Global Assessment of Biomass and Bioproduct Impacts on Socio-economics and Sustainability

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Report on sustainability impacts of the use of marginal areas and grassy biomass (D 5.4)

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Abbreviations

CO_2	Carbon dioxide
dLUC	Direct land-use change
EC	European Commission
EU	European Union
GHG	Greenhouse gas
iLUC	Indirect land-use change
LCA	Life cycle assessment
MJ	Megajoule (10^6 J)
RED	Renewable Energy Directive (EU Directive 2009/28/EC)
U.S.	United States (of America)

Preface

This report was elaborated in the framework of the Global-Bio-Pact project (Global Assessment of Biomass and Bioproduct Impacts on Socio-economics and Sustainability) which is supported by the European Commission's 7th Framework Programme for Research (FP7).

The main aim of Global-Bio-Pact is the improvement and harmonisation of global sustainability certification systems for biomass production, conversion systems and trade in order to prevent negative socio-economic impacts. A number of sustainability certification systems are already in place, but their main focus up to now is on environmental impacts such as greenhouse gas emissions or biodiversity.

A core activity of Global-Bio-Pact is the description of socio-economic impacts in different countries to collect practical experience about socio-economic impacts of biofuels and bioproducts under different environmental, legal, social, and economic framework conditions.

In recent years, concerns have been raised that the cultivation of non-food biomass crops will put additional pressure on global agricultural land and that the associated land use competition entails a number of unwanted environmental and social impacts. This report challenges two frequent hypotheses, according to which land-use competition and its negative side-effects can be reduced or mitigated: i) through the use of marginal (or degraded) land and/or ii) through the use of grassy biomass.

1 Introduction

In many parts of the world, climate change and concerns of security of supply are the main drivers for the promotion of the use of renewable resources. One of the main pillars of most strategies to mitigate climate change and save non-renewable resources is the use of biomass for energy. Strong incentives have been put in place to increase the use of biomass for energy both in the transport as well as in the energy supply sector (heat and/or power generation), mainly in the form of mandatory targets /U.S. Congress 2007/, /EP & CEC 2009/. Many countries have successfully implemented policies to foster biofuels and bioenergy, including tax exemptions or relief, feed-in tariffs or quotas. On the contrary, much less attention has been paid to the use of biomass for bioproducts, despite considerable potentials to mitigate climate change and save non-renewable resources /Rettenmaier et al. 2010a, b, c/. Nevertheless, the demand for industrial crops for biochemicals and biomaterials is expected to increase in the future since biomass is the only renewable source of carbon.

However, the use of biomass, and especially the use of dedicated crops for bioenergy and bioproducts, will put pressure on global agricultural land use /Bringezu et al. 2009/. At the same time, world population growth (projected to reach 9.3 billion people by 2050 according to /UN 2011/) and changing diets due to economic development lead to an additional demand for land for food and feed production. As a consequence, the already existing competition for land for the production of food, feed, fibre (bioproducts), fuel (bioenergy) and ecosystem services[1] might even aggravate over the next decades. Concerns have been raised both in terms of social and environmental impacts because land use competition might

- jeopardise food security /Eickhout 2007/ and give rise to social conflicts, and
- lead to an expansion of agricultural land, most likely at the cost of (semi-)natural ecosystems being converted into cropland. Several studies have pointed out the negative implications of such direct and indirect land-use changes, among others in terms of biodiversity loss and greenhouse gas emissions /Searchinger et al. 2008/, /Fargione et al. 2008/, /Gibbs et al 2008/, /Gallagher et al. 2008/, /Melillo et al. 2009/, /Ravidranath et al. 2009/.

In this context, two hypotheses are frequently put forward, according to which land-use competition and its negative side-effects can be reduced or mitigated i) through the use of marginal (or degraded) land and/or ii) through the use of grassy biomass.

This report aims to challenge these two hypothesis. Chapters 2 and 4.1 of this report review the concept of marginal land and the potential sustainability impacts of using such land, respectively. Chapters 3 and 4.2 of this report review the use of grassy biomass for biofuels and bioproducts and the associated potential sustainability impacts, respectively. Finally, chapter 5 discusses the findings and presents our conclusions. In the following, a more elaborate introduction to the use of marginal land and grassy biomass, respectively, is given.

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[1] Ecosystem services are the benefits people obtain from ecosystems. These include provisioning, regulating, and cultural services that directly affect people and supporting services needed to maintain the other services.

Use of marginal land

In order to mitigate this land-use competition and its negative side-effects, several studies have proposed to use marginal (or degraded) land for the production of biomass for energy /Fargione et al. 2008/, /Gallagher et al. 2008/, /Royal Society 2008/. ‘Marginal land’, however, is often incorrectly used as an umbrella term for all types of land ranging from fallow and abandoned land to degraded land. The crux is that land reported to be degraded is often the base of subsistence for the rural population /Berndes et al. 2003/ that it is critical to the survival of marginalised communities /Gaia foundation et al. 2008/.

Nevertheless, the idea has been taken up in the European Renewable Energy Directive (2009/28/EC, RED) which acknowledges that part of the increased demand for agricultural commodities will be met through an increase in the amount of land devoted to agriculture. More specifically, it is stated that *“the restoration of land that has been severely degraded or heavily contaminated and therefore cannot be used, in its present state, for agricultural purposes is a way of increasing the amount of land available for cultivation”* (preamble, 85). According to the RED (Annex V, part C, points 8 & 9), a bonus of 29 g CO_{2eq}/MJ is attributed to biofuels produced on such land[2].

Use of grassy biomass

The second focus of this report is on the use of grassy biomass. Grassy biomass can be obtained both from arable land (purpose-grown grassy crops), grassland (cuttings) and other (e.g. protected) areas. In the past few years, a controversial discussion on the net benefit of biofuels and bioenergy has been ongoing, showing that the use of biomass for energy is not environmentally friendly *per se*, simply because biomass is a renewable resource. Especially annual crops have repeatedly been criticised since they typically require more energy, fertiliser and pesticide input than perennial crops while achieving lower yields per unit area and lower net greenhouse gas (GHG) emission savings. Therefore, perennial crops, such as grasses, are attracting increasing interest as potential energy crops on arable land. **Several studies have argued that perennial grasses** cultivated on arable land **could reduce both land-use competition for arable land and environmental impacts** (/Tilman et al. 2006/, /Fargione et al. 2008/, /Rowe et al. 2009/, /Don et al. 2011/, /Valentine et al. 2012/).

In literature, it is (still) frequently argued that biofuels production should be shifted away from food crops such as starch/sugar and oil crops towards non-food (lignocellulosic) crops in order to avoid direct competition with food on the consumption side. Such competition is less stringent for biomass crops, however, this argument falls short since also such feedstock production competes for scarce resources, especially land /Dornburg et al. 2010/. Thus, the bottom line is the (increasing) land use associated with biomass production and not the fact that some of the crops are edible. In other words, the underlying problem is the increasing competition for land – the latter constituting a finite environmental resource /Diaz-Chavez 2012/ – which leads to rising prices for land (production costs) and consequently to higher prices for all agricultural commodities including first and foremost food. This in turn indeed – however indirectly – affects food security. Our report therefore does not distinguish between edible and non-edible crops.

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[2] According to the latest proposal by the European Commission /EC 2012/, points 8 and 9 shall be deleted. Instead of attributing a bonus to biofuels from degraded land, a malus (estimated indirect land-use change emissions) shall be attributed to biofuels from agricultural land.

Due to the same land-use competition – among others fuelled by biofuel policies – **grasslands are globally threatened of being converted into arable land which would result in a loss of biodiversity**. In Europe, permanent grasslands are already facing this pressure due to declining ruminant livestock numbers and forage demand. Alternative uses for biomass obtained from grasslands therefore urgently need to be developed to ensure that grassland can remain grassland. Scientists have proposed that **the use of grassy biomass for non-food purposes could actually be an option to conserve European grasslands, i.e. to avoid land-use changes** (/Rösch et al. 2009/, /Shekhar Sharma et al. 2011/). However, the fundamental question is whether economically viable options can be found which do not lead to an intensified use of high nature value grassland. **In case of land-use intensification, the use of grassy biomass for biofuels and bioproducts is a threat to biodiversity**. Taking both threats (land-use change and intensification) into account, the RED stipulates that biofuels shall not be made from raw material obtained from highly biodiverse grassland (Article 17 (3) (c)). However, an exact definition of such areas is still pending.

2 Marginal land: Definitions and extent

This chapter reviews the general concept of marginal land and related problems as well as a range of definitions – both scientific and regulatory. It also provides an overview of estimations regarding the extent of marginal land and the corresponding bioenergy potentials, both gathered from literature.

2.1 Definitions of marginal land

This section provides an overview of different definitions of marginal land and other related terms. First, scientific definitions are reviewed and then the regulatory definitions related to the different countries involved in the Global-Bio-Pact case study assessment are presented.

2.1.1 Scientific definitions

After a detailed overview of different definitions of marginal land, other terms used in the same context are described. Finally, one of the most recent approaches for assessing marginal land are presented and discussed.

Marginal land

In literature, various definitions or descriptions of the term marginal land can be found:

- Marginal land includes any other land not specifically listed under the following categories: arable land and land under permanent crops, permanent pastures, forests and woodland, built on areas, roads or barren lands /Rettenmaier et al. 2010d/.
- Marginal land refers to land with low inherent productivity, that has been abandoned or degraded, or is of low quality for agricultural uses /Cai et al. 2011/.
- 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 /Dale et al. 2010/.
- Marginal or degraded land is land unsuited for food production, e.g. with poor soils or harsh weather environments; and areas that have been degraded, e.g. through deforestation /Gallagher 2008/.
- Marginal lands are typically characterized by low productivity and reduced economic return or by severe constraints for agricultural cultivation. They are generally fragile and their use is environmentally risky /Kang et al. 2013/.

- Marginal land is defined by economics as land uses that are at the margin of economic viability. Evidently, the term marginal land is an economic approach which does not include subsistence agriculture. Hence, marginal land might supply food, feed, medical plants, fertilizer or fuel to local people, but not through a structured, market-based approach /Liu et al. 2011/.
- Marginal land is land of poor quality with regard to agricultural use, and unsuitable for housing and other uses /OECD 1997/.
- Marginal land is defined as an area where a cost-effective production is not possible, under given side conditions (e.g., soil productivity), cultivation techniques, agriculture policies as well as macro-economic and legal conditions /Schroers 2006/.
- Generally, marginal land is evaluated in terms of a cost/benefit analysis and is economically marginal; i.e. wasteland, grassland, saline land, bareland, reed swamp, tidal flat and unused land is considered to be potential marginal land suitable for biomass energy production /Tang et al. 2010/.
- The German Advisory Council on Global Change (WBGU) uses the term ‘marginal land’ as an umbrella term for (1) areas with little capacity for fulfilling a production or regulation function, and also for (2) areas that have lost their production and regulation function, sometimes to a significant extent /WBGU 2008/.
- The Food and Agriculture Organisation /FAO 1999/ defined marginal land as land having limitations which in aggregate are severe for sustained application of a given use. Increased in-puts to maintain productivity or benefits will be only marginally justified.

These numerous scientific definitions of marginal land clearly show its relative characteristic. Marginal land has various meanings in different disciplines and the coverage of marginal land differs /Tang et al. 2010/, /Liu et al. 2011/. Its definition varies depending on country, local conditions and the context it is used in. 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 /Dale et al. 2010/.

Fig. 2-1 shows the approach of /Wiegmann et al. 2008/ to define the various terms used in the context of or synonymously for marginal land.

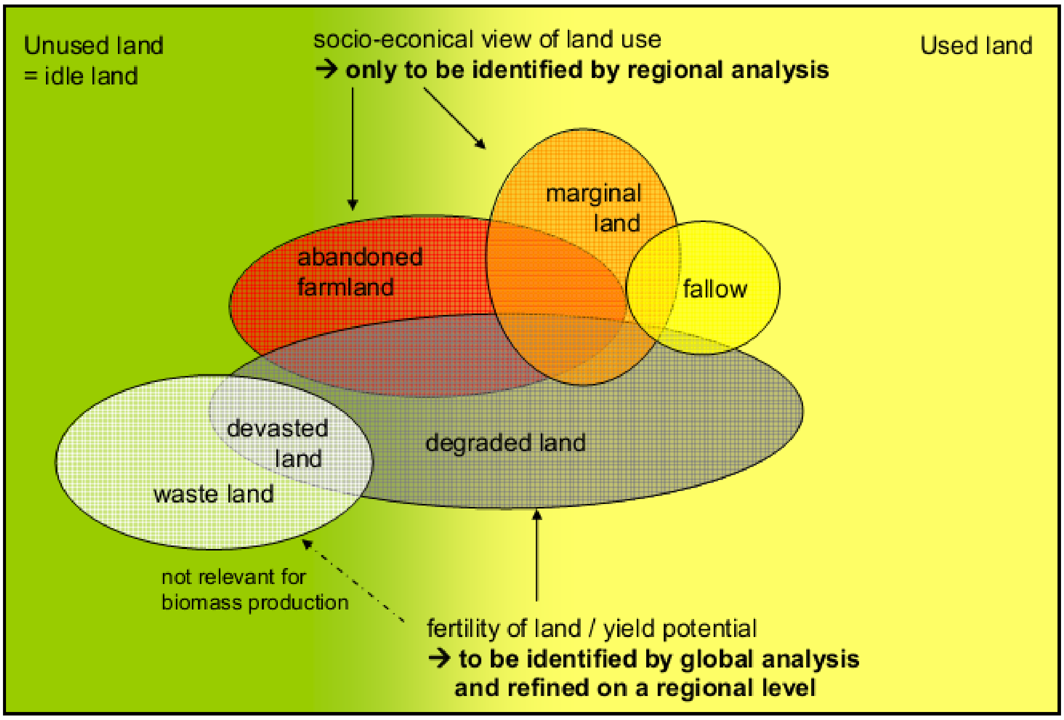

Fig. 2-1 Approach to identify land categories and their relationship /Wiegmann et al. 2008/

These different approaches have also been identified in the literature as follows:

Abandoned farmland / agricultural land

These lands have been defined as areas that have previously been used for agriculture or pasture and are not used this way any more due to degradation from intensive use and that have not been converted to forest or urban areas /Campbell et al. 2008/, /Field et al. 2008/. /Wiegmann et al. 2008/ distinguish different reasons for ceasing the agricultural use of the land: economical, political (e.g. set-aside land) or environmental (e.g. due to degradation).

Degraded land

Land degradation is the decline of natural land resources, commonly caused by improper use of the land by humans /Bergsma et al. 1996/. Land degradation is ultimately associated with a reduction of soil fertility and productivity. It is therefore related to land productivity potential and always connected to a long-term decline in ecosystem function and services, which cannot be recovered without aid /Cai et al. 2011/. Three aspects are important for defining land as degraded: The cause of degradation (only human- or both human- and natural-induced), whether the recovery might be aided or unaided and which time horizon is considered /Wiegmann et al. 2008/.

Fallow land

Fallow is a part of crop rotation and describes the temporary suspension of agricultural land for one or several vegetation periods to achieve a recovery of soil fertility /Wiegmann et al. 2008/.

Wasteland

Wasteland can not be used for any kind of agriculture under any conditions due to its physical and biological conditions /Cai et al. 2011/, /Wiegmann et al. 2008/. /Cai et al. 2011/ compare this to degraded land indicating better conditions of the wasteland in the past; a cultivation was once possible. /Wiegmann et al. 2008/, however, define the adverse physical and biological conditions as inherent of the respective land. Another definition describes wasteland as including natural grassland, sparse forestland, scrubland and unused land that may be used to grow energy crops /Tang et al. 2010/.

Used / unused land

These terms refer to a gradual change from land that is in various ways intensely used by humans to land that is not influenced by any (anthropogenic) land-use form. This gradual change makes it difficult to distinguish these two forms, especially if it comes to extensive land use. Here, a distinct border of land-use intensity beyond which the land might be defined as unused is hard to define /Wiegmann et al. 2008/.

Idle land

/Wiegmann et al. 2008/ and /Cai et al. 2011/ use idle land as synonym for unused land comprising all forms of the above-defined land forms. However, /Gallagher et al. 2008/ clearly emphasise the connection to agricultural land currently not being cultivated. Degraded land and wasteland are excluded and thereby distinguished it from the term unused land.

Like the different definitions of the term marginal land, the further terms related to this topic are just as diverse and unclear. Sometimes, e.g. regarding the definition of wasteland, they are even contradictory. Especially regarding the discussion about bioenergy production on marginal or degraded land various terms are combined with each other or even used synonymously, e.g. ‘unproductive land’, ‘idle land’, ‘wasteland’, ‘fallow land’ /Wicke et al. 2011/, /Rettenmaier et al. 2010d/. Regarding marginal land, this requires a further development and differentiation of its definition. The most recent scientific work on this topic /Kang et al. 2013/ distinguishes four different types of marginal land (physical, biological, environmental ecological and economic) – related to the respective constraints – as links in a successive assessment chain as shown in Fig. 2-2. The concept of /Kang et al. 2013/ is explained below the figure.

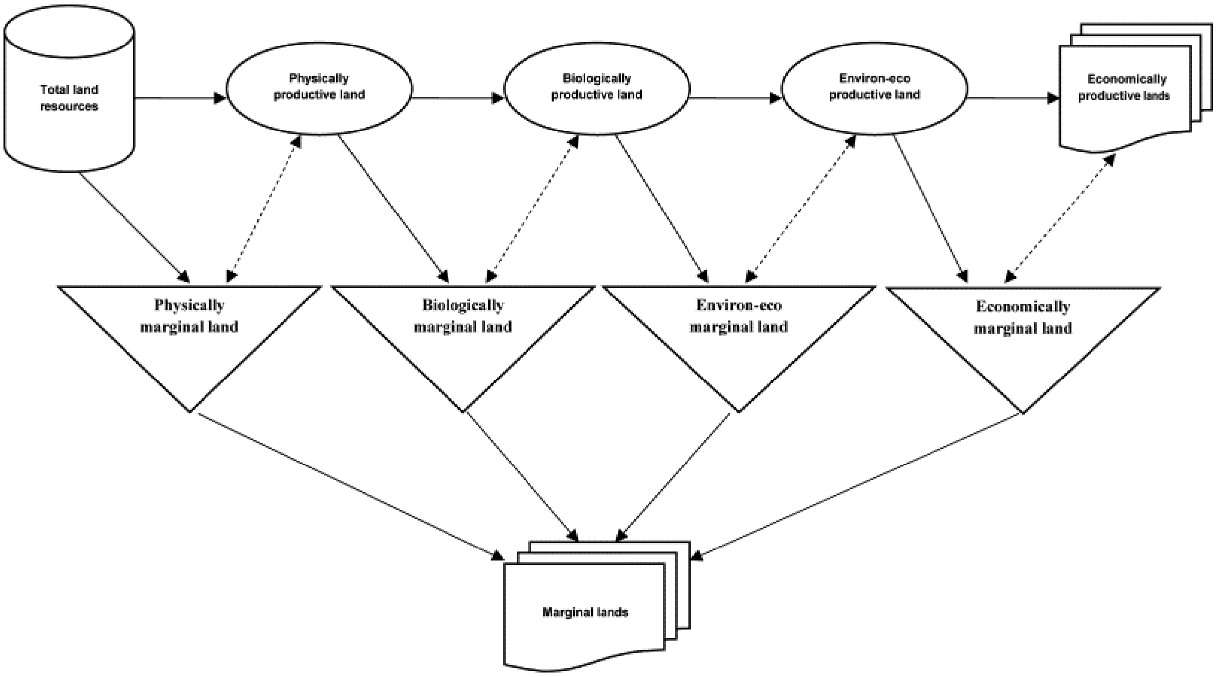

Fig. 2-2 A hierarchical marginal land assessment framework for diverse land use decision-makings /Kang et al. 2013/

At first, the total land resources or respective areas of interest are considered. This total land is reduced in the following by applying the different perspectives related to the different marginal land types one after the other. The physical perspective is considered first, dividing the total land into physically productive land and physically marginal land. The physically marginal land is generally unsuitable for any form of land management or agricultural production (e.g. rocky land with little soil, flooding or ponding areas). /Kang et al. 2013/ note that a transition of the physically productive land into marginal land (by degradation) and vice versa (by appropriate land management) might be possible. In the following step, only the physically productive land will be considered applying the other perspectives. Reasons for biologically marginal land are biological stresses and fragile or harsh natural conditions (e.g. coldness, drought, high or low ph soils). Environmentally ecologically marginal land is characterised by high risks or damages of environmental and ecological functions (e.g. areas of high biodiversity, wetlands). Economically marginal land is not profitable regarding the costs of production and the benefits. All four types of marginal land are dynamic and can be influenced – up to certain extend – by e.g. management practices.

The approach of considering constraints for any kind of productive use of the land rather makes this approach appear suitable for assessing the total productive land. Each step only considers one aspect for defining land as marginal (or productive), therefore omitting every other aspect that might be of importance. For example, physically marginal land might still be used in a very extensive way by local people or might be of some cultural or religious importance. These aspects are not considered in any step of the hierarchical framework. At the same time, this is one of the most criticised points of the assessment of marginal (or degraded) land for bioenergy production /Dale et al. 2010/, /Gaia foundation et al. 2008/, /Liu et al. 2011/.

2.1.2 Regulatory definitions

Beside scientific definitions, there are regulatory definitions from different countries in the world. This paragraph presents definitions of marginal land of a range of countries and institutions worldwide.

Europe

In European legislation, the term marginal land is not defined yet, however, closely related terms can be found in the European Renewable Energy Directive (2009/28/EC, RED) /EP & CEC 2009/. According to the RED, a bonus of 29 g CO_{2eq}/MJ will be attributed to biofuels produced on land that has been severely degraded or heavily contaminated and therefore cannot be used, in its present state, for agricultural purposes. The bonus of 29 g CO_{2eq}/MJ shall be attributed if evidence is provided that the land:

(a) was not in use for agriculture or any other activity in January 2008; and

(b) falls into one of the following categories:

(i) severely degraded land, including such land that was formerly in agricultural use;

(ii) heavily contaminated land.

The bonus of 29 g CO_{2eq}/MJ shall apply for a period of up to 10 years from the date of conversion of the land to agricultural use, provided that a steady increase in carbon stocks as well as a sizable reduction in erosion phenomena for land falling under (i) are ensured and that soil contamination for land falling under (ii) is reduced.

The categories referred to in point (b) are defined as follows:

- ‘severely degraded land’ means land that, for a significant period of time, has either been significantly salinated or presented significantly low organic matter content and has been severely eroded;
- ‘heavily contaminated land’ means land that is unfit for the cultivation of food and feed due to soil contamination.

Unfortunately, it is still unclear which areas fall under this definition.

Argentina

There are no legal definitions of marginal land in Argentina. INTA and the national scientific council commonly use the following definition: marginal lands have severe environmental restrictions (permanent or sporadic) and are not suitable for a consolidated agricultural production with stable yield and profit. According to /Hilbert 2012/, there is a lot of controversy around this terminology.

Brazil

According to /Machado Gerber 2012/ the Brazilian legislation does not define the term marginal land. Yet, there will be a legal definition of the term fallow land in the upcoming forest code. However, the clause defining fallow land has been vetoed by the president, which means that it will either have to be changed or removed from the forest code.

Costa Rica

According to the 1994 land classification decree (Decreto N° 23214-MAG-MIRENEM: Metodología Determinación Capacidad Uso Tierras Costa Rica) land classification is directly linked to land use possibilities and conservation practices /Fallot 2012/. It theoretically allows avoiding aberration such as cultivating degraded land before restoring it.

Land categories run from I (land adequate to any agricultural or forestry activity allowed by ecological criteria) to VIII (land that requires full conservation). The classification criteria include erosion (e.g. slope), soil (depth, texture, presence of stones, fertility, toxicity and salinity), drainage (e.g. flooding risk) and type of vegetation zone (duration of drought period, fog, wind).

- Agricultural land can be of categories I, II or III
  - Sustainable cultivation of category II land implies higher costs, on category III land, only certain species can be cultivated.
- Fragile or degraded land would correspond to categories IV, V and VI
  - On cat IV land, use is restricted to permanent and semipermanent vegetation with occasional annual crops under special conservation measures.
  - Cat V land remains suitable for pastures and forestry management
  - Cat VI land allows for forestry and agroforestry with conservation practices
- Categories VII and VIII cannot be considered except for native vegetation restoration or conservation.
  - Restoration and conservation efforts can bring some land from one category to another. Considering degraded land for energy crop imply to first invest in restoration practices.

Indonesia

In Indonesia, the following regulatory definitions can be found according to /Wright 2012/:

- *Degraded land* (literally ‘critical’) refers to land legally designated as having reduced ecological functions by the Ministry of Forestry, based on biophysical characteristics.
- *Unused/abandoned land* refers to land on which a permit has been issued but has not yet been utilized by the permit-holder.
- *Idle land, set-aside land* (literally ‘sleeping’) refers to areas that are considered unproductive according to national or provincial regulations.

Mali

The only regulatory definition in Malian legislation is found in forestry law N° 028 of 10 July 2010 according to which fallow land is defined as a cultivated area left for regeneration of the soil and natural vegetation /Ouattara 2012/.

Tanzania

In Tanzanian legislation an extensive list of legal definitions of various types can be found /Shuma 2012/:

- Fallow land: a land which is temporarily suspended in order to recover its fertility. This is a cropland that is not seeded for a season and it may or may not be ploughed. It is used as a method of restoring productivity and rotation of crops which is considered wasteful of humus and nitrogen. It is also refers to the interruption cultivation for one or several vegetation periods to achieve a refreshment/improvement of soil fertility
- Abandoned farm land: the land which is not subjected to any farming practices. The land which was previous used for agriculture or pasture, but that has been abandoned and left to the shrubs or woodlands. The land is abandoned intentionally and permanently and it appears that the former owner does not intend to use it for agricultural activities. One may have abandoned the land of contract rights by not doing what is required by the contract but this will not wave the land rights of using it for other uses.
  According to the Village Land Act 1999, land is considered to be abandoned if one or both of the following factors have existed;
    - When the owner did not use or occupy the subjected land for any purpose which also includes allowing land to lie fallow for the period of five years. Therefore the bolded word can refer to economic, political or environmental reasons.
    - If the occupier owes any rent, taxes or dues (with exclusion of the occupier villager whose life depends on agriculture or pastoralist)
- Degraded land: the land which its quality, top soil and water resources have deteriorated caused usually by excessive, inappropriate or unsustainable use. This occurs when there is the aggregate diminution of the productive potential of the land, including its major uses (rain-fed, arable, irrigated, rangeland, forest), its farming systems (e.g. smallholder subsistence) and its value as an economic resource. This is sometimes caused by the decline of natural land resources, commonly caused by improper use of the land.
- Devastated land: the land which its original use has been extensively destructed or ruin utterly caused by disasters, natural catastrophes, war, etc. The term is not much used in Tanzania since the magnitude of devastation of lands is less significant.
- Waste Land: the land which does not have appreciable vegetative cover or agricultural potential (due to salt flats, rock outcrops and arid mountain areas). This is barren land which cannot recover and is not relevant for production.
- Marginal land is defined as an area where a cost-effective production is not possible, under given side conditions (e.g. soil productivity), cultivation techniques, agriculture practices as well as macro-economic and legal conditions. The term marginal land is an economic approach which does not factor in subsistence agriculture.
- Unused land: a land which its use is not tied into major economic and productive activities to meet humans' needs. Unused land comprises abandoned farmland, devastated, hazardous and waste lands as well as reserved areas. Sometimes it is used to refer to the land which is unoccupied and occasionally used for extensive land-practices (e.g. collection of medicinal plants, social ritual activities, cutting poles, sporadic hunting, etc.)

- Reserved Land: A land which is reserved to serve for different purposes and its administration is conferred to a relevant authority. This includes the following;
  - Land reserved, designated or set aside under the provisions of the Forests Act, National Parks Act, Ngorongoro Conservation Area Act, Wildlife Conservation Act, Marine Parks and Reserves Act, Town and Country Planning Act, Highway Act, Public Recreation Grounds Act and Land Acquisition Act
  - Land parcel within a natural drainage system from which the water resource of the concerned drainage basin originates;
  - Land reserved for public utilities;
  - Land declared by order of the Minister, in accordance with the provisions of this Act, to be hazardous land.
- Hazardous Land: category of land which is likely to pose a danger to life or lead to the degradation of land or environment destruction. The following are considered as hazardous land.
  - Mangrove swamps and coral reefs;
  - Wetlands and offshore islands in the sea and lakes;
  - Land designated or used for the dumping of hazardous waste;
  - Land within sixty metres of a river bank or the shoreline of an inland lake;
  - Land on slopes with a gradient exceeding any angle which the minister shall, after taking account of proper scientific advice, specify;

2.2 Extent of marginal land

Several studies (/Hoogwijk et al. 2003/, /Hoogwijk et al. 2005/, /Tilman et al. 2006/, /Campbell et al. 2008/, /Dornburg et al. 2010/, /Nijsen et al. 2012/, /Field et al. 2008/, /Cai et al. 2011/) have investigated the technical bioenergy potential from degraded land on global and other scale. Table 2-1 gives a literature overview of selected studies.

Table 2-1 Literature overview of global bioenergy production on marginal land (and alike)

Reference	**Time horizon**	**Type of land considered**	**Area considered**	**Total area Mha**	**Yield t dm ha^{-1} yr^{-1}**	**Total potential EJ yr^{-1}**
Cai et al. 2011	Current	Abandoned and degraded cropland	USA, Europe, China, India, South America, Africa	320-702	Not given	19-98
Campbell et al. 2008	Current	Abandoned agricultural land	Global	385-472	4.3	32-41
Dornburg et al. 2010	2050	water scarce, marginal and degraded land (low-quality land with low biomass yields)	Global	Not given	Not given	70
Field et al. 2008	Current	Abandoned agricultural and pasture land	Global	386	Not given	27
Hoogwijk et al. 2003	2050	Degraded land (estimation from literature)	Global	430-580	1-10	8-110
Hoogwijk et al. 2005	2050	Low-productive land	Global	Not given	< 3	5-9
Nijsen et al. 2012	Current	Human-induced degraded land (without salt-affected land)	Global	386	8.9	32
Tilman et al. 2006	Current	Abandoned agricultural land and degraded land	Global	~ 500	Not given	45
Wicke 2011	2020	Salt-affected land	Global	971	3.1	56.2

The critical issue regarding the categorizing or quantification of the global land potential for bioenergy production refers to the applied methodology and partly to the underlying data. Especially the satellite imagery, widely applied (e.g. /Dornburg et al. 2010/, /Nijsen et al. 2012/, /Wicke 2011/), is problematic since such data only have a limited ability to give detailed assessment. This is due to the fact that some aspects simply can not be observed from far above. /Dale et al. 2010/ criticise that land assessed as marginal from far above might just be temporarily fallow or be used in non-traditional ways.

Regarding the underlying data, most of the above mentioned studies are using data produced by the GLASOD (Global Assessment of Soil Degradation) project which produced a world map of human-induced soil degradation in 1990. Soil scientists throughout the world collected the data using uniform guidelines. The type, extent, degree, rate and main causes of degradation were identified and listed within a database. /Sonneveld & Dent 2009/ conclude that the expert assessments in GLASOD (Global Assessment of Soil Degradation) are not very reliable. Moreover, GLASOD is also criticised for its low resolution not being appropriate for national breakdowns and its complex legend. The original GLASOD map from 1990 includes a single, average, score for large areas with a minimum size of 5625 km^2. /Nijsen et al. 2012/ have recently downscaled the map (Fig. 2-3) which now depicts the distribution of degraded areas and the severity of degradation across the world at a 5 min grid. Despite a missing update, GLASOD still is the most comprehensive database covering land degradation that occurred before 1990 /Franke et al. 2012/.

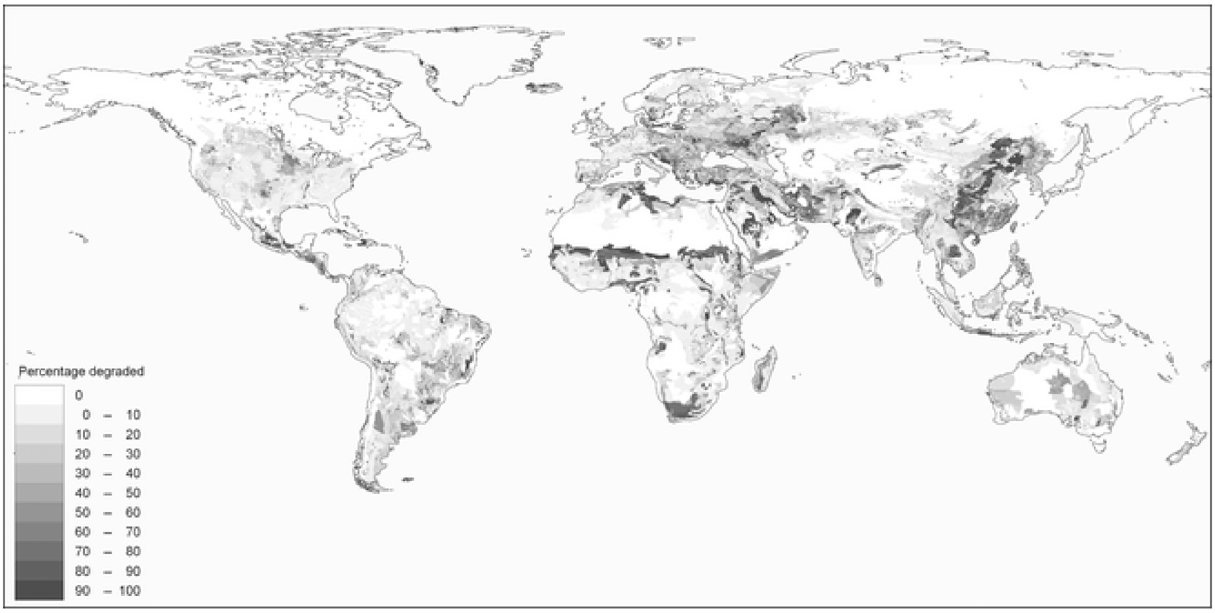

Fig. 2-3 Global overview of degraded lands at a 5 min scale (% of the land area that is affected by degradation) /Nijsen et al. 2012/

As a response to the need for up-to-date and comparable land degradation information, the LADA (Land Degradation Assessment in Drylands) project recently assessed the causes and impacts of land degradation at global, national and local levels in order to detect hot spots and identify remedial measures. LADA approached land degradation as a biophysical, social, economic and environmental issue that must be dealt with through a combination of geo-informational, scientific and local knowledge tools /FAO 2009/. The corresponding GLADIS (Global Land Degradation Information System) system is currently still under peer review. Meanwhile, the older GLASOD data has to be used.

/Fritsche et al. 2010/ propose an improved methodology for categorizing marginal or degraded land appropriate for bioenergy cultivation (see Fig. 2-4). They suggest combining a satellite-based top-down approach which broadly categorizes the potential available land. A five-step decision tree ensures the primary accordance with requirements regarding biodiversity, carbon stock of the soil and deforestation. The resulting land as well as sites not enough information is available for from the top-down analysis has to be checked on location by a bottom-up analysis. This analysis contains all aspects not adequately assessable by the top-down analysis (e.g. soil type and fertility, water availability, social aspects). Therefore, the important social aspects are considered as well, providing socio-economic as well as environmental disadvantages to be excluded or minimized /Fritsche et al. 2010/.

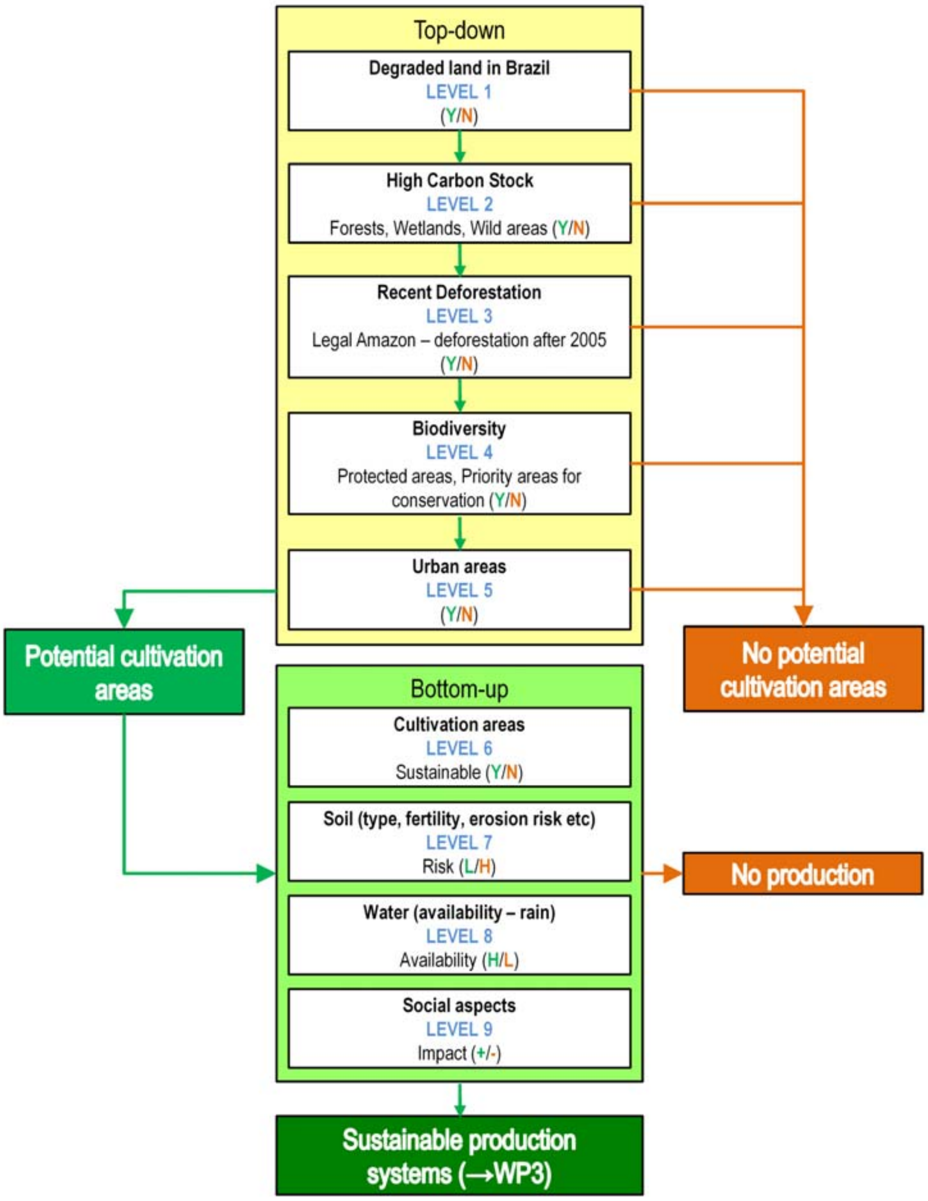

Fig. 2-4 Flowchart used to identify potential cultivation areas /Fritsche et al. 2010/

3 Grassy biomass

This chapter briefly presents three fundamentally different types of grassy biomass which could be used for bioenergy and bioproducts: i) annual and perennial herbaceous crops cultivated on arable land (chapter 3.1), ii) grassy biomass obtained from grasslands (chapter 3.2) and iii) other grassy biomass (chapter 3.3).

3.1 Purpose-grown grassy crops on arable land

Grassy crops are attracting increasing interest as potential energy crops, especially perennial grasses (chapter 3.1.2). The latter are said to require less energy, fertiliser and pesticide input than annual crops while achieving higher yields per unit area and higher net greenhouse gas (GHG) emission savings. Annual grasses (chapter 3.1.1) harvested and converted as whole crops, i.e. not separated into grains and straw (like classical cereals), can show advantages over other annual crops such as roots & tubers or oil crops.

Grassy crops can be used for bioenergy and bioproduct purposes in two different ways. If readily degradable biomass is sought after as a feedstock for fermentation processes (e.g. anaerobic digestion), the annual grasses are harvested early when they are still green. Else, if lignocellulose-rich biomass is targeted, the grassy crops are harvested after senescence.

3.1.1 Annual grasses

Typical annual grasses cultivated in the temperate zone include, among others, maize (*Zea mays* L.), sweet sorghum (*Sorghum bicolor* (L.) Moench), Sudan grass (*Sorghum sudanense* L.) and whole-crop silage from triticale (x *Triticale*) or forage rye (*Secale cereale* L.).

3.1.2 Perennial grasses

The most important tropical perennial grass is sugarcane (*Saccharum officinarum*), native to SE Asia. Its main product sugar is increasingly used for bioethanol production. Since the mid-1980s, perennial grasses are also promoted outside the tropics, especially in the U.S. and Europe. Table 3-1 lists the species towards which most of the research is dedicated.

Table 3-1 Perennial grasses grown in Europe /Lewandowski et al. 2003/

Common name	Latin name	Photosynthetic pathway	Origin
Switchgrass	*Panicum virgatum* L.	C4	N America
Miscanthus	*Miscanthus x giganteus*	C4	SE Asia
Giant reed	*Arundo donax* L.	C3	Europe
Reed canary grass	*Phalaris arundinacea* L.	C3	Europe

3.2 Grassy biomass from grasslands

3.2.1 Definitions of grassland

There are numerous scientific and regulatory definitions of grassland – almost as many as there are types of grassland. The definition of /White et al. 2000/ is of best available scientific evidence and represents the most accepted international standard: *"Grasslands are terrestrial ecosystems dominated by herbaceous and shrub vegetation and maintained by fire, grazing, drought and/or freezing temperatures"*. By using the terms *"herbaceous and shrub vegetation"* this grassland definition is broad enough to cover all grasslands in temperate and tropical zones including savannahs, steppes, scrublands and prairies.

As far as regulatory definitions in Europe are concerned, grassland is defined by Commission Decision 2000/115/EC /EC 2000/. Permanent pastures and meadow, for example, are defined as *"land other than rough grazing, not included in the crop rotation system, used for the permanent production (five years or longer) of green forage crops, whether sown or self-seeded and whether used for grazing or for harvesting as hay or silage"*.

In 2009, however, the European Renewable Energy Directive (2009/28/EC, RED) has caused a controversial debate by stipulating that *"raw materials used for the production of biofuels and bioliquids may not be produced on land that had the status of 'highly biodiverse' grassland in or after January 2008"*. Moreover, the RED introduced a distinction between 'natural' and 'non-natural' grassland. Being required to establish the criteria and geographic ranges to determine what areas must be considered as highly biodiverse grassland (outside as well as inside the territory of the EU), the Commission held a public consultation in late 2009 and early 2010. In total, 57 organisation contributed, among others proposing improved definitions of 'highly biodiverse', 'natural' and 'non-natural' grassland (e.g. /Lübbeke & Hennenberg 2009/). Unfortunately, a concluding decision by the EC is still pending.

3.2.2 Permanent grasslands

In many parts of the world, permanent grassland shapes the landscape and fulfils important functions in protecting nature, soil, and water. However, permanent grasslands are globally threatened of being converted into arable land – among others fuelled by biofuel policies.

European grasslands

In many regions of Europe, the traditional uses of permanent grassland for forage production (including regular cutting for conservation as silage or hay, or grazing) are disappearing due to declining numbers of ruminant livestock. On the other hand, the demand for biofuels/bioenergy and bioproducts is rising, mainly triggered by national policies including tax exemptions or relief, feed-in tariffs or quotas (see chapter 1). In the recent past, this has already lead to a significant conversion of grassland into arable land in some parts of Europe, e.g. in Germany /Lind et al. 2009/, /NABU & DVL 2009/.

In order to avoid land-use changes from grassland to arable land, which are undesirable both from a carbon stock, biodiversity and landscape conservation point of view, alternative uses for grasslands on the verge of being abandoned need to be urgently developed. Otherwise, these unmanaged grasslands will develop into a tangle of matted herbage and tussocks within one or two seasons and the fields will revert to scrubland within 5–10 years. /Rösch et al. 2009/ and /Shekhar Sharma et al. 2011/ have looked into several options, how grass and forage crops could be used for bioenergy purposes and biorefineries, respectively. However, from a biodiversity conservation point of view it is absolutely crucial that these options do not lead to land-use intensification, especially in the case of high nature value grassland.

Grasslands outside Europe

Agricultural expansion in general has already lead to a dramatic decline of permanent grasslands around the world. Prominent examples in South-America are the Brazilian Cerrado and Argentina's Pampa and Campos /Bustamante et al. 2009/, /Sawyer 2008/.

The Cerrado, located in Brazil's central highlands and covering approximately 21 % of the country /Klink & Machado 2005/, is a particular concern. The Cerrado is a mixture of different habitats, from dry forest and woodland savannah, to scrub and open grassland, penetrated by the streams and rivers of three major Brazilian drainage basins /Da Fonseca et al. 2004/. The Cerrado is very wildlife-rich and listed as a biodiversity hotspot with a high level of endemism by Conservation International. By 2004, agricultural expansion – mainly for large-scale soybean cultivation /WWF-UK 2011/ – had reduced the size of this unique habitat to 43% of its original size (approximately 2 million km^2). Only 2.2 % of the Cerrado is legally protected /BirdLife International 2008/ and around 1 % of the remaining Cerrado is lost every year /Butler 2007/.

The problem behind this land-use change is that – in addition to the irreversible loss of biodiversity – the soil and vegetation of the Cerrado have high carbon stocks. Converting Cerrado into agricultural land for the cultivation of annual crop thus results in a huge carbon debt and long payback times (/Fargione et al. 2008/, /Gibbs et al. 2008/), making any biofuel production from these crops both ineffective and potentially counterproductive for tackling climate change.

In reality, Cerrado is most often not directly replaced by dedicated crops for biofuel production (direct land-use change, dLUC). Rather, sugarcane and other crops for biofuel production expand in other regions of Brazil and displace soybean cultivation to the Cerrado (indirect land-use change, iLUC). This in turn could also push cattle ranchers and slash-and-burn farmers who had lived in the area before ever deeper into the Amazon rainforest /Butler 2007/, thus causing even higher iLUC-related GHG emissions.

In any case, both from a greenhouse gas emissions and biodiversity conservation point of view, it should be made sure that biofuel policies do not lead to conversion of grasslands to arable land, neither directly nor indirectly.

3.3 Other grassy biomass

3.3.1 Grassy biomass from politically abandoned arable land

In Europe, 10 % of arable land was politically set aside in the late 1980s, i.e. taken out of production. The objective was to reduce the amount of food produced by farmers by means of supply control. By reducing the area used for food production the surpluses on core markets for agricultural commodities, in particular cereals, could be brought under control. Changes to the rules were made on many occasions: being voluntary when it was introduced in 1988, set-aside became compulsory in 1992. At the same time, farmers were allowed to cultivate non-food biomass on set-aside land – which they increasingly did. Since technologies for the use of grassy biomass were unavailable at that time, farmers mainly cultivated rapeseed for biodiesel production. Of course, the alleged environmental benefits vanished to the same extent as set-aside was no longer (completely) taken out of production. The measure was temporarily suspended in 2008 (due to high prices for agricultural commodities) and definitively abolished in 2009 with the ‘Health Check’ reform.

In the United States, the Conservation Reserve Program (CRP) was launched in the mid-1980s. The CRP subsidises farmers for taking land out of production and planting grass, shrub and tree cover. Similar to set-aside land in Europe (abandoned for political reasons), lands deemed marginal for agriculture have been enrolled in the Conservation Reserve Program (CRP), providing important habitat for grassland species /Wiens et al. 2011/. In contrast to set-aside land in Europe, the CRP is specifically targeted (i) at marginal lands at high risk of soil erosion as well as “environmentally sensitive” land and (ii) at grassy biomass. Peaking at 15 million hectares in 2007, the extent of CRP lands decreased significantly to only 12 million hectares in February 2012 /USDA 2012/. Fewer contracts are being signed because CRP lands are partly reclaimed to meet the additional land area demand triggered by biofuels policies.

In the light of globally rising prices for agricultural commodities and considering the fact that Europe has abolished its set-aside policy, it is unlikely that large areas of arable land will remain out of production in the future. Therefore, politically abandoned arable land does not seem to be a long-term viable option for grassy biomass.

3.3.2 Grassy biomass from landscape conservation and protected areas

Grassy biomass can also be obtained through human activities aiming at landscape conservation and/or preservation of the grassland status of protected grasslands. In order to keep the landscape open and/or preserve the desired grassy vegetation, an extensive management (e.g. yearly cutting or extensive grazing) is needed which does not interfere with but rather supports the preservation of species richness and composition. Otherwise, grasslands would develop into scrubland within 5–10 years and potentially into forests – at least in those vegetation zones where forest forms the climax vegetation. However, most of these activities are not economically viable (protected areas are usually fully withdrawn from commercial use and yields are rather low) and require substantial support by society. Nevertheless, the analysis of biomass resource assessments has shown that the quantities are quite considerable in some countries /Rettenmaier et al. 2010d/.

4 Potential sustainability impacts

This chapter investigates the potential sustainability impacts of the use of marginal land (chapter 4.1) and of the use of grassy biomass (chapter 4.2), respectively. According to the widespread opinions presented in the introduction (chapter 1), both options are associated with positive impacts. These hypotheses will be challenged in the following.

4.1 Potential impacts of the use of marginal land

Of all the potential locations that might be tapped for increased biofuel production, marginal lands, abandoned croplands, and abandoned pasture lands appear to offer significant environmental and economic potential, particularly if the biofuel crops are perennial and if sustainable land-management practices are employed /Dale et al. 2010/. However, the impacts of the use of marginal land for the production of bioenergy are difficult to appraise since no clear definition for marginal land exists (see chapter 2.1). In the following the potential impacts regarding the environment (chapter 4.1.1) and socio-economic aspects (chapter 4.1.2) will be presented based on expert judgments and literature if available.

4.1.1 Environmental impacts

Whether marginal land offers positive or negative environmental impacts regarding the production of bioenergy is difficult to assess. The definition of marginal land proves to be difficult and differs widely in literature (see chapter 2.1). Therefore, the environmental impacts of a specific bioenergy production might be positive or negative depending on the actual site. In the following paragraphs potential positive (benefits) or negative (risks) impacts regarding greenhouse gas emissions, water, soil and biodiversity will be presented. In case of references from literature, the actual advantages or disadvantages will be given.

4.1.1.1 Greenhouse gas emissions

The impacts of bioenergy production on greenhouse gas emissions heavily depend on the type of marginal land used for the cultivation. If any dLUC or iLUC with a negative impact on the soil carbon stock takes place negative impacts regarding the greenhouse gas emissions will be the consequence. For example, the cultivation of Jatropha on sites with different above- and below-ground biomass as well as carbon stock results in completely different greenhouse gas balances /Reinhardt et al. 2007/. In case of carbon poor soils (e.g. scarce or no vegetation) greenhouse gas emissions were reduced by the cultivation of Jatropha. On carbon rich soils (e.g. medium vegetation) its cultivation results in additional greenhouse gas emissions /Reinhardt et al. 2007/.

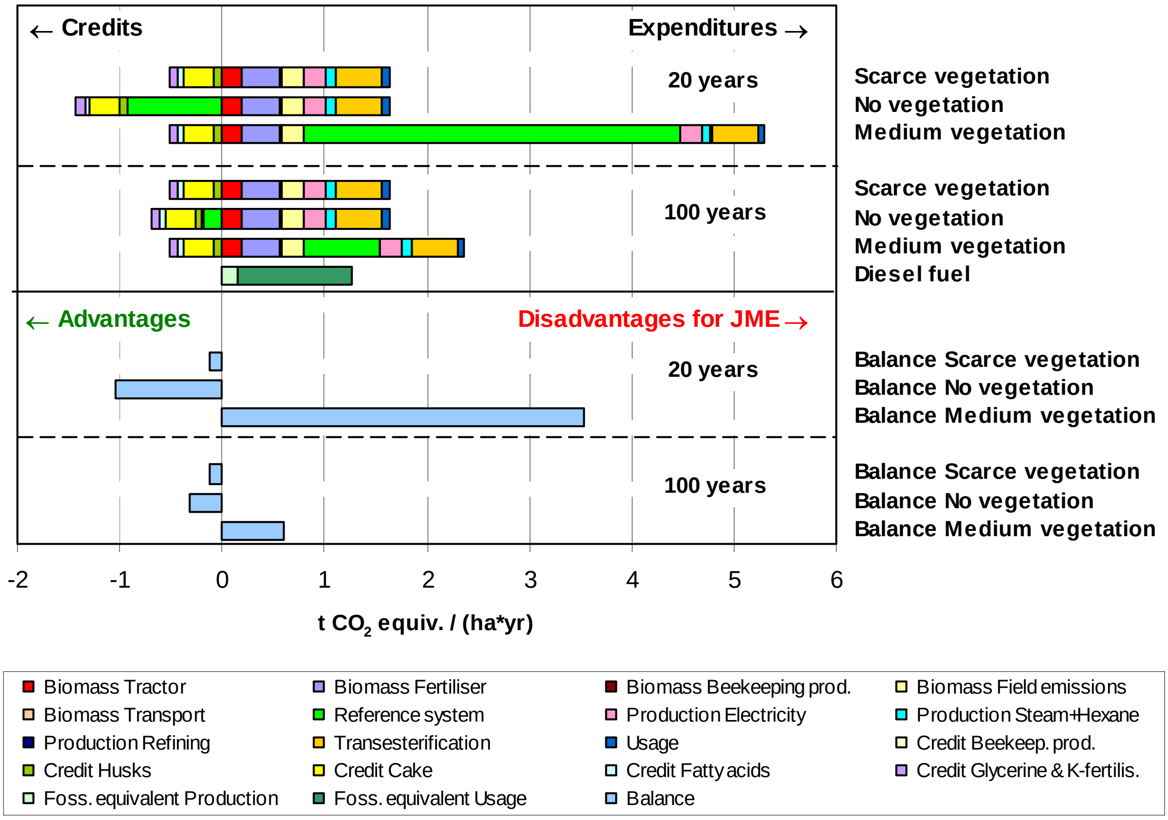

Fig. 4-1 Detailed greenhouse gas balance results for JME under consideration of three different alternative land uses (‘no vegetation’, ‘scarce vegetation’ and ‘medium vegetation’) and two different depreciation periods (20 and 100 years) /Reinhardt et al. 2007/

Another aspect influencing the performance of bioenergy production on marginal land is related to the farming system. In case of no-till farming or extensive farming the carbon stock of the soil will mainly be preserved. This results in the benefit of no additional greenhouse gas emissions. This can also be expected for bioenergy production from grassy biomass if the grass sod is preserved.

Since marginal land is less productive (by definition) than other e.g. agricultural land, higher inputs of fertilizers and other additives per MJ bioenergy are required. Also, the need for machinery and therefore the ratio of MJ of fossil fuel per MJ bioenergy is likely to be higher. Both of these aspects together result in an increase of greenhouse gas emissions as a huge disadvantage /Rathmann et al. 2010/.

4.1.1.2 Water

The impacts on water can be divided in those only valid for areas with low water availability and those generally valid. The benefits and risks related to areas of low water availability are the following:

- The cultivation of crops for bioenergy on marginal land might require irrigation. This involves the risk of negative impacts on the water availability.

- If bioenergy production is conducted by cultivating crops in extensive or intensive farming the resulting bare soil has potential risks on the water balance. The bare soil is connected to higher evapotranspiration compared to e.g. grassland and will result in lower water availability.

The general benefits and risks are the following:

- The use of herbicides and fertilizers show the risk of negative impacts on groundwater and adjacent water bodies.
- If degraded land is cultivated, the bioenergy production may result in an improvement of the physical soil structure. This has the benefit of positive impacts on the water balance of the soil.

4.1.1.3 Soil

If the marginal land used for the cultivation of bioenergy plants was previously degraded, there are two main potential benefits. First, the improvement of the physical soil structure results in a decreased surface runoff /Wicke 2011/. This reduces the risk of erosion and is therefore a clear benefit. Second, the cultivation of crops or grassy biomass on previously degraded land results in organic matter accumulation. This benefits the soil fertility. A general advantage of bioenergy crops, e.g. Jatropha, to improve the soil quality and control soil erosion has been cited in literature /Stromberg et al. 2010/, /Wicke 2011/. Also, the farming system has influence on the soil. No-till or low-till farming systems significantly reduce soil disturbance and erosion /Dale et al. 2010/.

4.1.1.4 Biodiversity

In general, monocultural plantations can have negative impacts on biodiversity /Royal Society 2008/. Therefore, cultivation of bioenergy crops on marginal land bares the risk of decreasing biodiversity. However, production of bioenergy on grassland or highly extensive agricultural land is connected to the potential benefit of increasing biodiversity if the land previously was degraded /Tilman et al. 2006/, /Wicke 2011/. Marginal land requires a higher input per MJ bioenergy /Rathmann et al. 2010/. Application of fertilizers and especially herbicides show the disadvantage of negatively affecting the biodiversity of a site. /Gaia foundation et al. 2008/ claim that so-called marginal land is important for the local biodiversity, and may act as a reservoir for endangered or useful species.

4.1.2 Socio-economic impacts

Almost one-third of the rural populations of developing countries – and a significantly higher proportion of the poor rural population – live in less-favoured marginal areas, many of which are either hillside or mountainous regions, or arid and semi-arid drylands. Many of these lands are environmentally fragile, and their soils, vegetation and landscapes are easily eroded /IFAD 2010/. These characteristics make poor people in rural areas more vulnerable and with less access to productive land. Most of the impacts on marginal land and the different types of non-productive land are related to rural poverty and lack of access to resources rather than exclusively to biofuel production.

Despite some definitions of marginal land and other land types (as per previous sections) have changed, some of the impacts have been rarely reviewed. A report conducted by CGIAR /FAO 1999/, reviewed some of these terms and the socio-economic constraints that they may have. This report also noted that the different terms were most of the times interchangeable and/or without a proper definition. Table 4-1 explains some of these differences and the socio-economic constraints.

The FAO report /1999/ also stressed that the range of possible uses of land is so wide and socio-economic conditions are so diverse that no definition can cover all the relevant factors.

Table 4-1 CGIAR’s proposed definitions and constraints. Source: /FAO 1999/

Definition	Biophysical Constraints	Socio-Econ. 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.	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[2]. 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

The socio-economic constraints mentioned in the table are still perceived in different regions. There have been several reports that for instance reviewed the potential use of marginal and degraded land and how they can be restored. For instance, /Bringezu et al. 2009/ considered degraded land as land that has been previously cultivated and become marginal due to soil degradation or other impacts resulting from inappropriate management or external factors (e.g. climate change); while abandoned land includes the degraded land with low productivity plus land with high productivity (e.g. where forest is regrowing).

This means that some biofuel crops can grow on degraded land and help restore its productivity. For example land contaminated with salt or with heavy metals could be restored (see /Ignaciuk 2006/ in /Bringezu et al. 2009/). This contributes to the local communities in restoring their livelihoods and contributing to increase the yields of the crops.

Additional factors increase the impacts of marginal areas, such as population growth combined with extreme poverty which pushes people into more marginal areas, and compels them to overuse the fragile resource base; the results include deforestation, soil erosion, desertification and reduced recharge of aquifers. As a result, resource degradation represents an increasing risk factor for many poor households /IFAD 2011/.

Other socio-economic impact to consider is that some degraded and “marginal” land is used by poorer households for different resources including biomass, building materials, fruit and nut collection and in some cases for subsistence crops /Sugrue 2008/. Particularly peri-urban areas where “undefined” land exists (this means might be any of the classifications of marginal, degraded or even favoured land) /Diaz-Chavez 2006/.

/Cotula et al. 2008/ also stated that competition for land resources between biofuel producers and poorer groups may result in the latter losing access to the land on which they depend. Furthermore, land that is productive and produces high yields is normally not the land available for the poor and if in need to choose crops to grow they will choose food crops.

4.2 Potential impacts of the use of grassy biomass

Depending on the type of grassy biomass (see chapter 3), the environmental and socio-economic impacts of its use for bioenergy and bioproducts may vary significantly. Thus, a separate assessment is needed for each type of grassy biomass. This is also due to the fact that the term ‘grassland’ is ambiguously defined (cf. unclear definition of ‘marginal land’).

4.2.1 Environmental impacts

In the following paragraphs benefits and risks of the use of grassy biomass for bioenergy and bioproducts regarding greenhouse gas emissions, water, soil and biodiversity are presented. To the extent possible, the impacts are differentiated according to the different types of grassy biomass defined in chapter 3. As already explained in section 3.2.2, land-use changes from permanent grassland to arable land are undesirable both from a carbon stock and biodiversity point of view. Therefore, this option disregarded in the following sections.

4.2.1.1 Greenhouse gas emissions

In the following the impact of bioenergy production from grassy biomass on greenhouse gas emissions is analysed.

Purpose-grown grassy crops on arable land

/Hanegraaf et al. 1998/ found maize as energy crop to be advantageous regarding reduction of greenhouse gas emissions compared to perennial grasses such as Miscanthus. Other studies, however, find annual crops (including maize) to have a lower performance than perennial crops regarding emissions of greenhouse gases both per area and per produced energy unit /Don et al. 2011/, /Rettenmaier et al. 2010c/. The reason for perennial grasses, especially Miscanthus, to have less impact regarding greenhouse gas emissions compared to annual crops is explained by its higher nitrogen use efficiency /Atkinson 2009/, /Don et al. 2011/, /Fazio & Monti 2011/. Thus, less N-fertiliser is needed and less N is lost as N_2O or nitrate resulting in significantly lower N_2O emissions (40 % to > 99 % compared to conventional annual crops) which are most important regarding the impact of agriculture on greenhouse gas emissions /Don et al. 2011/.

Another aspect positively influencing the greenhouse gas emissions of perennial grasses is the fact that – apart from the initiation of the fields – no tillage is necessary. Therefore no tillage-induced N mineralisation takes place, additionally minimizing the N_2O emissions from the soil /Don et al. 2011/, /Fazio & Monti 2011/. /Smeets et al. 2009/ emphasise the aspect that perennial grasses should be produced on former agricultural land rather than natural grassland since the conversion would also result in greenhouse gas emissions (see also /Fazio & Monti 2011/).

Grassy biomass from grasslands

As already explained in section 3.2.2, land-use changes from permanent grassland to arable land are undesirable from a greenhouse gas emissions point of view since grasslands usually have a high carbon stock. /Rösch et al. 2009/ found energy production from grassland (i.e. from grass silage or hay) to be beneficial in terms of reducing greenhouse gas emissions. However, regarding the benefits of not converting grassland into arable land, e.g. for maize cultivation, they note that preserving the grassland carbon stocks in an altered climate with high temporal variability and under high atmospheric CO_2 concentrations might become more and more difficult. Both aspects might saturate the carbon sink in soils /Rösch et al. 2009/.

Other grassy biomass

/Tilman et al. 2006/ propose to support low-input, high diversity (LIHD) mixtures of native grassland perennials on abandoned and degraded agricultural lands in the United States. According to the authors, this could contribute to greenhouse gas emission reduction. Furthermore, perennial grasses can reduce the application of agrochemicals which also contributes to less greenhouse gas emissions /Tilman et al. 2006/, /Wiens et al. 2011/.

4.2.1.2 Water

In the following the impact of bioenergy production from grassy biomass on water use and quality of surface and groundwater is analysed.

Purpose-grown grassy crops on arable land

Producing perennial grasses on arable land is considered to have a positive impact on the quality of ground and surface water. The application of little or no pesticides due to few natural pests and the lower application of fertilisers associated with reduced nutrient loss to the groundwater and adjacent water bodies are most advantageous in this regard /Lewandowski et al. 2003/, /Don et al. 2011/.

The water use of perennial grasses, e.g. Miscanthus, is mainly found to be much higher than from arable crops, potentially negatively affecting groundwater resources /Rowe et al. 2009/, /Smeets et al. 2009/. The main reasons for this is the deeper roots which enable grasses to reach deeper groundwater resources compared to arable crops. According to /Rowe et al 2009/ the reason for the higher water demand of Miscanthus compared to other crops are the combined higher growth rates, the high transpiration rates, the longer seasonal growth and the above mentioned deeper roots of higher complexity. /Smeets et al. 2009/ see the limited danger of overexploitation of fresh water reservoirs in connection with the higher water use of perennial grasses due to their higher overall evapotranspiration rate compared to annual crops. Nevertheless, they assess the impact of perennial grasses on fresh water reservoirs still limited, if no large areas of monocultures in single catchment areas or areas with low water availability are initiated. In this regard, they emphasise the influence of the size and location of such plantations. At the same time, they note the potential advantage of the high water use of perennial grasses for reducing peak flows and thereby reducing the risk of local flooding in flood-prone areas /Smeets et al. 2009/.

Grassy biomass from grasslands

/Rösch et al. 2009/ note that grassland biomass used for energy purposes shows good results regarding groundwater protection. It holds a crucial function due to its ability to lower the discharge of substances originating from the use of fertilisers and pesticides towards the groundwater compared to arable land. This results in low levels of nitrate and pesticides in grassland, leaching similar amounts to forests /Rösch et al. 2009/.

Other grassy biomass

The low-impact, high-diversity (LIHD) mixtures of perennial grasses grown on abandoned and degraded agricultural land (see chapter 4.2.1.1) may also contribute to cleaner ground and surface waters according to /Tilman et al. 2006/.

4.2.1.3 Soil

Purpose-grown grassy crops on arable land

The characteristics of second generation biofuels, e.g. perennial crops, to use all parts of a plant may have negative impacts on soil properties. Since no co-products (like straw) occur, that can be returned to the soil, all nutrients are removed from the field, respectively the soil. However, there is considerable biomass C accumulation in roots and rhizomes of perennial grasses and also litter, which contributes to soil improvements and might compensate the above described effect /Don et al 2011/, /Rowe et al. 2009/. Also, the rhizome systems of perennial grasses recycle nutrients resulting in an overall low demand for nutrient inputs /Lewandowski et al. 2003/. There is still some research needed on the particular effect of removing all biomass from the field during the harvest and its impact on soil properties.

In literature, the conversion of annual cropland to perennial crops is generally linked to an increase in soil organic carbon (SOC) /Atkinson 2009/, /Don et al. 2011/, /Lewandowski et al. 2003/, /Rowe et al. 2009/. However, most grassland store higher SOC stocks on average than cropland under similar site conditions, even considering the wide range of grassland management options /Don et al. 2011/. /Fernando et al 2010/ attribute the accumulation of organic matter and the structural enhancement of the soil of lignocellulosic crops (which also results in an overall enhancement of the soil structure) to their permanence, their high inputs of residues and the vigorous root development. Especially the no-tillage practice of perennial grasses after the establishment of the plantation is stated to positively influence the soil characteristics compared to annual crops, e.g. increasing the fertility of the soil /Atkinson 2009/, /Lewandowski et al. 2003/, /Rowe et al. 2009/. Further improvements to the soil from the cultivation of perennial crops are a reduced risk of erosion due to the no-tillage practices and the greater interception of rainfall and greater surface cover for a longer time period /Lewandowski et al. 2003/, /Fernando et al. 2010/, /Rowe et al. 2009/. /Smeets et al. 2009/ estimate the reduction of the erosion potential due to the conversion of conventional annual crops to Miscanthus and switchgrass at two third or more.

Grassy biomass from grasslands

/Rösch et al. 2009/ emphasise the positive impact of using grassland biomass for energy production compared to biomass from arable land regarding the soil. Especially the erosion potential and the compaction of the soil are much lower in case of grassland biomass. However, if pastures are converted to cultivate perennial grasses, the erosion potential of the soil is found to increase by a factor of two /Smeets et al. 2009/.

Other grassy biomass

The impacts of the cultivation of low-impact, high-diversity (LIHD) perennial grasses on abandoned and degraded agricultural land on soils are expected to be positive; i.e. the soil fertility is expected to be increased /Tilman et al. 2006/.

4.2.1.4 Biodiversity

Purpose-grown grassy crops on arable land

There is agreement in literature that the cultivation of perennial grasses generally provide higher biodiversity than conventional crops /Bellamy 2009/, /Dauber et al. 2010/, /Don et al. 2011/, /Smeets et al. 2009/. The reasons for this positive influence of perennial grasses on the biodiversity of especially birds, mammals and insects are numerous: lack of soil disturbance through absence of soil tillage and therefore better soil protection; low agrochemical (fertiliser and pesticides) inputs; longer rotation period; a greater richness of spatial structures providing a higher number of ecological niches; high below- and above-ground biomass to favour soil microfauna and shelter invertebrates and birds; fewer disturbances during the growing period and harvesting carried out in winter or even potentially after the breeding period of birds /Bellamy 2009/, /Dauber et al. 2010/, /Fernando et al. 2010/, Smeets et al. 2009/. /Bellamy 2009/ also states the possibility of non-crop plants and/or invertebrates to exist among perennial grasses in greater numbers than in other crop fields, thereby benefiting both seed and invertebrate-eating bird species.

/Bellamy 2009/, however, assessed the benefits of Miscanthus grown in the UK only to be temporary and expects them to decrease with the age of crops and as the crop management improves with experience. Other studies emphasise the importance of the field-scale management, the location compared to other vegetation types and the harvesting regime of the perennial grass plantations for their impact on the biodiversity /Dauber et al. 2010/, /Smeets et al. 2009/. Concluding, /Smeets et al. 2009/ found that the biodiversity of perennial grass plantations can be increased by an optimised size of the plantation and its location close to different types of vegetation as well as by a differentiated harvesting schedule. /Atkinson 2009/ notes the danger of e.g. Miscanthus, being a non-native species in the UK, potentially becoming invasive.

Grassy biomass from grasslands

As already explained in section 3.2.2, land-use changes from permanent grassland to arable land are undesirable from a biodiversity point of view. /Rösch et al. 2009/ note that especially low-input grassland is of high importance regarding biodiversity since it provides habitat for many endangered species. Therefore, the use of grassland biomass for energy purposes (as grass silage or hay) could preserve biodiversity and also the cultural landscape. However, similar to perennial grasses on agricultural land, the intensity of the use of grassland biomass strongly influences the biodiversity of the respective site. Especially the habitat and the time of cutting are of great importance. If the grassland management is intensified biodiversity can also be negatively influenced and decreased /Rösch et al. 2009/.

Other grassy biomass

The cultivation of low-impact, high-diversity (LIHD) perennial grasses on abandoned and degraded agricultural land is expected to create habitats of great biodiversity /Tilman et al. 2006/. /Wiens et al. 2011/ emphasise the advantage of native perennials regarding biodiversity, since they could be harvested after the first frost in autumn, so that birds, mammals and insects have got enough time for reproduction.

4.2.2 Socio-economic impacts

The literature on social impacts from grassy biomass and short rotation coppice (SRC) is limited. Most of it refers to the same topics of biomass produced for biofuels. Although most of the difference is that for SRC it might be referred to as the same as in forest management.

The literature also refers to some biofuel crops that can grow on degraded land and help restore its productivity. One example is switchgrass, which may even improve soil quality and productivity /Simpson et al. 2009/. Regarding the socio-economic implications as with the benefits of making productive marginal land, the use of grassy biomass may be of benefit in poor areas.

In the UK a study by /Haughton et al 2009/ determined through a participatory approach some social objectives in a project considering the mapping of environmental-friendly regions in the South and East of the UK for the introduction of Miscanthus and short rotation willow (*Salix* sp). The objectives selected by the participants included:

- Minimize transport movements
- Minimize additional vehicle movements
- Enhance rural quality of life
- Maintain and increase water availability
- Improve public enjoyment of the countryside
- Safeguard the historic environment

Although the project focused on the environmental issues (especially biodiversity), the framework on sustainability appraisal allowed to have the stakeholders views pointing out at social issues that were of concern in their region. The participatory framework also demonstrated that in securing a holistic understanding of the wide-ranging implications of large-scale, long-term changes to rural land-use in the wider context of sustainable land-use planning per se /Haughton et al. 2009/.

A study in the UK showed that both SRC and Miscanthus plantations were shown to be economically unviable under the conditions pre-Renewable Energy Directive (RED) /Scholes 1998/. A study done in Flanders /Garcia-Quijano et al. 2005/ showed that the establishment of short rotation energy forests (LOSRC) or energy crops (LOMISC) is a very efficient way of reducing emissions (CO_2) as far as land occupation and environmental impacts per functional unit are concerned. Nevertheless, it is a very expensive option because of the net costs for growing, transporting and using biofuel in a specialized power station are high with respect to the costs of electricity production in an efficient natural gas plant.

5 Discussion and conclusions

This report aims to challenge two frequent hypotheses, according to which land-use competition and its negative side-effects can be reduced or mitigated: i) through the use of marginal (or degraded) land and/or ii) through the use of grassy biomass. This chapter separately discusses the two hypotheses and presents our conclusions.

Use of marginal land

Recently, /PBL 2009/ investigated the expected near future developments in the production of biofuels to assess the availability of sustainable biofuels for the Netherlands in 2020 and the implications for sustainability components. Among others, the authors looked into the potential of marginal and degraded lands. They conclude that there are high hopes connected to these types of land, but that they are not unambiguously defined (see also chapter 2.1). The authors find it unlikely "*that much feedstock will be produced on marginal lands by 2020, as exploitation requires large amounts of external inputs*[3] *including water and nutrients and because institutional and infrastructural conditions have to be put in place as well. Improving the ecological conditions of marginal lands takes decades, while yield performance will be low and highly variable.*" In short: marginal lands give marginal yields.

IFEU and Imperial College largely share the views expressed above and come to the conclusion that **the concept of marginal land is not viable** and does not live up to the high expectations (the /Gaia foundation et al. 2008/ even call it a "myth") for the following reasons:

- **Unclear definition**: Marginal land is often incorrectly used as an umbrella term for all types of land ranging from fallow and abandoned land to degraded land. However, 'marginal' definitely is an economic term and therefore subject to the variable economic framework. Thus, it cannot be used as a stable definition. Unfortunately, other terms such as degraded land which are used synonymously are just as diverse and unclear.
  - From an environmental point of view, this creates huge problems since critical forest, peat and grassland ecosystems are often classified as "marginal" or "idle" if they are perceived as not contributing sufficiently to economic development /Gaia foundation et al. 2008/. According to /Elbersen et al. 2008/, biophysically favourable environments are classified as marginal, or secondary forest as degraded.
  - Also from a socio-economic point of view, the term 'marginal land' is problematic since land that is often described as "marginal" is in fact critical to the survival of the most marginalised communities. Governments often conveniently classify all sorts of lands as marginal – including those used by nomadic and pastoralist communities for grazing, small-scale farmers, indigenous peoples and women /Gaia foundation et al. 2008/.

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[3] Needed to overcome biophysical limitations, such as low and variable rainfall often with prolonged periods of drought, poor soil quality in terms of fertility, texture and structure and occasionally yield depressing or toxic conditions such as high salinity, high levels of aluminium or iron, etc.

- **Unclear extent and quality**: As a consequence of the unclear definition, the availability of marginal land, often identified as a major source of land for bioenergy, is highly uncertain. For the same reason, land quality is highly variable, depending on the biophysical limitations it suffers from.
    - Existing databases such as GLASOD are rather outdated.
    - Mapping the global extent of marginal/degraded land via remote sensing is challenging, since some biophysical aspects simply can not be observed via satellite imaginary. This is even more the case for socio-economic aspects, e.g. whether the land is used by nomadic and pastoralist communities or indigenous peoples. A combined top-down and bottom-up approach (e.g. /Fritsche et al. 2010/) would thus be needed to identify those areas, i.e. a ground-check is absolutely vital.
- **Unclear sustainability impacts**: As a consequence of the unclear definition and the unclear extent and quality, **it remains unclear if and to which degree marginal/degraded land could contribute to reduce land use competition**. Moreover, **it is difficult to generalise the sustainability impacts of the use of marginal land**.
    - In order to properly assess the environmental impacts associated with its use, it is crucial to know the exact marginal land in question. Land use-related impacts could be very positive, e.g. if the soil carbon stock was increased. However, if (semi-)natural land is used or grassland is converted into arable land, both the greenhouse gas balance (via soil carbon stocks) and biodiversity are negatively affected. In other words, a case-by-case evaluation is required since no general conclusion can be drawn.
    - However it is clear that – since marginal land is inherently less productive than fertile land – higher agricultural inputs (e.g. fertilizers) and therefore investments are required to obtain the same output as on fertile land. Thus, the environmental impacts are increased. Also, since many of these marginal lands are environmentally fragile, there is a considerable risk of irreversible degradation if inappropriately managed.
    - Moreover, due to generally unfavourable socio-economic conditions (rural poverty and lack of access to land), it is likely that non-food biomass cultivation leads to an intensification and capitalization of farming operations and thus to productivity enhancing measures. These limitations cast serious doubts whether realization of yield increases are possible in short periods of time.
- **Unclear future**: According to the RED (Annex V, part C, points 8 & 9), a bonus of 29 g CO_{2eq}/MJ is attributed to biofuels produced on degraded and heavily contaminated land. However, this bonus has not stimulated the use of such land for biomass feedstock cultivation. According to the latest proposal by the European Commission /EC 2012/, the bonus shall be replaced by a malus (estimated indirect land-use change emissions) which shall be attributed to all biofuels from agricultural land. Instead of incentivising the use of degraded and heavily contaminated land, the use of agricultural land is discouraged. The result in the end could still be the same, though.

Use of grassy biomass

The picture regarding the use of grassy biomass is somewhat clearer than for the use of marginal land. There are three fundamentally different types of grassy biomass which could be used for bioenergy and bioproducts: i) annual and perennial herbaceous crops cultivated on arable land, ii) grassy biomass obtained from grasslands and iii) other grassy biomass. In the following, they will be treated separately.

- **Purpose-grown grassy crops on arable land**:
    - The cultivation of perennial grasses on arable land (for the purpose of bioenergy and bioproducts) usually results in **lower *direct* environmental impacts compared to traditional crops** such as roots & tubers or oil crops. This is mainly due to higher product yields per unit area (i.e. seen from a bioenergy perspective). The advantage is less pronounced for annual grasses. Moreover, the impact on water resources and biodiversity is depending on local conditions and thus highly variable. Last but not least, a significant bandwidth/range of LCA results can be expected, both due to varying biomass yields and immature processes leading to lignocellulose-based biofuels.
    - However, when comparing different crops from a basket-of-products perspective, ***indirect* effects** have to be considered as well. In this case, the co-products obtained from traditional crops play an important role: if used as animal feed, they substitute conventional feed production and thus reduce the overall pressure on land. No such co-products are obtained from herbaceous crops. In other words, **grassy crops** are causing iLUC effects as well (potentially even worse) and **might not contribute to reduce land use competition**.
    - **The socio-economic impacts of perennial grasses are not fully understood yet.** More research is needed in this field. In Europe, farmers are still reluctant to dedicate their land to long-term cultivation of perennial crops both because of conflicting interests between farmers and biomass users regarding the duration of supply contracts and because it would reduce their opportunities to benefit from more volatile prices for agricultural commodities, which are mostly obtained from annual crops (in the latter case farmers can correct their decision once per year vs. once in 15-20 years in the case of perennial crops).
- **Grassy biomass from grasslands**:
    - **Unclear definition**: The term ‘grassland’ is ambiguously defined. Unfortunately, the RED has added to the confusion by introducing terms such as ‘highly biodiverse’, ‘natural’ and ‘non-natural’ grassland without providing a corresponding unambiguous definition. As a consequence, it is not fully clear, which areas are considered grassland.
    - **Land use change from permanent grassland to arable land are a no-go option**: land-use changes from permanent grassland to arable land are absolutely undesirable both from a carbon stock and biodiversity point of view.
    - **Through the use of cuttings from ‘surplus’ grasslands** (due to declining numbers of ruminant livestock) for the purpose of bioenergy and bioproducts, **synergies with a number of environmental issues could be exploited** (e.g. biodiversity conservation)

  – at least in Europe. Alternative uses for ‘surplus’ grasslands are urgently needed, however, in terms of environmental impacts it is absolutely crucial that these options do not lead to land-use intensification, especially in the case of high nature value grassland. The latter requirement casts serious doubts whether the potential contribution of grass cuttings is large enough to alleviate land use competition. Also, it has to be considered that in most parts of the world (i.e. outside Europe), per capita meat consumption is increasing. Thus, at global level, ‘surplus’ grasslands are **unlikely to contribute to a reduction of land use competition**.

- **Other grassy biomass**:
  - The use of grassy biomass obtained through human activities aiming at landscape conservation and/or preservation of the grassland status of protected grasslands offers many synergies with nature conservation – provided that the harvest of grassy biomass does not interfere with but rather supports the preservation of species richness and composition. Thus, it has **very positive environmental impacts**.
  - However, most of these activities are not economically viable (protected areas are usually fully withdrawn from commercial use and yields are rather low) and require substantial support by society. Nevertheless, the analysis of biomass resource assessments has shown that the quantities are quite considerable in some countries. At global level, however, this source of grassy biomass is **unlikely to contribute to a reduction of land use competition**.

Final conclusion

Our review has shown that it is rather unlikely that the use of marginal (or degraded) land and/or the use of grassy biomass can significantly contribute to alleviate land-use competition and its negative side-effects. We think that these frequently heard hypotheses are refuted.

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