Magic
Marginal lands for Growing Industrial Crops

WAGENINGEN UNIVERSITY & RESEARCH

Deliverable 2.1 Definition and classification of marginal lands suitable for industrial crops in Europe

WAGENINGEN UNIVERSITY & RESEARCH
100 years 1918 — 2018

ISRIC World Soil Information

Elbersen, B.[a], Eupen,van E.[a], Mantel, S.[b], Verzandvoort, S.[a] , Boogaard, H.[a] , Mucher, S.[a], Cicarreli, T.[a] & Elbersen, W.[a], Bai, Z.[b], Iqbal, Y.[c] , Cossel, M.[c], Ian MCallum, I.[g], Carrasco,J.[d], Ciria Ramos, C.[d], Monti, A.[e],Scordia, D.[f], Eleftheriadis, I.[h]

[a] Wageningen University & Research, Earth Informatics
[b] International Soil Reference and Information Centre (ISRIC)
[c] University of Hohenheim, Institute of Crop Science, Biobased Products and Energy Crops
[d] CIEMAT
[e] Alma Mater Studiorum - University of Bologna
[f] University of Catania, Agricultural, Food and Environment
[g] International Institute for Applied Systems Analysis (IIASA)
[h] Center for Renewable Energy Sources and Saving (CRES)

EU Horizon 2020; MAGIC; GA-No.: 727698

Table of contents

Table of contents II
1. Introduction 4
1.1. Context and objective 4
1.2 Policy context 5
1.3 QUICKScan working meeting in MAGIC 7
1.4 Outline of report 7
2. What are marginal lands? 8
2.1 Introduction 8
2.2. Definition of marginal lands 8
3. Main characteristics linked to marginal lands 19
3.1 Biophysical constraints of marginal lands 19
3.2. Socio-economic constraints of marginal lands 23
3.3 Sustainability and using marginal lands for non-food cropping 27
4. Mapping marginal lands in Europe suitable for industrial crops 30
4.1 Introduction 30
4.2 Mapping degraded lands 34
4.3 Contaminated lands 36
5 Conclusions and further steps to mapping marginal lands 42
5.1 Introduction 42
5.2. MAGIC Marginal Agro-Ecological Zonation (MAEZ) 43
5.3 Conclusions for the marginal land mapping approach 44
5.3.1 Definitions of marginal lands for the purpose of identifying opportunity gaps for industrial cropping 44
5.3.2 Biophysical constraints typical for marginal lands 47
5.3.3 Socio-economic constraints typical for marginal lands 48
5.3.4 Sustainability is a critical issue in relation to industrial cropping uses of marginal lands 49

5.4 Next steps: Mapping marginal lands and constructing the M-AEZ............... 51

References... - 53 -

1.Introduction

1.1. Context and objective

The purpose of the work in WP 2 of the MAGIC project is to map, characterise and analyse projections for current and future marginal lands in Europe facing natural constraints and provide a spatially explicit classification that will serve as a basis for developing sustainable best-practice options for industrial crops in Europe.

This report provides an overview of definitions of and approaches to identify and map marginal lands. It will particularly focus on presenting the current state-of-play regarding marginal land definition and mapping. This report will form the state-of-play overview on which basis the approach to mapping marginal lands in MAGIC is to be developed. This mapping approach is presented in Deliverable 2.6 of the MAGIC project (Elbersen et al., 2017).

In MAGIC the reason for identifying and mapping marginal lands is to use them for industrial cropping. Industrial crops (oil, lignocellulosic, carbohydrate and specialty crops) provide feedstocks for industrial applications, thereby fostering the bio economy (covering its increasing needs) and climate-change mitigation (low carbon energy and production of less fossil-feedstock dependent materials) while diversifying farmers' income. In MAGIC the cultivation of selected industrial crops on marginal land will be investigated in order to avoid land-use competition with food on higher value land. Special attention will be given to the development of resource-efficient varieties that can grow on marginal land areas facing natural constraints.

In the MAGIC project the mapping of marginal lands should result in a so-called 'Marginal Agro-Ecological Zonation '(M-AEZ) of Europe. It was already decided from the start of the project that natural constraints with regard to soil, climate and topographic factors should form an important starting point for mapping marginal lands.

Several projects have already been executed and papers and reports have been published on the definition, identification and sustainable use of lands for the production of biomass, mostly to be used for dedicated bioenergy crops (Cambell et al., 2008; Bai, et al., 2008; Cai, et al., 2011; Alcantara, et al., 2013 and Liu et al., 2017). In MAGIC the focus is wider as it focusses on industrial crops which can be used as feedstock for conversion in a wide variation of non-food products. The state-of-play in defining and identifying marginal lands will be presented in this report in order to ensure that in MAGIC we build on former work.

This report will specifically discuss the existing definitions of marginal lands and their identification and characterisation in Europe taking account of the fact that we strive to identify sustainable best-practice options for industrial crops in Europe. In this respect, there are three key sustainability considerations that need attention in our approach to define, characterise, map and classify marginal lands which are here considered potentially suitable for industrial crops production: (exclusion list following:)

1) we strive to identify best options to grow industrial crops on land that is not used for food production at this moment nor is likely to be used for it in the future. This consideration is of course rooted in the general political and scientific concern about indirect land use change (ILUC) effects and the food versus fuel discussion.

2) we need to identify marginal lands carefully in terms of their bio-physical characteristics because that determines the options for industrial crop choice and economic feasibility. After all, marginal lands in MAGIC will at least comprise of areas with natural constraints. Types of natural constraints and thresholds will be based on former work done by JRC and other approaches to establish agronomic suitability of soils, topography and climates.

3) we want to ensure that options for growing industrial crops are not destroying ecosystems services, but rather help to create co-benefits such as improving soil health and restoring productivity in the long run especially in case of degraded lands. To ensure this it will be necessary to identify marginal lands carefully in terms of their exact location and extent, but also in terms of the uses, environmental threats and ecosystem services present.

1.2 Policy context

Industrial crops can provide abundant renewable biomass feedstocks for the production of high added-value bio-based commodities (i.e. bio-plastics, bio-lubricants, bio-chemicals, pharmaceuticals, bio-composites, etc.) and bioenergy. In this respect industrial crops can contribute to the diversification of farmers' income and to the supply of renewable raw materials for industrial applications fostering the bio-based economy and climate-change mitigation. Hence, industrial cropping on marginal lands can be seen as an instrument to reach multiple EU policy targets in the field of enhancing rural development, boosting the bioeconomy development and reaching the challenging GHG mitigation targets of the Paris agreement.

The mapping of marginal lands and the evaluation of the potential for using this land for industrial crops is relevant in the context of several European policy ambitions. Increased demand for biomass for non-food applications started to be driven particularly by energy policies such as the Renewable Energy Directive (RED) (2009/EC/28), and the Fuel Quality Directives (Directive (EU) 2015/1513) and the Energy roadmap 2050. The focus on renewable energy shifted in recent years more towards stimulation of decarbonisation of the whole economy as became clear from the publication of the strategy “Innovating for Sustainable Growth—a Bioeconomy for Europe” in 2012 . Therefore, increased biomass feedstock use both in energy and chemical biobased industries is seen as an important instrument to bring GHG emissions down and thus decarbonize the economic sectors still relying most strongly on fossil feedstock.

Land demand is a sensitive issue as it is a scarce resource and many ecosystem services are related to good management of it. Because of this, good robust estimates of land availability for biomass production for non-food uses cannot be done without taking the complex sustainability constraints into account particularly in relation to the functioning of ecosystems and their services. The latter is also a key objective as set out in the EU Biodiversity Strategy to 2020 which sets a target to maintain and

enhance ecosystems and their services by establishing green infrastructures and restoring at least 15 % of degraded ecosystems by 2020. In the identification of marginal lands it is therefore important to understand what ecosystems are harbouring these lands as the use of these marginal lands for industrial cropping should not destroy these ecosystem service, but should rather go hand-in-hand.

The very comprehensive work done by the JRC (Van Oorschoven, et al., 2014 and Terres et al, 2014) on the common criteria to define ‘areas of natural constraints for agriculture’ in Europe has a political motivation; namely identifying the set of criteria for ‘areas facing natural constraints’ as referred to in EU Regulation 1305/2013 specifying the Common Agricultural Policy for the period 2014-2020. In this Regulation a revision of the delimitation of intermediate Less Favoured Areas (iLFAs) is required which demands a framework that covers the whole European biophysical diversity and should apply to agricultural activity in general and not to specific crops/production. Although the mapping of areas with natural constraints is driven by the reform of the CAP, the JRC work is a very useful basis for MAGIC’s work aimed at identifying marginal lands in Europe for industrial cropping.

1.3 QUICKScan working meeting in MAGIC

A drat version of this report was input in the discussions at the WP2 QUICKScan workshop held in September 2017. Outcome of the QUICKScan working meeting (see D2.6 Annex I for minutes) was also used to improve this report and more specifically to refine the definition of Marginal lands presented in this report. This definition will be used for designing the approach to mapping marginal lands in MAGIC as a basis to further investigate the potential use for sustainable industrial cropping. The reason to choose a brought definition of Marginal lands initially is rooted in the decision taken at the QUICKScan working meeting that WP2 should concentrate on mapping lands that are biophysically constrained, either by natural limitations and/or limitations imposed through unsustainable human management, and lands that remain unused by other activities (e.g. by agriculture, forestry, urban uses, etc.).

It was called a 'QUICKScan' workshop because it used the QUICKScan software for participatory mapping to facilitate the discussions (Verweij et al., 2016) at the WP 2 working meeting. QUICKScan is a method, process and spatially explicit tool, to jointly construct and evaluate mapped rules in a participatory setting. It enables to investigate visually and interactively the most important state of knowledge and data for mapping marginal lands.

1.4 Outline of report

In Chapter 2 an overview is given of definitions of marginal lands. Chapter 3 provides and overview of the main factors characterising these marginal lands according to the state-of-play. This will cover an overview of the marginality factors, the typical characteristics of land in terms of natural constraints as well as the socio-economic and accessibility factors that have already become apparent. Chapter 4 presents several examples of mapping marginal lands in a global and European context. In Chapter 5 the conclusions are presented in relation to the definition of marginal lands and the key biophysical, socioeconomic and environmental factors according to which marginal lands can best be identified, mapped and further characterised in the MAGIC project.

2. What are marginal lands?

2.1 Introduction

In this chapter an overview is given of the main definitions of marginal lands and how these give guidelines to identifying lands that can potentially be used for industrial crop production in Europe. In the next section first the key studies providing definitions and characteristics on marginal lands are presented. Overall, it becomes clear that marginality is generally determined by two main dimensions which can be classified in biophysical and socio-economic factors and these will be discussed more extensively in Sections 3 and 4. In the last section of this chapter conclusions on what main messages can be distilled from the literature review in relation to defining and identifying marginal lands in the context of cropping options for sustainable production of industrial crops in Europe.

2.2. Definition of marginal lands

In the 19th century the term 'marginal land' was introduced in the field of agro-economic research. Ricardo (1817) linked the term marginal lands to his land rent theory. The perspective of low productivity in terms of soil and climate constraints started to be linked to the marginal land concept around the beginning of the 20th century when it was introduced in the work of Hollander (1895) and Peterson & Galbraith (1932) as discussed in the SEEMLA project definition paper on marginal lands (Ivanina & Hanzhenko, 2015).

In the last 20 years the concept of marginal lands has obtained more scientific and policy interest under influence of the increasing pressure on land due to population growth, growing meat consumption and demand for biomass for non-food purposes (Dauber & Miyake, 2016; Kang et al., 2013). Marginal lands are seen as a potential source of land that can be used for food production, but even more for biomass for bioenergy and other non-food products (Kang et al., 2013; Dauber & Miyake, 2016; Liu et al., 2017; Dauber et al, 2012). Because of this the concept of 'marginal land' needed further definition and characterisation and this is a challenge for a couple of reasons.

Firstly, it was pointed out that defining marginality depends strongly on the use perspective that is taken since land that is marginal for one use, can be well suited for another use, e.g. land that is marginal for cropping can be well suited for grazing or forestry (FAO, CGIAR, 1999; James, 2010, Dale et al., 2010; Shortall, 2013). As Dale et al. (2010) indicates 'It (read 'marginal land') is a relative term; the same qualities used to classify a site as being "marginal" in one place or for one purpose can result in land being considered productive in another place or for a different purpose'. James (2010) gave the example that relatively productive land in Southern Spain may be categorized according the biophysical characteristics as relatively marginal in the Paris basin.

So when making an inventory of definitions of marginal lands it should be clear what use categories are taken as a starting point. Generally however, as indicated by Kang et al. (2013) the term ‘marginal lands’ is mostly used in relation to agricultural/cropping uses and are seldom applied to forest lands and grasslands/grazing lands. In the MAGIC project the perspective is rather clear as marginal lands need to be identified that can be assessed for their suitability to be used for industrial cropping. So the identification of the marginal lands in this WP 2 does not mean that the marginal land identified are suitable for industrial cropping, it is merely an indication of the type of marginal lands present in Europe and it should indicate towards marginal lands where competition with food production is likely to be avoided when used for production of industrial crops.

Secondly, many publications indicate that marginality of land has 2 dimensions; biophysical constraints and socio-economic constraints. In the different definitions of marginal lands sometimes more emphasis is placed on the biophysical constraints, while in other studies the focus is on economic and/or social factors or a combination (see Table 1). The different views on definitions of marginal lands from different perspectives is illustrated by the study of Shortall, (2013) who shows that there are different views in academic, consultancy, NGO, government and industry documents. Shortall identifies 3 separate definitions of the term: land unsuitable for food production, ambiguous lower quality land and economically marginal land. The first 2 are approaching marginal from the bio-physical side while the third takes the economic perspective. In MAGIC it has been decided that marginal lands need at least cover areas that are affected by natural constraints (Van Oorschoven et al., 2014 & Terres et al, 2014) and where competition with other uses should be avoided. So their definition and identification should ensure that both biophysical constraints and absence of other uses is covered.

Table 1 Examples of definitions of 'marginal lands' in different studies

Definitions of marginal lands	Source
Marginal lands are '… *the poorest lands utilised above the margin of rent-paying land'*	Hollander (1895)
Marginal land is .....'land where revenue is equal to cost of production'	Barlowe (1986)
the term 'marginal' '…..*is generally used more broadly to describe any lands that are not in commercial use in contrast to lands yielding net profit from services. Depending on time and place, marginal land may also refer to idle, under-utilized, barren, inaccessible, degraded, excess or abandoned lands, lands occupied by politically and economically marginalized populations, or land with characteristics that make a particular use unsustainable or inappropriate'.*	Dale et al. (2010), p.5
Marginal lands refer to *'….land uses at the margin of economic viability'*	Strijker, 2005
Marginal land refers to '…*an area where a cost-effective production is not possible, under given site conditions, cultivation techniques, agricultural policies as well- as macro-economic and legal conditions'*	Schroers, 2006
'degraded and marginal land refers to land with limited usefulness for any production or regulation function '	Schubert et al., 2009
'*Lands unsuited for food production, e.g. with poor soils or harsh weather environments and areas that have been degraded, e.g. through deforestation'*	Renewable Fuels Agency, 2008
'areas where cost-effective production is not possible, under given conditions (e.g. soil productivity), cultivation techniques, agricultural policies, as well as macro-economic and legal conditions'	Committee on Climate Change, 2011
'*Marginal land is more commonly defined as land where cost effective agricultural production is not possible under a given set of conditions*'	Turley et al., 2010
'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. Limited options for diversification without the use of inputs. With inappropriate management, risks of irreversible degradation'.	FAO-CGIAR, 1999

Thirdly, it became clear from many studies that the term 'marginal lands' were often mixed or synonymously used with terms like abandoned farmland, low productive, under-utilised or unused, contaminated, fragile, vulnerable, degraded or contaminated land (see Box 1 for use of different terms in different studies). This is particularly the case in studies that evaluate the options to use marginal lands for dedicated cropping of energy crops and direct and indirect land use impacts of increased demand for biofuels. The key assumption in such studies (Wicke, 2011; Valin et al., 2015, Plevin et al., 2013, Overmars, 2015, van Laan, 2015, Elbersen et al., 2013, Nsanganwimana et al., 2014, Frank et al., 2013; Lui et al., 2017) is that lands are/can be used for the production of biomass for biofuels that would otherwise remain unused. Unused land availability assumptions are however very challenging to make as they are mostly based on highly uncertain data sets and in none of the studies the estimates/ quantifications of these land resources are underpinned with empirical evidence (Gibbs & Salmon, 2015). The challenge of making reliable estimates of cropland expansion options is also confirmed in the study of Eitelberg et al. (2014) who show a range in cropland availability at global level ranging from 1552 to 5131 Mha, including the 1550 Mha that is already cropland. Part of the additional cropland availability above the current cropland area will need to come from lands regarded as 'unused, marginal, abandoned, underutilised'. Differences in estimates of cropland size by Eitelberg (2014) are attributed to institutional assumptions, i.e. which land covers/uses (e.g. forests or grasslands) are societally or governmentally allowed to convert to cropland, while there was little variation in biophysical assumptions.

A special category which may (partially) be overlapping with marginal lands is that of 'contaminated sites'. These sites (see Box 1) are characterised by presence of all kinds of pollutants that have such high concentrations that they form a hazard for humans, water quality , ecosystems, or other receptors. In these sites the biophysical constraints do not have a natural cause, but are caused by waste disposal, industrial and mining activities such as for oil extraction and production, and power plants, military sites and war affected zones, storages of chemical substances like oil and obsolete chemicals, transport spills on land (oil spill sites and other hazardous substance spills sites), nuclear sites and other sources. Some of these site may be interesting to be used for industrial crops, particularly for crops that can also be used for bioremediation on these sites (Fernando, 2005, Lewandowski et al. 2016, Cadoux et al., 2011; Hartley et al., 2009; Técher et al., 2012).

Box 1: Different terms referring to land categories partly overlapping with 'marginal lands' found in literature:

- For '**Surplus land**' Dauber et al. (2012) distinguishes two different origins:
    1. Land currently not in use for the production of food, animal feed, fibre and other renewable sources due to poor soil fertility or abiotic stress
    2. Land currently no longer needed for food and feed production because of intensification and rationalisation of production, resulting in yield increases and thus a reduced requirement for land.

  Dauber et al. (2012) also indicates that land falling in the first definition should be preferable to be used for bioenergy copping since it is questionable whether such intensification could be achieved in a 'sustainable and ethical manner' and whether it would 'indeed free up land for the purpose other than feeding the growing world population'.
- Dale et al. (2010) indicates that 'marginal lands' may also refer to **idle, under-utilized, barren, inaccessible, degraded, excess or abandoned lands**, lands occupied by politically and economically marginalized populations, or land with characteristics that make a particular use unsustainable or inappropriate'.
- Wiegman et al. (2008) provides a definition for different types of land categories:
    a. **Abandoned farmland** as land – within a cultural landscape (Schäfer 1992) – that was previous used for agriculture or pasture, but that has been abandoned and not converted to forest or urban areas (Field et al. 2008). The agricultural activities have been stopped for economical, political or environmental reasons, e.g. set-aside-land (politically) or degraded farmland (environmentally)
    b. For **degraded lands** Wiegman et al. (2008) identified 2 definitions:
        i. Land degradation is a long-term loss of ecosystem function and services, caused by disturbances from which the system cannot recover unaided

(UNEP 2007).

ii. Land degradation is the decline of natural land resources, commonly caused by improper use of the land (Bergsma et al. 1996).

c. **Waste land** is characterized by natural physical and biological conditions that are per se unfavourable for land-associated human activities (Oldeman et al. 1991). Within this category, land without appreciable vegetative cover or agricultural potential is included. According to Wiegman et al. (2008) these areas cannot be cultivated under any conditions and, therefore, are not suitable for bioenergy production, examples of these types of land include as identified in the GLASOD (Global Assessment of Human-induced Soil Degradation) map, six types were recognized: active dunes, salt flats, rock outcrops, deserts, ice caps and arid mountain regions.

d. **Fallow land** describes the temporary suspension of cultivation for one or several vegetation periods to achieve a recovery of soil fertility (Schäfer 1992). Fallow is a part of crop rotation.

- Wicke (2010) defined **unused land** as land that is not influenced by any anthropogenic land use forms. Unused land refers to both areas of undisturbed wildlife and to abandoned land where former land use activities were discontinued.

- **Fallow land** is defined by Krasuka et al., (2010) land that should not be viewed as surplus land which is permanently available, but as part of a production cycle.

- In FSS Eurostat (Council Regulation 543/2009) the definition of **Fallow land** (short term) is all arable land included in the crop rotation system, whether worked or not, but with no intention to produce a harvest for the duration of the crop year. The essential characteristic of fallow land is that it is left to recover normally for the whole crop year. Fallow land can be either bare land bearing no crops at all; land with spontaneous natural growth which may be used as feed or ploughed in; land sown exclusively for the production of green manure (green fallow). Long term fallow land refers to the same land as above, but is taken out of production for more consecutive years

- The specific definition in EC statistical sources (FSS, LPIS, IACS) of '**Permanent grassland and meadows no longer used for production purposes** is that this concerns land eligible for CAP payments as long as they are kept in a good agricultural condition according to the GAEC-standards' even though no productive use is made of it.

- **Contaminated site** refers to a well-defined area where the presence of soil contamination has been confirmed and this presents a potential risk to humans, water, ecosystems, or other receptors. Risk management measures (e.g., remediation) may be needed depending on the severity of the risk of adverse impacts to receptors under the current or planned use of the site (EEA, 2011).

- **"Potentially contaminated site"** refers to sites where unacceptable soil contamination is suspected but not verified, and detailed investigations need to be carried out to verify whether there is unacceptable risk of adverse impacts on receptors (EEA, 2011).

Fourthly, it is acknowledged in many studies that the characteristics specific to marginal lands can be considered as temporary, so marginality does not necessarily need to be a permanent state (Nalepa, 2011; Allen et al., 2013; Kang et al., 2013). This aspect is extensively discussed by Kang et al. (2013) and it is mentioned that there are two drivers that determine the dynamics in marginal lands:

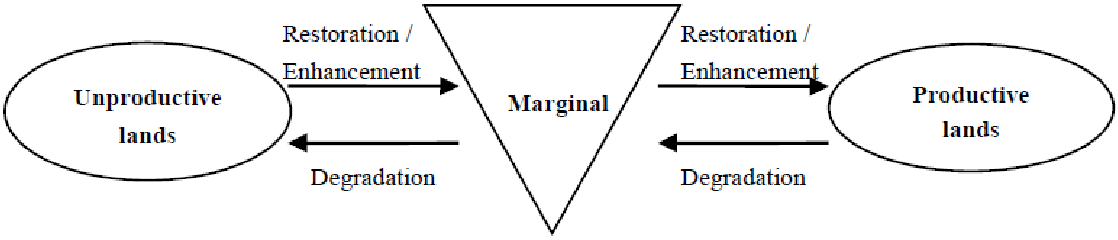
Firstly natural processes in combination with varied management and secondly by market changes (see also Figure 1). As to the first, processes are referred to in which productive lands become degraded because of bad land management and natural sensitivity to degradation. Because of the degradation process the lands are converted to the marginal land class and go out of use. Under influence of land management dynamics it is also possible that marginal lands become productive lands because of technical investments made to improve them (see Figure 1).

Secondly, changes in market demand may change profit margins making marginal lands taken into use or being abandoned. Both dynamics are possible and since markets change all the time it implies that marginal state is dynamic and not permanent and this is certainly the case in the current and nearby future in which demand for food and biomass for non-food applications is expected to increase strongly (Harvey & Pilgrim, 2011; Valin et al., 2015; Dauber & Miyake, 2016).

In MAGIC it is therefore important to not only identify lands that are currently falling in the marginal definition, but it should also be evaluated how the status of these lands is going to change in the future under influence of different policy and market forces including the demand for biomass from industrial crops. could also be considered in this group of drivers. Some land may become more marginal due to climate change (e.g. overgrazed land beyond the tipping point see for example the EU-CASCADE project). Other land may become less marginal e.g. due to CO_2 fertilization.

Especially relevant in MAGIC would be lands which suffer from degradation and which can be recovered through selection of appropriate perennial crops that help to restore the organic carbon levels or perennial crops on lands with slopes which will help to stop land degradation through erosion.

Figure 1: Dynamics in land use between marginal lands, productive (read 'favoured lands') and unproductive land (read 'degraded lands) (Kang et al., 2013)



In 1999 FAO commissioned the Consultative Group on International Agricultural Research (CGIAR) did very valuable work on defining different land types including marginal lands (see Table 2). The work was done to identify research priorities for marginal lands, but in order to do this there was a need to first propose a definition.

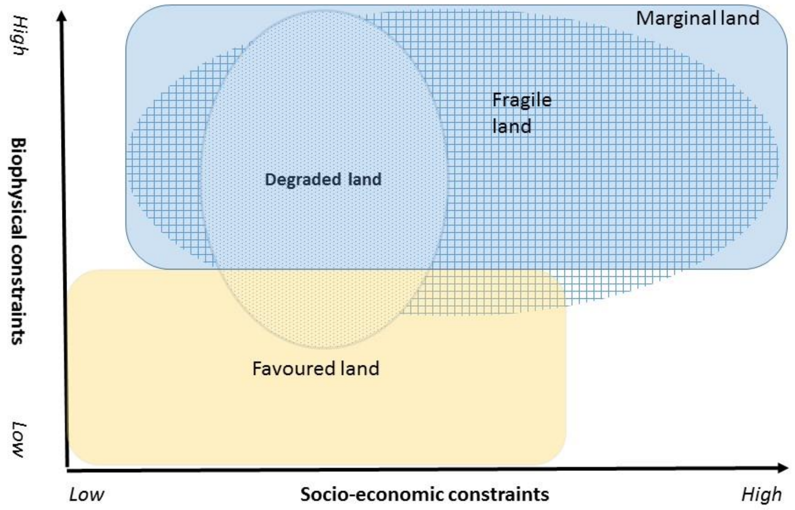
Table 2: Land types as defined by FAO-CGIAR (1999)

Definition	Biophysical Constraints	Socio-Economic Constraints
Favoured land: Land having no, or moderate limitations to sustained application under a given use. Moderate limitations will reduce benefits but an overall advantage will be gained from the use of inputs. Wide options for diversification. With proper management, risk of irreversible damage is low.	No or moderate constraints related to soil, climatic and terrain conditions. Soil fertility, if adequately maintained, is favourable. Relatively reliable rainfall and/or irrigation water.	The level of yields depends not only on favourable biophysical conditions, but on accessibility to inputs, market and credit facilities, and beneficial output/input ratios.
Marginal land: 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. Limited options for diversification without the use of inputs. With inappropriate management, risks of irreversible degradation.	Soil constraints (low fertility, poor drainage, shallowness, salinity), steepness of terrain, unfavourable climatic conditions[1].	Absence of markets difficult accessibility, restrictive land tenure, small holdings, poor infrastructure, unfavourable output/input ratios.
Fragile land: Land that is sensitive to land degradation, as a result of inappropriate human intervention. Sustained production requires specific management practices. Land use is limited to a narrow choice of options.	Soils of low fertility, erodible, steep terrain, high groundwater levels, flood-prone.	Population pressure, food deficits, competition for land from other sectors, unavailability or high cost of inputs.
Degraded land: Land that has lost part or all of its productive capacity as a result of inappropriate human intervention. Various forms and degrees of degradation, both reversible and irreversible, may occur. Rehabilitation of reversible forms of degradation requires investment.	Erosion, salinization, fertility depletion, lack of adequate drainage on soils and terrain prone to deterioration.	Population pressure, land shortage, inadequate support to agriculture, lack of institutional framework, high cost of rehabilitation, lack of investment.

In the CGIAR approach the 4 challenges inherent to defining and identifying marginal lands as discussed above are addressed: 1. for which land use is the land under concern considered marginal; 2. biophysical and socio-economic constraints, 3. The overlap in characteristics with abandoned farmland, low productive, under-utilised or unused, contaminated, fragile, vulnerable, degraded or contaminated land, and 4. the temporary character of aspects determining marginality.

Firstly, the FAO-CGIAR approach acknowledged that the perspective of what is 'marginal' is different per type of use perspective. Therefore they conclude that *'it only makes sense to define 'marginal land' in terms of a clearly defined specific situation*'. The starting point in MAGIC aiming to define and map marginal lands in Europe for industrial crops is therefore helpful as it makes the starting point specific. In the case of the FAO-CGIAR the perspective is agricultural land use. Secondly, the FAO-CGIAR approach acknowledges that marginality is both determined by biophysical and socio-economic constraints, which may apply separately or simultaneously. Thirdly, they acknowledge that there are different terms used that refer to marginal lands and because of this they proposed definitions for 4 types of land categories in order to create clarity and avoid further confusion in definitions. Fourthly, the dynamics of marginal condition of lands is acknowledge through showing in their definitions that lands can shift from one land use class to the other in time. The two latter points emphasise that the land types 'favoured land', 'marginal land', 'fragile land' and 'degraded land' are not mutually exclusive, particularly the marginal, fragile and degraded land classes, and their classification is also dynamic in time. What is clear however is that they can be positioned in a dynamic continuum of biophysical against socio- economic constraints (see Figure 2) which will help to position the 'marginal lands' to be identified in the MAGIC project to be used for industrial cropping.

Figure 2 Positioning of marginal lands compared to favoured, fragile and degraded lands (own elaboration from FAO-CGIAR, 1999)



When looking at Figure 2 it is clear that favoured agricultural land has limited biophysical and socio-economic constraints and, in relation to the biophysical constraints particularly it is the opposite of marginal land. This marginal land category is confronted with many and/or severe biophysical constraints, while the socio-economic constraints can range from low to very high. The fragile lands may overlap with favoured land but even more with marginal lands. Both fragile and marginal lands are more sensitive to degradation because of the overlap in biophysical constraints that make them sensitive to unsustainable uses by humans, such as in the case of steep slopes, low fertility or poor drainage. Under influence of factors like population pressures, land shortage and inadequate institutional governance fragile marginal lands have been converted into farmlands and with unsustainable management practices, they may have become degraded. Degraded lands largely overlap with fragile lands and thus with marginal lands, except that because of unsustainable land management the fragile situation has already turned into a situation of degradation. This degradation can be in a severe state (e.g. complete loss of topsoil), which implies that the land has gone out of use, but it can also be a less severe degradation state in which land use still applies. Generally, degraded lands overlap with fragile lands, but favoured lands can also become degraded if the use has been unsustainable for a long time. However, it should also be acknowledged that little consensus exists about how land degradation should exactly be defined and estimates of land degradation differ considerably and are very limited for Europe. However, when taking the perspective that the outcome of land degradation involves changes in land conditions that impose threats to ecosystem services, particularly those related to soil functions (Van der Esch et al., 2017; Stolte et al., 2016; Louwagie et al., 2009 and Bai, et al., 2008), the process is apparent in both favoured and unfavoured (read marginal) lands.

As to uses of the 4 different land types (Figure 2) it is important to understand that this typology based on FAO-CGIAR focusses on lands in use/or formally in use by agriculture. It excludes forest and woodlands. The favoured lands are entirely used for agricultural activities, mostly cropping, and are ’considered to be rainfed and irrigated agriculture in areas which are fertile (with and without chemical inputs), well-drained, with even topology, and (if irrigated) with adequate rainfall. They are at risk of degradation in case of mismanagement, but risk for this is low as is the vulnerability to irreversible damage. Hence, the only small overlap in Figure 2 of the favoured lands with the degraded land category.

The fragile lands and marginal lands can be expected to be mostly used for grazing rather than cropping, given that several of the biophysical constraints often overlap with low productivity factors, such as low fertility, high erodability or high groundwater levels. Contrary to the favoured lands, the marginal lands overlapping with the fragile lands are at a much higher risk of degradation and of irreversible damage.

Fragile lands can be seen as a sub-group of the marginal lands class. The biophysical constraints for these 2 classes largely overlap, although not all marginal lands are characterised by biophysical limitations that also make the land fragile. As to the socio-economic constraints marginal and fragile lands do not differ as these can range mostly from low/moderate to high. However, fragile lands located in more central locations where population pressure is higher it is more likely that the fragile lands have turned into degraded lands (see also Figure 2 and Table 2). After all, reasons for degradation are often related to unsustainable land uses driven by socio-economic factors such as high population pressures, land scarcity, lack of access to land and/or lack of financial capacity to properly manage the land.

So marginal lands are the opposite of favoured lands, as they biophysical constraints limiting sustained agricultural land use. Favoured and marginal lands do not need to differ in terms of socio-economic constraints present. However marginal lands are likely to more strongly overlap with areas where may socio-economic constraints apply.

In the perspective of FAO-CGIAR the 4 land types are still in use by agriculture, either cropping, grazing or agro-forestry. However, whether all these land types can indeed be considered in use is very much doubted, at least for the situation in Europe where the size of abandoned farmlands is large in specific countries such as France, Spain, Portugal, Greece, most CEEC countries (e.g. IEEP, 2010 and Elbersen et al., 2014). Furthermore expectations on extent of farmland abandonment by 2020 and 2030 for the EU, range between 1% and 10% (Keenleyside & Tucker, 2010; Elbersen et al., 2015), but estimates of lands at risk of farmland abandonment in Europe are much higher (e.g. Pointereau et al., 2008, Terres et al., 2013). So for marginal lands in Europe the current and future uses are unclear, although it is likely that part of the marginal, fragile and degraded lands are used for extensive forms of agriculture, such as grazing, while part of them are already abandoned or become abandoned in the future. Furthermore, since demands for land may increase in the future and part of the constraints of marginal lands are less limiting for certain forms of uses, marginal lands may still obtain an increasing productive function in the future. It is these two last points that need to be investigated further in MAGIC, particularly in relation to suitability for industrial crops and this can only be determined if we understand better where these marginal, fragile and degraded lands are located and what their exact characteristics are in terms of biophysical and socioeconomic constraints and ecosystem services and threats present.

3. Main characteristics linked to marginal lands

3.1 Biophysical constraints of marginal lands

From the former overview of definitions of marginal lands and their relative positioning to other types of land, it became clear that one key characteristic claimed in most definitions of marginal lands, is the presence of many/severe biophysical constraints. The question now is which constraints are mentioned in literature and if they are useful for distinguishing between marginal and non-marginal lands.

In the definition of FAO-CGIAR of marginal lands the typical biophysical constraints mentioned are: low fertility, poor drainage, shallowness, salinity, steepness of terrain and unfavourable climatic conditions. Furthermore, it is mentioned that increased inputs need to be used to maintain productivity of the soil in marginal lands.

There are several frameworks that focus entirely on the biophysical capabilities/limitations of the land for classifying lands that are suitable for cropping and pasturing/grazing and those that are less or not suitable (e.g. USDA-Land Capability Classification System (LCC) , Muencheberg by Mueller et al. (2010); Soil Quality Rating by Shepherd (2000), Murray et al. (1983) applied USDA-LCC to Iowa state and Louwagie et al. (2009) who mapped soil degradation in Europe. The USDA (US Department of Agriculture) for example developed a classification of 8 land classes to distinguish between lands that are suitable for cropping and pasturing activities and lands that are not without deterioration (See Table 3). This classification is aimed at classifying lands suitable for agricultural uses and lands that need to be protected through the Conservation Reserve Programme in need to be controlled for erosion risk (through the Food Security Act). The classification was developed already in the 1960s by the USDA and is still in use and was adopted by several other countries in the meantime.

Table 3: Land capability classification (LCC) elaborated by the USDA

Class	Description
1	Slight limitations that restrict their use
2	Moderate limitations that restrict the choice of plants or that require moderate conservation practices
3	Severe limitations that restrict the choice of plants or that require special conservation practices, or both
4	Very severe limitations that restrict the choice of plants or that require very careful management, or both
5	Little or no erosion but have other limitations, impractical to remove, that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat
6	Severe limitations that make them generally unsuitable for cultivation and that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat
7	Very severe limitations that make them unsuitable for cultivation and that restrict their use mainly to grazing, forestland, or wildlife habitat
8	Miscellaneous areas have limitations that preclude commercial plant production and

Class	Description
	that restrict their use to recreational purposes, wildlife habitat, watershed, or aesthetic purposes

According to the USDA classes 1 through 4 are considered capable of producing cultivated crops with good management and conservation treatment. Classes 5 through 7 are best suited to perennial vegetative species, but may be capable of producing some specialized crops with highly intensive management. Class 8 soils are not suitable for managed vegetative production. The perspective taken by the USDA is the capability of the land to be used for cropping, as pasture/range land and also the risk for land degradation. For the purpose of the mapping of marginal lands it is interesting to know that marginal lands are to fall in the class 4 to 8 (Kang et al., 2013), hence the expectation of the USDA that these classes are still suited for perennial vegetative species, but not for cultivated crops, mostly liked to food production. For the classification into the 8 main classes a sub-classification of the USDA-NCRS is used describing more specifically the biophysical constraints that are limiting in every main class:

• Subclass e is made up of soils for which the susceptibility to erosion is the dominant problem or hazard affecting their use. Erosion susceptibility and past erosion damage are the major soil factors that affect soils in this subclass. (refers to 'adverse terrain')

• Subclass w is made up of soils for which excess water is the dominant hazard or limitation affecting their use. Poor soil drainage, wetness, a high water table, and overflow are the factors that affect soils in this subclass. (refers to 'excessive wetness')

• Subclass s is made up of soils that have soil limitations within the rooting zone, such as shallowness of the rooting zone, stones, low moisture-holding capacity, low fertility that is difficult to correct, and salinity or sodium content. (refers to 'adverse chemical composition, low fertility and limitations in rooting')

• Subclass c is made up of soils for which the climate (the temperature or lack of moisture) is the major hazard or limitation affecting their use.(refers to 'adverse climate')

Beside classifications of land, there are also several approaches to assessing land limitations, by taking the suitability of the land for growing specific crops as a starting point. Much work on this has been done by the Food and Agricultural Organisation that developed a framework for land evaluation (FAO, 1976). This framework was integrated further in their framework for evaluating sustainable land management (FESLM) (FAO, 1993) which specifies land limitations for cultivation of specific crops. The system is flexible in that it requires to choose a specific agricultural use perspective such as the growing of sugarcane, wheat, pasture land. The framework covers land quality factors such as moisture availability, length of growing season, soil drainage class, depth to water, nutrient availability and salinity. FAO also adopted the Visual Soil Assessment (VSA) Guide developed initially for New Zealand by Shepherd (2000) and was further developed for a more general worldwide application (Shepherd et al, 2008). It gives guidelines on how to do a visual soil assessment of soil suitability for main crops like olives, vineyards, orchards, wheat, maize, other annual crops and pasture. The visual indicators of soil quality included in the VSA are measurable in the field and include soil texture, structure, porosity, colour, presence of earthworms, rooting depth, surface crusting and cover and soil erosion. So basically these are proxy indicators for soil limiting factors influencing fertility and machine operationability on the soil. Based on the observations in the field a scoring is developed according to which soils can be classified in poor, moderate and good classes. The lands in the 'poor' class are certainly overlapping with the marginal lands, particularly when they score 'poor' for all type of crops covered in the VSA as this implies low probability of use for food production and thus for competing uses when converted to industrial cropping.

Approaches to agro-ecological assessments by IIASA were strongly influenced by the work of Fischer et al. (2002, 2008) and were also aimed at identifying land availability for agriculture within different agro-environmental zones and also for the production of biofuel feedstock (Fischer et al., 2009 and Fischer et al., 2010). Central in the work done by Fischer et al. (2002 & 2008) is that suitability of land for agriculture use needs to be determined by three factors: 1) climatic factors for temperature and precipitation regime especially leading to constraints as drought, excessive wetness, short growing season 2) soil limiting factors such as low-productivity, shallow soils, stoniness, acidity, salinity, 3) topography particularly too steep slopes and therefore sensitive to erosion and inaccessible to machinery. It does not imply that constraints in all categories need to apply at the same time in the same place for classifying land as marginal and non-marginal, as long as one of the three biophysically constraining factor groups apply. This is in line with other studies (Cai et al., 2010; Gopalachrishnan et al., 2011) and also most land classifications (USDA-LCC, Muencheberg by Mueller et al., 2010; FAO, 1993; UK-land classification by Bibby et al., 1991 and FAO-CGIAR, 1999). The same biophysical constraints also come back in the framework proposed for identifying 'areas of natural constraints' by the European Commission Joint Research Centre (JRC) (Van Oorschoven, et al., 2014 and Terres et al, 2014).

As becomes clear from Table 4 all criteria proposed by Van Oorschoven et al. (2014) for identifying areas of natural constraints in Europe, cover limitations in the climatic, soil, and topographic constrains categories. The indicators proposed by JRC (Van Oorschoven,

2014) are in line with the ones proposed in other studies. However, whether threshold values distinguishing marginal and non-marginal are similarly chosen is to be seen as to be discussed in next Chapter 3, where the focus is on mapping marginal lands.

Table 4 The 8 biophysical factors defining areas of natural constraints as defined by JRC* and overlap with alternative studies proposing criteria for land classifications and delimitations of marginal lands

Criterion	Definition	Also proposed in alternative land classifications/definition studies:
CLIMATE		
Low Temperature	Length of Growing Period (LGP) (number of days) defined by number of days with daily average temperature > 5°C (LGPt5) OR Thermal-time sum (degree-days) for Growing Period defined by accumulated daily average temperature > 5°C.	• LPG identified as important constraint to rain fed agriculture by Fisher et al. (2002 &2008), Murray et al., (1983), Mueller et al (2010) • USDA-LCC & Mueller et al. (2010) refer to using 1) Soil Temperature regime (STRs) classification, 2) cumulative days dry in soil moisture control, 3) effective precipitation (inches)
Dryness	Ratio of the annual precipitation (P) to the annual potential evapotranspiration (PET)	
Excess soil Moisture	Number of days at or above Field capacity	• Muller et al., 2010 & USDA-LCC use frequency and inundation classes (marginal land would fall in frequent & very frequent inundation in combination with duration class brief, long, very long)
SOIL		
Limited Soil Drainage	Areas which are water logged for significant duration of the year	• Muller et al., 2010 & USDA-LCC, Fisher et al. (2002, 2008) use Natural drainage classification (marginal would fall in classes poorly drained, very poorly drained, subaqueous)
Unfavourable Texture and Stoniness*	Relative abundance of clay, silt, sand, organic matter (weight %) and coarse material (volumetric %) fractions	Unfavourable texture, stoniness, rooting depth are mentioned in all land classification and marginal land definition studies as very indicative for agricultural suitability (USDA-LCC & Mueller et al. (2010), Cai et al. (2010), Fischer, 2002, FAO, 1993)
Shallow Rooting Depth	Depth (cm) from soil surface to coherent hard rock or hard pan.	
TERRAIN		
Steep slope	Change of elevation with respect to planimetric distance (%).	Steepness of slopes is included in all land classifications and studies on marginal land definitions (USDA-LCC & Mueller et al. (2010), Cai et al. (2010), Fischer, 2002, FAO, 1993)

**Van Oorschoven, J., Terres, J-M., Toth, T. (Ed.) Jones,R., Le-Bas, C., Nachtergaele, F., Rossiter,D., Van Orshoven, J., Schulte, R., van Velthuizen, H. (2014) Updated common bio-physical criteria to define natural constraints for agriculture in Europe. Definition and scientific justification for the common biophysical criteria. JRC report EUR 26638 EN*
**Terres, JM. Hagyo, A. Wania A. (Eds.), Confalonieri R., Jones, B. Van Diepen K., Van Orshoven J. (2014). Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by specific constraints. Methodology and factsheets for plausible criteria combinations. JRC92686. doi: 10.2788/844501.*

3.2. Socio-economic constraints of marginal lands

In the literature on marginal land definitions and land classifications there is generally much consensus on the bio-physical limitations that characterise marginal lands, and that can be used for identifying them, while for the socio-economic constraints there is less consensus on the exact indicators.

In the FAO-CGIAR definition of marginal lands, the typical socio-economic factors defining them as marginal lands are absence of markets, difficult accessibility, restrictive land tenure, small holdings, poor infrastructure, and unfavourable output/input ratios.

To start with, the unfavourable output/input ratios is a characteristic widely recognised as being typical for marginal lands by the economic scientist starting with Ricardo (1817) and more recent like Barlow (1986), Strijker (2005) (see also Table 1). What was also shown by economist looking at marginal lands is that returns on lands are dynamic depending on the changing economic opportunities under influence of factors like innovations, markets, policies, but also increasingly through climate change (Kang et al., 2013; Strijker, 2005). Technical innovations and increased demand for food have declined the occurrence of marginal lands in Europe tremendously in the last centuries (e.g. Strijker, 2005 and Pollard, 1997). Within the MAGIC project the economic return from marginal lands is considered dynamic from the a start, particularly since it will be investigated if using this land for production of industrial crops will deliver a positive economic return while when using it as a food crop it will not. Given the dynamic nature of economic returns on marginal lands because of market drivers, the unfavourable input output ratio does not seem to be a stable indicator for identifying marginal lands, but for further characterisation to investigate the chances for competing uses on marginal lands it is useful though.

The second type of socio-economic characteristics for marginal lands, indicated in the FAO-CGIAR definition as 'absence of markets, difficult accessibility and bad infrastructure', are indeed mentioned in several studies as key factors characterising marginal lands (Dale, 2010; Kang et al., 2013). The relation between accessibility on opportunities for economic development are of course explained through the theory of Von Thunen (1826) saying that lands located further away from cities have more problems reaching economically efficient uses because of higher transport cost. This distance factor is therefore very influential in explaining why many marginal lands remain 'unused' or abandoned. Also in the work of JRC (Terres et al., 2013) on 'identifying farm lands at risk of abandonment' the relationship between a peripheral location and risk for land abandonment is confirmed by the inclusion of 'low population density and remoteness' as a key indicator. Ioffe & Nefedova (2004) showed that abandonment for (European) Russia is especially taking place where low natural fertility overlaps with low accessibility. On the other hand, one can question whether the distance factor is a key characteristic of all marginal lands, or more of an additional complicating factor for a part of the marginal lands. Biophysical limitations can be a reason for abandoning lands also when located in the centre (near a city/market) while lands with good soils located in isolated locations can still be used for agricultural production, in spite of their relative accessibility limitations. The work by Terres et al. (2013) confirms this too, as identifying 'lands at risk for farmland abandonment' can only be done through composite indicators combining relative location with the criteria of areas with natural constraints as identified in Van Oorschoven et al. (2014). There are three broad categories of drivers of farmland abandonment according to Terres et al. (2013):

- natural handicaps: poor environmental / biophysical suitability for agricultural activities.
- low farm stability and viability.
- negative drivers in the regional context and these are determined by low population density, remoteness and rent paid/low land prices.

For MAGIC it implies that the 'absence of markets, difficult accessibility and bad infrastructure' are factors that have to be taken up in the mapping approach as factors often characterising marginal lands, but they cannot be treated as single factors according to which marginal lands can be identified. At the same time it can be concluded that 'isolated location' can be used in combination with other bio-physical characteristics to detect marginal lands that have a higher chance of being abandoned now or in the near future.

The factor 'restrictive land tenure and small holdings' that is seen as typical to marginal lands in the FAO-CGIAR definition was not confirmed in many other studies providing marginal land definitions. In the FAO-CGIAR approach to marginal lands the specification of this socio-economic characteristic is however no surprise as marginal lands often overlap with areas of higher rural poverty. In such rural poverty situations access to lands is also more restricted and holdings are small. This however is more a global issue particularly important in marginal lands outside Europe. In this respect, the factor restrictive land tenure is not the most significant feature according to which marginal lands in Europe should be identified.

From the above discussion is can be concluded that socio-economic limitations have a clear influence on the development opportunities of regions, particularly where they occur in combination with biophysical limitations. Furthermore, the more remote/decentral regions are located the higher chance there is for abandonment of farmland.

The socio-economic constraints typically applicable to these marginal situations, as discussed above, are also the ones captured by the different rural typologies developed by the OECD (1994, 2011) and EC (2010 & 2017). For the mapping of marginal lands in MAGIC, these rural typologies could be a good starting point.

The OECD classifies rural areas in predominantly urban; intermediate; predominantly rural) based on the population density of districts (Local Administrative Unit Level 2 or LAU2). In 2009, the OECD extended its classification to include the remoteness dimension which was based on the approach developed by Dijkstra and Poelman (2008) for the EU and found significant socio-economic differences between rural regions close to a city and remote rural regions. Following this the urban-rural typology by OECD, based on population density, was further extended with a typology of areas based on accessiblity. The accessibility was quantified by calculating the driving time needed for a certain share of the population to reach an urban centre (>50,000 inh). The OECD approach (2011) was then taken further by the EC (20...) by mapping the sub-indicators at a higher spatial resolution level. The new urban-rural typology developed by the Commission takes the OECD approach based on districts and TL3 regions and applies it to population grid cells and to NUTS-3 regions. The resulting typology considers a region predominantly rural if less than half of its residents can drive to the centre of a city of at least 50 000 inhabitants within 45 minutes. If more than half of the region’s population can reach a city of at least 50 000, it is considered ‘intermediate’. The importance of adding this accessibility factor to the rural typology is confirmed by the Brezzi et al. (2011) who showed that remoteness of rural regions is a significant factor explaining regional outflows of working age population, and that remote rural regions appear economically more fragile with lower economic output rates as compared to more central regions. For MAGIC is confirms the need for creating new economic income opportunities with industrial cropping in remote rural regions but it also confirms that the remote location is an extra complicating factor.

Following the work by OECD and EC, the FARO project (Van Eupen et al., 2012) developed an alternative typology of rural areas in Europe at high spatial resolution not only classified by socio-economic factors, but also by environmental zone. The FARO project (Van Eupen et al., 2012) typology which has several advantages above the typologies elaborated by OECD and EC. Firstly, it is more dimensional as it combines indicators on agricultural land use, accessibility, population and economic activity density. Secondly it was developed using higher resolution data and the results are available at grid level. Thirdly, is has been generated through a robust statistical clustering. The clustering of factors takes account of environmental zone specific ranges and averages per factor to map the 3 typology classes of peri-urban, rural and deep rural areas per environmental zone. It allows for environmental zone specific thresholds in sub-indicator levels.

Box 1: Description of peri-urban, rural and deep rural areas classified in FARO (van Eupen et al., (2012)

The **Peri-urban Zone** is situated adjacent to the larger urban centres. In general, the zone has the highest population density and is responsible for generating high levels of GDP. These are good

locations for the tertiary sector, predominantly resulting in a relative small agricultural share of the total GDP. However, there is still a large, but progressively declining, percentage of land in

use for primary production, with wide geographical differences over the Environmental Zones of Europe. Depending on the Environmental Zone, the maximum travel time to an average city in these regions varies from around 60 to 200 min, and the average economic density from 2000 to less than 30 Euro per km2.

In the **Rural Zone**, population density is lower than in the Periurban zone. Incomes are average, but with wide geographical differences. A large proportion of land is used for agricultural production.

By definition, these regions have an average or higher value in one of the two defining axes (economic density vs. accessibility), but are never statistically high on both. Consequently, rural areas are not always very distant from major urban centres; in which case the economic density surrounding these cities will be relatively low. This can be observed in rural areas surrounding east-European cities, where both population density and GDP are much lower compared with those in north-western Europe.

The Deep-Rural Zone has a low or average value on one of the two defining axes, and never average or high values on both of the axes (economic density vs accessibility). In general, this zone has the lowest population density and the lowest average income. Within and between geographical regions there are major differences in the maximum travel time to services, which suggest that this class should be further subdivided, to provide more detail at local levels for specific stakeholders.

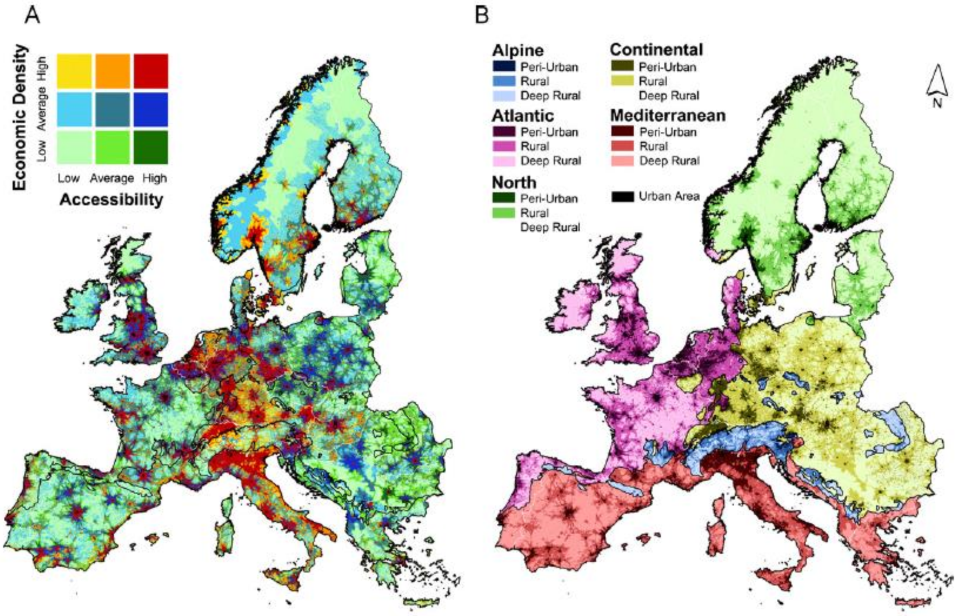


Fig. 5. (A) (Left) Final map with nine rurality classes based on Economic Density and Accessibility for each Aggregate Geographic Zone (AGZ) (Alpine, Atlantic, Continental, Mediterranean and North) derived from the 13 Environmental Zones of Metzger et al. (2005a,b). (B) (Right) Map of the three Rural Typology zones; Peri-Urban, Rural and Deep Rural within the five Aggregate Environmental Zones; Alpine, Atlantic, Continental, Mediterranean and North.

3.3 Sustainability and using marginal lands for non-food cropping

Sustainability for non-food biomass use, particularly for crop-based resources is an important issue in the policy and scientific debate for several years now because of direct and indirect effects on land use, competition with food production, biodiversity and other ecosystem services (Searchinger et al., 2008; Royal Society, 2008; Fargione et al., 2010; Edwards et al., 2010; EEA, 2013 & ETC-SIA, 2013; Valin et al., 2015; Dauber, 2012; Immerzeel, et al., 2014 etc.). However, there are many studies that claim that win-win situations can be created with the production of non-food crops on marginal lands. Dauber et al. (2012) for example believes in regional solutions for establishing sustainable bioenergy production systems including marginal land use that will have social, economic and ecological benefits. Smeets et al. (2009); Dale (2010); Fernando (2005), Zegada-Lizarazu et al. (2010), Zimmermann et al. (2012) all showed that using perennial grasses in low productive and degraded lands, for example in the US Conservation Reserve Programme, minimized soil erosion, helped to restore soil organic matter and decreased run-off of nutrients. Positive relationships between woody perennials and soil biodiversity were found by Rooney et al., (2009). When looking at land uses for non-food cropping several studies also indicate sustainability risks for marginal land uses such as loss of ecosystem services (Bindraban et al., 2009; Fargione, 2010; Berzky et al., 2011; Immerzeel, 2014; Plieninger & Gaertner, 2011), competition with food production (Royal

Society, 2008; Salomon et al, 2010; Harvey and Pilgrim, 2011) and GHG emissions (Spirtz, 2013; Valin et al., 2015; Frank et al., 2013; Lapola, 2010; Laborde, et al., 2011).

The options for creating co-benefits from the production of industrial crops on marginal lands depend very much on what type of land conversions are involved, the type of crops used, the management practices, and the presence of other uses and ecosystem services (EEA, 2013 & ETC-SIA, 2013; Immerzeel et al. , 2014). The sustainability implications of using marginal lands are inherently different from using good agricultural lands for industrial crops (EEA, 2013 & ETC-SIA, 2013; Immerzeel et al., 2014; Dale, 2010).

In marginal lands in Europe the risk for biodiversity loss is a factor that certainly needs specific attention particularly because it has been shown that High Nature Value (HNV) farmlands often coincide with areas of natural constraints which are typically overlapping with marginal lands. This overlap is not surprising as inherent to HNV farmland is that biodiversity values are higher because of the presence of extensive forms of farmland management and these farmland management systems are most often applied because of the natural constraints occurring in these farming areas (see Baldock, 1990, Beaufoy et al 1994, Bignal et al. 1994, Bignal & McCracken 1996a, 1996b; Andersen et al. 2003; Paracchini, 2008). Intensification of the farming activities in these lands may lead to unsustainable practices and land degradation. There is a clear coincidence between the places where farmland biodiversity has remained relatively stable and where the relative extensive traditional farming systems have continued to exist, while the opposite is true for the decline in farmland biodiversity and the shift towards more intensive and efficient farming systems (e.g. EEA, 2005; Heath et al., 2000). The main land cover in most HNV farmland areas is permanent grassland. In biodiversity terms this is the most important land use as extensively managed permanent grassland provides habitats for many specialised plant and animal species (Brak et al., 2004; Beaufoy et al., 1994, EEA, SOER, 2015). On the other hand, farmland abandonment is an important cause for loss of HNV farmland and thus biodiversity in more marginal areas of Europe. Whether introduction of industrial crops in such areas is a sustainable option remains to be seen however, as it needs to be tuned with the present biodiversity values. It may help to bring farmland abandonment down however.

Finding co-benefits through introducing new industrial cropping systems are realistic, particularly where it concerns threats to soil functions. According to Wezel et al. (2014) three are three meachanisms to prevent or minimize soil

In conclusion, we can state that the use of marginal lands for industrial cropping has many challenges particularly for making it a sustainable land use option. The sustainability impacts of growing industrial crops in marginal lands can be positive and negative, but depend very much on 1) whether other land uses are replaced by the industrial crops (leading to direct and indirect land use changes and potentially competition with food production); 2) whether biodiversity and other ecosystem service will be affected; 3) what industrial crops and management systems are to be used.

For the mapping of marginal lands in Europe in this MAGIC project it is therefore very important to not only identify these lands according to the biophysical and socio-economic constraints, but also classify them according to the (agricultural) land uses, the biodiversity and ecosystem services present and the environmental threats and vulnerabilities. Soil ecosystem functions and threats and the presence of High Nature Value farmland could be important classifying factors for marginal lands to be taken into account when developing industrial cropping options.

4. Mapping marginal lands in Europe suitable for industrial crops

4.1 Introduction

There are many scenario studies estimating marginal lands in the near and further future that can be used for extending food and non-food production (e.g. Hoogwijk et al., 2005 & 2009; Valin et al., 2015, Plevin et al., 2013, Overmars, 2015, van Laan, 2015, Elbersen et al., 2013, Nsanganwimana et al., 2014, Frank et al., 2013, Eitelberg et al. , 2014; Van Vuuren et al., 2009). These studies usually quantify how much land would be needed under different market, policy and technology scenarios and then match the demand to the land supply and calculate from that surplus land or model land use expansions into different land resources such as forests, pasture lands and also lands assumed to be falling in the marginal, degraded and/or unused land category. Several models take account of estimates of land extension coefficients applied to 'unused, marginal, abandoned, underutilised' land resources. To do this they first take often rather rough regional quantifications of these marginal or unused land categories based on relatively uncertain satellite based data sets on land cover and land use (e.g. Winrock MODIS or Corine Land Cover land categories).

There are also studies that take account of a more sophisticated land allocation model estimating production capability indices based on slope, rainfall, soil quality and accessibility and presence of infrastructure to determine likeliness of land conversion to cropping (e.g. Overmars, et al., 2015, Verburg et al., 2010; Havlik et al., 2011; Valin et al., 2015).

According to Gibbs and Salmon (2015) such model studies tend to overestimate the possibility of land extensions into marginal and degraded land resources. They explain this because of the lack of accurate data on the condition and exact location of degraded lands. The challenge of making reliable estimates of cropland expansions into marginal, unused, abandoned lands is confirmed by the wide variation in surface estimates for these lands in different studies. The example of Eitelberg et al. (2014) was already given in the former, showing a range in cropland availability at global level ranging from 1552 to 5131 Mha. Cambell et al, came to a total estimate of between 385 and 472 million hectares of marginal land at global scale.

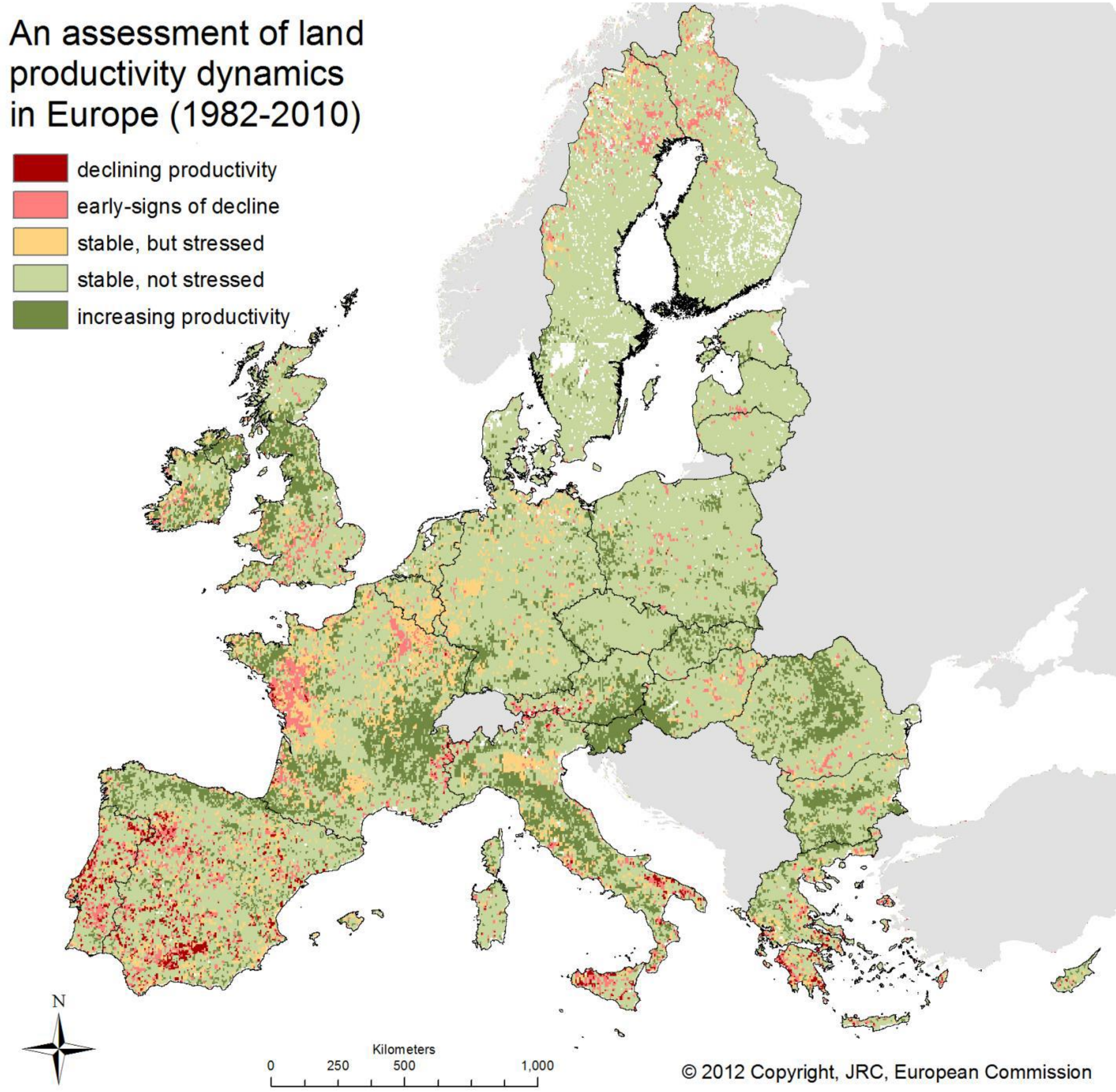
The studies that have implemented more precise mapping approaches for marginal lands are more limited (e.g. Cai et al., 2011; Li & Chan, 2009; Bai et al., 2008; Campbell et al., 2008). These approaches vary strongly, particularly because they do not take a similar definition of marginal lands, or they only take a sub-selection of characteristics of marginal lands into account. In Table 5 an overview of a selection of approaches is given.

Table 5 Overview of studies aimed at mapping marginal lands or overlapping land categories

Study	Type of land considered	Purpose	Geographic coverage	Identification method
Oldeman et al.,1990	Degraded lands	Identify the type, extend, degree and causes of land degradation	World	Expert opinion: In GLASOD project (UN commissioned) experts were consulted to estimate the status of soil degradation in relation to type, extent, degree, rate and causes.
Bai, et al., 2008	Degraded lands	Potential for bioenergy	World	Using long-term remotely sensed (satellite) data from which the normalized difference vegetation index (NDVI) is calculated (corrected for rain-use efficiency).
Campbell, et al., 2008.	Abandoned lands	Potential for bioenergy	World	Used data from the History Database of the Global Environment 3.0 (HYDE, 5minresolution) which are maps with crop and pasture shares for each grid cell for each decade between 1700 and 2000. Abandoned areas were determined from each grid cell that had decreasing agriculture areas over time. As a check, additional data was used on abandoned crop from the Centre for Sustainability and the Global Environment (SAGE) land use database.
Cai, et al., (2011)	Marginal lands, degraded cropland and abandoned lands	Potential for biofuels	World	A fuzzy logic modelling (FLM) technique to assess the land productivity. Uses a very wide selection of existing spatial datasets and generates from these land suitability indices following the USDA-LCC. FLM is used to treat the uncertainty of the global data sets and the fuzzy nature inherent in land classification according to multiple criteria.
Cherlet et al., 2013	Land degradation	Understanding land degradation and how it affects ecosystem services	Europe	Land productivity is calculated by combining long-term changes in standing biomass assessed using satellite observations data (5*5 km) (1982 to 2010). These are compared against locally defined maximum productivity levels, which are derived from a higher spatial resolution (1 x 1 km) dataset compiled from observations of the 'Vegetation' sensors on Europe's SPOT satellites (for period 2006 to 2010). This combination is the basis for determining land productivity dynamics and especially deviations. These indicate whether stable, declining or improving standing biomass dynamics have led to land productivity conditions that are at or below the current local potential.
Ceaușu, et al. (2015).	Marginal and abandoned lands and wilderness areas	Potential for rewilding	Europe	Used the VOLANTE project scenario results predicting abandonment toward 2040 and overlaid these with 4 wilderness metrics: 1) potential net primary productivity and net harvested primary productivity (Haberl et al., (2007). 2) Accessibility based on travel time considering terrain ruggedness and land-cover data from transport infrastructure to each pixel (Carver & Fritz 1999; EUROSTAT 2006). 3) the dPNV which is an estimate of the similarity between the current land cover(CLC 2000) and the potential natural vegetation (PNV by Bohn et al. (2000)). 4) Night light impact based on high resolution satellite imagery (NOAA National Geophysical Data Center 2012) which is the sum of impact scores from sources in radius of approx 10 km.
Alcantara, et al., (2013).	Abandoned lands	Food and non-food production	Central and Eastern Europe	Normalized difference vegetation indices (NDVI) calculated for 2003-2009 satellite data. Abandoned lands are covered by successional vegetation (e.g., grasslands, shrubs) during 2003-2009.
Liu et al. (2017)	Marginal lands	Bioenergy crops potential	Canada	Intersection was made of the national land cover map with a spatial assessment of land capability index based on climate, soil and landscape constraints.

The purpose of the mapping is in most studies to identify lands where feedstock for biofuels can be grown (Cai et al, 2011, Cambell et al., 2008, Bai et al., 2008; Alcanara, et al., 2013), but there are also studies that take nature conservation options 'bewildering' (Ceausu et al., 2015). The types of land mapped in the different studies overlap, but are obviously not defined in the same way.

Map 4.1 Land productivity dynamics as mapped by Cherlet et al. (2013) which are seen as proxy indicators for locations where land degradation processes are taking place.



Ideman et al., (1990), Bai (2008) and also Cherlet et al. (2013) take land degradation as a starting point. The identification of these lands is very different as the first one is entirely expert based and the second and third takes satellite data converted into normalized difference vegetation index (NDVI) or standing biomass, which are a more technical and objective classification approaches. According to Gibbs & Salmon (2015) however, satellite-based assessments are useful to capture recent or on-going degradation of lands by measuring changes in productivity, but satellite-based assessments will not capture the full picture of all degraded lands. This particularly refers to those lands degraded long ago, or fine gradients that exist between degraded and non-degraded grasslands. At the same time Gibbs & Salmon (2015) also indicate that future advances in remote sensing, including hyperspectral data, may allow finer distinctions for vegetation and soil degradation gradients.

In Ceausu et al., (2015), Alcantara et al. (2013), and Campbell et al., (2008) the focus is on identifying ‘abandoned’ lands in which in all 3 studies very different data sets and approaches are used. Ceausu et al. (2015) uses European specific data sources such as the potential net primary productivity and net harvested primary productivity (Haberl et al., 2007), an index for travel time, potential natural vegetation and night light impact. Alcantara et al. (2013) bases it entirely on NDVI calculations from time series from satellite imagery and Cambell et al. (2008) analyses historic land use data detecting dynamics in land use.

The mapping approaches that are most focussed on identifying marginal lands as fitting to the FAO-CGIAR definition of marginal lands are by Cai et al. (2011) and Liu et al. (2017). Liu et al. (2017) chooses to only identify marginal lands according to biophysical constraints. The approach by Cai et al. (2011) takes account of the wide spectrum of global data available on soil, weather/climate and topography and combines these in a biophysical model of agricultural productivity taking account of the USDA-LCC. The result is a classification of land productivity globally in three classes: low, marginal, and regular. By combining these classes with land cover and land use data sets, the model is further tuned to match the distribution of cropland in a global land cover map and areas of pasture land in the FAO database.

The mapping approaches in Table 5, provide useful examples for the marginal land mapping approach to be applied in MAGIC for the purpose of growing industrial crops on marginal lands in Europe. The studies provide useful indications on:

1) possible indicators for identifying marginal lands based on biophysical constraints (see Cai et al, 2011 and Liu, et al., 2017), based on socio-economic constraints (e.g. Ceaușu, et al., 2015), marginal lands overlapping with abandoned lands (Alcantara, et al. 2013; Campbell, et al., 2008) and marginal lands overlapping with degraded lands (Bai, 2008 & Cai et al., 2011)

2) Marginal lands overlapping with high biodiversity values (e.g. Ceaușu, et al., 2015)

3) Potential data sets available to identify marginal, degraded and abandoned lands (e.g. all studies in Table 5)

4) Potential methods for mapping marginal, abandoned and degraded lands following the multicriteria approach (Cai, et al., 2011) the use of satellite information and NDVI index (Alcantara et al., 2013, Cherlet et al., 2013 & Bai et al., 2008) and historic land use change data (Campbell, et al., 2008.)

4.2 Mapping degraded lands

Although in the former (in Table 5) examples were presented of studies that mapped land degradation (Cherlet, et al., 2013 and Bai et al., 2008), it should be acknowledged that the resulting maps were more referring to places where processes of land degradation were expected to take place in terms of land functions. The concept of land degradation is rather complex and there is no consensus on the exact definition, let alone of the way it should be mapped in Europe. Different approaches to mapping the concept are seen, ranging from mapping the extend according to perceptions of experts (Oldeman et al., 1990) to mapping more the outcome of degradation in terms of changes in land conditions and ecosystem functions and threats to ecosystem services, particularly those related to the productive capacity of lands and different soil functions (Van der Esch et al., 2017; Stolte et al., 2016; Cherlet et al., 2013; Louwagie et al., 2009 and Bai, et al., 2008).

In the JRC approach (Cherlet et al., 2013) the definition provided by the UNCCD (1994) was taken as a starting point to come to mapping a proxy for land degradation which is dynamics in land productivity. In this UNDCC convention (1994) land degradation in drylands is defined as “reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation”.

The challenge of mapping land degradation is, given the definition above, that the process has different stages and outcomes and to fully understand it one needs to know the original status of the land, in terms of soil and vegetation status, before the degradation started. In the PBL scenario study (Vam Esch et al., 2017) for the UNCCD Global land Outlook, this was also seen as a challenge, and the pragmatic choice was made to not claim to map land degradation. Instead it assesses changes in land condition and related ecosystem functions and services are estimated and expressed in a number of quantitative indicators related to the three factors determining land condition: soils, land cover (i.e. vegetation) and biodiversity. This land condition can then be expressed in indicators such as net primary productivity, soil organic carbon, topsoil depth, vegetative cover, soil nutrient balance, aridity and biodiversity.

Also in the study by Cherlet et al. (2013) only one of the conditions of land influenced by land degradation was mapped expressed in dynamics in biomass productivity. More specifically it tried to determine whether stable, declining or improving standing biomass dynamics occurred that have led to land productivity conditions that are at or below the current local potential. The approach by Bai et al. (2008) also linked land degradation to land productivity and also focussed on long-term decline in vegetation, assessed using long-term, remotely sensed normalized difference vegetation index (NDVI) data.

In the RECARE project (Stolte et al., 2015) the focus was specifically on soil degradation and this is assessed by evaluating and mapping the main soil functions and their threats. Also in this study the link is made between degradation and ecosystem functions and the outcome of the degradation (effect on soil functions) as mapped in RECARE, rather than focussing on the process of degrdation itself.

In conclusion: in MAGIC marginal lands under focus should include degraded lands. However, actual state and rate of land degradation in Europe is not available and given the comlexity of this phenomenon it should also be acknowledged that mapping land degradation as part of MAGIC will not be feasible. Instead MAGIC should make use of the several studies that mapped proxies of land degradation by focussing on the functions and threats of lands and ecosystem services that are influenced by land degradation. These particularly relate to soil functions, vegetation change and biodiversity.

The EU CASCADE project did investigated tipping points in drylands, beyond which drylands enter in an accelerated state of degradation, which cannot be restored. These shifts lead to major losses in biodiversity and concomitant ecosystem services. The project focussed on a couple of study sites in Southern Europe to investigate the process, but it did not generate maps of areas where tipping points across the European territory.

4.3 Contaminated lands

A special category of land which can be called marginal lands is that of polluted sites. If we focus only on point source pollution according to Toth et al. (2016) heavy metals together with mineral oils, are the most frequent contaminants in European soils, at least for as far as available data can confirm this.

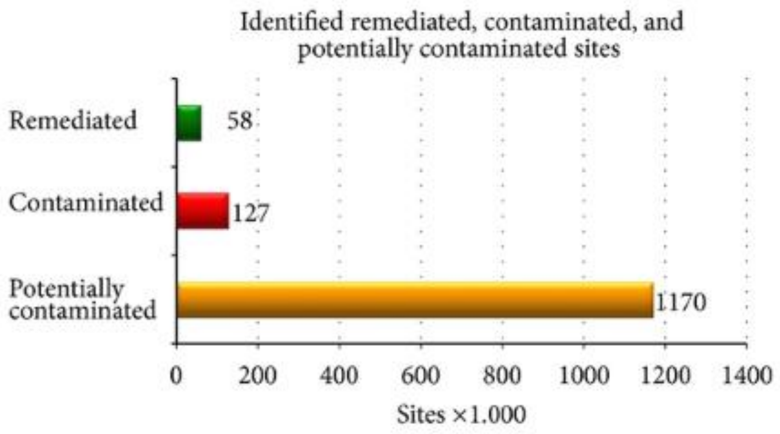
The problem of point-source contamination has been acknowledged in policy. In 2001 already the European Environment Agency (EEA) in cooperation with EEA affiliated countries started to develop a core set of policy relevant indicators, among which the indicator “Progress in the Management of Contaminated Sites” (CSI015). Also in the 7th Environment Action Programme (OJEU, 2013) of the EU sets the aim that by 2020 “soil is adequately protected and the remediation of contaminated sites is well underway”.

Since 2001, data collections in relation to the indicator Progress in the Management of Contaminated Sites” (CSI015) were launched 4 times by EEA: the last one in 2006, with contribution from member countries of the European Environment Information and Observation Network (EIONET). In the period 2011-2012, the European Soil Data Centre (ESDAC) organized a similar campaign in order to update the CSI015. For the monitoring of soil contamination clear definitions were also developed by the EEA-EIONET (see also Box 1) for contaminated sites which are ‘sites characterised by presence of all kinds of pollutants that have such high concentrations that they form a hazard for humans, water quality , ecosystems, or other receptors’. Based on the survey among European countries Van Liedekerke et al. (2014) estimates the number of potentially contaminated sites in Europe to 2.5 Million. Since the information is based on point sources information it only gives number of sites, but does not provide an area size for the sites.

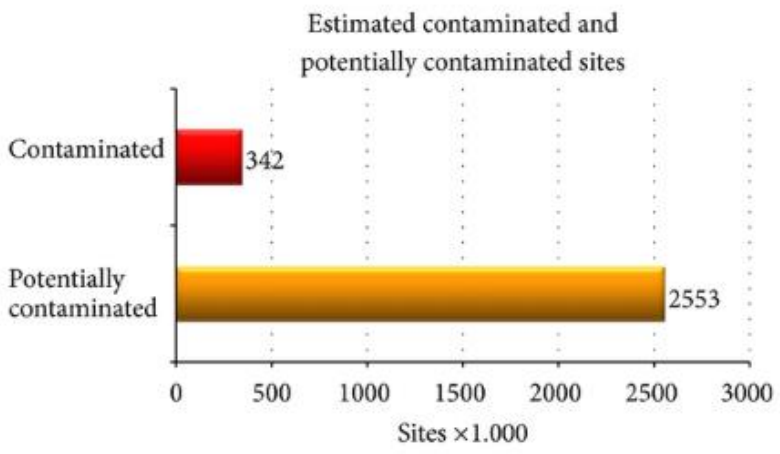
In these contaminated sites the biophysical constraints do not have a natural cause, but are caused by waste disposal, industrial and mining activities such as for oil extraction and production, and power plants, military sites and war affected zones, storages of chemical substances like oil and obsolete chemicals, transport spills on land (oil spill sites and other hazardous substance spills sites), nuclear sites and other sources. Some of these site may be interesting to be used for industrial crops, particularly for crops that can also be used for bioremediation on these sites (Fernando, 2005, Lewandowski et al. 2016, Cadoux et al., 2011; Hartley et al., 2009; Técher et al., 2012).

It is challenging to obtain a complete picture of contaminated sites in Europe as not all countries have provided data to the survey request organised through the EEA EOINET and the ESDAC and the data refer to point information and do not provide area estimates. However, the coverage is improving every year. Panagos et al. (2013) reported the status based on reports from 33 European countries and extrapolated the results to all 38 European countries (See Figure 3).

Figure 3 First map: Overview of identified and estimated remediated (RS), potentially (PCS), and contaminated Sites (CS) in Europe based on reported data by 33 countries (source; Panagos et al., 2013). Second map: extrapolated data to 38 European countries.



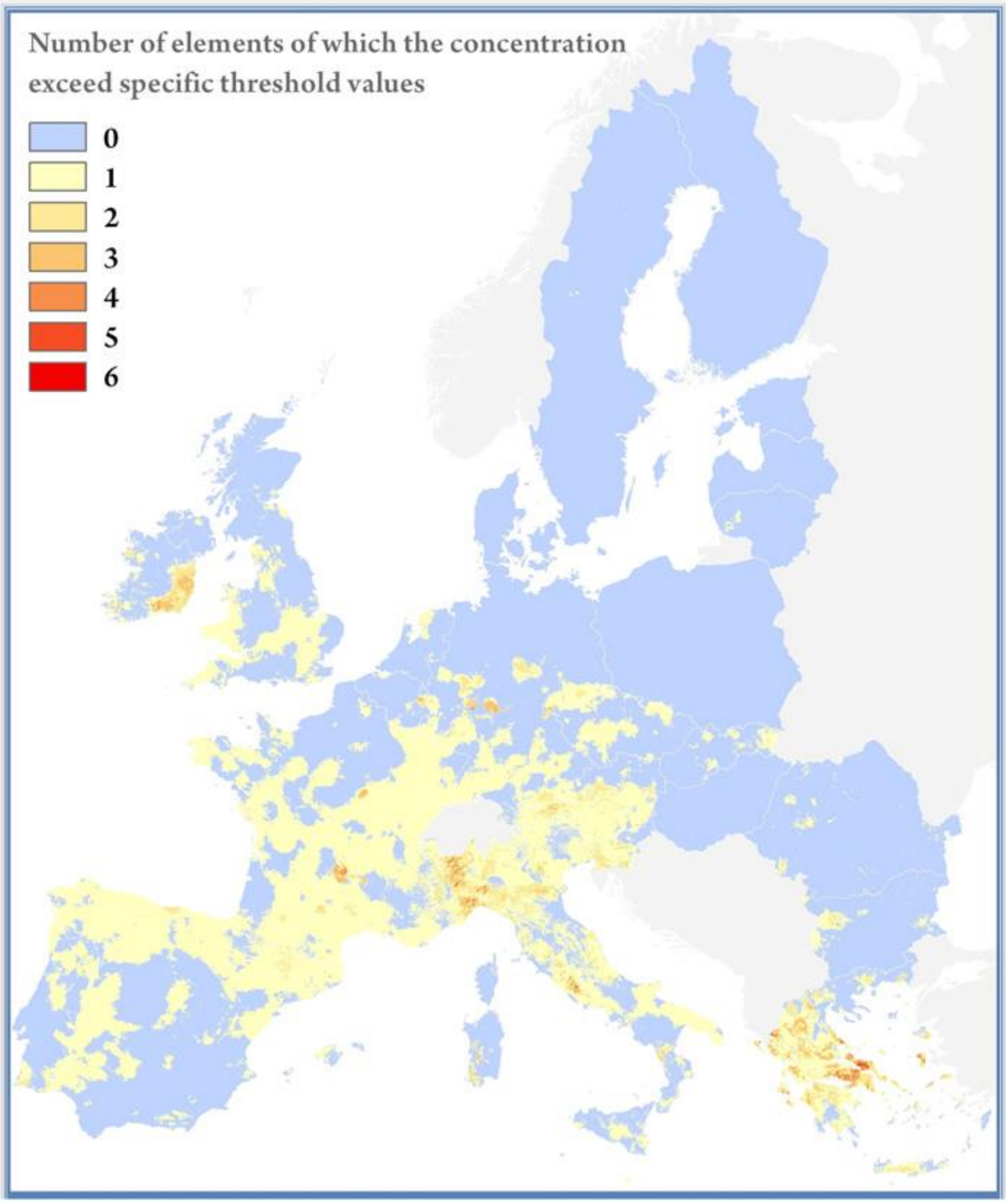
(a)



The information from the EEA and ESDAC on contaminated sites is available through point data and provides detailed information on types and source of contaminants. A limitation of these data might be that it does not include sites which have been remediated already years ago, but still have limited uses.

Beside the national survey data from EEA-EIONET and ESDAC, there is also the LUCAS Topsoil Survey for EU that provides data on heavy metal content of the topsoil and also for glyphosate and its main metabolite aminomethylphosphonic acid (AMPA) in EU agricultural topsoils. The results of this were analysed by the JRC (heavy matals in Toth et al., 2016 and Glyphosate in Silva et al., 2017). For heavy matals the data were also extrapolated to the whole EU (EU-27) surface (Toth et al., 2016). The resulting maps show the concentrations of various heavy metals in the topsoil which can either have a natural origin or come from anthropogenic sources. Human activities are of course an important source of pollution which can come from point sources (e.g. mines, industrial sites) or through diffuse contamination of larger land surfaces. The resulting maps (See Figure 4) provide an indication of the hotspots of heavy metal pollution, but it does not enable to distinguish between the source of contamination.

Figure 4 Heavy metals in topsoil in Europe (Toth et al, 2016) based on extrapolated LUCAS data in which top soil measurements were made for heavy metals concentration (As, Cd, Cr, Cu, Pb, Zn, Sb. Co & Ni) (Source: Toth et al., 2016)



The assessment by Toth et al. (2016), based only on LUCAS Topsoil Survey shows that most of the heavy metal elements remain under the corresponding threshold values in the majority of the EU surface. However, one or more of the elements exceed the applied threshold concentration on 1.2 million km2, which is 28.3% of the total EU surface area and refers particularly to regions in Western Central Europe (Saxony, Ruhr region in Germany, around Nimes and Lyon in France, Luik in Belgium), Central Italy, Greece and South-East Ireland (see Figure 3). These lands exceeding the threshold value for heavy metals can be regarded 'polluted', but whether they should also be defined as 'marginal' because of this is disputable. The threshold value exceedance is not directly limiting the use of these lands for food production, although it is likely that consumption of food produced on these lands may contain too high levels of metals forming a threat to human health. Furthermore high heavy metal levels are also threatening biodiversity.

In MAGIC contaminated soils and sites will be included in the M-AEZ classification. In the first instance we will focus on metals in agricultural soils, these can be natural background contaminations, but can also be caused by humans as a result of mining and municipal and industrial wastes (Toth, et al., 2015; Reiman et al., 2014). In the second step (to be implemented in 2019, contaminated sites outside agricultural lands will also be mapped.

The metal content of agricultural soils will be included in the M-AEZ as an extra variable in the group of adverse chemical composition limitation group. High metal content in agricultural soils can be seen as a soil limitation, even though the source maybe human induced.

GEMAS data (Reiman et al., 2014) together with LUCAS soil data are likely to be the best data to be used for the mapping of metal levels and/or contaminations in agricultural. Since these data are all point source data we will need to work with extrapolated data. Extrapolated data are available to the MAGIC project and are currently collected.

WP 4 will work on trials with industrial crops to bring down metal contamination in soils. WP4 needs a further understanding of where the main contamination areas are for four main metals (and in what combination with soil characteristics they occur. Focus will therefore be on cadmium, zinc, lead and nickel as is already decided in WP4. Cadmium has several more anthropogenic sources. It is a wide spread contamination problem as it occurs where too intensive phosphate fertilization has taken place. It can be seen as a large contamination problem worldwide. Hyper-accumulation in plants applies more to nickel.

For WP 4 an overview will be generated of what are the top metal contaminations (for these four metal types) in Europe in terms of area share in marginal agricultural lands and in terms of type of metals and contamination levels.

Since the focus in WP 4 on bioremediation options with industrial crops it will also need to be decided what type of soils are most commonly occurring in the main contamination areas. Soil characteristics are very influential on whether plants can take up the metals easily. Particularly the pH level is important which is strongly influenced by the presence of calcium.

Soil characteristics in combination with metal contaminations are very relevant to understand better the behavior of bioremediation options and will therefore be mapped in combination.

5 Conclusions and further steps to mapping marginal lands

5.1 Introduction

This report specifically discussed the existing definitions of marginal lands and their identification and characterisation in Europe taking account of the fact that we strive to identify sustainable best-practice options for industrial crops in Europe. In this respect, there are three key considerations that need attention in our approach to defining, characterising, mapping and classifying marginal lands:

Firstly, we strive to identify best options to grow industrial crops on land that is not used for food production at this moment nor is likely to be used for it in the future. This consideration is of course rooted in the general political and scientific concern about indirect land use change (ILUC) effects. ILUC refers to a process in which new demand for biomass additional to the existing food demand leads to a displacement in land use for existing food production as it needs to be produced elsewhere. This displacement leads directly or indirectly (through a number of other displacement steps) to conversion of natural (e.g. (tropical rain) forests, savannah and wetlands) and semi-natural lands (e.g. extensively grazed grasslands) into agricultural land and this again leads to an increase of Green House Gas (GHG) emissions and to loss of (semi) natural habitats with adverse effects on biodiversity. By focusing on marginal lands in this MAGIC project we expect to identify options for growing industrial crops without displacement effects.

Secondly, marginal lands in MAGIC will at least comprise of areas with natural constraints as was agreed in the project definition. Types of natural constraints and thresholds will be based on former work done by JRC (Van Oorschovn et al., 2014 and Terres et al., 2014) and other approaches to establish agronomic suitability of soils, topography and climates. For both the identification and characterization of marginal lands the soil, topographic and climate factors will play an important role. For the identification of sustainable best-practice options for industrial crops in Europe we need to ensure that these focus on marginality characteristics that are most commonly appearing in every environmental region in Europe, because the mapping of marginal lands is an important basis for selecting and testing the industrial crop types and development of best practices.

Thirdly, we want to ensure that options for growing industrial crops are not destroying ecosystems services, but rather create co-benefits. To ensure this it will be needed to identify marginal lands carefully in terms of their exact location and extend, but also in terms of the uses, environmental threats and ecosystem services present. Marginal lands, even though not used for cropping, may still be extensively grazed at very irregular time intervals and/or have important functions in terms of provisioning of habitats for flora and fauna, water regulation, carbon sequestration, recreation and hunting etc. Marginal land may also be under threat of/in a stage of degradation, possibly irreversible, and this situation may require measures to turn around this process. The production of certain industrial crops may create a win-win in case it can help to turn or stop the degradation, e.g. crop perennials on lands that are under threat of soil erosion. The mapping of marginal lands will therefore need to go together with a good characterization of these lands in order to be able to establish if sustainable cropping of industrial crops is at all an option or that only specific crops in specific management systems can be tuned sustainably with the ecosystem services present.

5.2. MAGIC Marginal Agro-Ecological Zonation (MAEZ)

The MAGIC project promised to deliver a spatially explicit database (MAP-DB) of a Marginal Agro-Ecological Zonation (M-AEZ) of Europe. The M-AEZ will be a spatially explicit classification of marginal lands serving as a basis for developing sustainable best-practice options for industrial crops in Europe. The M-AEZ should incorporate all variables according to which lands have been identified and classified in marginal and non-marginal lands. It should also enable the presentation of the marginal land areas according to a flexible choice of other classifying variables to be discussed further in this chapter. The M-AEZ should also provide all underlying statistics per relevant marginal land class according to classifying and descriptive variables. The M-AEZ should enable approaching the classification according to different user perspectives.

In every new version of the M-AEZ the quality of the data contained will improve and grow as more evaluation and validation of results has been done and an increasing amount of characteristics is added to the marginal land strata. MAP-DB will be made accessible in the project website after one year of the project and will be up-dated with further validated and refined results in years 2, 3 and 4 of the project.

5.3 Conclusions for the marginal land mapping approach

5.3.1 Definitions of marginal lands for the purpose of identifying opportunity gaps for industrial cropping

When going through references in which the definitions for marginal lands are discussed it becomes clear that there are 4 key characteristics typical for marginal lands which are:

1) that defining marginality depends strongly on the use perspective that is taken since land that is marginal for one use (e.g. cropping), can be well suited for another use (e.g. extensive grazing or forestry)

2) Marginality of land has 2 main dimensions: it has bio-physical constraints and socio-economic constraints

3) that the term 'marginal lands' is often associated, mixed or synonymously used with terms like abandoned farmland, low productive, under-utilised or unused, fallow, contaminated, fragile, vulnerable and degraded land

4) that marginality is a dynamic feature which can change in time

These 4 typical characteristics of marginal lands need to be guiding in choosing the best definition of marginal lands that can be a starting point for the identification of land potentially suited for industrial cropping. The three requirements from the perspective of MAGIC were presented in the introduction of this chapter and imply that the envelope of land taken as the starting point for mapping of marginal lands can be very broad as long as competition with food production and adverse ecosystem service effects are avoided now and also in the future. Preferably, it should help to identify types of lands where industrial cropping helps to create co-benefits. These lands can be lands that were in agricultural use at some moment in the near or further past, but also lands that had another non-agricultural use in the past and remain unused in the current situation because of pollution problems.

Marginal lands with an agricultural use history

Given the 4 typical characteristics for marginal lands as identified in the literature review, and the perspective of the industrial cropping use, it is clear that the definition of marginal lands from the FAO-CGIAR (1999) is a useful start, but in principle only focusses on lands with a current or past agricultural use status. It defines marginal lands as:

'Land having limitations which in aggregate are severe for sustained use due to:

a) increased inputs to maintain productivity,

b) low fertility, poor drainage, shallowness, salinity, steepness of terrain, unfavourable climatic conditions,

c) difficult market accessibility, small holdings, poor infrastructure and

d) limited options for diversification'

This definition takes the perspective of agricultural use, combines biophysical and socio-economic limitations and provides clear guidance on how to position marginal lands from favoured lands, which are currently used for food production. On the other hand, the FAO-CGIAR also distinguishes 2 other land categories such as 'fragile' and 'degraded' lands, which from the perspective of industrial cropping may be interesting land categories too, particularly if these lands are unused. This is likely to be the case for certain types of fragile lands and also for degraded lands, provided the level of constraints or the stage of degradation is making it unsuited for food production use at the current moment. At the same time, the level of degradation also needs to be reversible enough to make the land suitable for certain types of industrial crops. Whether this is the case, needs to be part of further research work within the MAGIC project, but it implies initially that degraded lands are to be mapped, this however can only be done indirectly by focussing on the effect of land degradation on ecosystem functions, rather than on the degradation process itself. State and rate of land degradation has never been mapped sofar, but land and ecosystem conditions and their threats have and can be regarded as proxy indicators for land degradation.

In conclusion, for the purpose of the MAGIC project the focus should be on lands having clear bio-physical constraints and are likely to be abandoned by food producing activities. This potentially applies to three categories of (former) agricultural lands defined by FAO-CGIAR:

1) Marginal lands

2) Fragile lands

3) Degraded lands

Contaminated sites located both in and outside former agricultural lands

A special category of land that is not yet covered by this definition as it generally falls outside the historic agricultural land use class, is the contaminated land category, particularly land affected by point-source pollution. Given that industrial crops can have a remediation function and produce feedstock that does not go into the food market, these types of lands certainly provide opportunities for production. Luckily more data are being collected by JRC and EEA on the location of these sites and the types of contaminations.

Wider defuse pollution with heavy metals and glyphosate in top soils measured in LUCAS survey and analysed by the JRC (Toth et al., 2016 and Sylva et al., 2017) are indicating towards a human induced degradation of soils. In principle these polluted lands should also be included in the degraded land category.

Both the contaminated sites and the areas affected by defuse pollution by heavy metals and glyphosate could be used in MAGIC to obtain information on what type of contaminations are most common in every environmental zone of Europe and in combination with what type of biophysical and socio-economic context they occur.

Definition of marginal lands used in MAGIC

The MAGIC definition of marginal lands to be identified for further investigation of its potential use for sustainable industrial cropping will therefore start from what FAO-CGIAR defines as marginal, fragile and degraded lands and EEA as contaminated lands. So the combined definition of these 4 types of lands form the MAGIC definition of marginal lands:

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 definition will be guiding for the initial mapping of marginal lands in MAGIC. However, given the aim of MAGIC that the identification of marginal lands should support the development of sustainable best-practice options for industrial crops in Europe, there are additional requirements connected to mapping and classifying marginal lands:

1) The limitations for marginal lands should focus at the minimum on the biophysical constraints according to which JRC proposes to identify lands with ‘natural constraints’.

2) Indirect land use effects and competition with food production should be avoided which implies that marginal lands need to be classified further in used and unused marginal lands and lands where the biophysical limitations no longer apply because of improvement measures facilitating productive agriculture.

3) In MAGIC the aim is to focus on sustainable solutions by developing industrial cropping options that create win-win options in that feedstock is produced while at the same time improving the ecosystem service delivery of land. Adverse effects on ecosystem services should be avoided at the minimum. Further mapping of marginal lands it implies that a further classification of marginal lands according to ecosystem service present and threats to these services would be required.

5.3.2 Biophysical constraints typical for marginal lands

As to biophysical constraints for the marginal lands both FAO-CGIAR, and main land classification approaches (e.g. USDA-LCC, Mueller et al. (2010), Cai et al. (2010), Fischer, 2002 and 2008) underpin well the choice of indicators proposed by JRC (van Oorschoven et al., 2014, Terres et al., 2014) to identify areas on natural constraints in the EU. So on the level of criteria proposed for biophysical constraints typical to marginal lands the following factors will be used in MAGIC which can be clustered in 6 classes:

- Adverse climate
    a. Low temperature
    b. Dryness
- Excessive wetness
    a. Excess soil moisture
    b. Limited soil drainage
- Adverse chemical composition of soil
- Low fertility of soil
- Limitations in rooting
    a. Unfavourable soil texture and stoniness
    b. Shallow rooting depth

• Adverse terrain

a. Steep slope

5.3.3 Socio-economic constraints typical for marginal lands

As to the socio-economic limitations the FAO-CGIAR definition and the literature is not conclusive, particularly because it also to covers characteristics typical for marginal lands outside Europe. Overall there seems to be consensus about the fact that on marginal lands the input/output relationship is unfavourable making it difficult to obtain a positive income return from these lands when used for food production. However, at the same time it is acknowledged that this economic margin constraint is very dynamic in time under influence of changes in technologies, markets and policies. In the MAGIC project the evaluation of economic returns obtained from marginal lands when used for industrial crops and food crops will certainly be evaluated extensively, particularly to establish whether industrial crops are options for these lands while avoiding competition with food production. However, given the dynamic nature of this constraint and the fact that economic returns are part of a separate sustainability evaluation in the MAGIC project, this economic return constraint will not be used to identify marginal lands initially.

As to socio-economic constraints regarding 'limited access to markets, difficult accessibility and bad infrastructure' it can be concluded that many marginal lands have these characteristics, but these are less uniformly applicable then the bio-physical constraints. In other words marginal lands are indeed often located in decentral locations, but it does not mean that all decentrally located lands are marginal. On the other hand, the more decentral marginal lands are the higher the chances are for negative returns on cropping activities given higher cost to process and transport harvested products to markets. Marginal lands in decentral locations also have a higher chance to remain unused for food production and therefore the chance to compete with food production on these lands is lower when used for industrial crops. Because of this it is concluded that locational factors like accessibility and bad infrastructure can be used to identify marginal lands for the purpose of MAGIC, but only in combination with the bio-physical constraints as proposed above.

As to the fragile and particularly the degraded land category the socio-economic constraints can be very different. They can refer to situations where there is actually high population pressure and land scarcity. Because of these socio-economic circumstances in combination with the fragile soil characteristics the human induced degradation process was started. The human factor can also be relevant in the case of lands that were heavily constrained by biophysical factors, but through technical measures the constraints have been neutralised such as in the case of irrigation, drainage or other soil improvement measures. The human factor influencing the state of marginality of lands needs to be taken into account when identifying these marginal lands. It is however recommended to first identify the marginal lands according to biophysical constraints and use the human management as a secondary information layer to further classify marginal lands and evaluate their suitability for production of industrial crops.

5.3.4 Sustainability is a critical issue in relation to industrial cropping uses of marginal lands

Since the aim of MAGIC is to identify options for the use of marginal lands for industrial non-food cropping, sustainability is a critical issue. The sustainability impacts of growing industrial crops in marginal lands can be positive and negative, and depend on several aspects:

1) whether other land uses are replaced by the industrial crops (leading to direct and indirect land use changes and potentially competition with food production);

2) whether biodiversity and other ecosystem services will be affected (including through e.g. through soil erosion decline, N leaching and GHG emission changes, etc.);

3) what industrial crops and management systems are to be used.

4) Effects on rural development – e.g land that is marginal land for food production but productive for miscanthus or another industrial crops could be a source of additional income and contribute towards rural development.

In the identification it therefore needs to be ensured that marginal lands identified are classified further according to key characteristics supporting the evaluation according to sustainable use for industrial crops. In the Table 6 suggestions are given for descriptive characteristics that support a risk evaluation and identification of co-benefits of industrial cropping options on marginal lands in relation to the sustainability aspects mentioned above.

Table 6 Descriptive characteristics according to which marginal lands identified in MAGIC need to be classified in order to support the analysis of their sustainable use for industrial crops

Sustainability aspect	Relevant classification factor	Why relevant?
Risk for competition with food production and direct and indirect land use changes	Current uses	Avoid competition with food
	Abandonment status	Avoid competition with food
	Access to markets	Lower transport cost in delivery chain or focus on feedstock delivery to local markets instead of urban markets
	Accessibility	
	Status of infrastructure present in region	
	Access to land, land ownership	Reaching large enough and secure feedstock delivery chains to make it economically feasible
Risk for negative & potential positive effects of land conversion to industrial crops on biodiversity and other ecosystem services	Presence of protected nature areas (e.g. Natura2000, wetlands)	Loss of biodiversity through industrial cropping should be avoided
	Presence of HNV farmlands	
	Erosion risk	Industrial cropping solutions should not adversely affect but rather positively contribute improving soil and water resources.
	Water protection areas	
	Leaching risk	
	Water depletion risk	
Type of industrial crops and management systems to be used	Bio-physical constraints (climatic, soil and terrain limitations as mentioned above)	Industrial crop types and management systems need to be designed that are best adapted to the soil and climatic characteristics in marginal lands. This requires detailed data on soil and climate per marginal land class in every environmental zone in Europe.
	Relative accessibility	The infrastructural circumstances have important influence on the organisation of the logistics in a feedstock delivery chain
	Infrastructure present	
Contribution to rural development	Population development & ageing	Regions with declining and ageing populations need new sources of income to stop population decline
	Employment opportunities	In regions with limited economic activities the need for finding alternative income options is larger
	Dependency on agricultural sector, agricultural income & dependency on subsidies	If a region has a large dependency on agriculture and income is low there is need for alternative income opportunities with higher returns
	Land abandonment	Abandonment is indicator for declining agricultural sector nd indicates toward the need to find alternative income opportunities and also indicates towards opportunity gaps for industrial cropping.

5.4 Next steps: Mapping marginal lands and constructing the M-AEZ

The approach to mapping marginal lands in MAGIC and the results of this mapping will be presented in D2.6. Different succeeding versions of a spatially explicit database (MAP-DB) of a Marginal Agro-Ecological Zonation (M-AEZ) of Europe will be generated. In deliverable 2.6 the methodological approach to mapping the first version of Marginal Agro-Ecological Zonation (M-AEZ) in MAGIC is presented. The approach to mapping will take the conclusions presented in this report as an important basis.

The M-AEZ will be a spatially explicit classification of marginal lands serving as a knowledge base for developing sustainable best-practice options for industrial crops in Europe (in WP3 and 4). The M-AEZ should incorporate all variables according to which lands have been identified as marginal and it should enable the presentation of the marginal land areas according to a flexible choice of a wide diversity of classifying variables proposed in this report. These classifying variables indicated as important have been summarised in this chapter and relate to current land management or absence of it, socio-economic characteristics clustered in a rural typology and ecosystem services and threats to ecosystem services. As the the ecosystem services the focus will initially be on biodiversity and soil functions and threats.

Based on the literature review on marginal lands and the requirements from the MAGIC project discussed in this report the MAGIC definition for marginal lands has been proposed. The proposed definition starts from a combined definition of marginal, fragile and degraded lands as defined by FAO-CGIAR and of contaminated lands as defined by EEA. The reason to choose these combinations of land types initially is rooted in the decision taken at the QUICKScan working meeting that WP2 should concentrate on mapping lands that are biophysically constrained, either by natural limitations and/or limitations imposed through unsustainable human management, and lands that remain unused by other activities (e.g. by agriculture, forestry, urban uses, etc.).

References

Alcantara, C., Kuemmerle, T., Baumann, M., Bragina,E., Griffiths, P., Hostert, P., Knorn, J, Muller, D., Prishchepov A., Schierhorn, F., Sieber, A. & Radeloff, V. (2013). Mapping the extend of abandoned farmland in Central and Eastern Europe using MODIS time series satellite data. Environ. Res. Lett. 8 (2013) 035035 (9pp). doi:10.1088/1748-9326/8/3/035035

Allen, B., Kretschmer, B., Kieve, D., Smith, C., and Baldock, D. (2013). Biofuels and ILUC – Q&A: Answers to common questions surrounding the ILUC debate. Biofuel ExChange briefing No 5, Institute for European Environmental Policy, London.

Andersen, E., Baldock, D., Bennett, H., Beaufoy, G., Bignal, E., Brouwer, F., Elbersen, B., Eiden, G., Godeschalk, F., Jones, G., McCracken, D.I., Nieuwenhuizen, W., van Eupen, M., Hennekens, S. & Zervas, G. 2003. Developing a high nature value indicator. Report for the European Environment Agency. Copenhagen. Further work of the EEA and JRC is documented under: http//eea.eionet.europa.eu/Public/irc/envirowindows/hnv/library.

Bai, Z. G.; Dent, D. L.; Olsson, L.; Schaepman, M. E. Proxy Global Assessment of Land Degradation. Soil Use Manage. 2008, 24 (3), 223–234.

Barlowe, R. (1986). Land Resource Economics. The Economics of Real Estate. Prentice Hall.

Bergsma, E. et al. 1996: Terminology for Soil Erosion and Conservation; International Society of Soil Science; Vienna

Beaufoy, G., Baldock, D. & Clark, J., 1994. The nature of farming: Low intensity farming systems in nine European countries. Institute for European Environmental Policy (IEEP), London.

Bertzky, M., Kapos, V. and Scharlemann, J.P.W., 2011. Indirect land use change from biofuels production: implications for biodiversity. JNCC Report, No. 456

Bibby, J., Douglas, H., Thomasson, A. and Robertson, J. (1991). Land Capability Classification for Agriculture. Aberdeen: Macaulay Land Use Research Institute.

Bignal, E.M. & McCracken, D.I., 1996. Low-intensity farming systems in the conservation of the countryside. Journal of Applied Ecology, 33: 413-424.

Bignal, E.M. & McCracken, D.I., 2000. The nature conservation value of European traditional farming systems. Environmental Reviews, 8:149-171

Bindraban PS, Bulte EH, Conijn SG (2009). Can large-scale biofuels production be sustainable by 2020. Agricultural Systems, 101,197-199.

Brak, B., Hilarides, L., Elbersen, B. & Wingerden, W. Van, 2004. Extensive livestock systems and biodiversity: The case of Islay. Alterra report 1100. Wageningen.

Brezzi, M.; Dijkstra, L. & Ruiz, V. (2011). OECD extended regional typology. The economic performance of remote rural regions. OECD Regional development working papers 2011/06.

Cai, X., Zhang, X., & Wang, D. (2011). Land availability for biofuel production. Environmental Science and Technology, 45(1), 334e339. http://dx.doi.org/10.1021/es103338e.

Campbell, J. E.; Lobell, D. B.; Genova, R. C.; Field, C. B. The Global Potential of Bioenergy on Abandoned Agriculture Lands. Environ. Sci. Technol. 2008, 42, 5791–5794.
Ceaușu, S., Hofmann, M., Navarro, L., Carver, S., Verburg, P. & Pereira, H. (2015). Mapping opportunities and challenges for rewilding in Europe. Conservation Biology, Volume 29, No. 4, 1017–1027
Cherlet, M. Ivits, E. T ó th, G.and Jones, A. (2013). Land Productivity Dynamics in Europe Towards Valuation of Land Degradation in the EU. EUR 26500 EN. 2013.
Committee on Climate Change(2011).Global and UK Bioenergy Supply Scenarios.Committee on Climate Change, London.
Dale, V., Kline, K., Wiens, J., and Fargione, J. (2010). Biofuels: Implications for Land Use and Biodiversity. Biofuels and Sustainability Reports, 1-13. http://www.esa.org/biofuelsreports/.
Dauber, J., Brown, C., Fernando, A., Finnan, J., Krasuska, E., Ponitka, J., Styles, D., Trän, D., Groenigen, K., Weih, M., and Zah, R. (2012). Bioenergy from “surplus” land: environmental and socio-economic implications. BioRisk, 7, 5-50.
Dauber, J. & Miyake, S. (2016). To integrate or to segregate food crop and energy crop cultivation at the landscape scale? Perspectives on biodiversity conservation in agriculture in Europe. Energy, Sustainability and Society (2016) 6:25
Dijkstra, L. and H. Poelman (2008) “Remote Rural Regions: How the proximity to a city influences the performances of rural regions” Regional Focus No 1. http://ec.europa.eu/regional_policy/sources/docgener/focus/2009_01_metropolitan.pdf
Elbersen, B. et al., 2013. Assessing the effect of stricter sustainability criteria on EU biomass crop potential. Biofuels Bioproducts & Biorefining-Biofpr, 7(2), pp.173–192. Available at: http://onlinelibrary.wiley.com/doi/10.1002/bbb.1396/abstract.
Elbersen, B.; Beaufoy, G., Jones, G., Noij, G-J., Doorn, A., Breman, B. & Hazeu, G. (2014). Aspects of data on diverse relationships between agriculture and the environment. Report for DG-Environment. Contract no. 07-0307/2012/633993/ETU/B1. Alterra. Wageningen, April 2014.
Elbersen, B. et al., 2015. Outlook of spatial biomass value chains in EU 28. , (September 2015), p.270.
Eitelberg, D., van Vliet, J. & Verburg, P. (2015). A review of global potentially available cropland estimates and their consequences for model-based assessments. Global Change Biology (2015) 21, 1236–1248, doi: 10.1111/gcb.12733
Eupen, M., Metzger, M.J.; Perez-Soba, M; Verburg, P.; van Doorn, A. & Bunce, R.G.H. (2012). A rural typology for strategic European policies. Land use Policy 29 (2012) p. 473-482.
European Environment Agency (2013). Review of the EU bioenergy potential from a resource efficiency perspective.
European Environment Agency (2005). Agriculture and environment in EU-15 – the IRENA indicator report. European Environmental Agency. Copenhagen.
European Environment Agency (2015). State of nature. EU Results from reporting under the nature directives 2007–2012. EEA Technical report No 2/2015
European Environment Agency, 2015 The European environment — state and outlook 2015 EEA Copenhagen

ETC-SIA (2013). Elbersen, B.S.; Fritsche, U.; Overmars, K.; J.P. Lesschen, Staritsky, I; Ros, J.; Zulka, K.P.; Brodski, L.; Eerens, H.; K. Hennenberg (2013). Review of the EU bioenergy potential from a resource efficiency perspective. A follow-up to EEA report No 7/2006. ETC-SIA technical report. (July 2013)

European Environment Agency (EEA) (2011), http://www.eea.europa .eu/data-and-maps/indicators/progress-in-management-of-contaminated-sites/progress-in-management-of-contaminated, 2011.

Fargione, J.E., Plevin, R.J. & Hill, J.D., 2010. The Ecological Impact of Biofuels. Annual Review of Ecology, Evolution, and Systematics, 41(1), pp.351–377.

Fernando, A. (2005). Fitorremediacao por Miscanthus x giganteus de solos contaminados com metais pesados, PhD Thesis, Universidade Nova de Lisboa, Lisbon.

Fischer, G., Velthuizen, H., Shah, M., and Nachtergaele, F. (2002). Global agro-ecological assessment for agriculture in the 21st century. Methodology and results. International Inst. for Applied Systems Analysis, Laxenburg, Austria.

Fischer, G., Hizsnyik, E., Prieler, S., Shah, M., and Velthuizen, H. (2009). Biofuels and food security – implication of accelerated biofuels production. Summary of the OFID study prepared by IIASA, Vienna, Austria.

Fischer, G., Prieler, S., Velthuizen, H., Berndes, G., Faaij, A., Londo, M., and Wit, M. (2010). Biofuel production potentials in Europe. Sustainable use of cultivated land and pastures, Part II: Land use scenarios. Biomass and Bioenergy, 34, 173-187.

Food and Agricultural Organisation (FAO), Consultative Group on International Agricultural Research (CGIAR), (1999); Research Priorities for Marginal Lands, the Framework for Prioritizing Land Types in Agricultural Research, the Rural Poverty and Land Degradation: A Reality Check for the CGIAR; CHAPTER 2 - DEFINITIONS AND CONTEXT. Document No.:SDR/TAC:IAR/99/12

Food and Agricultural Organization of United Nations (FAO). (1993). FESLM: an international framework for evaluating sustainable land management. World Resources Report, 73, FAO, Rome, Italy.

Fargione, J.E., Plevin, R.J. & Hill, J.D., 2010. The Ecological Impact of Biofuels. Annual Review of Ecology, Evolution, and Systematics, 41(1), pp.351–377.

Frank, S. et al., 2013. How effective are the sustainability criteria accompanying the European Union 2020 biofuel targets? GCB Bioenergy, 5(3), pp.306–314. Available at: http://dx.doi.org/10.1111/j.1757-1707.2012.01188.x.

Gibbs, H.K. & Salmon J.M. (2015). Mapping the world's degraded lands. Applied Geography 57 (2015) 12-21

Gopalakrishnan, G., Negri, M., Wang, M., Wu, M., Snyder, S., and LaFreniere, L.. (2009). Biofuels, land, and water: A systems approach to sustainability. Environ. Sci. Technol, 43, 6094–6100.

Harvey, M. & Pilgrim, S., 2011. The new competition for land: Food, energy, and climate change. Food Policy, 36, pp.S40–S51.

Heath, M.F., and M.I. Evans, editors. 2000. Important bird areas in Europe: Priority sites for conservation. 2 vols. BirdLife International, Cambridge, UK.

Hoffmann L.B. (ed.) (2000). Stimulating positive linkages between agriculture and biodiversity. Recommendations for building blocks for the EC-Agricultural Action Plan on Biodiversity. (European Centre for Nature Conservation, Tilburg, The Netherlands). ECNC Technical report series)

Hollander, J. (1895). The concept of marginal rent. Q. J. Econ., 9, 175-187.

Hoogwijk, M., Faaij, A., de Vries, B., Turkenburg, W., 2009. Exploration of regional and global cost - supply curves of biomass energy from short - rotation crops at abandoned cropland and rest land under four IPCC SRES land - use scenarios. Biomass and Bioenergy 33(1): 26 - 43.
Hoogwijk, M., Faaij, A., Eickhout, B., De Vries, B., Turkenburg, W., 2005. Potential of biomass energy out to 2100, for four IPCC SRES land - use scenarios. Biomass and Bioenergy 29(4): 225 - 257.
Ioffe, G & Nefedova, T. (2004) Marginal Farmland in European Russia, Eurasian Geography and Economics, 45:1, 45-59 http://dx.doi.org/10.2747/1538-7216.45.1.45
Immerzeel, D.J. et al., 2014. Biodiversity impacts of bioenergy crop production: a state-of-the-art review. Global Change Biology Bioenergy, 6(3), pp.183–209. Available at: http://doi.wiley.com/10.1111/gcbb.12067 [Accessed September 19, 2016].
James, L. (2010). Theory and Identification of Marginal Land and Factors Determining Land Use Change. Paper provided by Michigan State University, Department of Agricultural, Food, and Resource Economics in its series Graduate Research Masters Degree Plan B Papers with number 98203.
Kang, S., Post, W., Nichols, J., Wang, D., West, T., Bandaru, V., and Izaurralde, R. (2013). Marginal Lands. Concept, Assessment and Management. Journal of Agricultural Science, 5, 129-139. http://dx.doi.org/10.5539/jas.v5n5p129.
Keenleyside, C and Tucker, G M (2010) Farmland Abandonment in the EU: an Assessment of Trends and Prospects. Report prepared for WWF. Institute for European Environmental Policy, London.
Laborde, D. 2011. Assessing the land use change consequences of European biofuel licies. Final report ATLASS consortium. Contract no. TRADE/07/A2; Washington DC: IFPRI http://trade.ec.europa.eu/doclib/docs/2011/october/tradoc_148289.pdf (accessed 1 July 2012)
Lewandowski, I., et al. (2016). Progress on Optimizing Miscanthus Biomass Production for the European Bioeconomy:Results of the EU FP7 Project OPTIMISC. ORIGINAL RESEARCH published: 18 November 2016. doi: 10.3389/fpls.2016.01620
Liu, T., Huffman, T., Kulshreshtha, S., McConkey, B., Du, Y., Green,M., Liu, J., Shang, J., Geng, X. (2017). Bioenergy production on marginal land in Canada: Potential, economic feasibility, and greenhouse gas emissions impacts. Applied Energy (205), (2017), pp 477-485. http://dx.doi.org/10.1016/j.apenergy.2017.07.126
Louwagie, G., Gay, S., and Burrell, A. (2009). Addressing soil degradation in EU agriculture: Relevant processes, practices, and policies. Report on the project “Sustainable agriculture and soil conservation (SoCo).” JRC Scientifi c and Technical Reports. Office for Official Publications of the European Communities, Luxembourg.
Meuller, L., Schindler, U., Behrendt, A., Eulenstein, F. & Dannowski, R. (2010). The Meuncheberg Soil Quality Rating (SQR). Field manual for detecting and assessing properties and limitations of soils for cropping and grazing. Leibniz-Centre for Agricultural Landscape Research (ZALF) e. V., Muencheberg, Germany

Miyake, S. et al., 2012. Land-use and environmental pressures resulting from current and future bioenergy crop expansion: A review. Journal of Rural Studies, 28(4), pp.650–658. Available at: http://www.sciencedirect.com/science/article/pii/S0743016712000770.

Nalepa, R. (2011). A question of scale. The construction of marginal lands and the limitations of global land classifications. International conference on Global land grabbing, 6-8 April.

Nsanganwimana, F. et al., 2014. Suitability of Miscanthus species for managing inorganic and organic contaminated land and restoring ecosystem services. A review. Journal of Environmental Management, 143, pp.123–134. Available at: http://www.sciencedirect.com/science/article/pii/S0301479714002163.

OECD (1994). Creating Rural Indicators for Shaping Territorial Policy Organisation for Economic Co-operation and Development. OECD Publications and Information Centre, Paris, 93 pp.

OECD (2011). OECD Regional typology. Directorate for Public Governance and Territorial Development. https://www.oecd.org/cfe/regional-policy/OECD_regional_typology_Nov2012.pdf (accessed November 2017)

Oldeman, L et al. 1991: World map of the status of human-induced soil degradation: an explanatory note; International Soil Reference and Information Centre/UNEP; Wageningen/Nairobi http://www.isric.org/isric/webdocs/Docs/ISRIC_Report_1991_07.pdf

Overmars, K. et al., 2015. Estimates of indirect land use change from biofuels based on historical data, Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC91339/eur26819_online.pdf.

Overmars, K., Stehfest, E., Ros, J.P.M., Gerdien Prins, A. (2011), ‘Indirect land use change emissions related to EU biofuel consumption: an analysis based on historical data’. Environmental Science and Policy, 14, 248–257.

Panagos et al, (2013). Contaminated Sites in Europe: Review of the Current Situation Based on Data Collected through a European Network. Journal of Environmental and Public Health Vol. 2013 (2013), Article ID 158764, 11 pages

Paracchini, M. L.; Petersen, J.-E.; Hoogeveen, Y.; Bamps, C.; Burfield, I. and van Swaay, C., 2008. High Nature Value Farmland in Europe. An estimate of the distribution patterns on the basis of land cover and biodiversity data. JRC Scientific and Technical Reports. European Communities, Luxembourg http://agrienv.jrc.ec.europa.eu/activities_HNV.htm

Peterson, G., and Galbraith, J. (1932). The Concept of Marginal Land. American Journal of Agricultural Economics, 14.2, 295.

Plevin, R.J., Kammen, D.M. & Levin, S.A., 2013. Indirect Land Use and Greenhouse Gas Impacts of Biofuels. In Encyclopedia of Biodiversity (Second Edition). Waltham: Academic Press, pp. 293–297. Available at: http://www.sciencedirect.com/science/article/pii/B9780123847195003646.

Plieninger, T., and Gaertner, M. (2011). Harnessing degraded lands for biodiversity conservation. Journal for Nature Conservation, 19, 18-23.

Pointereau, P., Coulon, F., Girard, P., Lambotte, M., Stuczynski, M.,Sánchez Ortega, V., Del Rio, V. Editors: E.Anguiano, C.Bamps, JM. Terres (2008), Analysis of Farmland Abandonment and the Extent Data requirements, availability and gaps in AEIs in Europe 108 Second set of AEIs and

Location of Agricultural Areas that are Actually Abandoned or are in Risk to be Abandoned. EUR 23411EN – 2008.
Pollard, S. (1997). Marginal Europe. The contribution of marginal lands since the middle ages: Clarendon Press.
Renewable Fuels Agency., (2008). The Gallagher Review of the indirect effects of biofuels production. Review literature and arts of the Americas, Sussex.
Ricardo, D. (1817). On the principles of political economy and taxation. London, UK: J. M. Dent and sons, ltd.
Royal Society, 2008 Sustainable biofuels: prospects and challenges. Policy document 01/08, January.
Schäfer, M. 1992: Wörterbuch der Biologie – Ökologie; Jena (3 ed.)
Shepherd, G., Stagnari, F., Pisante, M., and Benites, J. (2008). Visual Soil Assessment VSA Field Guides – Annual Crops. Rome: Food and Agriculture Organization of The United Nations.
Shepherd, G. (2001). Visual Soil Assessment, Volume 1: Field guide for cropping and pastoral grazing on flat to rolling country. Palmerston North, New Zealand: Landcare Research.
Schroers J.O. 2006: Zur Entwicklung der Landnutzung auf Grenzstandorten in Abhängikeit agrarmarktpolitischer, agrarstrukturpolitischer und produktions-technologischer Rahmenbedingungen. University of Giessen, Germany. http://geb.uni-giessen.de/geb/volltexte/2007/4511/
Schubert, R., Schellnhuber, H. J., Buchmann, N., Epiney, A., Grieβhammer, R., Kulessa, M.,
Messner, D., Rahmstorf, S., Schmid, J., 2009. Future bioenergy and sustainable land use. London and Sterling, VA: Earthscan. German Advisory Council on Global Change (WBGU). from: http://www.wbgu.de/wbgu_jg2008_en.pdf.
Shortall, O. (2013). Marginal land for energy crops. Exploring definitions and embedded assumptions Energy Policy, 62, 19-27. http//dx.doi.org/10.1016/j.enpol.2013.07.048
Schroers, J. (2006). Towards the development of marginal land use depending on the framework of agricultural market, policy and production techniques. University of Giessen, Germany.
Silva, V.; Montanarella, L.; Jones, A.; Fernández-Ugalde, O., Mol, H.G.J., Ritsema, C. & Geissen, V. (2017). Distribution of glyphosate and aminomethylphosphonic acid (AMPA) in agricultural topsoils of the European Union. Science of the total Environment. Accepted 10 October 2017. Available online 15 October 2017 (http://www.sciencedirect.com/science/article/pii/S0048969717327973?via%3Dihub)
Smeets, E., Lewandowski, I., and Faaij, A. (2009). The economical and environmental performance of miscanthus and switchgrass production and supply chains in a European setting. Renewable and Sustainable Energy Reviews, 13, 1230-1245.
Stolte, J; Tesfai, M; Øygarden, L.; Kværnø, S.; Keizer, J.; Verheijen, F. & Panagos, P. Ballabio, C; Hessel, R (2017); Soil threats in Europe; EUR 27607 EN; doi:10.2788/488054 (print); doi:10.2788/828742 (online)
Strijker, D. (2005). Marginal lands in Europe - causes of decline. Basic Appl. Ecol., 6, 99-106. http://dx.doi.org/10.1016/j.baae.2005.01.001
Terres, JM. Hagyo, A. Wania A. (Eds.), Confalonieri R., Jones, B. Van Diepen K., Van Oorshoven J. (2014). Scientific contribution on combining biophysical criteria underpinning the delineation of agricultural areas affected by

specific constraints. Methodology and factsheets for plausible criteria combinations. JRC92686. doi: 10.2788/844501.
Terres J.M., Anguiano E, Nisini L (2013) Assessing the risk of farmland abandonment in the EU Technical assistance to define key factors and drivers, process data sets and provide results Administrative Arrangement #AGRI-2011-0295 between DG Agriculture and Rural Development and JRC Study on farmland abandonment – Deliverable 1
Toth, G, Hermann, T., Szatmari, G. & Pasztor, L. (2016). Maps of heavy metals in the soils of the European Union and proposed priority areas for detailed assessment. Science of the Total Environment 565 (2016) 1054–1062. http://dx.doi.org/10.1016/j.scitotenv.2016.05.115.
Turley, D., Taylor, M., Laybourn, R, Hughes, J., Kilpatrick, J, Procter, C, Wilson, L., et al., (2010). Assessement of the availability of marginal and idle land for bioenergy crop production. Vol. 5, London.
UNEP (United Nations Environment Programme) 2007: Global Environment Outlook (GEO-4); Nairobi http://unep.org/geo/geo4/media/
USDA-Land Capability Classification System (LCC) (1961).
Vadym Ivanina, Oleksandr Hanzhenko (Eds.) (2016). D 2.1 Report of general understanding of Marginal lands. Horizon 2020 research and innovation programme under grant agreement no. 691874.
Valin, H. et al., 2015. The land use change impact of biofuels consumed in the EU Quantification of area and greenhouse gas impacts. , (2015), p.261.
Van der Laan, C. et al., 2016. Mitigation of unwanted direct and indirect land-use change – an integrated approach illustrated for palm oil, pulpwood, rubber and rice production in North and East Kalimantan, Indonesia. GCB Bioenergy, p.n/a-n/a. Available at: http://dx.doi.org/10.1111/gcbb.12353.
Van Liedekerke, M., Prokop, G., Rabl - Berger, S., Kibblewhite, M., Louwagie, G., 2014. Progress in the Management of Contaminated Sites in Europe. EUR 26376. Publications, Office of the European Union. Luxembourg (68 pp).
Van Oorschoven, J., Terres, J-M., Toth, T. (Ed.) Jones,R., Le-Bas, C., Nachtergaele, F., Rossiter,D., Van Orshoven, J., Schulte, R., van Velthuizen, H. (2014) Updated common bio-physical criteria to define natural constraints for agriculture in Europe. Definition and scientific justification for the common biophysical criteria. JRC report EUR 26638 EN
Verburg, P.H. and Overmars, K.P., 2009. Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. Landscape Ecology 24(9): 1167-1181. http://dx.doi.org/10.1007/s10980-009-9355-7
Verstegen, J.A., van der Hilst, F., Woltjer, G., Karssenberg, D., de Jong, S.M. & Faaij, A.P.C., 2016. What can and can't we say about indirect land-use change in Brazil using an integrated economic - land-use change model? GCB Bioenergy, 8(3), pp.561–578. Available at: http://doi.wiley.com/10.1111/gcbb.12270 [Accessed September 22, 2016].
Von Thunen, J. and Wartenberg, C. (1966). Von Thunen's Isolated State: An English Edition of Der Isolierte Staat (1826). Trans. Carla M. Wartenberg. Oxford: Pergamon.
Wiegmann, K., Hennenberg, K. J., Fritsche, U. R. (2008). Degraded land and sustainable bioenergy feedstock production. Paper presented at the joint international workshop on high natural value criteria and potential for sustainable use of degraded Lands, Paris.

Wicke, B. (2011). Bioenergy production on degraded and marginal land. Assessing its potentials, economic performance, and environmental impacts for different settings and geographical scales. PhD Thesis Utrecht University. Copernicus Institute. ISBN 978 - 90 - 8672 - 050 - 7
Zegada-Lizarazu, W., Elbersen, H., Cosentino, S., Zatta, A., Alexopoulou, E., and Monti, A. (2010). Agronomic aspects of future energy crops in Europe. Biofuels, Bioproducts & Biorefining, 4, 674-691.
Zimmermann, J., Dauber, J., and Jones, M. (2012). Soil carbon sequestration during the establishment phase of Miscanthus x giganteus: a regional-scale study on commercial farms using 13C natural abundance. GCB Bioenergy, 4, 453-461.