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Marginal lands

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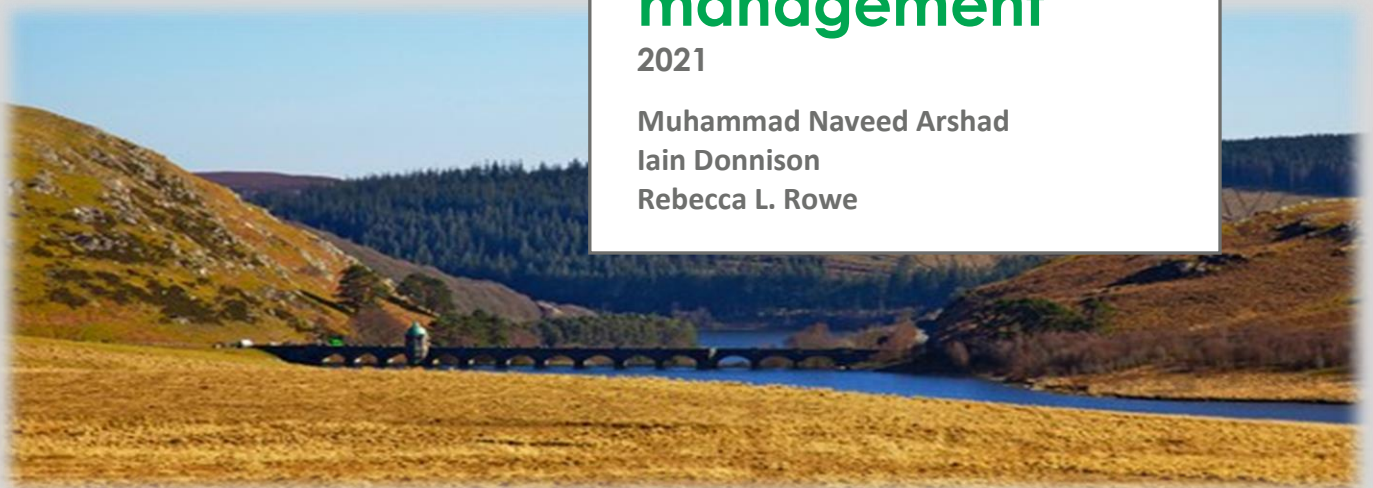
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The concept of marginal land has been broadly applied, yet a generalised understanding and knowledge of marginal land in terms of concept, assessment, and management are limited and diverse. The definition of marginal land and assessment methods vary across time, space and discipline to meet multiple management goals. In this report we explore current definitions and how they influence assessments of the availability of marginal lands within the UK and Europe. We use this to make recommendations for the most appropriate application of the marginal land concept in relation to bioenergy cropping. In other words, where the opportunities are to plant energy crops and with what potential impacts.

Marginal lands: Concept, classification criteria and management

2021

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Iain Donnison
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Reference

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This report is a critical review of marginal land and opinions and discussions provided by subject experts. All errors and omissions are ours.



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Aberystwyth University is a public research university in Aberystwyth, Wales. Aberystwyth was a founding member institution of the former federal University of Wales. The university has over 8,000 students studying across 3 academic faculties and 17 departments.



UK Centre for Ecology & Hydrology is a centre for excellence in environmental science across water, land and air. The organisation has a long history of investigating, monitoring and modelling environmental change, and its science makes a difference in the world.

1. Introduction

In the UK the expansion of lignocellulosic crops is supported in a number of policy documents (Committee on Climate Change, 2018, 2019; 2020). Biomass from cellulosic bioenergy crops is expected to play a substantial role in future energy systems of the UK, and also to contribute to greenhouse gas removal through the use of bioenergy and carbon capture and storage (BECCS). However, land is a limited resource, and all land is multi-functional, needed for food, feed, timber, and fibre production, as well as for nature conservation and climate protection. Integrated policies for energy, land use and water management are therefore required.

To use land for bioenergy crop production, it is important to understand and assess the impacts of such cultivation on food supply and the environment. To avoid potential competition with food crops, in both the UK and more widely in Europe, it has been proposed that the expansion of these crops should be focused on marginal agricultural land.

However, marginal land is poorly defined, leading to difficulties in the assessment of both the amount and location of land availability for bioenergy crops, and thus hampering efforts to assess the potential economic, environmental and societal impact of bioenergy crop expansion.

The concept of marginal land is not new and was used as a term in the 19th century by Ricardo (1817). The concept of marginal land has been broadly applied, yet a generalised understanding and knowledge of marginal land as a concept, and its assessment and management are limited, and equally diverse. The definition of marginal land varies across time, location and discipline with objectives to meet multiple management goals. What “marginal” land is depends on context with the definition varying by country, locality, and the organisation/researcher studying the topic. It 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 (Allen *et al.*, 2016; Edrisi and Abhilash, 2016; Lewis and Kelly, 2014). Therefore, there are great uncertainties among the estimates of availability and suitability of marginal land.

Crop yield potentials from marginal lands of British Isles have not been fully quantified although it is generally assumed that lower biomass yields can be expected from marginal lands (Meehan *et al.*, 2017). Economically, land is marginal if the combination of yields and prices barely covers cost of production. In practice, the term 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 (Kang *et al.*, 2013).

Concerns arise when definitions or classifications of marginal land are used to justify change to a new land use without adequately considering land's diverse values (figure 1). Land values may include ecological services the land provides, spiritual and cultural values that the land holds for local populations, and the often-overlooked traditional uses by lower income groups that depend on marginal lands for their livelihoods.

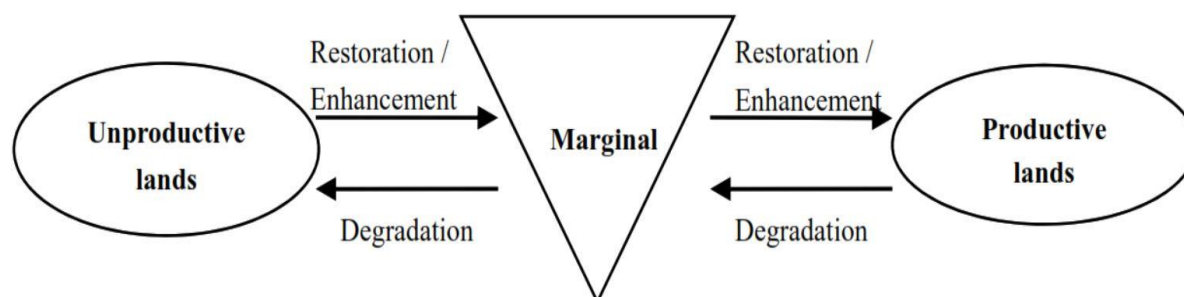


Figure 1: A transitional state of land uses – marginal lands

1.1 Definitions

It is important that the different advantages, disadvantages and implications of the definitions are clearly communicated, to avoid unrealistic expectations about the role of marginal land in overcoming land use controversies (Shortall, 2013). Three separate definitions of the term “marginal land” have been used by stakeholders in the UK including academics, consultants, NGOs, government and industry. These definitions are: (1) land unsuitable for food production (Nuffield Council on Bioethics,

2011; Renewable Fuels Agency, 2008); (2) ambiguous lower quality land (Bauen *et al.* 2010); and (3) economically marginal land (HM Government, 2009; Turley, 2010; Committee on Climate Change, 2011). Technical, normative and political assumptions are embedded within these definitions. Another related term “marginally suitable land” used by the Royal Commission on Environmental Pollution (RCEP, 2004) refers to “land with low yield potential and/or severe harvesting conditions”.

Definitions of marginal agricultural lands have also been proposed which incorporate the role of human intervention. For example, Elbersen *et al.* (2018) defined marginal land as ‘lands having limitations which in aggregate are severe for sustained application of a given use and/or are sensitive to land degradation, as a result of inappropriate human intervention, and/or have lost already part or all of their productive capacity as a result of inappropriate human intervention and also include contaminated and potentially contaminated sites that form a potential risk to humans, water, ecosystems, or other receptors’.

When defining land available for novel crops, such as for bioenergy, idle or degraded land may be considered alongside, or have definitions that partially overlap with, those used elsewhere for marginal lands, as in the Gallagher Review where idle land was defined as “former or current agricultural land that will not otherwise be used for food production and other unused land that is potentially suitable for agricultural production”. This definition was used to include arable land set aside from production, and at one stage included almost 600,000 ha in the UK.

Defra (2010) recognised that for land of low agricultural productivity there are likely to be changes in use based on economic and social drivers. For example, there is the potential for overlaps in marginal and idle land with a continuum in terms of likelihood and timescale over which land will enter or be removed from commercial arable or livestock production. There is also potential overlap in the definition of marginal and degraded lands, used by the Renewable Fuels Agency (2008). These definitions were based on the suitability of the land for food production, with marginal lands defined as lands unsuited to food production (e.g. on poor soils) and degraded lands as areas that have been degraded, making them unsuited to food production). With human actions potentially causing “poor soils” (Elbersen *et al.*, 2018), the

correct differentiation will depend on the availability of accurate land use history or expert opinion.

Gopalakrishnan *et al.* (2011) defined marginal land partly on the basis of suitability for different crops, so “marginal for conventional crops but not marginal for biofuel crops or other functions, based on economic, soil health, and environmental criteria”.

Broadly these definitions fall into two key categories (although any single definition may incorporate aspects of both):

Economic definition: An area where cost-effective production is not possible, under given site conditions, cultivation techniques, agricultural policies as well as macro-economic and legal conditions (Schroers, 2006); where revenue is just equal to costs of production (Galbraith, 1932).

Physical and production definition: Marginality is based on soil suitability with restrictions often being adopted by soil scientists and agronomists for the purpose of land use planning. This definition refers to land of poor quality for agriculture, susceptibility to erosion or other degradation (Lal, 2005).

1.2 Various terms of marginal land

The contrasting definitions of marginal land are also reflected in the number of terms that are used in association with marginal land, including: unproductive land, waste land, under-utilized land, idle land, abandoned land, degraded land, surplus land, barren land, carbon-poor land, fallow land, set aside land, waste land, reclaimed land, and contaminated land.

1.3 Constraints/challenges

To explore marginal land definitions in greater detail the broad economic and physical based definitions of land marginality can be disaggregated into four major challenges or constraints, which in isolation or in combination limit the land use.

- Climatic Constraints
- Geophysical Constraints

- Socio-ecological Challenges
- Economic Challenges

The quantification of the individual and combined effect of these challenges is important for land use policymaking including that for bioenergy cropping.

These challenges can render a site marginal under economic and social-ecological aspects, such as environmental protection, biodiversity conservation, infrastructure, markets and landscape appearance (Dale *et al.*, 2010). The spatial distributions of bio-physical limitations on rain-fed agricultural land have been assessed using soil and terrain maps (figure 2). These have been used to identify the areas of EU terrestrial rural land that experience various constraints on agricultural production in relation to temperature, slope, wetness and soils (Allen *et al.*, 2016). Severe soil constraints are apparent in the northern UK particularly upland areas, with acidic and often waterlogged soils dominated by semi-natural vegetation. The constraints are derived using the Global AEZ methodology applied to European datasets (FAO/IIASA, 2007; Eliasson *et al.*, 2007).

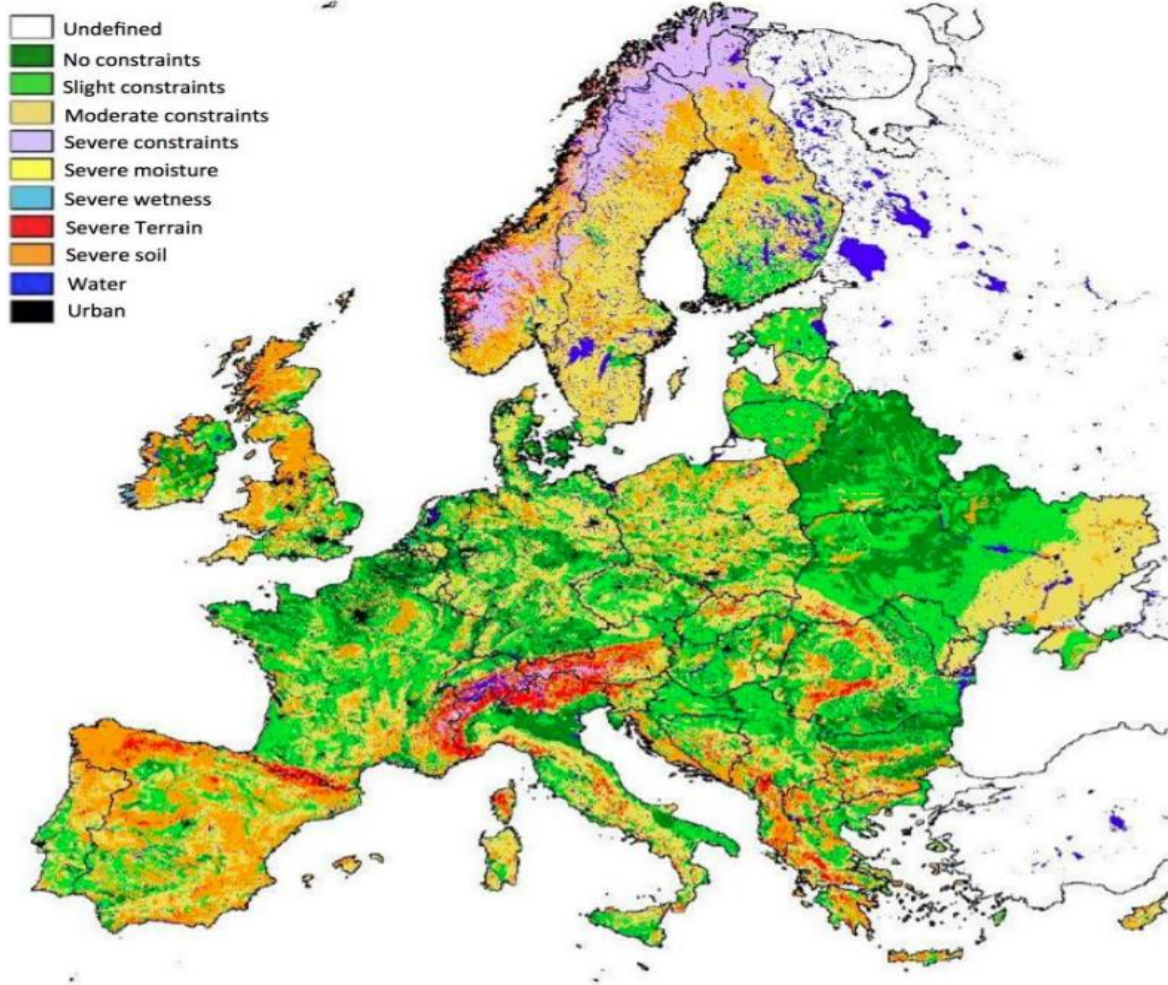


Figure 2: Map of bio-physical constraints determining land use for Europe.

2. Basic criteria of marginal land

It may be challenging to establish global or unified marginal land criteria because of different management goals across regions and countries. Ideally such criteria should be comparable and adjustable for a range of land use planning and policy making needs. The risk of implicit biases and value-based assumptions within land categorisations have previously been highlighted (Borras *et al.*, 2010; Franco *et al.*, 2010; Nalepa and Bauer, 2012). These authors highlight the gap between abstract categorisations of land types and the actual situation on the ground, as well as the effects this can have on different interest groups. Table 1 lists the definitions used within a number of key policy documents and publications relevant to the UK, with each definition assessed against the four key constraints and challenges defined in section 1.3 above. Geophysical constraints are the most commonly used criteria (in ten of 15 studies). This is likely because they can be linked to national soil maps and other readily available data, making them simpler to define and apply. In contrast Economic definitions are the least used criteria (in four of 15 studies), possibly reflecting the greater difficulty in assessing this constraint.

Table 1: Basic criteria used to describe marginal land in a range of reports, with ticks indicating the definitions used by each study.

Publication (year)	Climatic	Geophysical (Climate, Soil, Terrain)	Socio- Ecological	Economic
FAO (1993)		✓	✓	
Eliasson <i>et al.</i> (2007)		✓		
Renewable Fuels Agency (2008)	✓	✓		
Fischer <i>et al.</i> (2009)	✓	✓	✓	
Milbrandt and Overend (2009)	✓	✓	✓	
Dale <i>et al.</i> (2010)				✓
Tang <i>et al.</i> (2010)				✓
Cai <i>et al.</i> (2010)				✓
Defra (2010)	✓	✓	✓	
Nuffield Council on Bioethics (2011)		✓		
Gopalakrishnan (2011)		✓	✓	
Kang <i>et al.</i> (2013)	✓	✓	✓	
Orshoven <i>et al.</i> (2014)	✓	✓	✓	
Meehan <i>et al.</i> (2017)	✓			
Sallustio <i>et al.</i> (2018)				✓

3. Mapping marginal lands: Methods to identify the quantity of marginal lands

Wide variation in the estimates of marginal land availability have been attributed to ambiguity in the definition and characterisation of marginal land, together with uncertainty in assessments of land availability. The high level of uncertainty is due to the difficulty in identifying and combining environmental, economic and social constraints across a landscape, or even globally, with potentially limited data. For novel crops, such as bioenergy crops, variability can be further increased due to uncertainty over, or in some cases failure to fully exploit, their full potential (Dauber *et al.*, 2012). Methods for identifying marginal lands are qualitative, empirical, and quantitative and some very subjective (Kang *et al.*, 2013). Such methods also reflect specific management goals on croplands across countries that vary with location and time. Examples of qualitative, quantitative and system-based assessments of marginal land availability are described below, highlighting the difference in methodology and criteria used for various land types.

A) Qualitative:

1. Severe limitations of production are classified as marginal lands (Hamdar, 1999).
2. If one limiting factor of crop production such as soil, landscape and climate exists, the land is marginal (Biggs, 2007).
3. Wastelands, paddy lands or lands fallow in winter are identified as marginal lands in China (Tang *et al.*, 2010).
4. Inadequate rainfall or other limitations used to describe marginality (Government of South Australia, 1940).


B) Quantitative:

1. On the basis of land capability classification, Larson *et al.* (1988) used a productivity index and an erosion resistivity index to identify marginal agricultural lands in Minnesota.
2. Smith *et al.* (2000) developed a threat identification model for land sustainability assessment where marginal lands were identified with expert knowledge of local land management and their potential effects.

3. Breuning-Masen *et al.* (1990) classified steep, wet and drought prone soils as marginal, and generated marginal land maps based on soil information in Denmark.
4. Recent satellite data and historic information of land cover dynamics in Germany were used to detect the trend of abandonment of cultivation lands and further to identify marginal lands (Reger, Otte, & Waldhardt, 2007).

When using quantitative methods to assess the amount of marginal land suitable for a particular crop or land use, methodologies use a stepwise approach. Starting with a broad assessment of all marginal land, they then apply constraints to exclude any unsuitable land for the crop of interest, resulting in a prediction of the available marginal land (table 2).

Table 2: Methodology of assessing marginal land using quantitative method

All Marginal Lands	Methodology
<div style="text-align: center;">  </div> <p data-bbox="204 1352 596 1391">Available Marginal Lands</p>	<ol style="list-style-type: none"> 1. Start with all marginal lands (in some areas there is an overlap of different categories) 2. Exclude deserts, cold regions, and ice/glacier areas 3. Exclude protected areas 4. Exclude water features (wetlands, lakes, swamps) 5. Exclude forests, agricultural lands, urban areas, herbaceous and bare lands under intensive and extensive pastoralism

Within this process the choice of which land uses to exclude can result in variations between studies. Choices are normally based on, expert opinion, policy and/or current research, although they may also be selected to explore potential impacts of changes in policy or to predict impacts of future changes in diet, population or climate.

C) System approach:

Systems approaches have been used to consider land functions and social-economic impacts. For example, a land information system can direct the assessment, management and monitoring of marginal land (figure 3). A systems approach covers the use of land databases and considers land functions to classify land based on associated risks. It can further define and direct land use planning and management. With the recent advancements in the generation of high resolution spatial data, dynamic two-way models can be developed and used to update information as needed. Examples of productive and marginal land classifications using a system approach are:

1. Land suitability classification (FAO, 1978)
2. Land capability classification (LCC) (USDA, 2010)
3. Agricultural Land Classification of England and Wales (MAFF, 2018)
4. National scale land capability for agriculture – Scotland (Scottish Government, 2017)

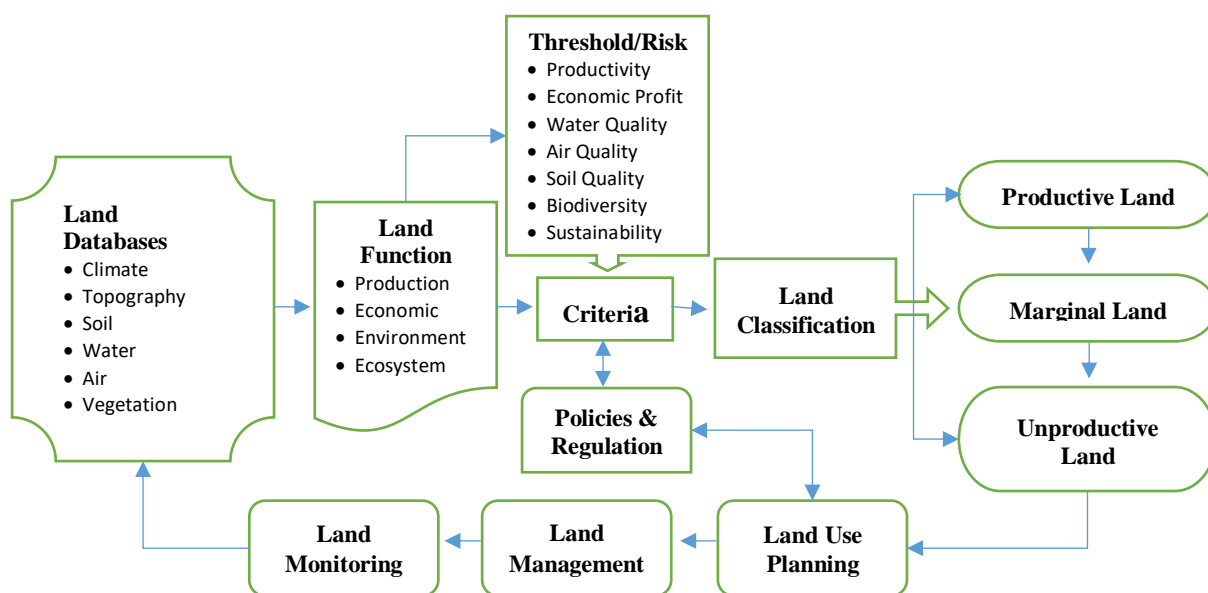


Figure 3: Land-information system for assessment, monitoring and management of marginal land

3.1 Marginal or abandoned land in Europe

There is no EU dataset that provides a comprehensive picture of ‘marginal’ land, mainly due to the lack of a consistent or agreed definition (Allen *et al.*, 2016).

Numerous definitions and assessments have, however, been applied or conducted that assess the availability of marginal land, or analogous land classifications. Hart *et al.* (2013) described three categories of abandoned land in the European countries that differed between regions.

1. **Transitional abandonment:** It has been observed particularly in Central and Eastern Europe as a result of restructuring and land reforms, and in other Member States as a result of compulsory set-aside, until this was abolished in 2008, or as a result of land use change. Transitional abandonment can be seen also in areas that are economically marginal in production terms. These areas can move in and out of agricultural use depending on market prices for certain commodities. They can appear also in an (peri) urban context with areas waiting for development as well as the result of other factors, such as following a family death, etc.
2. **Semi-abandonment or hidden abandonment:** Where the land is used by the farmer but with a very low level of management. The land is not formally abandoned and is subject to some form of management, which might be simply to keep it available for future use, for example for recreation and tourism. Such land may also be subject to the minimum management necessary to meet cross-compliance requirements by those claiming direct payments under the CAP. Very extensive or intermittent farming operations may also fall into this category, not least on semi-subsistence farms and in dry and more mountainous areas, including those characterised as High Nature Value (HNV) farming. Such extensive farming is generally associated with very low or sometimes zero direct economic returns, but may be continued for personal or social reasons, to complement other income streams, for example from hunting and tourism, or for nature and landscape conservation (or simply to maintain a long term family investment). It may also attract subsidy payments and probably does so over large areas.
3. **Actual abandonment:** Where the farmland is not used at all for a sustained period of time. The vegetation may change through natural succession into tall herb, bush and forest ecosystems after a period, depending on climatic and soil conditions. On rich and wet soils the outcome is likely to be forest ecosystems but, in contrast, on poor dry soils in southeast Europe, it can be

‘steppe-like’ grassland vegetation that is able to survive for many years without any active management such as mowing or grazing.”

Farmland abandonment resulted from a combination of diverse factors (Terres and Nisini, 2013; Alcantara *et al*, 2013; Moravec and Zemeckis, 2007; Pointereau *et al*, 2008). As described above, such categories include geographic, ecological and agronomic factors; demographic and socio-economic drivers; the impact of policy; institutional factors and historic circumstances which add complexity across the EU. This again highlights the benefits of a system approach, which allows for the incorporation of social-economic factors. Marginal definitions may exist at different geographical levels (Brouwer, 1997), for example:

- (a) Regional: in Europe, a region may be marginal in broad physical and socio-economic terms, with predominantly unfavourable conditions and uncompetitive forms of agriculture involving low productivity and income levels, remoteness from markets, and aging populations. The possibility of widespread marginalisation in such a region may be considered high, although there may also be agricultural areas which are highly productive and competitive.
- (b) Local areas: within a region, certain types of land use may become marginal as a result of changing socio-economic and technological conditions. Grazing marshes provide a good example. Such areas may exist even within generally very productive regions.
- (c) Farm level: an individual farm may be uncompetitive for a variety of reasons, such as small size, fragmented land, degraded infrastructure and capital equipment, or the age of the farmer. Generally, such holdings are taken over by other farmers or land uses, depending on local conditions. In more marginal regions, total farm abandonment may occur.
- (d) Within a holding, an individual plot of land may be marginal due to physical handicaps, such as poor access, steep slopes, waterlogging or distance from the main holding.

3.2 Marginal land classification of Europe

Current EU assessments of areas of marginal land or analogous land descriptions are described below.

3.2.1 EU Less Favoured Areas (LFA)

The Joint Research Centre published a technical report on redefinition of LFA with the term first established in 1975. Certain rural areas are classified as LFA because conditions for farming are more difficult due to natural constraints, which increase production costs and reduce agricultural yields. There are four classifications of LFA with each category covering a specific cluster of natural limitations in which the continuation of agricultural land use is threatened.

- (A) **Mountain areas** are characterised as those areas limited by a short growing season because of a high altitude, or by steep slopes at a lower altitude, or by a combination of the two.
- (B) **Other LFA** are those areas in danger of abandonment of agricultural land use and where the conservation of the countryside is necessary. They exhibit all of the following limitations: land of poor productivity, low productivity of the natural environment, and a low or dwindling population predominantly dependent on agricultural activity.
- (C) **Areas affected by specific limitations** are areas where farming should be to conserve or improve the environment, maintain the countryside, preserve the touristic potential, or to protect the coastline.
- (D) **Areas subjected to environmental restrictions** are areas with restrictions on agricultural usage resulting from the implementation of limitations on agricultural land use imposed by the EC.

In 2004, the surface area classified as LFA in the EU 25 Member States accounted for 91 million hectares, which represents 54% of the utilised agricultural area of the EU (CEC, 2004). Of the total LFA classified, the category 2 (Other LFA) represented as much as 66%. Category 3 (specific limitations) cannot exceed 10% of the area of the Member State concerned. The spatial distributions of the municipalities/communes classified as LFA in Europe are shown in Figure 4.

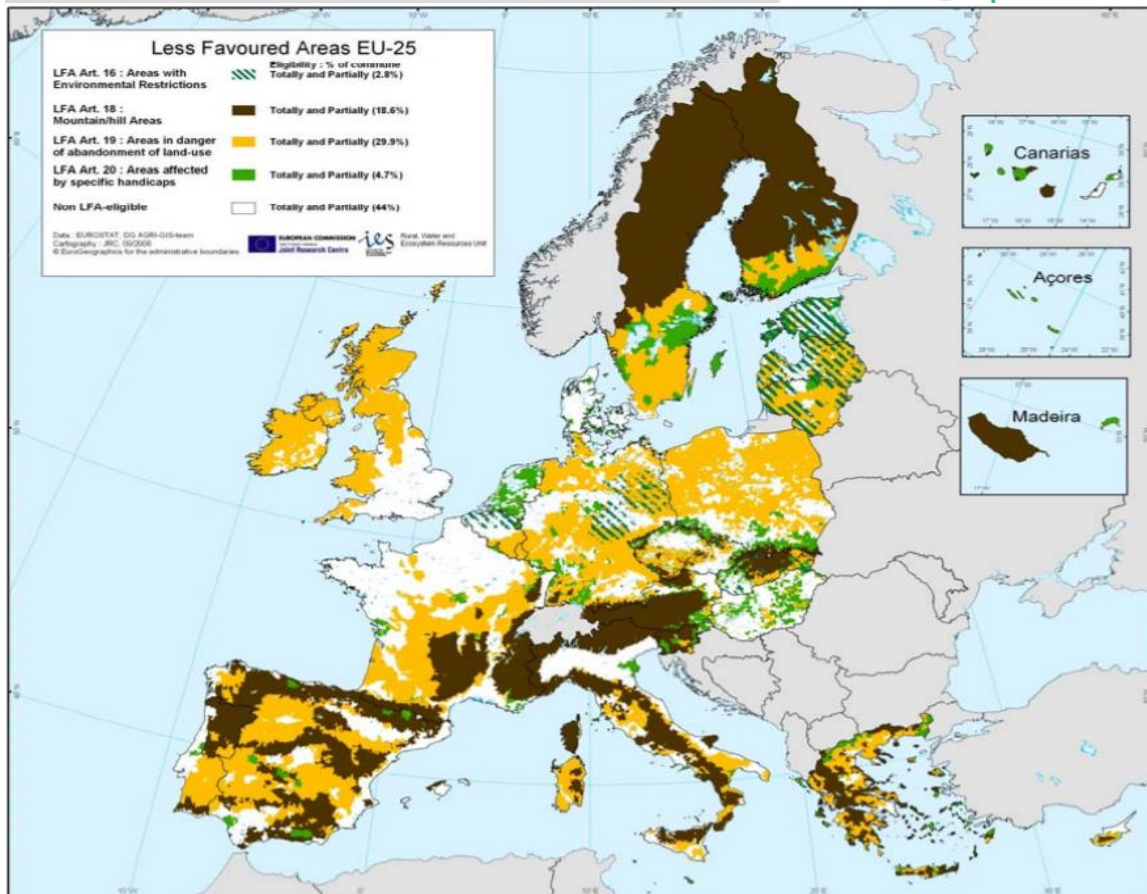


Figure 4: Map of the Less Favoured Areas (LFA) in Europe (CEC, 2004)

3.2.2 Fallow land

Estel *et al.* (2015) used a remote sensing approach to map active and fallow farmland across Europe using a MODIS NDVI time series and a Random Forests classifier. Moderate fallow frequencies occurred in central European countries, including Germany, Poland, and Czech Republic, as well as in Ireland and the UK (figure 5). The maximum value of twelve indicated permanently fallow land and the minimum value of zero indicated permanent active farmland. Across Europe 334 million hectares (Mha) or 63% of the farmland was fallow at least once and 95 Mha (18%) were predominantly fallow (seven or more fallow years) during the observation period (2001-12). A total of 14 Mha (3%) was identified as permanent fallow (i.e., unmanaged).

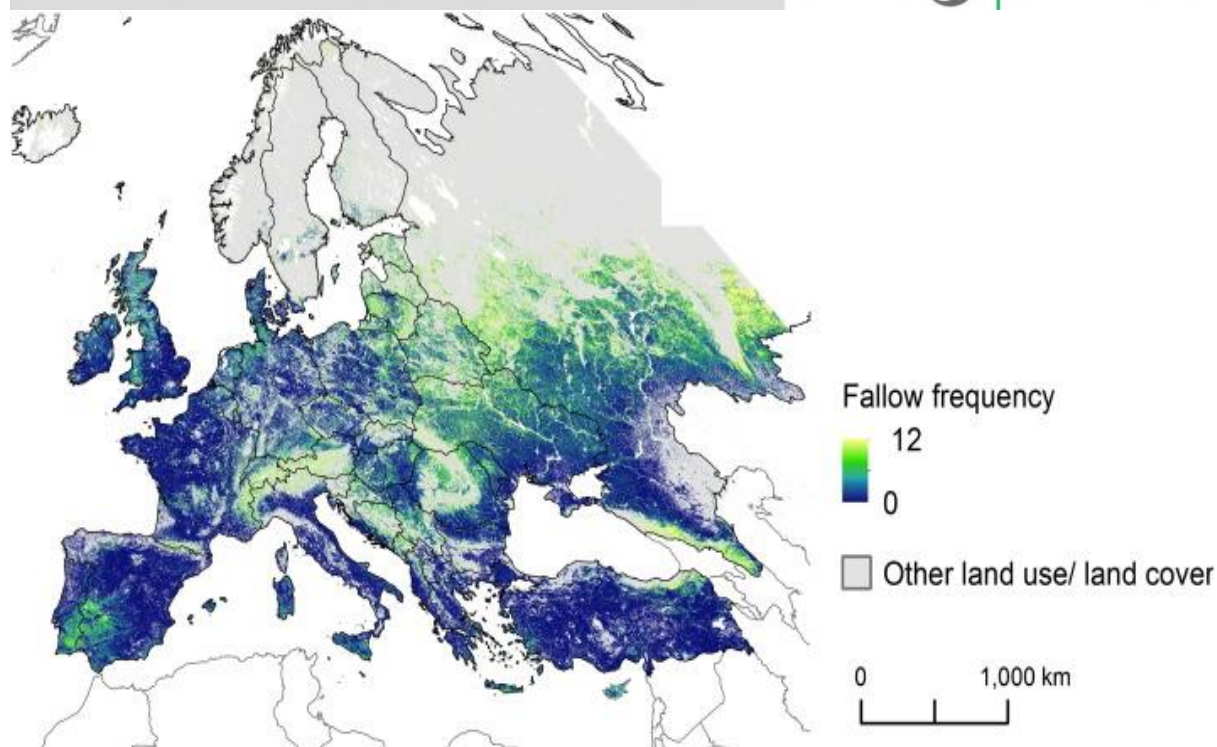


Figure 5: Map of the frequency of fallow years from 2001 to 2012 across Europe

3.2.3 Marginal land in Eastern Europe (ENEA)

The Web GIS M2RES database, coordinated by the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), provides data on marginal land areas within the eastern Europe region (Italy, Slovenia, Greece, Romania, Bulgaria, Hungary, Austria, Montenegro, Serbia, Albania) suitable for the production of renewable energy sources, including photovoltaic, solar-thermal, wind, hydroelectric, biomass, and biogas (figure 6). Marginal land areas are defined in this case as “Areas that, for various reasons, are normally considered 'useless' and often remain 'unused', if not abandoned.” Marginal land areas included: current and former landfill sites; abandoned quarries; areas unsuitable for agricultural use or unproductive (non suitable for buildings, no values or natural constraints); former military areas; abandoned industrial areas (Allen *et al.*, 2016).

Alcantara *et al.* (2013) quantified the extent of abandoned farmland, both croplands and pastures, across the European region using a MODIS NDVI satellite image time series from 2004 to 2006 with support vector machine classifications. Abandoned farmland was widespread, totalling 53 Mha, particularly in temperate European Russia (32 Mha), northern and western Ukraine, and Belarus.

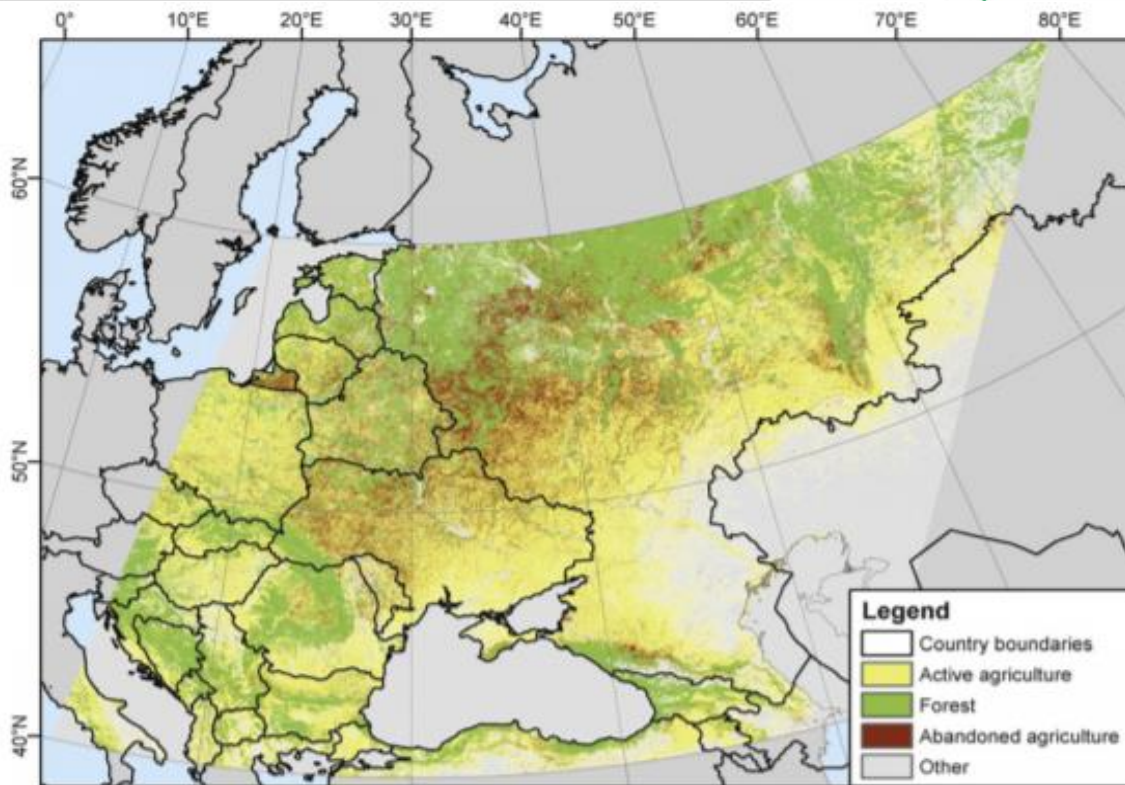


Figure 6: Land cover classification for Central and Eastern Europe.

3.2.4 SRQ approach

Gerwin *et al.* (2018) quantified marginal land in Europe using GIS tools. Classification was based on the Muencheberg Soil Quality Rating (SQR) system to distinguish lower and high-quality soils. Soils with SQR scores below 40 were regarded as marginal. The SQR scores correlate to biomass yields of bioenergy crops.

The first outcome was the calculation of the SQR index incorporating all 8 basic indicators and 11 hazard indicators (H 2: salinization, H 3: sodification, H 4: acidification, H 6: soil depth above hard rock, H 7: drought, H 8: flooding or extreme waterlogging, H 9: steep slope, H 10: rock at the surface, H 11: high percentage of coarse soil texture fragments, H 12: unsuitable soil thermal regime and H 13: disturbance by humans).

A total of 257 Mha of land in Europe belongs to the poor and very poor classes of the SQR index and is identified as marginal. This area corresponds to 46 % of the overall area investigated (figure 7).

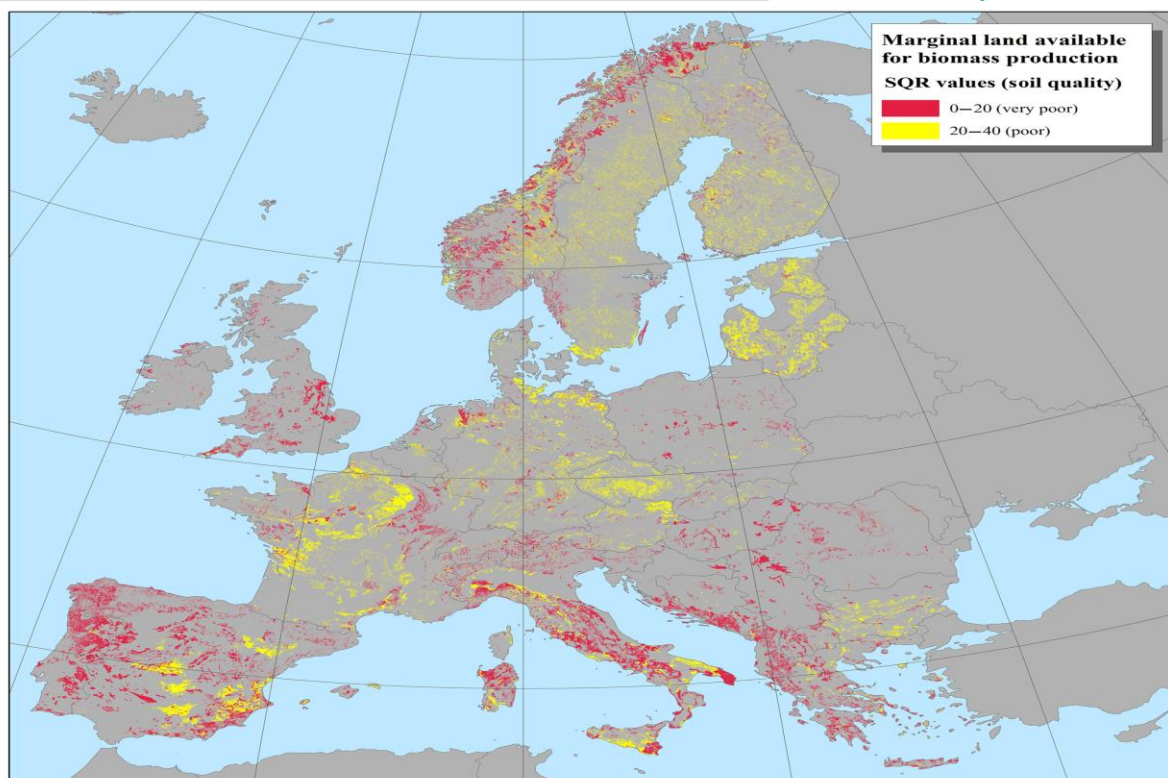


Figure 7: Marginal land available for biomass production for bioenergy purposes in Europe.

3.2.5 Marginal Agro-Ecological Zones in Europe

Marginal Agro-Ecological Zones were developed by Cossel *et al.* (2019) based on various bio-physical constraints and socio-economic challenges. According to category 1 ('natural constraints'), the marginal area across European land surfaces is widely scattered across Europe (Figure 8) and in total amounted to 65 Mha, in aggregate the size of France.

Across Europe, the most prevailing constraints were identified as adverse rooting conditions, (155,519 km²), adverse climatic conditions (112,096 km²) and excessive soil wetness (108,081 km²). The total marginal arable land characterized by soil constraints accounts for 535,000 km². This is about 155,000 km² more than reported by Gerwin *et al.* (2018). It is likely that this difference results from the use of different thresholds for determining what is marginal (and what is not).

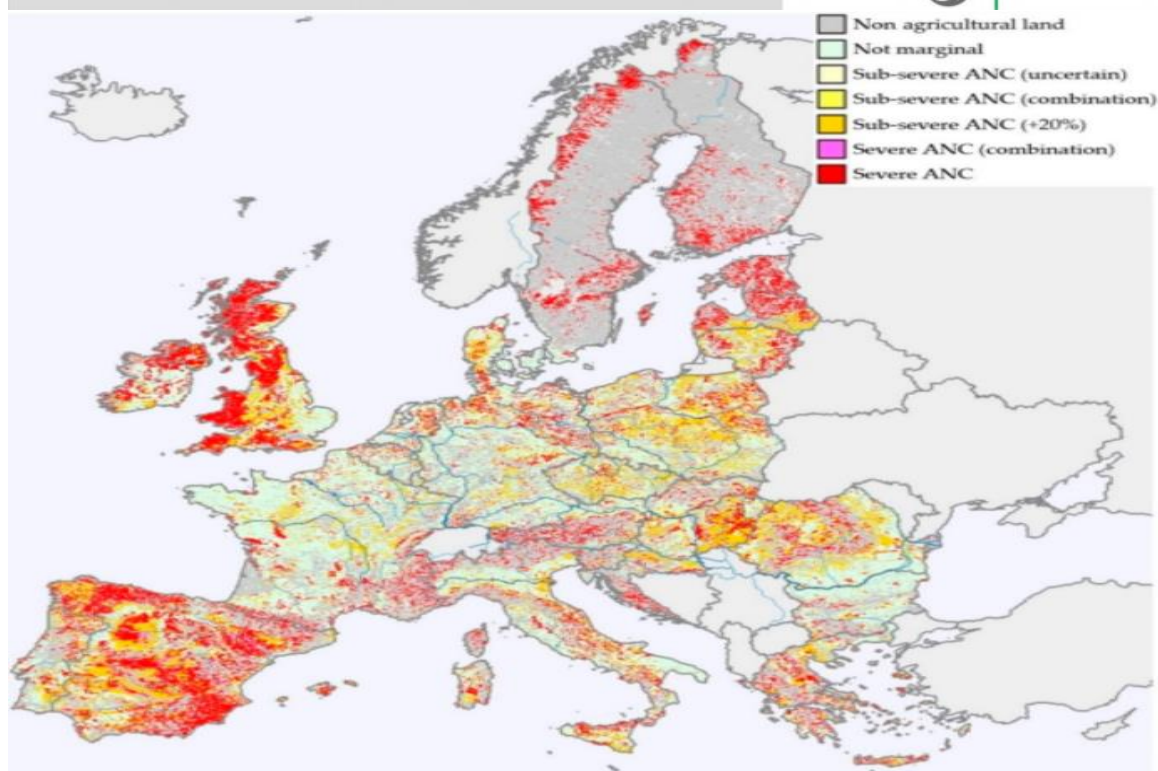


Figure 8: Marginal agricultural lands based on bio-physical constraints across Europe.

3.3 Marginal land in the UK and Ireland

3.3.1 Ireland:

O'Mara (2008) reported that 56% of the land area in Ireland can be classified as difficult or marginal. This area being divided into 0.8 Mha of lowland, mineral wet land, 1.1 Mha of hill or mountain land, and 1.2 Mha of peat. Turley *et al.* (2010) described that there will be a maximum possible area of marginal land, however the actual area described in reports will depend on policy, economics, social trends, ecological factors, and logistical limitations and is therefore likely to be smaller. Caution should also be applied in the use of any peatland for land use change, including for perennial bioenergy crop production, due to the risk of losses in soil carbon.

3.3.2 England and Wales

A project was initiated by Defra in 2009-10 to assess the availability of marginal or idle land for bioenergy crop production in England and Wales following the definition of marginal land in the Gallagher Review (Renewable Fuels Agency, 2008). The key land areas of interest identified were existing land resources of

agricultural value including land currently fallow or in voluntary set-aside, arable land where production of arable crops was of marginal profitability and grassland where stocking rates had declined. Land resources with no current productive agricultural value included hedgerows and lowland bracken, urban spaces, road and rail margins and brownfield sites (Defra, 2010). Overall, this report estimated there was 2.7 Mha of marginal land consisting of a mix off:

- Uncropped arable land, including fallow land, field margins, and field corners, which account for approximately 14% (20,300 ha) of the total area (145,000 ha).
- Economically marginal arable and pasture land that is currently used for food production, which accounts for approximately 66% of the total area (1,787,100 ha).
- 'Idle' land, including roadside verges, railway embankments, canal towpaths, golf courses, sports turf, hedgerows, and brownfield land, which accounted for approximately 20% (173,500 ha) of the total area (867,700 ha).

3.3.3 UK classifications of land productivity

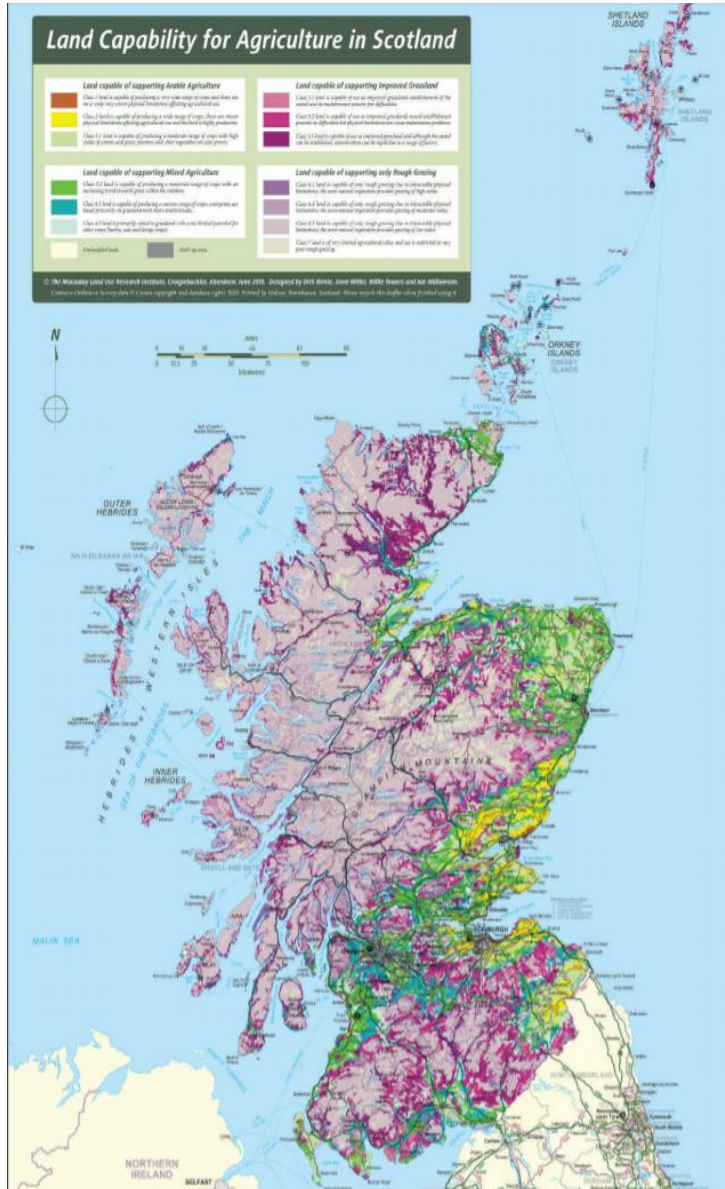
An approach that is consistently used to assess the marginality of land both nationally and internationally are schemes which rank land based on its productive capacity for cropping. This is the Agricultural Land Classification (ALC) in England, Land Capability for Scotland, and Predicted Agricultural Land Classification for Wales (Figure 9).

In the ALC scheme for England, Grades 1 to 3a are considered the most valuable and versatile lands whilst Grades 3b to 5 are considered moderate to very poor and these lands are considered marginal (Natural England, 2012).

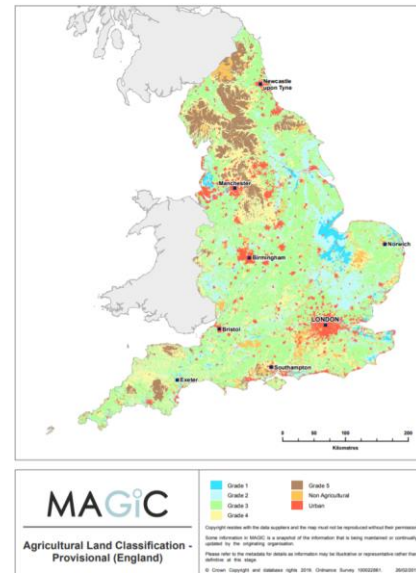
The National Scale Land Capability for Agriculture Map of Scotland provides information on the types of crops that may be grown in different areas dependent on environmental and soil characteristics (Scottish Government, 2017). Class 4.1 to 7 are considered as marginal (figure 9).

Welsh Government launched the Predictive Agricultural Land Classification Map in 2017. It replaced the Provisional Agricultural Land Classification Map for Wales. Planning policy defines grades 1 to 3a as the 'best and most versatile'

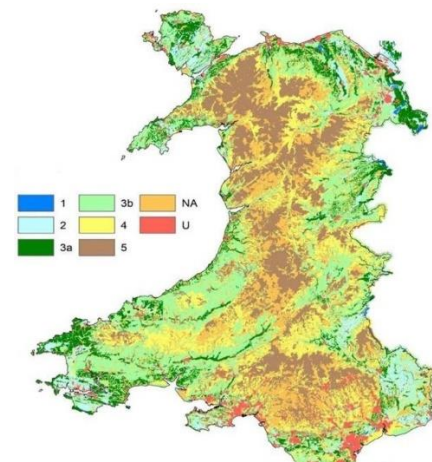
agricultural land (7% or 0.15 Mha) of the land in Wales whereas grades 4 and 5 are considered as marginal lands/ less favourable areas covering more than 60% (1.24 Mha) of the land (Welsh Government, 2017).



(A) National Scale Land Capability for Agriculture in Scotland.



(B) Agricultural Land Classification of England.



(B) Predictive Agricultural Land Classification of Wales.

Figure 9: UK classifications of land productivity

4. Conclusion

The definition of marginal land varies worldwide, however, there are some commonalities of approach including the use of four key constraints and challenges; 1) climatic, 2) geophysical, 3) social ecological and 4) economic. Definitions of

marginality are not just based on qualitative factors such as land fertility but also on political drivers and social values. These factors vary between countries, regions, communities and individuals according to contrasting relationships with the land. Marginality is therefore inherently subjective. It is also not fixed as improvements in agri-technology and agronomy can bring economically marginal land back into production, whilst changing markets can make once profitable land marginal. This complexity, however, does not detract from the efforts to assess the availability of marginal land, rather it highlights the importance of efforts to make such assessments as transparent and holistic as possible, incorporating not just climatic and geophysical factors but also social, environmental and economic ones.

To summarise the definition of marginal land may be difficult but the term is useful in identifying those land areas where opportunities for either new cropping options (e.g. bioenergy or industrial crops) or agri-tech innovations can be deployed, or conservation and broader ecosystem services explored.

In Table 3, the predicted areas of marginal land across Europe and within the UK are summarised. The areas identified do vary between studies, partly due to differences in the definitions; however, it is also clear that marginal lands represent a potentially sizeable land resource for the production of bioenergy crops.

The definition of marginal land and assessment methods vary over time, location and according to the priority of the management goals. A systems approach to consider multiple factors when classifying marginal land brings advantages including for more robust decision making. There is a debate on how marginal land should be used when food crop production is not an option. Biomass crops represent one option for the use of marginal land, where bioenergy, biofuels or bioproducts can be produced from the harvested biomass. In addition, bioenergy when combined with carbon, capture and storage (BECCS), negative carbon emissions can be created which is an important technology for delivering on net zero targets.

Table 3: Comparison of marginal land area in different parts of Europe

Term Used	Europe	Eastern Europe	Ireland	United Kingdom
Abandoned or Idle Land	5.3 Mha <i>(Roques et al., 2011)</i>	52.5 Mha <i>(Alcantara et al., 2013)</i>	-	-
Marginal Land or Less Favoured Area	25% or 257 Mha <i>(Gerwin et al., 2018)</i> 54% (CEC, 2004)	-	56% or 8.4 Mha <i>(O'Mara, 2008)</i>	60% or 1.24 Mha of Wales <i>(Welsh Government, 2017)</i>

Bioenergy crops also have the potential to be further optimised by increasing their abiotic stress tolerance (Taylor *et al.*, 2019). However, some marginal land can be very challenging for any crop production and may require very careful selection of agronomy, genotype, and species selection (Pancaldi & Trindade, 2020). Most typically extreme marginality can be a result of contamination with salt (less of an issue in the UK than it is in other geographies) or a result of legacy industrial activity. In one study, Lord (2015) describes a comparison of four energy crops on brownfield sites in NE England. This followed the application of a green manure to improve the soil and under these marginal conditions, reed canary grass out-performed Miscanthus, willow and switchgrass. Pollution from previous mining or smelting industries can be extremely challenging but some plant strategies for metal exclusion could be used in future plant breeding strategies (Rusinowski *et al.*, 2019). However, in the most extreme situations it is possible that even the potential for biomass production is limited and the focus needs to be on phytoremediation until the soil health is sufficiently improved.

Even if biomass crops are productive on marginal land, wider social and environmental factors also need to be considered. System based approaches provide a mechanism to consider such factors and incorporate them into policy and decision making. We propose from our study and review of the topic, that assessment tools should be developed that help to unify approaches on the definition of marginal land that include the following:

- The land's existing and previous uses.
- The land's productive potential for multiple types of agricultural production.
- The net carbon impact of changing land use.
- The land's existing and potential environmental value.
- Social implications of its use.

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