lower on marginal agricultural lands compared to fertile agricultural lands [9,12–17]. According to Elbersen et al. [12], marginal agricultural lands can be defined as '*lands having limitations which in aggregate are severe for sustained application of a given use and/or are sensitive to land degradation, as a result of inappropriate human intervention, and/or have lost already part or all of their productive capacity as a result of inappropriate human intervention and also include contaminated and potentially contaminated sites that form a potential risk to humans, water, ecosystems, or other receptors*'. The implementation of a low-input approach that can potentially reduce the risk to humans, water, ecosystems or other receptors is mainly dependent on the farming system and requires site-specific consideration [18,19].

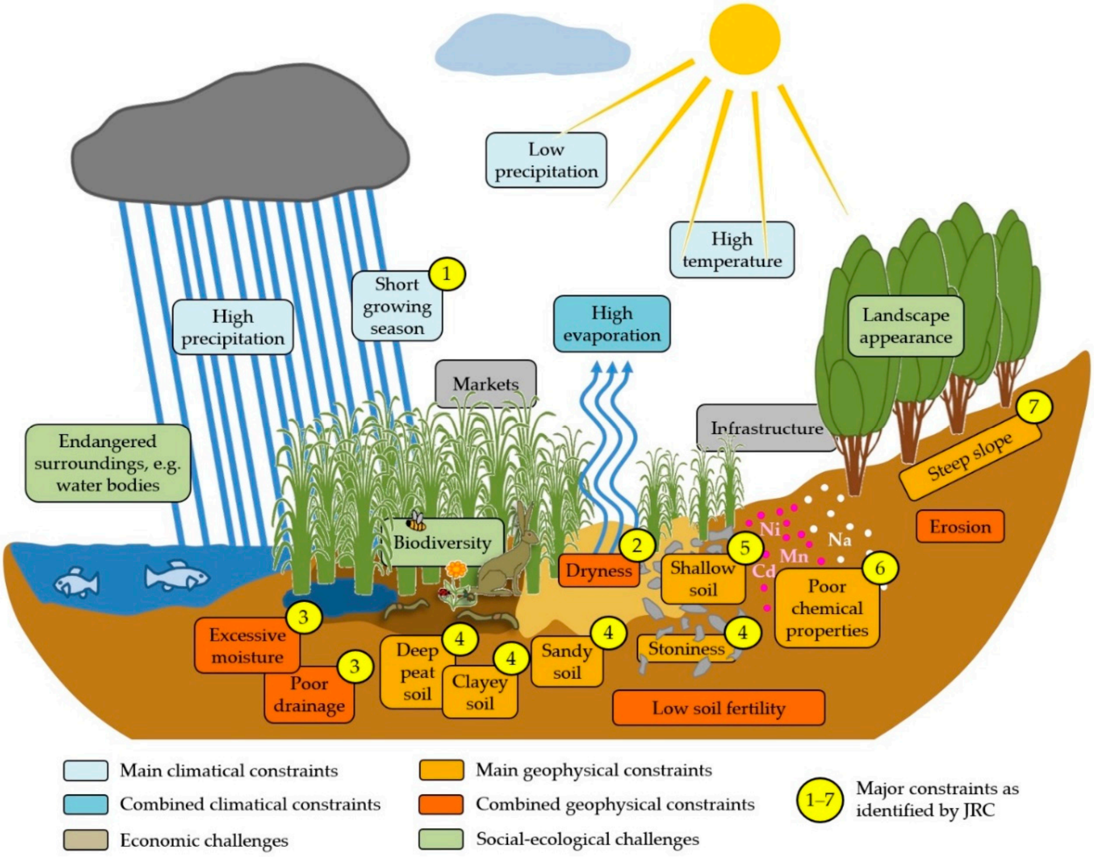

Figure 2. Illustration of relevant biophysical constraints and both economic and social-ecological challenges selected for marginal agricultural land low-input systems (Source: This study). Numbers 1–7 indicate the major biophysical constraints on marginal lands as defined by the Joint Research Centre (JRC) [20–22]. The other parameters either influence (main constraints) or follow on (combined constraints) from the major biophysical constraints, which limit the site-specific plant growth suitability (Table A1). The economic and social-ecological challenges have been added, due to their increasing relevance for modern agricultural systems [23–26]. These challenges can render a site marginal under both economic and social-ecological aspects, such as environmental protection, biodiversity conservation, infrastructure, markets and landscape appearance.

2. Material and Methods

For ethical reasons, low-input industrial crop cultivation on marginal agricultural lands is to be preferred in order to reduce competition for agricultural land use with both food crop cultivation and biodiversity conservation [9,27–30]. As favorable agricultural lands should primarily be used for food crop cultivation, this study focuses on the use of marginal agricultural lands for low-input industrial crop cultivation. Consequently, it aimed at:

1. Mapping the major climatic and biophysical constraints across European marginal agricultural lands;
2. Assessing the growth suitability of pre-selected industrial crops under the prevailing climatic and biophysical constraints; and
3. The development of social-ecologically friendly marginal agricultural land low-input systems (MALLIS) for industrial crop cultivation.

To address the above-mentioned research objectives, a thorough literature review was conducted using the search engines of SCOPUS (Elsevier, B.V.) and Google Scholar (Google LLC.). The pre-selection of the industrial crops (Table 1) which was based on a multi-criteria analysis (among others, the maturity of knowledge on industrial crops on marginal land and crops' productivity on marginal land) did not form part of this study. Instead, the study deals with the further evaluation of the growth suitability of 19 promising industrial crops (Table 1), and thus how they meet the requirements for successful development of MALLIS.

Table 1. Overview of physiological and technical characteristics of the industrial crops.

Crop		Physiology		
Common Name	**Binomial Name**	**Life Cycle**	**Photo-Synzthetic Pathway**	**Purpose/Type of Use**
Biomass sorghum	*Sorghum bicolor* L. Moench	Annual	C4	Multipurpose
Camelina	*Camelina sativa* L. Crantz	Annual	C3	Oil
Cardoon	*Cynara cardunculus* L.	Perennial	C3	Multipurpose
Castor bean	*Ricinus communis* L.	Annual	C3	Oil
Crambe	*Crambe abyssinica* Hochst Ex Re Fries	Annual	C3	Oil
Ethiopian mustard	*Brassica carinata* A. Braun	Annual	C3	Oil
Giant reed	*Arundo donax* L.	Perennial	C3	Lignocellulosic
Hemp	*Cannabis sativa* L.	Annual	C3	Multipurpose
Lupin	*Lupinus mutabilis* Sweet	Perennial	C3	Multipurpose
Miscanthus	*Miscanthus × giganteus* Greef et Deuter	Perennial	C4	Lignocellulosic
Pennycress	*Thlaspi arvense* L.	Annual	C3	Oil
Poplar	*Populus* spp.	Perennial	C3	Lignocellulosic
Reed canary grass	*Phalaris arundinacea* L.	Perennial	C3	Lignocellulosic
Safflower	*Carthamus tinctorius* L.	Annual	C3	Oil
Siberian elm	*Ulmus pumila* L.	Perennial	C3	Lignocellulosic
Switchgrass	*Panicum virgatum* L.	Perennial	C4	Lignocellulosic
Tall wheatgrass	*Thinopyrum ponticum* Podp. Z.-W. Liu and R.-C. Wang	Perennial	C3	Lignocellulosic
African fodder cane	*Saccharum spontaneum* L. ssp. *aegyptiacum* (Willd.) Hack.	Perennial	C4	Lignocellulosic
Willow	*Salix* spp.	Perennial	C3	Lignocellulosic

The following sub-sections present the concepts underlying the key elements of this study. These key elements are (i) the identification of marginal agro-ecological zones (M-AEZ), (ii) the determination of the growth suitability of the pre-selected industrial crops in the prevailing M-AEZ, and (iii) the development of MALLIS for industrial crop cultivation.

2.1. The Identification of Marginal Agro-Ecological Zones (M-AEZ)

To achieve the first two key elements, mapping was performed as follows: Marginal agricultural lands were mapped [31] according to the biophysical limitations defined and classified by JRC [20–22]. The mapping was limited to a so-called 'agricultural mask'. This mask includes all land that was classified in an agricultural land cover class in at least one of the four Corine Land Cover (CLC) versions (1990, 2000, 2006, and 2012). Further details of the methodological approaches are provided in the following sub-sections.

2.2. Determination of the Growth Suitability of the Pre-Selected Industrial Crops in the Prevailing M-AEZ

The approach to mapping the growth suitability of the 19 pre-selected crops involves the identification of the minimum and maximum climate and soil requirements per crop. The growth suitability requirements of the selected industrial crops were determined according to the literature [32,33]. They were used to map and calculate both the distribution and size of the crop-specific growth suitability areas across European marginal agricultural land. The thresholds for the suitability parameters were set as the starting point at which the crop can grow and survive. The suitable area is, thus, given as the area where all suitability factors are within the minimum and maximum range. In this mapping assessment, a distinction was made between suitable and unsuitable area per crop. However, no further classification of the suitable area was made, for example, into high to low suitability. For an easier interpretation of the results, the European land surface was divided into the three agro-ecological zones (AEZ): Mediterranean (AEZ1), Atlantic (AEZ2) and Continental and Boreal (AEZ3) (Figure 3, Table 2). Each combination of an AEZ with at least one biophysical constraint (Table A1) refers to as 'M-AEZ' (Table 2).

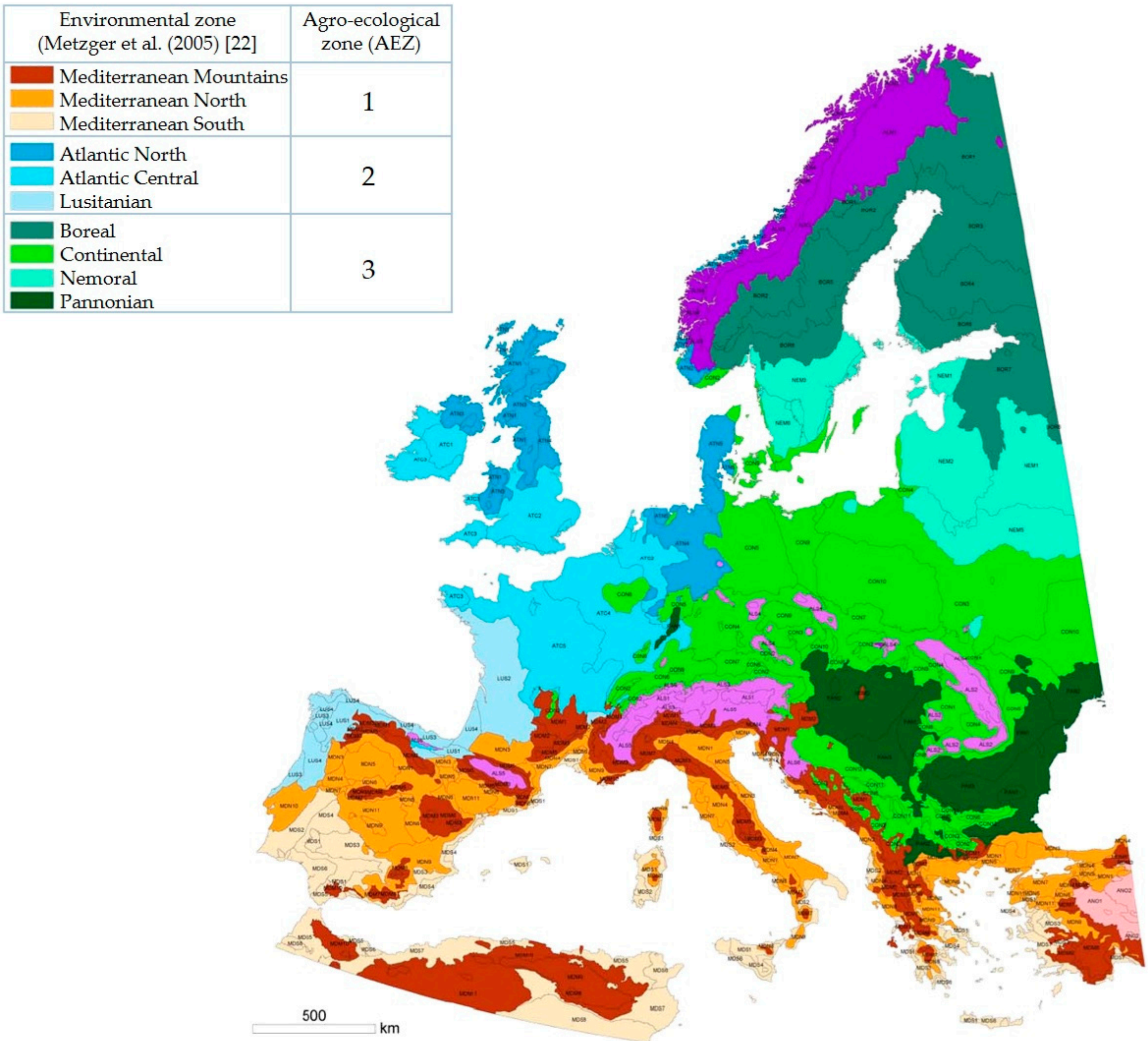

Figure 3. Distribution of agro-ecological zones (AEZ) taken into consideration for the development of marginal agricultural land low-input systems (MALLIS) for industrial crops across Europe (modified from Reference [34]).

The basic crop-specific biophysical growth requirements were compiled according to Ramirez-Almeyda et al. (2017) [32]. Each biophysical parameter was divided into a number of classes. For instance, the parameter "precipitation" was divided into eight classes (in mm a^{-1}): 0–100, 100–200, 200–300, 300–400, 400–500, 500–600, 600–800, and 800–1000 (Table A2). Afterwards, the growth suitability of each crop was ranked according to these classes based on available literature. Additionally, the basic climatic growth requirements of the crops were compiled (Table 3).

Table 2. Relevance of the constraints and constraint combinations expressed as agricultural area (km^2) per AEZ.

Constraint(-s) [a]	AEZ 1	AEZ 2	AEZ 3	AEZ 1-3
RT	62,247	51,823	41,449	155,519
CL	27,752	4564	79,780	112,096
WT	2526	65,322	40,233	108,081
TR	31,332	5710	11,362	48,404
RT-TR	15,636	14,656	2157	32,449
CL-RT	25,675	593	6064	32,332
CL-WT	701	13,141	16,263	30,105
FE	15,205	3087	5246	23,538
CH	6883	3642	11,987	22,512
CL-FE	14,527	291	3524	18,342
WT-RT	348	10,541	1745	12,634
CL-TR	2920	1577	4189	8686
CL-RT-TR	4240	1072	1150	6462
CL-WT-RT	95	1531	3472	5098
CL-WT-TR	12	4663	61	4736
CL-FE-RT	4272	47	97	4416
CL-FE-RT-TR	4272	47	97	4416
CL-WT-RT-TR	603	2361	1421	4385
CL-FE-TR	151	2361	1421	3933
WT-TR	51	1935	976	2962
FE-RT	1268	603	289	2160
CL-WT-FE	0	1344	594	1938
WT-RT-TR	4	1158	58	1220
WT-FE	11	986	198	1195
CL-CH	1173	0	0	1173
FE-CH	200	1	950	1151
CH-TR	273	46	654	973
CL-WT-FE-RT	0	185	697	882
CH-RT	280	107	195	582
WT-CH	37	239	154	430
CL-WT-FE-TR	0	417	1	418
CL-WT-FE-RT-TR	1	143	106	250
CL-FE-CH	244	0	0	244
FE-TR	117	49	51	217
WT-FE-RT	0	87	10	97
WT-FE-TR	0	77	1	78
CL-CH-RT	54	0	0	54
FE-RT-TR	7	32	6	45
CH-RT-TR	26	2	16	44
CL-CH-TR	18	0	0	18
FE-CH-TR	1	0	17	18
FE-CH-RT	4	0	7	11
CL-WT-CH	5	0	0	5
WT-FE-CH	0	0	1	1
Total marginal	218,962	192,302	235,569	646,833
Total not marginal	422,565	538,855	704,818	1,666,238
Total	641,527	731,157	940,387	2,313,071

[a] CH: Salinity or sodicity; CL: Low temperature, high temperature or dryness; FE: Acidity, alkalinity or soil organic matter; RT: Shallow rooting depth or unfavorable texture; TR: Steep slope; WT: Limited soil drainage or excess soil moisture.

Table 3. Main thermal growth requirements of the 19 pre-selected industrial crops.

Crop	Factors of Thermal Growth Requirements		
	Base Temperature (°C)	Minimum Length of Growing Season (d)	Minimum of Growing Degree Days [a] (Thermal Time, °C d)
Biomass sorghum	8	100	1500
Camelina	5	90	1000
Cardoon	7.5	120	1100
Castor bean	10	135	1500
Crambe	5	100	1200
Ethiopian mustard	5	120	2000
Giant reed	5	210	1843
Hemp	6	90	1400
Lupin	0	222	2260
Miscanthus	5	78	1700
Pennycress	4	90	1200
Poplar	0	180	2200
Reed canary grass	0	111	2000
Safflower	2	120	1800
Siberian elm	6	150	2000
Switchgrass	6	140	2060
Tall wheatgrass	4	90	1200
Wild sugarcane	10	210	2400
Willow	2	180	2000

[a] Accumulated mean daily temperature equal to or above than the crop-specific base temperature.

When mapping the crop-specific growth suitability areas, we only considered whether a crop could potentially grow. We did not take different yield levels into account. In the constraint-specific ranking, classes 0 and 1 were denoted as not suitable. Therefore, if any of the basic climatic growth requirements are not met or any of the constraint-specific rankings falls within class 0 or 1, the area is designated as 'not suitable'. The result was an overview of the potential growth suitability of the pre-selected industrial crops across European marginal agricultural land. This means that only agricultural areas were considered; woodlands and urban areas were excluded from the mapping of marginal agricultural land.

2.3. Definition and Methodology of Marginal Land Low-Input Systems (MALLIS) Development for Industrial Crops

In this sub-section, the definition of best-practice low-input management systems for the pre-selected industrial crops (Table 1) is elaborated. This ties in with current knowledge on best low-input agricultural practices for food crop production on good soils [6]. The concept of best-practice low-input agricultural cropping systems considers management approaches from many categories of agricultural production, including organic, integrated, conservation agriculture and mixed crop-livestock farming [35–37]. These all have one constant: Low-input agricultural practices seek to optimize the use of on-farm resources while minimizing off-farm resources [6,35,36]. This leads to a more 'closed' cycle of production (and less external inputs) [37]. Note, that this more closed production cycle requires both more advanced agronomic skills [38,39] and additional links within the value chain, such as application of biochar [40–49] or phosphate salt recovery from the digestates [50,51]. Therefore, practical guidelines for industrial crops are also under development within the MAGIC project.

Agronomic strategies for the successful application of low-input agricultural practices in a crop management system should be seen as a set of strategies that take into consideration both the interactions between plants, soil, the atmosphere and the efficient use of inputs to enable the highest output with minimal (on-farm and/or off-farm) input supply [6,52–54]. Agronomic strategies for low-input systems may also match good agricultural practices—cultivation practices that address economic, social and environmental sustainability [37] for high-quality food and non-food agricultural products [38,55]. Such practices include the implementation of appropriate crop rotations, pasture management, manure application, soil management that maintains or improves soil organic matter, and other land-use practices, as well as conservation tillage practices [8,37,48].

Diversity in crop rotations is a way to reduce reliance on synthetic chemicals, control weeds and pests, maintain soil fertility and reduce soil erosion, prevent soil-borne diseases, leading to the reduction of off-farm inputs [54]. Reduced soil tillage is a way to reduce soil erosion, improve water buffer capacity, and increase both soil fertility and organic matter [37]. Water management is a major challenge in the Common Agricultural Policy (CAP) and requires the monitoring of soil and crop water status to schedule irrigation efficiently. Fertilizers and agrochemicals should be applied following the good agricultural practices, e.g., to replace only the amount of nutrients that were extracted by harvest [37].

Crop protection should be done in a way that maximizes the biological prevention of pests and diseases, in particular by promoting integrated pest management (IPM) and though appropriate rates and timings of agrochemicals. Preventive crop protection can also be supported by the selection of resistant cultivars and varieties, crop sequences, crop associations (e.g., intercropping), and proper cultural practices [35].

The development of 'marginal agricultural land low-input systems', referred to as 'MALLIS', is based on the following definition: 'MALLIS is defined as a set of low-input practices which are relevant management components to form viable cropping systems on marginal (arable) lands under specific climatic conditions and are sustainable in both socio-economic and environmental terms'. The implementation of MALLIS should enable farmers to cultivate industrial crops on marginal agricultural lands, considering both economic and socio-environmental aspects. Consequently, MALLIS should not only allow for profitable net farm income under the challenging biophysical growth conditions of marginal lands. It also helps to (i) reduce off-farm inputs, such as synthetic fertilizer, pesticides and energy (e.g., for water pumps, fuel, crop harvest machinery, storage, processing, etc.) and (ii) mitigate negative macro-economic externalities (GHG emissions, biodiversity loss, ground- and surface water contamination, soil organic matter loss, erosion, degradation, land-use change), while (iii) ensuring feasible economic benefits at farm level. Therefore, the development of MALLIS considers not only the biophysical constraints, but also socio-economic and ecological demands of the respective areas.

The conceptualization of MALLIS development always begins with the selection of the most promising industrial crop, because all other agricultural practices (tillage, fertilization, weeding, irrigation, etc.) strongly depend on the type and site-specific performance of the crop. This MAEZ-specific growth-suitability ranking (and mapping) of the pre-selected industrial crops was based on the crop-suitability rankings. The basic climatical growth suitability thresholds are presented in Table 3. After the identification of suitable crops, the conceptualization of MALLIS for MAEZ was done on a general level (regional scale), since detailed best practice recommendations for the optimized management of agricultural practices very much depend on local conditions (field-to-farm scale) [56–60]. Therefore, the MALLIS for the new field trials to be conducted in the MAGIC project (field-to-farm scale) were developed considering three main MAEZ criteria:

- The crop's performance according to site-specific climatic and geographic conditions, especially under given biophysical constraints;
- The kind and quality of biomass required in the given infrastructure, processing industries and distribution channels (markets);
- The agricultural status of the farm(s), e.g., the techniques, knowledge and resources available to ensure successful cultivation of the crop.

3. Results and Discussion

3.1. Marginal Agro-Ecological Zones in Europe

As illustrated in Figure 2, there are various biophysical constraints and socio-economic challenges which need to be considered for MALLIS development. Table 2 shows the relevance of the numerous biophysical constraint combinations within each of the three AEZ. According to category 1 ('*natural constraints*'), the total marginal area across European land surface amounts to 646,833 km^2 (Table 2)—an area as large as France. However, this marginal agricultural land is widely scattered across Europe (Figure 4). Furthermore, there were 38 combinations of ≥ 2 constraints identified (Table 2). Across Europe, the most prevailing constraints are adverse rooting conditions, (155,519 km^2), adverse climatic conditions (112,096 km^2) and excessive soil wetness (108,081 km^2). The total marginal arable land characterized by soil constraints accounts for about 535,000 km^2. This is about 155,000 km^2 more than reported by Gerwin et al. (2018) (380,000 km^2) [56,61]. It is likely that this difference results from the use of different thresholds for determining what is marginal and what is not. However, both values are within the same range.

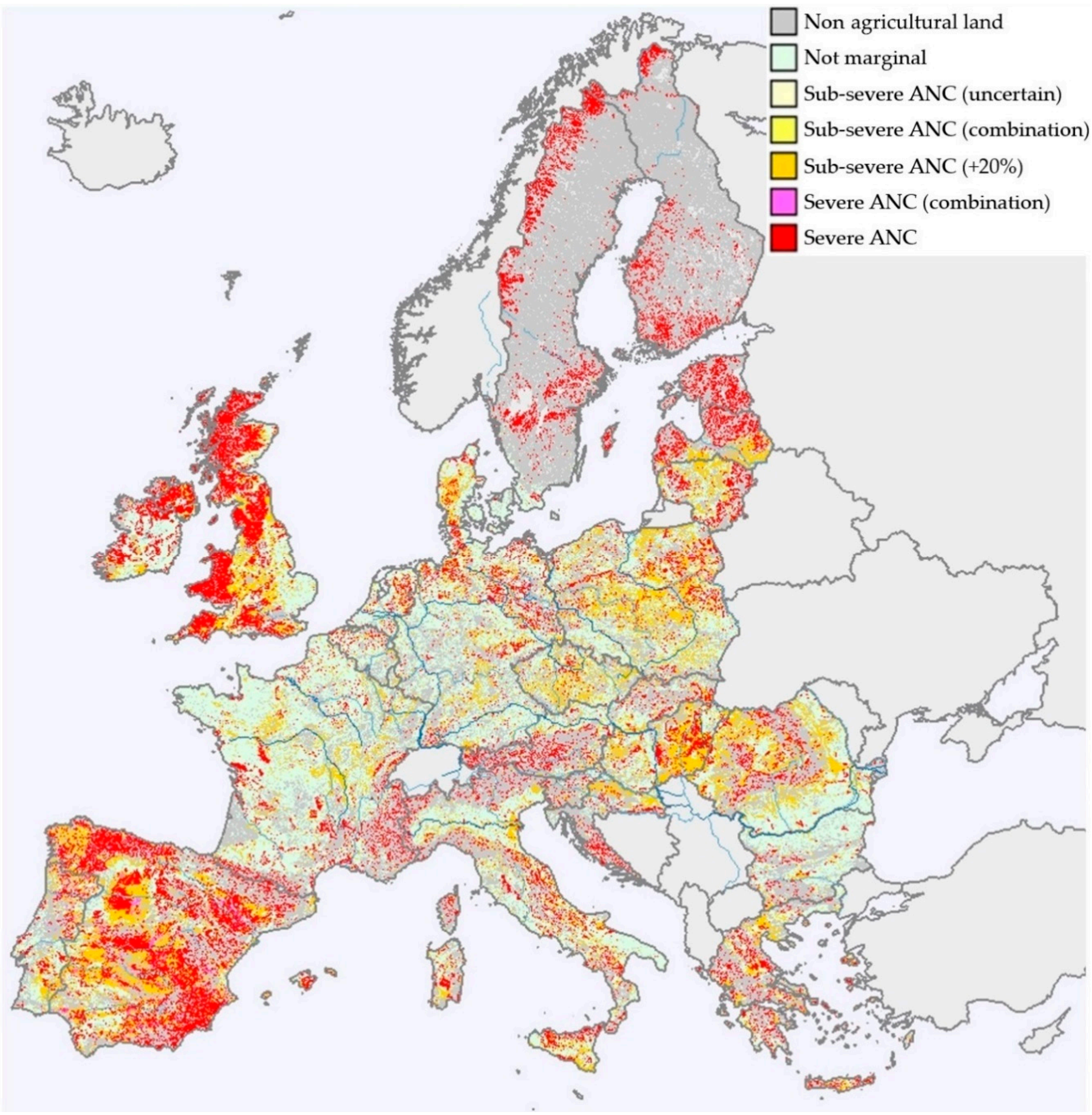

Figure 4. Marginal agricultural lands based on biophysical constraints in Europe (ANC = agricultural natural constraint) (Source: This study).

3.2. The Growth Suitability of the Pre-Selected Industrial Crops in the Prevailing M-AEZ

Potentially suitable industrial crops were identified for virtually all types of marginal agricultural land across Europe (Table A3). Each AEZ appears to have its own best-adapted industrial crops. A closer look at the type of biomass reveals that, for instance, oil crops are more suitable for Mediterranean regions than for the Atlantic region (Table A3). Among the woody lignocellulosic crops, Siberian elm outperforms poplar in the Mediterranean region (Table A3). The dominating lignocellulosic crops are tall wheatgrass, followed by reed canary grass and miscanthus (Table A3).

3.3. Marginal Agricultural Land Low-Input Systems (MALLIS) for Industrial Crop Cultivation

Sections 3.1 and 3.2 revealed both the major M-AEZ in Europe and the growth suitability of the pre-selected industrial crops. This section explains how MALLIS could be developed using the information on M-AEZ and the crops' growth suitabilities. Furthermore, it discusses which other aspects need to be taken into account for MALLIS development in order to improve both the economic and social-ecological sustainability of the MALLIS in the long term.

3.3.1. Agricultural Measures for MALLIS Development

The potential effects of structured and systematic agricultural measures on agriculture facing biophysical constraints are provided in Tables A4 and A5. Furthermore, the literature review revealed that there are several ways to overcome each of the biophysical constraints. Tables A4 and A5 provide an overview of the suitability of agricultural management options for dealing with the prevailing biophysical constraints on marginal agricultural lands. For example, the use of mulch helps to increase the soil thermal time, and thus increase the yield level in regions affected by water limitations and low temperatures [62].

3.3.2. Environmental Threats and Social Requirements

MALLIS implementations at a regional scale should also take both environmental threats and social requirements into consideration. Marginal agricultural lands could be characterized as fragile environments being highly susceptible to any types of external disturbance and input [6,12,63]. Key measures that can be highly recommended for the improvement of resilience include (i) the selection of low-demanding industrial crops (reduces the amount of fertilizers, and thus the risk of nutrient-leaching) [27], (ii) the development of heterogeneous landscape concepts (many small fields rather than only a few large fields) [64–67], and (iii) the implementation of agricultural diversification measures (intercropping, crop rotations, wildflower strips) [35,68,69]. Consequently, the assessment of the environmental performance of MALLIS should not be exclusively based on the global warming potential, but also on a number of other environmental impact categories, such as human toxicity threats, marine ecotoxicity, freshwater eutrophication and freshwater ecotoxicity, biodiversity and soil quality, pollution [70], and use of resources, e.g., water resources [71]. However, to enable a long-term sustainable implementation of MALLIS, besides the environmental impact categories, the social demands and the economic and market aspects must also be taken into account. The potential and viability of agricultural investments have to take into account land and labor costs, inputs, such as mechanical equipment costs, and income (which is linked with the market opportunities) [72]. The socioeconomic impacts can be measured via quantitative and qualitative parameters [73]. Moreover, aspects related to technological viability should also be taken into consideration. The yield loss associated with cultivation on marginal agricultural land may lead to higher contents of nutrients, such as nitrogen and potassium in the biomass, which may complicate further processing of the biomass [74]. Generally, this means that the prevailing structures of the existing agricultural systems [75], the farm typology [76], and the behavior patterns of the rural communities [24,77] require specific bottom-up research structures, such as the Integrated Renewable Energy Potential Assessment (IREPA) [78]. This would enable a better adaptation of MALLIS to the farm diversity [76,77] and the local community.

Finally, this could potentially have a positive influence on the overall public acceptance of the MALLIS [79].

3.3.3. Biodiversity Conservation

Another aspect worthy of discussion is the ecosystem functionality [80] of the pre-selected industrial crops in terms of biodiversity conservation. Concerning the soil ecological functions fulfilled by pedofauna, recent works on the following of bioenergy crops establishment on marginal contaminated soils showed that belowground fauna was stimulated [81]. Higher densities and diversity of soil invertebrates were found under miscanthus compared to annual cropping systems [82], as well as the positive effect on microbial diversity [83]. These crops were specifically selected as representative of those that deliver the most important crop-based biomass resources for current biomass industries. However, the recent (alarming) decrease in pollinator abundances across Central European landscapes [23,25] may induce changes in the priorities for crop selection, and thus the development of MALLIS in the future. For example, pollinator-supporting traits, such as nectar provision and high resistance to pests and diseases could become more important than economic traits, such as biomass yield and biomass quality if public awareness of this topic continues to increase [84]. There are a number of reports on alternative pollinator-supporting industrial crops, such as perennial wild plants [85–89], cup plant (*Silphium perfoliatum* L.) [90–92], sida (*Sida hermaphrodita* L.) [93–95], and amaranth (*Amaranthus hypochondriacus* L.) [96–98]. However, many of the pre-selected industrial crops are also expected to have positive effects on pollinators. These include camelina [99–101], crambe [100,102], safflower [103,104], lupin [105,106], cardoon [107,108] and willow [63,109,110]. In addition, the suitability of the MALLIS for habitat networking in combination with other highly diverse cropping systems, such as species-rich meadows [111] should be investigated to improve the overall efficiency of the MALLIS for biodiversity conservation. Also, marginal land can anchor rich biodiversity components (plants with high significance for locals, e.g., for medicinal or food purposes), and change of land use should take this element into account [112].

3.3.4. Explanatory Setup of a MALLIS on a Shallow Stony Soil

This section provides an example on how MALLIS could be implemented on a marginal agricultural site characterized by two biophysical constraints [21]: (i) Shallow soil (<35 cm topsoil depth); and (ii) stoniness (≥15% of topsoil volume is coarse material, rock outcrop or boulder). Due to these constraints, both the rooting conditions and the soil fertility are lower than in deep soils. It is economically not feasible to grow food crops under these conditions, and thus, the cultivation of certain industrial crops would not compete with food security on sites like this. However, not all industrial crops are able to grow well under these conditions either. Thus, the identification of a best-adapted industrial crop is the first step in developing a site-specifically suitable MALLIS. In this case, perennial crops, such as miscanthus and switchgrass are found to be suitable because (i) they do not require soil tillage and sowing each year compared to annual crops which helps both increasing soil fertility [113,114] and reducing erosion [115] in the long term, (ii) they can manage to root deep enough despite shallow soil, because their root systems are stronger and more developed than those of annual crops, and (iii) the climatic conditions meet the crop-specific growth requirements. In this case, the perennial C4-grass miscanthus (*Miscanthus* × *giganteus* Greef et Deuter) was chosen (Figure 5), due to its low demanding nature and high biomass yield potential under challenging conditions [116]. This is part of ongoing research on the cultivation of miscanthus on marginal agricultural lands in MAGIC [117]. In the EU-funded project 'GRACE' (Grant agreement ID: 745012), it is also investigated how the cultivation of miscanthus on marginal agricultural lands can be optimized [118].

Preliminary results of a field trial in southwest Germany indicate that miscanthus can establish well (Figure 5) under the given conditions [119]. The dry matter yield (DMY) averages 13 Mg ha^{-1} a^{-1} from the second year onwards [119]. This is a medium DMY level compared with miscanthus grown on good soil [116,120,121]. However, it should be mentioned that miscanthus requires very low nitrogen (N) fertilization [122], especially when harvested for combustion in winter [60,123]. This is because miscanthus has very efficient nutrient-recycling when harvested in winter [79,124]. The low demand for nitrogen fertilization renders a key low-input factor [6,32] of this MALLIS, due to an improvement of the on-farm/off-farm-ratio in favor of the on-farm inputs. Furthermore, low N fertilization levels help improve the ecosystem services of miscanthus cultivation, such as groundwater protection, environmental protection [26,80,120], while maintaining the soil nitrogen balance [125]. Overall, both the improved ecosystem services and low production costs justify the medium DMY level of miscanthus at comparable marginal agricultural sites (shallow soil, stoniness, etc.). Consequently, MALLIS must be developed under careful consideration of the given site-specific conditions [57]. Therefore, the major development steps are (i) the identification of the growth conditions and the biophysical constraints [20,20,22], (ii) the selection of best-adapted crops, and (iii) the conceptualization of best-adapted site-specific low-input agricultural practices.

Figure 5. Four-year old miscanthus (*Miscanthus* × *giganteus* Greef et Deuter) grown on a shallow stony soil in southwest Germany.

3.4. Recommendations and Outlook

The results of the suitability mapping are in line with the available literature [17,56,61,121,126–128]. Uncertainties were identified within the basic climatic requirements, because in some cases the distribution does not meet the expectations. This could be caused by the wide genetic variation within both perennial crop species, such as switchgrass and miscanthus, and annual crop species, such as camelina and safflower. To improve the representability, the basic climatic growth requirements should either include ranges (minimum–maximum) for each parameter per crop or different genotypes for each crop. For instance, there is a wide genetic variation among miscanthus genotypes with regard to their heat and cold tolerance [129–131]. For some annual industrial crops, such as camelina and safflower, winter-annual genotypes are also available [132–135]. It would very likely further increase the potential growth suitability of the pre-selected industrial crops to take these genetic variations into account. Nevertheless, this study provides valuable first insights into the potential distribution of growth suitability, contributing to an improved crop selection for the development of MALLIS across Europe.

The results of this study indicate that there are large areas potentially available for industrial crop cultivation. This is in line with available literature [17,56,61,126,127]. In many cases there are ≥2 crops suitable for the same area (Table A3). Thus, careful consideration should be given to the selection of crops or their most favorable combination according to the site conditions [136]. For an adequate crop selection, site-specific conditions other than the growth suitability should also be considered, such as the local social-ecological needs and the distance to the markets. For instance, if a site is prone to erosion, a perennial cropping system would be preferable to an annual (rotational) cropping system [115,137–139]. This could help ensure a more sustainable biomass production from both an environmental and economic point of view in the long term [140]. It would reduce the risk of further degradation through erosion, and thus help maintain or even improve the resilience of the given agroecosystem [14,141,142].

In this study, the growth suitability of the crops did not include yield and quality levels. This means that potential differences in yield or biomass quality between suitable industrial crops for the various types of marginal land across Europe remain unclear. Furthermore, the study did not cover macroeconomic aspects, such as infrastructure and market accessibility, which also play a vital role in the determination of the best site-specific crop selections across European marginal agricultural lands. In some cases, the suitability of an industrial crop also depends on the local conditions of the farms. For example, either the technical equipment or the know-how may impede an optimal MALLIS implementation. However, this study contributes to the ongoing research into how biomass for a growing bioeconomy can be provided in low-input systems, as the growth suitability of the crops forms the basis for the successful development of MALLIS. The site-specific growth suitability presented here are also available in the form of a decision support system [136]. This aims at enabling the selection of suitable case study regions for further optimization of site-specific MALLIS for industrial crop cultivation. In addition, the missing links mentioned above, including detailed information on the best crop- and site-specific harvesting technology and guidelines for farmers are also explored in the EU Horizon 2020 project MAGIC (GA 727698) [117]. As climate-change-forced shifts in the distribution of both marginal agricultural land and growth suitability of the industrial crops are to be expected [126,143–145], they are also under investigation [58,146]. This could help to better prepare European agriculture for the projected severe effects of climate change [143,144,147].

4. Conclusions

This study introduces the concept of marginal agricultural land low-input systems (MALLIS) for industrial crop cultivation. MALLIS are defined as sets of agricultural low-input practices to form viable cropping systems on marginal agricultural lands under specific climatic conditions. These sets of practices are intended to be holistically sustainable in both social-ecological and economic terms. The study identified the climatic and geophysical constraints on biomass production and the ability of 19 industrial crops to cope with these limitations. Overall, the industrial crops showed high suitability for low-input cultivation on marginal agricultural lands across Europe. However, further investigations of MALLIS are required to investigate their social-ecological sustainability and climate change effects on marginal agricultural lands.

Author Contributions: Conceptualization, M.V.C., I.L. (Iris Lewandowski), Y.I., D.S., S.L.C., O.M., I.E., F.Z., D.L., S.N., I.L. (Isabelle Lamy), L.C., M.S., J.E.C., P.C., I.M., L.M.T., E.N.V.L., W.E., A.L.F., E.G.P. and E.A.; Data curation, M.V.C., I.S., M.V.E., S.M., D.S., F.Z., I.M. and E.A.; Formal analysis, M.V.C., B.E., I.S. and M.V.E.; Funding acquisition, I.L. (Iris Lewandowski), S.L.C., A.M. and E.A.; Investigation, M.V.C., I.M., A.L.F. and E.A.; Methodology, M.V.C., I.L. (Iris Lewandowski), B.E., I.S., M.V.E., S.M., D.S., G.T., S.L.C., O.M., I.E., F.Z., D.L., I.L. (Isabelle Lamy), J.E.C., P.C., I.M., L.M.T., E.N.V.L., A.L.F., E.G.P. and E.A.; Project administration, E.A.; Resources, M.V.C., S.M., F.Z., I.M., E.N.V.L. and E.A.; Software, I.S., M.V.E. and I.M.; Supervision, I.L. (Iris Lewandowski), B.E., S.L.C., A.M., D.L., J.E.C., L.M.T., A.L.F. and E.A.; Validation, M.V.C., B.E., I.S., M.V.E., D.S., G.T., S.L.C., O.M., I.E., F.Z., A.M., D.L., I.L. (Isabelle Lamy), J.E.C., P.C., I.M., L.M.T., E.N.V.L., A.L.F., E.G.P. and E.A.; Visualization, M.V.C., B.E., I.S. and

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Funding: This research received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 727698. The article processing charge was funded by the European Union's Horizon 2020 research and innovation program under grant agreement No 727698.

Acknowledgments: The authors are thankful to Nicole Gaudet for proof-reading the manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

Table A1. Overview of the three categories of marginality constraints as classified within this deliverable. Category 1 was adapted from Reference [20]. Categories 2 and 3 were developed based on the literature review.

Constraint Category	Factor Category	Thresholds/Specifications
Category 1: "Natural constraint based marginality"	Low temperature (insufficient thermal time)	Length of growing period ≤ 180 days Thermal time sum ≤ 1500 degree days
	Dryness—Too dry conditions	Precipitation/Potential Evapotranspiration (P/ET ≤ 0.5)
	Limited soil drainage and excess soil moisture	Wet 80 cm > 6 months Wet 40 cm > 11 months Poorly or very poorly drained Gleyic colour pattern within 40 cm Soil moisture above field capacity for >230 days (excessive soil moisture)
	Unfavorable soil texture and stoniness	Topsoil with stones (15% of topsoil volume is coarse material, rock outcrop, boulder) Texture class in half of the soil in a profile of 100 cm vertical depth is sand, loamy sand Organic soil, defined as having organic matter ≥ 30% of at least 40 cm Topsoil with 30% or more clay and presence of vertical properties within 100 cm
	Shallow rooting depth	The physical anchorage of the rooting system (rooting depth ≤ 30 cm) The provision/storage of nutrients and water The possibility of mechanized tillage
	Poor chemical properties (Soil salinity, soil sodicity, soil acidity)	The possibility of mechanized tillage Limitation to plant growth, due to toxic elements in soil Vulnerability to waterlogging Damage to soil structure (and consequently increase in risk of erosion) Limited availability of nutrients for plants Salinity ≥ 4 dS/m in topsoil Sodicity ≥ 6 ESP in half or more of the 100-cm surface layer Soil Acidity of topsoil with pH (H20) ≤ 5
	Steep slope	Slope ≥ 15%
Category 2: "Socio-economic-political constraints"		Lack of awareness (alternative strategies—lack of know-how, etc.) Social norms (adoption of same cropping patterns as done by elders) Economic viability, especially of set-aside, small land holdings Lack of infrastructure Lack of policies Lack of government programs, such as extension services
Category 3: "Endangered Sites"		Lands which are currently productive, but will be transformed into marginal lands in the long term if not managed properly (also, lack of know-how or lack of awareness from farmers/government).

Table A2. Crop-suitability ranking (from 0 = unsuitable to 4 = very suitable, whereas both 0 and 1 were defined as marginal) according to precipitation.

Crop	Precipitation Classes (mm year^{-1} or mm (Growth Season of Annuals)$^{-1}$)							
	0–100	**100–200**	**200–300**	**300–400**	**400–500**	**500–600**	**600–800**	**800–1000**
Biomass sorghum	0	1	2	3	4	4	4	4
Camelina	3	4	4	4	4	4	2	2
Cardoon	0	0	0	1	2	3	3	4
Castor bean	1	2	2	3	3	4	4	4
Crambe	3	4	4	4	4	4	2	2
Ethiopian mustard	2	3	3	3	3	4	4	4
Giant reed	0	0	1	1	2	3	4	4
Hemp	0	1	2	3	4	4	4	3
Lupin	0	1	2	2	3	4	4	4
Miscanthus	0	0	0	0	1	2	3	4
Pennycress	1	1	2	4	4	4	4	4
Poplar	0	0	0	0	0	0	2	3
Reed canary grass	0	0	0	0	0	0	2	3
Safflower	0	1	2	3	4	4	4	3
Siberian elm	0	0	1	2	3	4	4	4
Switchgrass	0	0	0	1	2	3	4	4
Tall wheatgrass	0	0	1	3	4	4	4	4
Wild sugarcane	0	1	1	2	3	4	4	4
Willow	0	0	0	0	0	0	2	3

Table A3. Total area (km^2) per selected industrial crop suitable for cultivation on marginal land across Europe (EU-28) and share (%) of marginal land suitable for cultivation of the crop.

Crop	AEZ 1		AEZ 2		AEZ 3		AEZ 1–3	
	km^2	**%**	**km^2**	**%**	**km^2**	**%**	**Km^2**	**%**
Biomass sorghum	193,118	88	31,322	16	6323	3	230,763	36
Camelina	209,761	96	186,018	97	183,667	78	579,446	90
Cardoon	172,804	79	71,822	37	83,249	35	327,875	51
Castor	160,990	74	10,658	6	3412	1	175,060	27
Crambe	216,577	99	175,244	91	130,959	56	522,780	86
Ethiopian mustard	184,988	84	43,177	22	10,111	4	238,276	37
Giant reed	129,501	59	2459	1	1173	0	133,133	21
Hemp	162,794	74	80,422	42	17,392	7	260,608	41
Lupin	201,888	92	36,790	19	37,162	16	275,840	43
Miscanthus	130,634	60	83,820	44	88,010	37	302,464	48
Pennycress	208,388	95	64,812	34	76,465	32	349,665	56
Poplar	48,166	22	159,938	83	150,428	64	358,532	60
Reed canary grass	45,863	21	124,828	65	147,470	63	318,161	53
Safflower	201,689	7	145,382	76	16,164	92	363,235	58
Siberian elm	179,148	82	20,611	11	28,261	12	228,020	36
Switchgrass	160,238	73	19,732	10	26,628	11	206,598	32
Tall wheatgrass	211,255	96	151,166	79	172,355	73	534,776	88
Wild sugarcane	46,516	21	252	0	0	0	46,768	7
Willow	56,880	26	164,191	85	119,536	51	340,607	56
Average	153,747	66	82,771	43	68,356	33	304,874	49

Table A4. Suitability ranking of selected agricultural management options for competing with the prevailing biophysical constraints on arable marginal lands (from −3 = strong negative effect to +3 = strong positive effect).

Agricultural Management Options	**Biophysical Constraints**												
	Climatical			**Soil/Terrain**									
	Low Temperature	**High Temperature**	**Dryness**	**Excessive Moisture**	**Poor Soil Drainage**	**Unfav. Texture/Stoniness**	**Shallow Rooting Depth**	**Steep Slope**	**Low Soil Fertility**	**Alkalinity**	**Acidity**	**Salinity**	**Other Contamination**
Structured measures													
Line irrigation	−1	0	1	−3	−3	−1	1	−3	1	0	0	1	0
Sprinkler irrigation	0	2	2	−3	0	2	1	1	1	1	1	1	0
Microirrigation (drip irrigation)	0	0	3	−3	1	3	3	2	2	0	0	2	0
Deficit irrigation technique	0	0	3	−3	1	2	2	3	3	1	1	−1	0
Terracing	0	0	0	0	0	0	0	3	0	0	0	0	0
Field shaping, planting density and geometry	0	0	1	1	0	2	2	1	0	0	0	0	0
Hedges	1	0	0	1	1	0	0	1	0	0	0	0	0
Water channels	−1	0	−3	2	3	0	0	−3	0	1	1	0	0
Systematic measures													
Catch crops	1	2	1	2	3	1	−1	0	1	0	0	1	1
Crop rotation	0	0	1	0	1	2	1	−1	2	0	0	1	2
Agroforestry	0	0	1	2	2	2	1	3	2	2	2	0	2
Intercropping	1	1	2	2	2	1	0	2	1	1	1	1	1
Mixed cropping	1	1	1	2	1	2	0	1	2	1	1	1	1
Crop selection													
Deep roots	1	2	3	2	3	−1	−3	2	1	1	1	1	0
Shallow roots	1	0	−3	−1	−2	2	3	1	0	0	0	0	0
C3-Metabolism	3	1	0	0	0	0	0	0	0	0	0	0	0
C4-Metabolism	1	3	2	0	0	0	0	0	0	0	0	1	0
Annual lifecycle	0	0	0	−2	−3	0	0	0	1	0	0	1	1
Biennial lifecycle	1	1	1	1	1	0	1	1	2	0	0	1	1
Perennial lifecycle	2	1	3	2	2	1	2	2	3	1	1	2	1

Table A5. Suitability ranking of selected components of agricultural management systems for competing with the prevailing biophysical constraints on arable marginal lands (from −3 = strong negative effect to +3 = strong positive effect).

Components of Management System	Biophysical Constraints												
	Climatic				Soil/Terrain								
	Low Temperature	High Temperature	Dryness	Excessive Moisture	Poor Soil Drainage	Unfav. Texture/Stoniness	Shallow Rooting Depth	Steep Slope	Low Soil Fertility	Alkalinity	Acidity	Salinity	Other Contamination
Soil cultivation													
Full till	1	−2	−2	−3	−1	−1	−1	−3	−1	1	1	0	1
Reduced till	−1	1	1	1	1	1	1	−1	1	0	0	0	1
Precision tillage	3	2	2	0	2	2	1	1	2	0	0	0	1
No till	2	3	3	2	1	2	2	3	2	0	0	0	0
Living mulch	1	−2	−2	3	1	1	−1	2	2	1	1	1	−1
Cover soil with film	2	1	2	−1	−2	2	1	1	1	0	0	−1	−1
Harvest residuals	2	−1	−1	0	1	1	−1	−3	2	1	1	0	−1
Establishment													
Pesticides [a]	1	0	1	1	2	1	0	0	1	1	1	1	0
Micronutrients [a]	1	1	1	1	1	2	1	0	3	0	1	1	−1
Bio-stimulators [a]	0	0	1	1	1	2	1	0	2	1	1	1	0
Rhizomes	1	1	1	−1	0	1	1	1	1	−1	−1	0	0
Plantlets	1	2	2	1	1	2	2	2	2	0	0	1	0
Collars	1	2	2	−1	0	0	−1	1	1	−1	−1	−1	0
Unrooted cuttings	1	2	0	2	1	0	−1	2	0	1	1	1	0
Crop protection													
Pesticides	1	1	1	1	−1	0	0	2	1	1	1	1	0
Biological pest control	1	0	0	2	2	2	0	1	1	0	0	0	0
Crop rotation strategy	2	1	2	1	2	2	1	1	2	1	1	1	2
Mechanical weeding	1	1	1	−1	0	−1	−1	−3	1	0	−1	−1	0
Thermal weeding	3	1	1	2	2	2	0	0	2	0	0	−1	0
Chemical weeding	1	1	1	0	−1	2	1	1	0	0	0	1	0
Biological weeding	2	1	−1	2	2	1	1	2	1	1	1	1	1
Cover soil with film	2	1	1	0	0	2	2	2	−2	0	0	0	0
Fertilization													
Broadcast application	−1	1	1	−1	1	1	0	1	1	0	0	0	0
Ground level application	0	1	1	0	0	1	0	−1	1	0	0	−1	0
Injection	1	2	1	0	2	0	−1	1	1	0	0	0	0
Organic fertilizer	2	3	3	−1	−1	2	1	2	3	2	2	2	3
Liming	1	0	0	1	1	2	0	0	2	−1	3	−2	0
Chemical fertilizer	1	1	1	−1	1	1	1	−1	3	−1	−1	−2	0
Solid	2	1	2	1	1	2	0	0	1	0	0	1	0
Liquid	2	−3	−3	−1	1	1	0	0	1	0	1	0	0
Spring application	−1	2	2	1	1	1	0	0	1	0	0	0	0
Summer application	−2	1	2	1	1	1	0	0	1	0	0	0	0
Autumn application	0	0	0	−1	1	0	0	1	−1	0	0	0	0
Winter application	0	0	0	−2	−1	0	0	−1	0	0	0	0	0
One application	1	−1	−1	1	1	−1	1	1	1	0	0	0	0
>1 applications	1	1	1	−1	−1	1	−1	−1	2	0	0	0	0

[a] Priming of seeds and planting material.

References

1. Staffas, L.; Gustavsson, M.; McCormick, K. Strategies and policies for the bioeconomy and bio-based economy: An analysis of official national approaches. *Sustainability* **2013**, *5*, 2751–2769. [CrossRef]
2. Lewandowski, I. Securing a sustainable biomass supply in a growing bioeconomy. *Glob. Food Secur.* **2015**, *6*, 34–42. [CrossRef]
3. Scarlat, N.; Dallemand, J.F.; Monforti-Ferrario, F.; Nita, V. The role of biomass and bioenergy in a future bioeconomy: Policies and facts. *Environ. Dev.* **2015**, *15*, 3–34. [CrossRef]
4. Scarlat, N.; Dallemand, J.F.; Fahl, F. Biogas: Developments and perspectives in Europe. *Renew. Energy* **2018**, *129*, 457–472. [CrossRef]
5. Fernando, A.L.; Boléo, S.; Barbosa, B.; Costa, J.; Duarte, M.P.; Monti, A. Perennial Grass Production Opportunities on Marginal Mediterranean Land. *Bioenergy Res.* **2015**, *8*, 1523–1537. [CrossRef]
6. Biala, K.; Terres, J.M.; Pointereau, P.; Paracchini, M.L. Low Input Farming Systems: An opportunity to develop sustainable agriculture. *Proc. JRC Summer Univ. Ranco.* **2007**, 2–5. [CrossRef]
7. Lewandowski, I.; Lippe, M.; Castro-Montoya, J.; Dickhöfer, U.; Langenberger, G.; Pucher, J.; Schließmann, U.; Derwenskus, F.; Schmid-Staiger, U.; Lippert, C. Primary Production. In *Bioeconomy*; Springer: Cham, Switzerland, 2018; pp. 95–175.
8. Pulighe, G.; Bonati, G.; Fabiani, S.; Barsali, T.; Lupia, F.; Vanino, S.; Nino, P.; Arca, P.; Roggero, P.P. 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. [CrossRef]
9. Dale, V.H.; Kline, K.L.; Wiens, J.; Fargione, J. *Biofuels: Implications for Land Use and Biodiversity*; Ecological Society of America: Washington, DC, USA, 2010.
10. Liu, T.T.; McConkey, B.G.; Ma, Z.Y.; Liu, Z.G.; Li, X.; Cheng, L.L. Strengths, Weaknessness, Opportunities and Threats Analysis of Bioenergy Production on Marginal Land. *Energy Procedia* **2011**, *5*, 2378–2386. [CrossRef]
11. Zhuang, D.; Jiang, D.; Liu, L.; Huang, Y. Assessment of bioenergy potential on marginal land in China. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1050–1056. [CrossRef]
12. Elbersen, B.; Van Verzandvoort, M.; Boogaard, S.; Mucher, S.; Cicarelli, T.; Elbersen, W.; Mantel, S.; Bai, Z.; MCallum, I.; Iqbal, Y.; et al. *Definition and Classification of Marginal Lands Suitable for Industrial Crops in Europe (EU Deliverable)*; WUR: Wageningen, The Netherlands, 2018; p. 44.
13. Edrisi, S.A.; Abhilash, P.C. Exploring marginal and degraded lands for biomass and bioenergy production: An Indian scenario. *Renew. Sustain. Energy Rev.* **2016**, *54*, 1537–1551. [CrossRef]
14. Folke, C. Resilience: The emergence of a perspective for social–ecological systems analyses. *Glob. Environ. Chang.* **2006**, *16*, 253–267. [CrossRef]
15. Elmqvist, T.; Folke, C.; Nyström, M.; Peterson, G.; Bengtsson, J.; Walker, B.; Norberg, J. Response diversity, ecosystem change, and resilience. *Front. Ecol. Environ.* **2003**, *1*, 488–494. [CrossRef]
16. Ciria, C.S.; Sanz, M.; Carrasco, J.; Ciria, P. Identification of Arable Marginal Lands under Rainfed Conditions for Bioenergy Purposes in Spain. *Sustainability* **2019**, *11*, 1833. [CrossRef]
17. Krasuska, E.; Cadórniga, C.; Tenorio, J.L.; Testa, G.; Scordia, D. Potential land availability for energy crops production in Europe. *Biofuels Bioprod. Biorefin.* **2010**, *4*, 658–673. [CrossRef]
18. Elbersen, B.S.; Andersen, E. Low-input farming systems: Their general characteristics, identification and quantification. In *Low Input Farming Systems: An. Opportunity to Develop Sustainable Agriculture*; OPOCE: Brussels, Belgium, 2008; p. 12.
19. Fernando, A.L.; Costa, J.; Barbosa, B.; Monti, A.; Rettenmaier, N. Environmental impact assessment of perennial crops cultivation on marginal soils in the Mediterranean Region. *Biomass Bioenergy* **2018**, *111*, 174–186. [CrossRef]
20. Van Orshoven, J.; Terres, J.M.; Tóth, T. Updated common bio-physical criteria to define natural constraints for agriculture in Europe. In *JRC Scientific and Technical Reports*; Publications Office of the European Union: Brussels, Belgium, 2012.
21. Van Orshoven, J.; Terres, J.M.; Tóth, T. Updated common bio-physical criteria to define natural constraints for agriculture in Europe—Definition and scientific justification for the common biophysical criteria. In *JRC Scientific and Technical Reports*; Publications Office of the European Union: Brussels, Belgium, 2014. [CrossRef]

22. Terres, J.M.; Hagyo, A.; Wania, A. Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by specific constraints: Methodology and factsheets for plausible criteria combinations. In *JRC Scientific and Technical Reports*; Publications Office of the European Union: Brussels, Belgium, 2014.
23. Hallmann, C.A.; Sorg, M.; Jongejans, E.; Siepel, H.; Hofland, N.; Schwan, H.; Stenmans, W.; Müller, A.; Sumser, H.; Hörren, T. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE* **2017**, *12*, e0185809. [CrossRef] [PubMed]
24. Huth, E.; Paltrinieri, S.; Thiele, J. Bioenergy and its effects on landscape aesthetics—A survey contrasting conventional and wild crop biomass production. *Biomass Bioenergy* **2019**, *122*, 313–321. [CrossRef]
25. Potts, S.G.; Imperatriz-Fonseca, V.L.; Ngo, H.T.; Biesmeijer, J.C.; Breeze, T.D.; Dicks, L.V.; Garibaldi, L.A.; Hill, R.; Settele, J.; Vanbergen, A.J. *Summary for Policymakers of the Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production*; Bonn, Germany, 2016; ISBN 978-92-807-3568-0.
26. Svoboda, N.; Taube, F.; Kluß, C.; Wienforth, B.; Kage, H.; Ohl, S.; Hartung, E.; Herrmann, A. Crop production for biogas and water protection—A trade-off? *Agric. Ecosyst. Environ.* **2013**, *177*, 36–47. [CrossRef]
27. Lewandowski, I. The role of perennial biomass crops in a growing bioeconomy. In *Perennial Biomass Crops for a Resource-Constrained World*; Springer: Cham, Switzerland, 2016; pp. 3–13. [CrossRef]
28. Monti, A.; Alexopoulou, E. Non-food crops in marginal land: An illusion or a reality? *Biofuels Bioprod. Biorefin.* **2017**, *11*, 937–938. [CrossRef]
29. Tilman, D.; Socolow, R.; Foley, J.A.; Hill, J.; Larson, E.; Lynd, L.; Pacala, S.; Reilly, J.; Searchinger, T.; Somerville, C. Beneficial biofuels—The food, energy, and environment trilemma. *Science* **2009**, *325*, 270–271. [CrossRef]
30. Araújo, K.; Mahajan, D.; Kerr, R.; Silva, M.D. Global biofuels at the crossroads: An overview of technical, policy, and investment complexities in the sustainability of biofuel development. *Agriculture* **2017**, *7*, 32. [CrossRef]
31. Elbersen, B.; Van Eupen, M.; Verzandvoort, S.; Boogaard, H.; Mucher, S.; Cicarreli, T.; Elbersen, W.; Mantel, S.; Bai, Z.; Mcallum, I.; et al. *Methodological Approaches to Identify and Map Marginal Land Suitable for Industrial Crops in Europe*; WUR: Wageningen, The Netherlands, 2018; p. 142.
32. Ramirez-Almeyda, J.; Elbersen, B.; Monti, A.; Staritsky, I.; Panoutsou, C.; Alexopoulou, E.; Schrijver, R.; Elbersen, W. Assessing the Potentials for Nonfood Crops. In *Modeling and Optimization of Biomass Supply Chains*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 219–251.
33. FAO Ecocrop. Food and Agriculture Organization of the UN 2007. Available online: http://ecocrop.fao.org/ecocrop/srv/en/cropSearchForm (accessed on 13 August 2019).
34. Metzger, M.J.; Bunce, R.G.H.; Jongman, R.H.; Mücher, C.A.; Watkins, J.W. A climatic stratification of the environment of Europe. *Glob. Ecol. Biogeogr.* **2005**, *14*, 549–563. [CrossRef]
35. Altieri, M.A.; Nicholls, C.I.; Montalba, R. Technological Approaches to Sustainable Agriculture at a Crossroads: An Agroecological Perspective. *Sustainability* **2017**, *9*, 349. [CrossRef]
36. Altieri, M.A.; Nicholls, C.I.; Henao, A.; Lana, M.A. Agroecology and the design of climate change-resilient farming systems. *Agron. Sustain. Dev.* **2015**, *35*, 869–890. [CrossRef]
37. Arthurson, V.; Jäderlund, L. Utilization of natural farm resources for promoting high energy efficiency in low-input organic farming. *Energies* **2011**, *4*, 804–817. [CrossRef]
38. Francis, C.; Lieblein, G.; Gliessman, S.; Breland, T.A.; Creamer, N.; Harwood, R.; Salomonsson, L.; Helenius, J.; Rickerl, D.; Salvador, R.; et al. Agroecology: The ecology of food systems. *J. Sustain. Agric.* **2003**, *22*, 99–118. [CrossRef]
39. Altieri, M.A.; Merrick, L. In situ conservation of crop genetic resources through maintenance of traditional farming systems. *Econ. Bot.* **1987**, *41*, 86–96. [CrossRef]
40. De Jesus Duarte, S.; Glaser, B.; Cerri, C.E.P. Effect of biochar particle size on physical, hydrological and chemical properties of loamy and sandy tropical soils. *Agronomy* **2019**, *9*, 165. [CrossRef]
41. Sánchez-Monedero, M.A.; Cayuela, M.L.; Sánchez-García, M.; Vandecasteele, B.; D'Hose, T.; López, G.; Martínez-Gaitán, C.; Kuikman, P.J.; Sinicco, T.; Mondini, C. Agronomic evaluation of biochar, compost and biochar-blended compost across different cropping systems: Perspective from the European project FERTIPLUS. *Agronomy* **2019**, *9*, 225. [CrossRef]

42. Horel, Á.; Tóth, E.; Gelybó, G.; Dencso, M.; Farkas, C. Biochar amendment affects soil water and CO_2 regime during Capsicum annuum plant growth. *Agronomy* **2019**, *9*, 58. [CrossRef]
43. Speratti, A.B.; Johnson, M.S.; Sousa, H.M.; Torres, G.N.; Couto, E.G. Impact of different agricultural waste biochars on maize biomass and soil water content in a Brazilian Cerrado Arenosol. *Agronomy* **2017**, *7*, 49. [CrossRef]
44. Zhang, Y.; Idowu, O.J.; Brewer, C.E. Using agricultural residue biochar to improve soil quality of desert soils. *Agriculture* **2016**, *6*, 10. [CrossRef]
45. O'toole, A.; Moni, C.; Weldon, S.; Schols, A.; Carnol, M.; Bosman, B.; Rasse, D.P. Miscanthus biochar had limited effects on soil physical properties, microbial biomass, and grain yield in a four-year field experiment in Norway. *Agriculture* **2018**, *8*, 171. [CrossRef]
46. Guizani, C.; Jeguirim, M.; Valin, S.; Limousy, L.; Salvador, S. Biomass chars: The effects of pyrolysis conditions on their morphology, structure, chemical properties and reactivity. *Energies* **2017**, *10*, 796. [CrossRef]
47. Qian, K.; Kumar, A.; Patil, K.; Bellmer, D.; Wang, D.; Yuan, W.; Huhnke, R.L. Effects of biomass feedstocks and gasification conditions on the physiochemical properties of char. *Energies* **2013**, *6*, 3972–3986. [CrossRef]
48. Lehmann, J.; Rillig, M.C.; Thies, J.; Masiello, C.A.; Hockaday, W.C.; Crowley, D. Biochar effects on soil biota—A review. *Soil Biol. Biochem.* **2011**, *43*, 1812–1836. [CrossRef]
49. Ahmad, M.; Rajapaksha, A.U.; Lim, J.E.; Zhang, M.; Bolan, N.; Mohan, D.; Vithanage, M.; Lee, S.S.; Ok, Y.S. Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere* **2014**, *99*, 19–33. [CrossRef] [PubMed]
50. Ehmann, A.; Bach, I.M.; Laopeamthong, S.; Bilbao, J.; Lewandowski, I. Can phosphate salts recovered from manure replace conventional phosphate fertilizer? *Agriculture* **2017**, *7*, 1. [CrossRef]
51. Bergfeldt, B.; Morgano, M.T.; Leibold, H.; Richter, F.; Stapf, D. Recovery of phosphorus and other nutrients during pyrolysis of chicken manure. *Agriculture* **2018**, *8*, 187. [CrossRef]
52. Tilman, D.; Hill, J.; Lehman, C. Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass. *Science* **2006**, *314*, 1598–1600. [CrossRef]
53. Weigelt, A.; Weisser, W.W.; Buchmann, N.; Scherer-Lorenzen, M. Biodiversity for multifunctional grasslands: Equal productivity in high-diversity low-input and low-diversity high-input systems. *Biogeosciences* **2009**, *6*, 1695–1706. [CrossRef]
54. Altieri, M.A. The ecological role of biodiversity in agroecosystems. *Agric. Ecosyst. Environ.* **1999**, *74*, 19–31. [CrossRef]
55. Mockshell, J.; Kamanda, J. Beyond the Agroecological and Sustainable Agricultural Intensification Debate: Is Blended Sustainability the Way Forward? In *Discussion Paper*; Deutsches Institut für Entwicklungspolitik gGmbH: Bonn, Germany, 2017; pp. 1–42.
56. Galatsidas, S.; Gounaris, N.; Vlachaki, D.; Dimitriadis, E.; Kiourtsis, F.; Keramitzis, D.; Gerwin, W.; Repmann, F.; Rettenmaier, N.; Reinhardt, G. Revealing Bioenergy Potentials: Mapping Marginal Lands in Europe-The SEEMLA Approach. In Proceedings of the 26th European Biomass Conference and Exhibition, Copenhagen, Denmark, 14–18 May 2018; Available online: https://opus4.kobv.de/opus4-UBICO/frontdoor/index/index/docId/22081 (accessed on 9 July 2019).
57. Monti, A.; Zegada-Lizarazu, W.; Zanetti, F.; Casler, M. Chapter Two—Nitrogen Fertilization Management of Switchgrass, Miscanthus and Giant Reed: A Review. In *Advances in Agronomy*; Sparks, D.L., Ed.; Academic Press: Cambridge, MA, USA, 2019; Volume 153, pp. 87–119.
58. Von Cossel, M.; Winkler, B.; Wagner, M.; Lask, J.; Magenau, E.; Bauerle, A.; Von Cossel, V.; Warrach-Sagi, K.; Elbersen, B.; Staritsky, I.; et al. The future of bioenergy crops cultivation. *Agronomy*. unpublished.
59. Sun, Y.; Druecker, H.; Hartung, E.; Hueging, H.; Cheng, Q.; Zeng, Q.; Sheng, W.; Lin, J.; Roller, O.; Paetzold, S.; et al. Map-based investigation of soil physical conditions and crop yield using diverse sensor techniques. *Soil Tillage Res.* **2011**, *112*, 149–158. [CrossRef]
60. Kiesel, A.; Nunn, C.; Iqbal, Y.; Van der Weijde, T.; Wagner, M.; Özgüven, M.; Tarakanov, I.; Kalinina, O.; Trindade, L.M.; Clifton-Brown, J.; et al. Site-specific management of miscanthus genotypes for combustion and anaerobic digestion: A comparison of energy yields. *Front. Plant Sci.* **2017**, *8*, 927. [CrossRef] [PubMed]
61. Gerwin, W.; Repmann, F.; Galatsidas, S.; Vlachaki, D.; Gounaris, N.; Baumgarten, W.; Volkmann, C.; Keramitzis, D.; Kiourtsis, F.; Freese, D. Assessment and quantification of marginal lands for biomass production in Europe using soil-quality indicators. *Soil* **2018**, *4*, 267–290. [CrossRef]

62. Bu, L.; Liu, J.; Zhu, L.; Luo, S.; Chen, X.; Li, S.; Lee Hill, R.; Zhao, Y. The effects of mulching on maize growth, yield and water use in a semi-arid region. *Agric. Water Manag.* **2013**, *123*, 71–78. [CrossRef]
63. Lazdina, D.; Bardule, A.; Lazdins, A.; Stola, J. Use of waste water sludge and wood ash as fertiliser for Salix cultivation in acid peat soils. *Agron. Res.* **2011**, *9*, 305–314.
64. Holzschuh, A.; Dainese, M.; González-Varo, J.P.; Mudri-Stojnić, S.; Riedinger, V.; Rundlöf, M.; Scheper, J.; Wickens, J.B.; Wickens, V.J.; Bommarco, R.; et al. Mass-flowering crops dilute pollinator abundance in agricultural landscapes across Europe. *Ecol. Lett.* **2016**, *19*, 1228–1236. [CrossRef]
65. Allan, J.D. LANDSCAPES AND RIVERSCAPES: The Influence of Land Use on Stream Ecosystems. *Annu. Rev. Ecol. Evol. Syst.* **2004**, *35*, 257–284. [CrossRef]
66. Fahrig, L. How much habitat is enough? *Biol. Conserv.* **2001**, *100*, 65–74. [CrossRef]
67. Fischer, J.; Brosi, B.; Daily, G.C.; Ehrlich, P.R.; Goldman, R.; Goldstein, J.; Lindenmayer, D.B.; Manning, A.D.; Mooney, H.A.; Pejchar, L.; et al. Should agricultural policies encourage land sparing or wildlife-friendly farming? *Front. Ecol. Environ.* **2008**, *6*, 380–385. [CrossRef]
68. Von Cossel, M. *Agricultural Diversification of Biogas Crop Cultivation*; University of Hohenheim: Stuttgart, Germany, 2019; Available online: http://opus.uni-hohenheim.de/volltexte/2019/1600/ (accessed on 13 August 2019).
69. Von Cossel, M.; Mangold, A.; Iqbal, Y.; Hartung, J.; Lewandowski, I.; Kiesel, A. How to Generate Yield in the First Year—A Three-Year Experiment on Miscanthus (Miscanthus × giganteus (Greef et Deuter)) Establishment under Maize (Zea mays L.). *Agronomy* **2019**, *9*, 237. [CrossRef]
70. Wagner, M. Methodological Approaches for Assessing the Environmental Performance of Perennial Crop-Based Value Chains. Dissertation, University of Hohenheim, Hohenheim, Germany, 2018. Available online: http://opus.uni-hohenheim.de/volltexte/2018/1433/ (accessed on 13 August 2019).
71. Barbosa, B.; Costa, J.; Fernando, A.L.; Papazoglou, E.G. Wastewater reuse for fiber crops cultivation as a strategy to mitigate desertification. *Ind. Crop. Prod.* **2015**, *68*, 17–23. [CrossRef]
72. Soldatos, P. Economic aspects of bioenergy production from perennial grasses in marginal lands of South Europe. *Bioenergy Res.* **2015**, *8*, 1562–1573. [CrossRef]
73. Fernando, A.L.; Rettenmaier, N.; Soldatos, P.; Panoutsou, C. Sustainability of Perennial Crops Production for Bioenergy and Bioproducts. In *Perennial Grasses for Bioenergy and Bioproducts*; Alexopoulou, E., Ed.; Academic Press: Cambridge, MA, USA, 2018; pp. 245–283.
74. Barbosa, B.; Costa, J.; Fernando, A.L. Production of Energy Crops in Heavy Metals Contaminated Land: Opportunities and Risks. In *Land Allocation for Biomass Crops: Challenges and Opportunities with Changing Land Use*; Li, R., Monti, A., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 83–102.
75. Leopold, A. *A Sand County Almanac*; Oxford University Press: Oxford, UK, 1949.
76. Alvarez, S.; Timler, C.J.; Michalscheck, M.; Paas, W.; Descheemaeker, K.; Tittonell, P.; Andersson, J.A.; Groot, J.C.J. Capturing farm diversity with hypothesis-based typologies: An innovative methodological framework for farming system typology development. *PLoS ONE* **2018**, *13*, e0194757. [CrossRef] [PubMed]
77. Michalscheck, M. *On Smallholder Farm and Farmer Diversity*; Wageningen University & Research: Wageningen, The Netherlands, 2019.
78. Winkler, B.; Lemke, S.; Ritter, J.; Lewandowski, I. Integrated assessment of renewable energy potential: Approach and application in rural South Africa. *Environ. Innov. Soc. Transit.* **2017**, *24*, 17–31. [CrossRef]
79. Kiesel, A.; Wagner, M.; Lewandowski, I. Environmental performance of miscanthus, switchgrass and maize: Can C4 perennials increase the sustainability of biogas production? *Sustainability* **2017**, *9*, 5. [CrossRef]
80. De Groot, R.S.; Wilson, M.A.; Boumans, R.M. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecol. Econ.* **2002**, *41*, 393–408. [CrossRef]
81. Chauvat, M.; Perez, G.; Hedde, M.; Lamy, I. Establishment of bioenergy crops on metal contaminated soils stimulates belowground fauna. *Biomass Bioenergy* **2014**, *62*, 207–211. [CrossRef]
82. Hedde, M.; van Oort, F.; Renouf, E.; Thénard, J.; Lamy, I. Dynamics of soil fauna after plantation of perennial energy crops on polluted soils. *Appl. Soil Ecol.* **2013**, *66*, 29–39. [CrossRef]
83. Bourgeois, E.; Dequiedt, S.; Lelièvre, M.; van Oort, F.; Lamy, I.; Maron, P.A.; Ranjard, L. Positive effect of the Miscanthus bioenergy crop on microbial diversity in wastewater-contaminated soil. *Environ. Chem. Lett.* **2015**, *13*, 495–501. [CrossRef]
84. TEEB. *Guidance Manual for TEEB Country Studies-Version 1.0*; Institute for European Environmental Policy: Geneva, Switzerland, 2013.

85. Von Cossel, M.; Lewandowski, I. Perennial wild plant mixtures for biomass production: Impact of species composition dynamics on yield performance over a five-year cultivation period in southwest Germany. *Eur. J. Agron.* **2016**, *79*, 74–89. [CrossRef]
86. Vollrath, B.; Werner, A.; Degenbeck, M.; Illies, I.; Zeller, J.; Marzini, K. *Energetische Verwertung von Kräuterreichen Ansaaten in der Agrarlandschaft und im Siedlungsbereich-Eine Ökologische und Wirtschaftliche Alternative bei der Biogasproduktion*; Energie aus Wildpflanzen; Bayerische Landesanstalt für Weinbau und Gartenbau: Veitshöchheim, Germany, 2012; p. 207.
87. Von Cossel, M.; Steberl, K.; Hartung, J.; Agra Pereira, L.; Kiesel, A.; Lewandowski, I. Methane yield and species diversity dynamics of perennial wild plant mixtures established alone, under cover crop maize (Zea mays L.) and after spring barley (Hordeum vulgare L.). *GCB Bioenergy* **2019**. [CrossRef]
88. Weißhuhn, P.; Reckling, M.; Stachow, U.; Wiggering, H. Supporting Agricultural Ecosystem Services through the Integration of Perennial Polycultures into Crop Rotations. *Sustainability* **2017**, *9*, 2267. [CrossRef]
89. Emmerling, C.; Schmidt, A.; Ruf, T.; von Francken-Welz, H.; Thielen, S. Impact of newly introduced perennial bioenergy crops on soil quality parameters at three different locations in W-Germany. *J. Plant Nutr. Soil Sci.* **2017**, *180*, 759–767. [CrossRef]
90. Gansberger, M.; Montgomery, L.F.R.; Liebhard, P. Botanical characteristics, crop management and potential of Silphium perfoliatum L. as a renewable resource for biogas production: A review. *Ind. Crop. Prod.* **2015**, *63*, 362–372. [CrossRef]
91. Mast, B.; Lemmer, A.; Oechsner, H.; Reinhardt-Hanisch, A.; Claupein, W.; Graeff-Hönninger, S. Methane yield potential of novel perennial biogas crops influenced by harvest date. *Ind. Crop. Prod.* **2014**, *58*, 194–203. [CrossRef]
92. Bufe, C.; Korevaar, H. *Evaluation of Additional Crops for Dutch List of Ecological Focus Area: Evaluation of Miscanthus, Silphium Perfoliatum, Fallow Sown in with Melliferous Plants and Sunflowers in Seed Mixtures for Catch Crops*; Wageningen Research Foundation (WR) business unit Agrosystems Research: Lelystad, The Netherlands, 2018.
93. Nabel, M.; Barbosa, D.B.P.; Horsch, D.; Jablonowski, N.D. Energy Crop (Sida Hermaphrodita) Fertilization Using Digestate under Marginal Soil Conditions: A Dose-response Experiment. *Energy Procedia* **2014**, *59*, 127–133. [CrossRef]
94. Nabel, M.; Temperton, V.M.; Poorter, H.; Lücke, A.; Jablonowski, N.D. Energizing marginal soils—The establishment of the energy crop Sida hermaphrodita as dependent on digestate fertilization, NPK, and legume intercropping. *Biomass Bioenergy* **2016**, *87*, 9–16. [CrossRef]
95. Jablonowski, N.D.; Kollmann, T.; Nabel, M.; Damm, T.; Klose, H.; Müller, M.; Bläsing, M.; Seebold, S.; Krafft, S.; Kuperjans, I.; et al. Valorization of Sida (Sida hermaphrodita) biomass for multiple energy purposes. *GCB Bioenergy* **2017**, *9*, 202–214. [CrossRef]
96. Von Cossel, M.; Möhring, J.; Kiesel, A.; Lewandowski, I. Methane yield performance of amaranth (Amaranthus hypochondriacus L.) and its suitability for legume intercropping in comparison to maize (Zea mays L.). *Ind. Crops Prod.* **2017**, *103*, 107–121. [CrossRef]
97. Eberl, V.; Fahlbusch, W.; Fritz, M.; Sauer, B. *Screening und Selektion von Amarantsorten und Linien als Spurenelementreiches Biogassubstrat*; Berichte aus dem TFZ; Technologie-und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe: Straubing, Germany, 2014; p. 120.
98. Eberl, V.; Fritz, M. *Amarant als Spurenelementreiches Biogassubstrat*; Biogas Forum Bayern; Technologie-und Förderzentrum (TFZ) im Kompetenzzentrum für Nachwachsende Rohstoffe: Straubing, Germany, 2018.
99. Righini, D.; Zanetti, F.; Martínez-Force, E.; Mandrioli, M.; Toschi, T.G.; Monti, A. Shifting sowing of camelina from spring to autumn enhances the oil quality for bio-based applications in response to temperature and seed carbon stock. *Ind. Crop. Prod.* **2019**, *137*, 66–73. [CrossRef]
100. Stolarski, M.J.; Krzyżaniak, M.; Kwiatkowski, J.; Tworkowski, J.; Szczukowski, S. Energy and economic efficiency of camelina and crambe biomass production on a large-scale farm in north-eastern Poland. *Energy* **2018**, *150*, 770–780. [CrossRef]
101. Stolarski, M.J.; Krzyżaniak, M.; Tworkowski, J.; Załuski, D.; Kwiatkowski, J.; Szczukowski, S. Camelina and crambe production – Energy efficiency indices depending on nitrogen fertilizer application. *Ind. Crop. Prod.* **2019**, *137*, 386–395. [CrossRef]
102. Righini, D.; Zanetti, F.; Monti, A. The bio-based economy can serve as the springboard for camelina and crambe to quit the limbo. *OCL* **2016**, *23*, 23. [CrossRef]

103. Dordas, C.A.; Sioulas, C. Dry matter and nitrogen accumulation, partitioning, and retranslocation in safflower (Carthamus tinctorius L.) as affected by nitrogen fertilization. *Field Crop. Res.* **2009**, *110*, 35–43. [CrossRef]
104. Bassil, E.S.; Kaffka, S.R. Response of safflower (Carthamus tinctorius L.) to saline soils and irrigation II. Crop response to salinity. *Agric. Water Manag.* **2002**, *54*, 81–92. [CrossRef]
105. Rodrigues, M.L.; Pacheco, C.M.A.; Chaves, M.M. Soil-plant water relations, root distribution and biomass partitioning in Lupinus albus L. under drought conditions. *J. Exp. Bot.* **1995**, *46*, 947–956. [CrossRef]
106. Huyghe, C. White lupin (Lupinus albus L.). *Field Crop. Res.* **1997**, *53*, 147–160. [CrossRef]
107. Mauromicale, G.; Sortino, O.; Pesce, G.R.; Agnello, M.; Mauro, R.P. Suitability of cultivated and wild cardoon as a sustainable bioenergy crop for low input cultivation in low quality Mediterranean soils. *Ind. Crop. Prod.* **2014**, *57*, 82–89. [CrossRef]
108. Francaviglia, R.; Bruno, A.; Falcucci, M.; Farina, R.; Renzi, G.; Russo, D.E.; Sepe, L.; Neri, U. Yields and quality of Cynara cardunculus L. wild and cultivated cardoon genotypes. A case study from a marginal land in Central Italy. *Eur. J. Agron.* **2016**, *72*, 10–19. [CrossRef]
109. Pučka, I.; Lazdiņa, D. Review about investigations of Salix spp. in Europe. In Proceedings of the Annual 19th International Scientific Conference Proceedings, "Research for Rural Development", Jelgava, Latvia, 15–17 May 2013; Latvia University of Agriculture: Jelgava, Latvia, 2013; Volume 2, pp. 13–19.
110. Stolarski, M.J.; Niksa, D.; Krzyżaniak, M.; Tworkowski, J.; Szczukowski, S. Willow productivity from small-and large-scale experimental plantations in Poland from 2000 to 2017. *Renew. Sustain. Energy Rev.* **2019**, *101*, 461–475. [CrossRef]
111. Boob, M.; Truckses, B.; Seither, M.; Elsäs ser, M.; Thumm, U.; Lewandowski, I. Management effects on botanical composition of species-rich meadows within the Natura 2000 network. *Biodivers. Conserv.* **2019**, *28*, 729–750. [CrossRef]
112. Dauber, J.; Brown, C.; Fernando, A.L.; Finnan, J.; Krasuska, E.; Ponitka, J.; Styles, D.; Thrän, D.; Van Groenigen, K.J.; Weih, M. Bioenergy from" surplus" land: Environmental and socio-economic implications. *BioRisk* **2012**, *7*, 5–50. [CrossRef]
113. Felten, D.; Emmerling, C. Effects of bioenergy crop cultivation on earthworm communities—A comparative study of perennial (Miscanthus) and annual crops with consideration of graded land-use intensity. *Appl. Soil Ecol.* **2011**, *49*, 167–177. [CrossRef]
114. Emmerling, C.; Pude, R. Introducing Miscanthus to the greening measures of the EU Common Agricultural Policy. *Gcb Bioenergy* **2017**, *9*, 274–279. [CrossRef]
115. Cosentino, S.L.; Copani, V.; Scalici, G.; Scordia, D.; Testa, G. Soil erosion mitigation by perennial species under Mediterranean environment. *BioEnergy Res.* **2015**, *8*, 1538–1547. [CrossRef]
116. Anderson, E.; Arundale, R.; Maughan, M.; Oladeinde, A.; Wycislo, A.; Voigt, T. Growth and agronomy of Miscanthus x giganteus for biomass production. *Biofuels* **2011**, *2*, 71–87. [CrossRef]
117. MAGIC. Marginal Lands for Growing Industrial Crops: Turning a Burden into an Opportunity. Available online: http://magic-h2020.eu/ (accessed on 14 June 2019).
118. GRACE. GRowing Advanced Industrial Crops on Marginal Lands for Biorefineries. Available online: https://www.grace-bbi.eu/project/ (accessed on 14 June 2019).
119. Von Cossel, M.; Lewandowski, I. Miscanthus (Miscanthus x giganteus Greef et Deuter) cultivation on a shallow stony soil in southwest Germany. Manuscript unpublished.
120. Mangold, A.; Winkler, B.; Von Cossel, M.; Iqbal, Y.; Kiesel, A.; Lewandowski, I. Implementing miscanthus into sustainable farming systems: A review on agronomic practices, capital and labor demand. Review article, under review, unpublished.
121. Fajardy, M.; Chiquier, S.; Mac Dowell, N. Investigating the BECCS resource nexus: Delivering sustainable negative emissions. *Energy Environ. Sci.* **2018**, *11*, 3408–3430. [CrossRef]
122. Heaton, E.; Voigt, T.; Long, S.P. A quantitative review comparing the yields of two candidate C4 perennial biomass crops in relation to nitrogen, temperature and water. *Biomass Bioenergy* **2004**, *27*, 21–30. [CrossRef]
123. Iqbal, Y.; Kiesel, A.; Wagner, M.; Nunn, C.; Kalinina, O.; Hastings, A.F.S.J.; Clifton-Brown, J.C.; Lewandowski, I. Harvest Time Optimization for Combustion Quality of Different Miscanthus Genotypes across Europe. *Front. Plant Sci.* **2017**, *8*. [CrossRef] [PubMed]
124. Lewandowski, I.; Schmidt, U. Nitrogen, energy and land use efficiencies of miscanthus, reed canary grass and triticale as determined by the boundary line approach. *Agric. Ecosyst. Environ.* **2006**, *112*, 335–346. [CrossRef]

125. Sastre, C.M.; Carrasco, J.; Barro, R.; González-Arechavala, Y.; Maletta, E.; Santos, A.M.; Ciria, P. Improving bioenergy sustainability evaluations by using soil nitrogen balance coupled with life cycle assessment: A case study for electricity generated from rye biomass. *Appl. Energy* **2016**, *179*, 847–863. [CrossRef]
126. Tuck, G.; Glendining, M.J.; Smith, P.; House, J.I.; Wattenbach, M. The potential distribution of bioenergy crops in Europe under present and future climate. *Biomass Bioenergy* **2006**, *30*, 183–197. [CrossRef]
127. Cosentino, S.L.; Testa, G.; Scordia, D.; Alexopoulou, E. Future yields assessment of bioenergy crops in relation to climate change and technological development in Europe. *Ital. J. Agron.* **2012**, *7*, 22. [CrossRef]
128. Cai, X.; Zhang, X.; Wang, D. Land availability for biofuel production. *Environ. Sci. Technol.* **2011**, *45*, 334–339. [CrossRef] [PubMed]
129. Iqbal, Y.; Lewandowski, I. Inter-annual variation in biomass combustion quality traits over five years in fifteen Miscanthus genotypes in south Germany. *Fuel Process. Technol.* **2014**, *121*, 47–55. [CrossRef]
130. Kalinina, O.; Nunn, C.; Sanderson, R.; Hastings, A.F.S.; van der Weijde, T.; Özgüven, M.; Tarakanov, I.; Schüle, H.; Trindade, L.M.; Dolstra, O.; et al. Extending Miscanthus Cultivation with Novel Germplasm at Six Contrasting Sites. *Front. Plant Sci.* **2017**, *8*, 185. [CrossRef]
131. Clifton-Brown, J.; Hastings, A.; Mos, M.; McCalmont, J.P.; Ashman, C.; Awty-Carroll, D.; Cerazy, J.; Chiang, Y.-C.; Cosentino, S.; Cracroft-Eley, W.; et al. Progress in upscaling Miscanthus biomass production for the European bio-economy with seed-based hybrids. *GCB Bioenergy* **2017**, *9*, 6–17. [CrossRef]
132. Johnson, R.C.; Petrie, S.E.; Franchini, M.C.; Evans, M. Yield and yield components of winter-type safflower. *Crop. Sci.* **2012**, *52*, 2358–2364. [CrossRef]
133. Jamshidmoghaddam, M.; Pourdad, S.S. Genotype$\times$ environment interactions for seed yield in rainfed winter safflower (Carthamus tinctorius L.) multi-environment trials in Iran. *Euphytica* **2013**, *190*, 357–369. [CrossRef]
134. Gesch, R.W.; Matthees, H.L.; Alvarez, A.L.; Gardner, R.D. Winter camelina: Crop growth, seed yield, and quality response to cultivar and seeding rate. *Crop. Sci.* **2018**, *58*, 2089. [CrossRef]
135. Walia, M.K.; Wells, M.S.; Cubins, J.; Wyse, D.; Gardner, R.D.; Forcella, F.; Gesch, R. Winter camelina seed yield and quality responses to harvest time. *Ind. Crop. Prod.* **2018**, *124*, 765–775. [CrossRef]
136. MAGIC DSS MAGIC Decision Support System Marginal Lands and Industrial Crops. Available online: https://iiasa-spatial.maps.arcgis.com/apps/webappviewer/index.html?id=a813940c9ac14c298238c1742dd9dd3c (accessed on 28 April 2019).
137. Kort, J.; Collins, M.; Ditsch, D. A review of soil erosion potential associated with biomass crops. *Biomass Bioenergy* **1998**, *14*, 351–359. [CrossRef]
138. Vaughan, D.H.; Cundiff, J.S.; Parrish, D.J. Herbaceous crops on marginal sites Erosion and economics. *Biomass* **1989**, *20*, 199–208. [CrossRef]
139. 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*, 415–422. [CrossRef]
140. Dauber, J.; Jones, M.B.; Stout, J.C. The impact of biomass crop cultivation on temperate biodiversity. *Gcb Bioenergy* **2010**, *2*, 289–309. [CrossRef]
141. Folke, C.; Carpenter, S.; Walker, B.; Scheffer, M.; Elmqvist, T.; Gunderson, L.; Holling, C.S. Regime shifts, resilience, and biodiversity in ecosystem management. *Annu. Rev. Ecol. Evol. Syst.* **2004**, *35*, 557–581. [CrossRef]
142. Deutsch, L.; Folke, C.; Skånberg, K. The critical natural capital of ecosystem performance as insurance for human well-being. *Ecol. Econ.* **2003**, *44*, 205–217. [CrossRef]
143. Teuling, A.J. A hot future for European droughts. *Nat. Clim. Chang.* **2018**, *8*, 364. [CrossRef]
144. Samaniego, L.; Thober, S.; Kumar, R.; Wanders, N.; Rakovec, O.; Pan, M.; Zink, M.; Sheffield, J.; Wood, E.F.; Marx, A. Anthropogenic warming exacerbates European soil moisture droughts. *Nat. Clim. Chang.* **2018**, *8*, 421. [CrossRef]
145. Garbolino, E.; Daniel, W.; Hinojos Mendoza, G. Expected Global Warming Impacts on the Spatial Distribution and Productivity for 2050 of Five Species of Trees Used in the Wood Energy Supply Chain in France. *Energies* **2018**, *11*, 3372. [CrossRef]

146. Von Cossel, M.; Mohr, V.; Elbersen, B.; Staritsky, I.; Van Eupen, M.; Mantel, S.; Iqbal, I.; Happe, S.; Scordia, D.; Cosentino, S.L.; et al. How to feed the European bioeconomy in the future? Climate change-forced shifts in growth suitability of industrial crops until 2100. unpublished.
147. Pachauri, R.K.; Allen, M.R.; Barros, V.R.; Broome, J.; Cramer, W.; Christ, R.; Church, J.A.; Clarke, L.; Dahe, Q.; Dasgupta, P. *Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2014.