BIOMASS AND BIOENERGY XXX (2012) 1–14

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Is energy cropping in Europe compatible with biodiversity? – Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes

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ARTICLE INFO

Article history:
Received 12 December 2011
Received in revised form
15 May 2012
Accepted 18 September 2012
Available online xxx

Keywords:
Biomass
Biodiversity
Bioenergy
EU
Conversion

ABSTRACT

Based on literature and six country studies (Belgium, Denmark, Finland, Netherlands, Sweden, Slovakia) this paper discusses the compatibility of the EU 2020 targets for renewable energy with conservation of biodiversity.

We conclude that increased demand for biomass for bioenergy purposes may lead to a continued conversion of valuable habitats into productive lands and to intensification, which both have negative effects on biodiversity. On the other hand, increased demand for biomass also provides opportunities for biodiversity, both within existing productive lands and in abandoned or degraded lands. Perennial crops may lead to increased diversity in crop patterns, lower input uses, and higher landscape structural diversity which may all have positive effects on biodiversity.

In production forest opportunities exist to harvest primary wood residues. Removal of these forest residues under strict sustainability conditions may become economically attractive with increased biomass demand.

An additional biomass potential is represented by recreation areas, road-side verges, semi-natural and natural areas and lands which have no other use because they have been abandoned, polluted or degraded.

Whether effects of cropping of biomass and/or removal of biomass has positive or negative impact on biodiversity depends strongly on specific regional circumstances, the type of land and land use shifts involved and the associated management practices in general. However, it is clear that in the six countries studied certain types of biomass crops are likely to be more sustainable than others.

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http://dx.doi.org/10.1016/j.biombioe.2012.09.054

1. Introduction

1.1. *Policy environment and perspectives for renewable energy*

The EU Directive on the promotion of the use of energy from renewable sources 2009/28/EC [1] sets an overall target of 20% renewable energy to be reached by 2020, and a 10% target for renewable energy sources including biofuels in total final energy used for transport. The Directive is accompanied by an obligatory sustainability scheme to be applied for all imported and domestic biofuels in vehicles. Following an assessment of the sustainability requirements for the use of solid and gaseous biomass sources (SEC (2010) 65), the Commission has provided member states with recommendations on content of national sustainability criteria for solid biomass [2]. These recommendations are currently (2012) being assessed, evaluating whether mandatory standards are needed (at the moment of writing this paper, the outcome of the assessment was not yet known). The main reason for accompanying these targets with sustainability schemes is to ensure that biomass production does not counteract the very aim of the climate and energy package, namely mitigating climate change by reducing greenhouse gas (GHG) emissions. The second aim is to avoid negative effects on biodiversity, freshwater availability and other ecosystem services.

The European Sustainable Development Strategy (SDS) emphasises the importance to combat a further decline of biodiversity, to sustainably manage natural resources and to stop climate change [3]. According to the EU SDS these objectives should be integrated in *all* policies of the EU including the energy, agricultural and forest sector. The proposed sustainability criteria point specifically at biodiversity, greenhouse gas emissions and energy conversion efficiency, as well as monitoring the origin of biomass.

The three types of energy for which biomass can be used – transport fuel, electricity and heating/cooling – use different (while overlapping) types of biomass and therefore translate into different land uses. In the case of transport fuel, it is commonly accepted, given the current state of fuel conversion technology, that until 2020 almost all primary biofuel feedstock will come from crops used for ethanol and biodiesel production. These are mainly rotational crops commonly grown on traditional arable farms. They include starch crops (e.g. wheat, potatoes, grain maize, barley and rye), sugar crops (e.g. sugar beet, sweet sorghum) and oil crops (e.g. oilseed rape, sunflower, soy-bean). The clear target of 10% of renewable energy sources in total final energy used for transport by 2020 can be translated into areas of these crops relatively easy. As from 2015 to 2020 it can be expected that efficient 2nd generation techniques will be developed for converting ligno-cellulose (woody or grassy) crops and by-products into transport fuels (see e.g. [4]). Part of the biomass for biofuels can also come from forestry, nature conservation areas and other land use categories. In agriculture the main crops delivering ligno-cellulose material are short rotation coppice crops like willow and poplar or perennial grasses like *Miscanthus*, switchgrass, reed canary grass (*Phalaris arundinacea*) or giant reed (*Arundo donax*).

In the case of electricity, the targets that exist until 2020 are more difficult to connect directly to future agricultural land use, because of the wide range of renewable energy sources that could be used. Wood biomass is generally the most important source, but feedstock for electricity generation can come from agricultural crops like short rotation coppice and perennial grasses, or it can be wastes or by-products from agriculture, forestry and other industries, urban waste or imported pre-prepared fuel.

1.2. *Sustainability and biodiversity effects of bioenergy harvesting*

Although it is difficult to estimate the exact area of land required for bioenergy crops, it is clear that the pressure on land will increase strongly under a growing biomass demand [5]. This may cause adverse effects on biodiversity as it may lead to the further intensification of existing land uses, both in agricultural and forest lands, but also the conversion of non-cropped biodiversity-rich land into cropped or forested area [6]. The conversion of e.g. biodiversity-rich grasslands is meant to be prevented by the sustainability scheme for biofuels introduced by the EU Renewable Energy Directive. There is an increasing resistance against using existing arable land for the production of biomass at the expense of food and feed production [7], since it can induce substantial negative environmental effects [8]. Food security, especially in developing countries, may be affected, and bioenergy production may push food and feed production into uncultivated areas causing loss of valuable natural habitats (e.g. tropical rain forest and savannah) and to tremendous releases of greenhouse gases (GHGs) from soils [9,10]. This could also be a consequence of the EU countries increasingly relying on imported biomass for bioenergy.

In the last few years there is an increasing number of scientific papers discussing effects of biomass energy cropping on biodiversity: [6,11–18]. The general mechanisms influencing biodiversity when affected by the multitude of bioenergy cropping systems can briefly be characterised as follows. Intensification as brought about by converting long-term or permanent crops into annual management and harvest practices is detrimental [14,15]. Introducing energy cropping into an existing intensive cropping system with annuals will generally benefit biodiversity if the energy crop is multiannual [14]. This will enhance biodiversity provided that management does not counteract by increasing pesticide use or harvest disturbance. There will always be some species benefitting from land use management, but the loss of habitat diversity will be more pronounced than the gain in such opportunistic species. As management practices are composed of a range of techniques the particular combination finally determines the net impact on biodiversity. This includes practices at the landscape level such as maintaining corridors, hedgerows, etc. [19,20]. Also soil organic stocks are affected, as was demonstrated for *Miscanthus* [21].

1.3. *Focus of the paper*

Given the above considerations, it is clear that for reaching the proposed renewable energy targets in a sustainable way, land resources need to be identified that can be used for biomass production and/or harvesting without causing losses in biodiversity. In this paper we investigate whether and how the EU renewable energy targets and the reduction of biodiversity loss are compatible. We focus especially on

- the opportunities for cropping and/or harvesting biomass resources without compromising biodiversity, and
- the main knowledge gaps for proper evaluation of the consequences of an increased renewable energy share from terrestrial resources in the EU for present and future biodiversity.

2. Materials and methods

2.1. *Information sources and country case studies*

Three types of information sources have been used for answering the research questions of this paper:

1) a literature survey into the effects on biodiversity of land use changes and changes in management of different productive and non-productive land resources related to bioenergy production. Relevant studies were selected mainly on the basis of papers in scientific journals and in publicly available study reports.
2) a selection of six EU country case studies, executed according to a similar outline, as much as possible aiming at comparable information on policies, stimulation measures, present share of renewable biomass based energy, risks, etc. For six countries information was available to the authors. They represent a range of central-western lowland European (Denmark, Belgium, Netherlands), northern European (Sweden, Finland) and central-eastern European (Slovakia) countries with varying land use intensities and bioenergy policies.
3) National Renewable Energy Action Plans and other international reports and statistics to supplement the information on biomass for bioenergy from the country case studies.

The focus in this paper is on biomass derived from terrestrial systems used for conversion into energy. They include farmland, forests, natural and semi-natural areas, recreation areas, hedgerows and road-side verges. The study was limited to biomass produced by land systems, thus excluding the secondary biomass flows embodied in urban residue streams, and biofuels imported. Attention is mainly directed to the European situation although the principles in relation to biodiversity effects discussed can also be applied to situations outside Europe. The case studies have been carried out on the basis of official data locally available and local expert knowledge.

In this paper we adopt the broad biodiversity definition of the Convention on Biological Diversity (1992): the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems [22]. We have focussed on terrestrial habitat quality and associated species diversity, and the functional relationships that are conditional for this diversity.

The timeframe taken for the assessment especially in relation to conversion technologies to become commercial is the next 15 years. This is the period within which the EU bioenergy targets for 2020 need to be realised and within which it can be expected that 2nd generation biofuel technologies based on ligno-cellulosic feedstock become commercial and perennials can be expected to become the preferential feedstock crops. The effects on biodiversity to be discussed imply not only those caused by land use changes but also effects of changes in land management associated with an increased demand for biomass.

2.2. *Main types of land based resources providing biomass feedstock*

In this study, five types of land resources are distinguished as a basis for further analysis: agricultural lands (including categories of semi-natural lands that are used for agricultural activities), forests, natural lands, abandoned lands, and urban green and recreation areas.

These five main categories can be characterised in a mutually exclusive way according to the BioHab system of classification [23]. Agricultural lands include all cultivated areas, also grasslands which are included in the herbaceous categories of this classification. If falling in semi-natural categories there must be some evidence of agricultural management (grazing by domestic animals, cutting or mowing). The forest category includes all habitats with woody species above 2 m high (this can include also urban areas). Natural lands are qualified as non-managed, including areas of herbaceous vegetation or grass left unused and with no evidence of cutting. The abandoned land class is the most difficult one to characterise and identify. It includes areas formerly used for agriculture or other management activities (e.g. recreation, mining etc.) that can now be qualified as not being managed, and in case of former agricultural lands there is evidence of colonisation by woody vegetation.

The most common land resources providing biomass for bioenergy production at present are agricultural and forest lands. Mainly in Finland and Sweden, former peat mining areas are used for bioenergy cropping as well. In some countries abandoned land are used. Also other land use types produce biomass feedstock (e.g. urban green; road side verges) but their use is still limited. Forest biomass is usually a by-product from the forest (primary forest residues) and paper industry (secondary forest residues) [24]. Primary forest products are rarely used for bioenergy generation.

Bioenergy feedstock is generally differentiated in four categories [25].

- *Primary by-products*: At the source = sugar beet tops, straw, verge grass, prunings, greenhouse residues, etc.
- *Secondary by-products*, later in the production chain = potato peels, sugar beet pulp, sawdust, etc.
- *Tertiary by-products*, has had a use = used frying oil, slaughterhouse waste, animal manure, organic household wastes, used paper, demolition wood.
- *Specific crops*, oilseed rape (*Brassica napus*), energy grain (*Miscanthus* sp.), switchgrass (*Panicum virgatum*), short rotation coppice, sugar beet for ethanol, etc.

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All this feedstock can either be produced on the European market or be imported.

3. Results

3.1. *Renewable energy targets, biomass demand and pressures on terrestrial resources*

EU countries (and the case study countries alike) differ in the gaps they need to fill to reach the 2020 renewable energy targets. These are reported in the National Renewable Energy Action Plans (NREAP) published in 2010 [26] (Table 1). These gaps are due to a combination of factors of which important ones are political preferences, the types of renewable resources already available, land resource and by-product availability, related competing uses and transport and accessibility issues.

In 2011 the countries were supposed to report on their achieving. Some of the countries have not yet (mid 2012) submitted the reports, but for four of the case countries, the distance to target can be assessed, as well as the dependence on imports (Table 1).

The share of final energy consumption that is aimed to come from biomass based sources varies between countries in their overview of the 2005 and 2020 renewable energy targets (Table 1). The shares in Northern European countries are already quite high while Belgium and The Netherlands have very low shares. Denmark, Finland and Sweden have by far the largest targets for 2020. This implies that in relative terms their renewable energy shares do not need to rise as strongly as in Belgium, The Netherlands and Slovakia.

The main source of renewables in all countries is biomass. Especially Belgium, but also Finland and Denmark, depend very heavily on biomass-based energy to reach its 2020 target. In Belgium the biomass production has to grow from 26.4 PJ in 2005 to 183.7 PJ in 2020 which is an increase of almost 700%. Also in The Netherlands and Slovakia growth of biomass based energy production will need to increase tremendously in relative terms. In Sweden, relative growth in biomass based energy is limited to 50% between 2005 and 2020 but since the overall renewable energy share is meant to increase to 49% this still implies an absolute growth in biomass based energy potential of 167 PJ.

The reports on achievement in 2010 show that Sweden had already almost accomplished the target for renewable energy consumption as share of total, and a significant growth (4–5% of total consumption) has taken place in Denmark and Slovakia, while the distance to target for Denmark is still substantial (Table 1). In The Netherlands, the growth is yet small, and the distance to target large.

Some trade takes place within the European countries and import from outside EU is also an important source for some countries. E.g. Denmark imports about 23% of the biomass for bioenergy from other EU countries, while 4% is imported from outside EU, and The Netherlands import 14% from outside EU (North American wood pellets). While some uncertainty is related to these numbers (the Swedish report mentions that the focus of background reports has not been on origin), it is clear that domestic challenges in finding sources for bioenergy are still significant in most case countries.

The largest part of the biomass resources is aimed for conversion to electricity and heat while for biofuel generation the absolute biomass input shares are smaller in all case study countries, and the growth since 2005 is small.

3.2. *Use of land based bioenergy resources*

The present land resources delivering the main biomass feedstock for the renewable energy vary widely between the countries (Table 2). As a consequence, estimates of the amount of energy produced by the different resources also vary greatly. From the overview in Table 2 it is clear that wood and wood chips from own forests are the main source of bioenergy in all countries. However, the Northern countries Sweden and Finland have a much larger forest area relative to the total land area, and therefore derive significantly larger quantities of energy from their forest resources, i.e. forest residues from wood and paper industry, than countries with smaller land areas and relatively larger share of agricultural land. However, the production of energy from wood is three times higher in Finland than in Sweden. In some cases the

Table 1 – Overall renewable energy targets and biomass based energy targets from National Renewable Energy Action Plans. Source: [26].

	Renewable energy 2005 (NREAP)				Renewable energy target 2020 (NREAP)		Bioenergy target 2020 (NREAP): final energy consumption
	Proportion final energy consumption	Final energy consumption (PJ)	Biomass final energy consumption (PJ)	Proportion biomass total renewables	Proportion final energy consumption	Final energy consumption (PJ)	Biofuels(PJ)
Belgium	2.2%	29.3	26.4	90.1%	13%	226.1	33.5
Denmark	16.5%	113.0	83.7	74.1%	30%	209.4	12.6
Finland	28.8%	318.2	264.7	83.2%	38%	448.0	25.1
Netherlands	2.5%	54.4	45.2	83.1%	14%	305.7	33.5
Slovakia	6.7%	33.5	15.1	45.1%	14%	71.2	4.2
Sweden	39.7%	573.6	323.4	56.4%	49%	824.8	33.5
EU-27		4132.6			20%	10237.2	1222.6

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harvesting is so intensive that also stumps are harvested as feedstock. Still, targeted felling of forest for biomass harvesting is practically not occurring at this stage in these two countries. Other important sources of energy in these two countries are significant areas of perennials such as reed canary grass and willow. A last category used as biomass source in Sweden and especially Finland is peat. This source is not harvested in the other investigated countries, although peat land surfaces are also quite significant. In Denmark forest land contributes considerably to the bioenergy production. Contrary to the situation in Sweden and Finland, in Denmark targeted felling of forest for electricity and heat generation is a common practice.

The forest area specified in the 2nd column of Table 2 relates to the total forest area with wood harvesting. This does not imply that all harvested wood from this area is used for bioenergy production. In most cases only the by-products from the paper and saw mills using this wood are transformed into bioenergy. In Belgium, Slovakia and The Netherlands harvesting of energy wood in forests is hardly practiced and contrary to Sweden and Finland, logging residues are not used and neither are stumps harvested.

The other main biomass land resource is agricultural land. The area with energy crops is clearly almost absent in Belgium, The Netherlands and Finland, while in Sweden, Denmark and Slovakia dedicated cropping of either biofuel crops or perennials or both have taken off – either in the form of 1st generation crops like rape or cereals, or to a minor extent perennials. In the Slovak Republic a considerable tendency of land abandonment can be noted, currently about 3000–4000 km^2 of unused farmland exist, providing opportunities for biomass cropping. Some conversion into rapidly growing wood plantations has already taken place. Most of the production is exported to the Czech Republic, Hungary and Austria.

An important source of biomass for bioenergy is straw from cereal crops. More than 25% of this resource goes into electricity and heat production in Denmark. Strikingly this does not happen in the Netherlands, Belgium or Slovakia despite large land areas with cereal production. Especially in Slovakia, land abandonment following the reforms before and after entering the EU has created new potentials for bioenergy production.

In some countries, particularly Denmark and the Netherlands, the planning system does not allow any increase in agricultural land and furthermore crop land reductions due to urbanisation, infrastructural development and environmental regulations must be foreseen. EEA formerly estimated a nearly zero potential for Danish production of energy crops [27]. However, there is much focus on the renewable energy issues in research and development strategies, as well in the EU research agenda as in national strategic research agendas. Recent studies indicate that progress in agricultural productivity and management practises, combining rotations, biogas and environmental measures in a smart way may have considerable potential to make agriculture net energy producer, with concurrent reductions in GHG emission [28].

All countries included in this study aim at increasing their share of biomass for energy production (Table 3). However, given the current levels of biomass production, these targets will not be reached without significant increases in the production of biomass for energy.

3.3. *Possible effects of biomass demand on biodiversity in the land use categories*

For the case-study countries studied, the directions of effects on biodiversity from increased biomass cropping and harvesting can be roughly estimated given the limited information presented above and the summary in Table 3. In the following we combine all relevant information on the systematic assessment of opportunities and threats to biodiversity for the case-study countries.

3.3.1. *Agricultural lands*

The effects on biodiversity of biomass cropping in agricultural lands mainly depend on the types of land use changes induced and the type of biomass crops and land management practices used (Table 4).

3.3.1.1. Conversion from food and feed production to biomass cropping. Although not the most likely scenario from an economic perspective, shifts from intensive food and feed production to biomass for energy cropping are often mentioned as a possibility [7,8,29,30]. This land-use category includes the most intensive cropping practices like horticulture and all specialised arable and mixed livestock activities in Europe. Harvests include a high share of cereals in their rotation, including winter wheat or barley, rice, and high input fodder crops like maize. The harvests also include specialised permanent crops such as high intensity olive groves,

Bioenergy target 2020 (NREAP): final energy consumption					Reported for 2010			
Biomass electricity (PJ)	Biomass heat & cooling (PJ)	Total biomass (PJ)	Proportion biomass total renewables	Proportion growth in biomass energy 2005–2020	Proportion final energy consumption	Domestic (PJ)	Imported from within EU (PJ)	Imported from outside EU (PJ)
83.7	83.7	201.0	90.1%	667.7%				
33.5	108.9	154.9	73.5%	83.3%	21.80%	91.7	29.5	5.1
46.1	276.3	347.5	77.4%	31.0%				
58.6	62.8	159.1	51.6%	250.5%	3.70%	100.0	4.8	18.3
4.2	29.3	37.7	52.3%	148.5%	10.20%	35.0	0.0	0.3
58.6	393.6	489.9	59.2%	51.1%	47.80%	478.4	36.8	14.4
929.5	3567.3	5723.6	56.0%					

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Table 2 – Main biomass land resources and related present energy production (reference year 2007–2008).

Country	Terrestrial sources potentially used for production (surface ha) [a]		Estimate of terrestrial surface yearly used for biomass recovery including for energy [b]		Domestic renewable energy production	
Belgium [62]	Total area:	3,071,000 ha	1) Forest suitable for production:	0.47 mln ha	1) Total roundwood production [d]:	4.95 mln m^3
	% Agricultural area:	57 %				
	% Forest area:	20 %	2) Energy crops:	16,532 ha	Wood chips	0.4 PJ/yr
	% Natural area:	2 %	Rapeseed [c]	9,657 ha	Wood households	3.3 PJ/yr
	% Artificial area:	21 %	Maize [c]	540 ha	Biofuel (transport)	2.2 PJ/yr
			Cereals [c]	6,300 ha		
			Perennials [c]	35 ha		
Denmark [63]	Total area:	4,667,000 ha	1) Forest suitable for production:	0.30 mln ha (it is estimated that 43% of fellings is used for energy)	1) Total roundwood production [d]:	2.56 mln m^3
	% Agricultural area:	75 %				145.6 PJ/yr
	% Forest area:	9 %	2) Energy crops:	478,000 ha	2) Renewables (2007):	59.9 PJ/yr
	% Natural area:	5 %	Rape [c]	94,000 ha	Wood	18.3 PJ/yr
	% Artificial area:	7 %	Straw (cereal)	363,000 ha	Straw	3.9 PJ/yr
			Willow [c]	2,500 ha	Biogas	30.1 PJ/yr
					Waste biodegradable	
Finland [14], [64]	Total area:	33,499,800 ha	1) Forest suitable for production:	14.16 mln ha, of which estimated 145,000 ha/yr for energy	1) Total roundwood production [d]:	56.9 mln m^3
	% Agricultural area:	9 %				280 PJ/yr
	% Forest area:	58 %	2) Energy crops:	17,065 ha	2) Energy production from:	< 1 PJ/yr
	% Natural area:	23 %	Rapeseed	821 ha	Wood	n.a.
	% Artificial area:	1 %	Cereals	440 ha	Straw	n.a.
			Willow	7 ha	Reed canary grass	
			Reed canary grass	15,763 ha	Energy crops	
The Netherlands [65]	Total area:	3,817,800 ha	1) Forest suitable for production:	0.21 mln ha	1) Total roundwood production [d]:	1.0 mln m^3
	% Agricultural area:	61 %			2) Energy production from:	
	% Forest area:	8 %	2) Energy crops:	3,000 ha	Wood	8.0 PJ/yr#
	% Natural area:	4 %	Rapeseed [c]	2,500 ha	Biogas	8.2 PJ/yr#
	% Artificial area:	13 %	Maize [c]	500 ha	Bioenergy crops for biofuels	15.6 PJ/yr##
						# the national statistics do not distinguish between imported and domestic biomass
						## incl. imports, probably > 90% of total
Slovakia [66], [67]	Total area:	4,901,600 ha	1) Forest suitable for production:	1.9 mln ha	1) Total roundwood production [d]:	8.9 mln m^3
	% Agricultural area:	50 %			2) Energy production from:	
	% Forest area:	40 %	2) Energy crops:	80,000 ha	Forest biomass	16.9 PJ/yr
	% Natural area:	5 %	Rapeseed [c]	25,000 ha	Agricultural biomass for burning	28.6 PJ/yr
	% Artificial area:	6 %	Sunflower [c]	55,000 ha	Wood-processing industry	22.0 PJ/yr
					Biomass for biofuels	7.0 PJ/yr
					Biogas	6.9 PJ/yr
					Biomass for electricity	40.6 PJ/yr

Sweden [68]	Total area: 44,799,100 ha % Agricultural area: 9 % % Forest area: 54 % % Natural area: 27 % % Artificial area: 1 %	1) Forest suitable for production: 21.14 mln ha, of which it is estimated that 700,000 to 900,000 ha/yr are used for energy 2) Energy crops: 100,000 ha Rapeseed 50,000 ha Cereals 35,000 ha Reed canary grass 780 ha Willow 13,000 ha Hemp 390 ha	1) Total roundwood production [d]: 77.2 mln m^3 2) Energy production from: Wood 130.0 PJ/yr Straw 1.2 PJ/yr Energy crops n.a.

a Source Corine Land Cover 2006, and the country studies referred to in the 1st column.
b Source: [14], unless otherwise indicated.
c Source: [60].
d Source: FAOSTAT (2009). Data refer to 2007.

vineyards, fruit orchards and citrus. Management input levels are very high, especially in relation to crop protection measures. Moreover, in central and southern parts of Europe these specialised crops also require much irrigation. It is expected that conversion from food and feed production to biomass for energy cropping may take place temporarily over limited areas in countries with a very flexible farm planning, like the Netherlands, Germany and Denmark [7]. Generally, these areas have practically no overlap with areas harbouring a high biodiversity, included in for example the High Nature Value (HNV) farmland [31] and/or Annex I Habitat categories [32]. The conversions of these land use types towards biomass for energy production would therefore not be likely to have major biodiversity impacts and might even improve the situation as it may lead to lower input use (e.g. water, pesticides and thus to lower water depletion and GHG emission risks [13]). However, direct positive effects will be more difficult to reach as biodiversity cannot always be brought back if already lost e.g. regarding plant diversity and soil organisms. The creation of so-called concentrations of more extensive farming for biomass production in these farmlands in the form of areal, linear or point elements of different sizes, could create opportunities (e.g. shelter belts, wildlife corridors) for improving the connectivity and permeability of the landscape. This will certainly be the case where these intensive farmlands have become large obstacles in a landscape where important bird species still continue to occur [16]. Also if the land use conversion would be from annual to perennial bioenergy crops, the potential for increased biodiversity would be present.

3.3.1.2. Conversion from medium intensity agricultural lands into bioenergy cropping. Conversions in the medium intensity land use categories may take place, including the more intensive permanent grasslands, short term set-aside and the more extensively grown food and feed crops [33]. These land use types can clearly be associated with certain types of farmland biodiversity values (e.g. farmland birds and mammals). So some part of the HNV farmland categories or Annex I habitat categories, certainly those important for specific bird populations, are overlapping with part of this group. The switch to biomass crops and the effects on biodiversity can be both positive and negative depending on the species involved. The indirect effects on biodiversity through improvement of water and soil quality may come when switched to perennial biomass crops [34]. But this latter shift may also lead to increased water consumption in places where this is scarce. This type of conversion may be expected all over Europe in cases where farmers intend to diversify their farm income, and where the hay production is not critical to the farming system, which implies a considerable threat for biodiversity.

3.3.1.3. Conversion from low intensity agricultural lands into biomass cropping. Land use types of low management intensity can be converted to biomass cropping [35–38]. These include farmland with high biodiversity values such as agroforestry areas (e.g. the *dehesas* and *montados* of Spain and Portugal [39]), long term set-aside and fallow lands, permanent grasslands of low grazing intensity and grazed shrub

Table 3 – Bioenergy targets and terrestrial resources.

	Population density[c] inh/km^2	Total biomass demand 2020[d] PJ	Total biomass demand for biofuels 2020[d] PJ	Total biofuel article 21.2 target[f,d] PJ	Total biofuel import 2020[d] PJ	Total biomass demand for heat & electricity[d] PJ	Land resources (2005) * 1000 ha[a] Total	Agriculture Total	Agriculture Annual + perennial crops	Agriculture Permanent grassland	Forest	% high nature value farmland[b]	% of UAA under natura 2000[e]	% forest area under natura 2000[e]
Belgium	344	202.7	33.1	5.4	0.0	170.0	3028	1385	519	866	667	19.5	7.3	33.6
Denmark	126	153.7	10.9	10.9	10.9	142.4	4243	2707	2585	189	500	5	4.9	15.9
Finland	16	346.7	23.4	19.7	0.0	323.2	30459	2274	33	2241	22500	44.9	0.9	10.6
Netherlands	394	158.7	34.8	24.7	21.8	123.5	3376	1921	980	941	365	14.1	4.6	38
Slovakia	99	37.7	2.5	2.5	0.0	35.2	4810	1941	524	1417	1929	22	16.3	45.2
Sweden	20	488.6	33.9	10.5	12.1	454.7	41033	3216	513	2703	27528	23.6	4.3	9

a FAOSTAT data 2005.
b Based on Ref. [31].
c Eurostat data 2008.
d Based on Ref. [26].
e European Union, Directorate General for Agriculture and Rural Development, Rural development in the European Union. Statistical and Economic information. Report 2010. http://ec.europa.eu/agriculture/agrista/rurdev2010/RD_Report_2010.pdf.
f This refers to the share of biofuel consumption to be based on ligno-cellulose material (e.g. 2nd generation biofuels).

lands, heathlands and moors. Many of these coincide with categories like High Nature Value farmland or agricultural Annex I habitats of the EU Habitat Directive [31,32]. Any change in use and management may put valuable farmland biodiversity at risk. However, if these land use categories are threatened by abandonment or underutilisation, the continuation of extensive management through the removal of biomass could be a good option for maintaining the natural richness of the systems. This type of conversion, which presents substantial threats to biodiversity can be expected all over Europe, especially associated with conversion into forest plantations [40].

3.3.2. *Forests*

There are clear differences in the utilisation of forests for bioenergy, between Scandinavia (Finland and Sweden) and countries in Central and Western Europe (Slovakia, Belgium, The Netherlands).

In Scandinavia the harvesting of energy wood in forests is already very important for the energy production and common practice in many forests. According to our own data, in Southern-Finland in 50% of the forests also the crown biomass is harvested and in 5% of the forests the stumps as well. This procedure was reported already 10 years ago [41].

The intensity of the forest harvesting in Scandinavia can have negative impacts on biodiversity [14] through:

- Loss of dead wood, which is considered the most important factor adversely affecting biodiversity in managed forests.
- Removal of stumps and roots and logging residues can also have a negative impact on forest plant species diversity and soil fauna, as well as on saproxylic species [42].
- Increased fertilisation (N and wood ash) may have impacts on vegetation [43,44].

Although in Belgium and the Netherlands the exploitation of forests is relatively intensive there is still limited use of forests for harvesting of bioenergy feedstock. The latter is also the case for Slovakia. In these countries logging residues are not used, stumps are not harvested and the yearly harvest is not more than 60% of the annual growth (stem wood) [30]. In these countries more harvesting for biomass for energy does not automatically lead to a loss in biodiversity. The use of logging residues and material from early thinnings in forestry for energy production is in many cases positive for biodiversity, through a decrease of the amount of sudden decomposition of organic matter in balanced forest ecosystems. However, research is needed to assess how much biomass can be harvested in different forest types with positive impacts or without negative impacts on biodiversity.

3.3.3. *Nature protection areas*

Specific conclusions on harvesting of biomass for energy from nature protection areas are difficult to draw because very little experience has been gained until now. Overall it is clear that this concerns vulnerable ecosystems in which disturbance of the natural equilibrium is negative for biodiversity. Removal of biomass should therefore be done very carefully and measured out well within strict limits of conservation

Please cite this article in press as: Pedroli B, et al., Is energy cropping in Europe compatible with biodiversity? – Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes, Biomass and Bioenergy (2012), http://dx.doi.org/10.1016/j.biombioe.2012.09.054

Table 4 – Overview of biodiversity effects resulting from land use transitions toward different types of dedicated bioenergy cropping (after Ref. [69]).

Type of land use transition	Present land use categories	Type of crops/use	Typical biodiversity values	Negative impacts on habitat quality	Negative impacts on species	Positive impacts on habitat quality	Positive impacts on species
From *very intensive land use* to bioenergy crops	Horticulture in glasshouses, polytunnels, horticulture, root crops	Flowers, vegetables strawberries, flower bulbs, vegetables, potatoes, sugar beet	None, biodiversity values have already disappeared	None	None	Fertilisers, herbicides and pesticides reduced. Improved soil and water quality, water availability for non-agricultural uses (e.g. biodiversity)	Higher landscape structural diversity improving connectivity and permeability of the landscape for birds and invertebrate species. Improved soil biodiversity
From *intensive arable and permanent crops* to bioenergy crops	Sugar, starch and oil crops, intensive fodder crops, permanent crops	Winter wheat, barley, maize, rice, rye, rape, sunflower, temporary grass; fruit orchards, citrus, nuts, olive groves and vineyards	None, biodiversity values have practically already disappeared, except for some more common farmland birds and mammals	Shift to a more intensive crop: higher input use and tillage, negative implications for water (pollution and eutrophication) and soil quality (pollution, erosion and compaction)	Shift from permanent crops to rotational arable: tillage increases with major impacts on soil and water quality, soil organisms	Shifts from rotational arable and permanent crops to perennials: less fertilisers, pesticides, herbicides and water use; positive impacts on soil and water quality, water availability	Shifts from arable to perennials crops: lower mechanisation (tillage) beneficial to soil biodiversity; greater diversity in landscape structure, connectivity and permeability of the landscape for birds and mammals
From *medium to low intensive land uses* to bioenergy crops	Permanent grass (intensive); fodder crops – with short term fallow; extensive arable	Grass, silage production, grazing, triticale, alfalfa, etc. Summer wheat, barley, rye, etc.	Some HNV farmland areas found in this category, certainly those supporting meadow and steppe birds (e.g. lapwing, partridge, great bustard). Practically no Annex 1 habitat types occurring here.	Shift to more intensive crops (e.g. to sugar beet, OSR): higher input use and mechanisation (tillage) with negative implications for water and soil quality (pollution, erosion and compaction)	Conversion to bioenergy crops may lead to loss of habitat for a range of mammal, bird and invertebrate species	If perennials are exchanged for intensive permanent grassland this may lower input of fertilisers and positive effect on water quality, but increased tillage (although limited) may encourage soil erosion.	Some species (certain birds and small mammals) might profit from introduction of perennial crops in typical open monotonous permanent grassland or arable landscapes as they provide shelter and nesting opportunities.
From *low intensive land uses* to bioenergy crops	Agro-forestry (incl. Dehesas, Montados) Traditional + long-term fallow (Mediterranean) scrub, moors and heathlands Permanent grass (extensive) Wetlands	(Cork) oak, olives, chestnuts, trees-grass, trees-cereals, sometimes grazed with pigs, goats, cows; fallow; some very extensive grazing	This type most strongly coincides with high nature value farmland. Many Annex I habitat and species types occur in this group.	Shift to bioenergy cropping: changes in traditional management, increased input uses, more mechanisation and disturbance of landscape structure, negatively influencing water quality and quantity and soil quality	Shift to bioenergy crops: adverse effect on farmland biodiversity leading to direct loss of farmland habitats and specific landscape structure with equilibrium between low intensity agricultural management and a mix of species of different biota	Low intensive management (biomass removal) may enhance nature value. Biomass demand could be an economic stimulus to continue managing these areas instead of completely abandoning them.	Extensive management of semi-natural grasslands creates more opportunities for a wider diversity of farmland birds, invertebrates and small mammals.

objectives [45]. The question is then whether this can at all be made economically viable. There is in fact no evidence in the statistics from the case studies that these lands are used for biomass harvesting, except for small scale household use (heating).

Some types of nature are semi-natural (heather, reed-cultures, alms, etc. [46]). Without harvesting, these areas will develop into other nature types which are less desirable from a biodiversity point of view [47]. However, generally it is important to use small-scale harvesting techniques to preserve biodiversity [45], which do not offer much room for biomass harvesting for energy production purposes.

Another example of removal of biomass from a natural or semi-natural ecosystem is peat-winning. Peat excavation from mires has initial drastic effects on biodiversity; both species composition and whole habitats are affected [48]. Some studies have shown successful restoration (e.g. [49]), while other excavation sites are permanently changed into a different habitat type [50]. There is also much literature on the environmental and health consequences of peat combustion (see e.g. [51,52]). Peat harvesting should be considered as a threat to biodiversity in most cases, although on very small scale it is sometimes suggested that it could contribute to biodiversity conservation [53]. It should be pointed out, however, that peat is not really renewable biomass [14]. There is only 20% of the original carbon of phytomass left in peat, about the same as in oil or coal. Thus peat should be considered as a fossil fuel.

3.3.4. *Abandoned or degraded lands*

Several studies have shown that there are large biomass resources available on abandoned or degraded lands [9,36,40], that may help to meet the world's ever-growing energy demands. Campbell et al. [37] estimate that the global area of abandoned agricultural land is 385–472 million hectares, which could satisfy almost 8% of current global energy demand. However, the socio-economic context (land rights, subsistence farming) may vary widely. Conversion of abandoned lands into biomass cropping may have positive effects on biodiversity rehabilitation, provided that chosen crops offer habitats for traditional farmland species. Furthermore, well-planned biomass harvesting may alleviate the management costs of semi-natural lands, when the management objectives require removal of nutrients or of shrubs and trees. In Mediterranean environments, biodiversity may even be enhanced when biomass harvesting decreases the risk of forest fires.

3.3.5. *Urban green and recreation areas*

The urban land resources with considerable biomass potential and where biomass harvesting is best to be combined with biodiversity include street plantations, road side verges, urban green and many types of recreation areas [54,55]. Removal of biomass is part of the normal maintenance of these areas. Conversion of removed biomass towards energy or other products will only increase the economic efficiency of managing these areas. Although these land resources tend to have a lower cost-effectiveness compared to energy crops or forest residues, they could provide a large biomass potential, provided sufficiently high financial incentives are in place, especially in countries where the management of these types of plantations is well organised, and where biomass power stations are widespread, like Denmark, Netherlands, Germany and the UK, see e.g. [56].

4. Discussion

4.1. *Bioenergy: threats to biodiversity*

There is a large variation in conditions and land use types that determines the exact consequences of conversion. However, little scientific evidence appears to be available yet on these effects. Some preliminary hypotheses are discussed below.

Bioenergy harvesting results in a number of threats to biodiversity. Increased biomass cropping may lead to further intensification of farming and to the conversion of habitats of high biodiversity value to arable land with decreased biodiversity. This effect may even be amplified through the increased pressure on the land otherwise available for food production. Conversion to biomass cropping in sensitive areas (either dryland or wetland) is especially threatening to biodiversity, due to substantial changes in water management and, hence, soil ecosystems. Decreased landscape diversity may result in loss of pollinators, weakened natural pest control and misbalance in ecosystem functions.

The increased demand for biomass may further increase the pressure on precious High Nature Value farmland and forest resources with high biodiversity value.

Harvesting too much of dead wood from forests may have negative impact on soil fauna and biodiversity in plant species. Also, disturbance by more frequent management of the forests may negatively affect soils and biodiversity. Finally, peat harvesting should be considered a threat for biodiversity in most cases.

4.2. *Towards sustainable bioenergy harvesting*

In contrast to the above-mentioned threats, the use of bioenergy also provides opportunities for improved biodiversity.

When highly intensive arable land is converted into diversified biomass cropping, this can certainly lead to a biodiversity increase through decreasing adverse inputs and – especially with perennial crops – decreasing disturbance of soil and the biota in general. If abandoned lands are converted into biomass cropping, this may have positive effects on biodiversity rehabilitation when crops are chosen that offer habitats to traditional farmland species. Well-planned biomass harvesting may alleviate the management costs of semi-natural lands, when the management objectives require removal of nutrients or shrubs and trees.

The use of logging residues and material from early thinnings in forestry for energy production is in many cases positive for biodiversity, through a decrease of the amount of sudden decomposition of organic matter in balanced forest ecosystems. In Mediterranean ecosystems biodiversity may be enhanced by biomass harvesting through a decreased risk of forest fires.

Perennial biomass crops may be planted as shelter belts, offering new habitats and migration opportunities for plant and animal species. The same applies for street plantations in urban environments, or new landscape structures in agricultural regions.

Within agricultural lands certain conversions to biomass crops, especially perennial crops, may lead to increased diversity in cropping patterns, lower input uses, and higher landscape structural diversity which may all have positive direct or indirect effects on biodiversity [14]. The extent to which this will be positive all depends, however, on what land use shifts are taking place, in terms of new crops and new management practices, and the scale of change. In The Netherlands, Belgium and Denmark introduction of bioenergy crops may help to decrease the intensity of farming in terms of declines in inputs and mechanisation and enhancement of landscape diversity and structure, especially if perennial crops are introduced. However, in these highly intensive agricultural production areas it is also likely that introduction of bioenergy crops will lead to increased demand for imports and thus to indirect land use changes. However, recent studies indicate that a stronger focus on smarter production and management methods may reveal new opportunities combining efforts for energy production, reduction of GHG emissions and environmental protection in agriculture [28].

In production forest there are also opportunities to harvest additional wood residues which have not been removed for existing forest industry purposes. Removal of these wood residues may become economically attractive under increased biomass demand. It should however carefully be investigated to which extent additional removal of wood can be combined without damaging biodiversity or soil nutrient balance, or causing leakage of mercury [57]. In countries like Sweden and Finland which have already a most efficient forest management and high harvest rates, the chances of increased biomass removal leading to biodiversity loss are much higher than in countries like Slovakia, Netherlands and Flanders where harvest rates are much lower.

Additionally, there is a considerable biomass potential that can be exploited from lands that have other land use functions, such as recreation areas, road side verges, semi-natural and natural areas and lands that have no present use because they have been abandoned, polluted or degraded. The multifunctional land use option is particularly interesting for the highly urbanised, densely populated regions like those of The Netherlands and Belgium. Options for the use of abandoned lands are an interesting option for a country like Slovakia; intensification of production in more robust areas – leaving less robust areas to perennial crops – may open opportunities to produce the same amounts of food and fodder (i.e. no indirect land use change) while also improving landscape diversity in terms of biodiversity. Removal of additional biomass from nature conservation areas can further be investigated in all case countries but suitability strongly depends on the type of ecosystems present.

It should also be mentioned that we cannot only focus on the need to prevent biodiversity loss or create synergies with biomass cropping and harvesting in Europe only. EU's increased demand for biomass will cause many direct and indirect land use changes outside Europe as well. Firstly, since the land potential within the EU is limited or it is less economical to bring additional land into arable use for biomass production, international imports of biomass will increase. At the same time it may also lead to higher demands of food and feed imports into Europe if part of domestic food and feed production is replaced with biomass. One way or the other, pressures on land and related increased pressure on biodiversity will be more severe outside Europe. The principles described in this study apply to land use conversions and related biodiversity effects in all places of the world. The main concern is however that if these occur in Europe, legislation and control will often be in place that may prevent negative shifts, while in many parts of the non-European world the protection against adverse land use conversions is less effective.

5. Conclusions

5.1. *Biodiversity effects differentiated for regions of Europe*

From our study it can be concluded that connected to the predominant methods of biomass production in dependence on geographical characteristics, also the most conspicuous biodiversity effects are differing. The following adverse effects are associated with the various bioenergy production options, typical for the regions studied:

5.1.1. *Conversion of agricultural lands into biomass production areas (especially central Europe)*

- conversion of high nature value agricultural lands with low production potential into monocultures of biomass production;
- threats for territorial stability by shifting agricultural production;
- increase of natural risks and hazards in monoculture production systems.

5.1.2. *Forest biomass and – less extensive – peat exploitation (especially northern Europe)*

- decrease of amount of dead wood and of biodiversity in soil organisms, microbial activity and diversity;
- increasing acidification and eutrophication;
- physical soil disturbance;
- disturbance of the hydrological cycle;
- decrease of rare and high nature value peat ecosystems.

5.1.3. *Use of animal manure and energy maize in small scale biogas installations (especially the lowlands: Belgium, Netherlands and Denmark)*

- acidification through NH_3-emission;
- overuse of cuttings in agricultural landscapes;
- loss of permanent grassland, converted into energy maize cropping.

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5.2. The challenge of increasing bioenergy cropping

The six case study countries as well as the EU at large have decided on substantial challenges in terms of increasing the shares of renewable sources of energy in the energy systems. A substantial part of this increase will rely on biomass for bioenergy, and increases in all countries have been reached since 2005, however revealing large differences in growth in the preceding years, as well as large differences in the distance to target. Intensification and expansion or reclaiming of the cultivated areas are some of the solutions sought. Some studies point to smart combinations of intensification, management and environmental protection as pathways to increased bioenergy potential release. The quality of combinations and land use change and practices will have implications for biodiversity development.

The way biodiversity is affected depends on the point of departure in land use – intensive, medium intensive and extensive land uses – and also to which type of bioenergy crop it is converted into. Sometimes no conversion takes place – rape can be used for fodder as well as for bioenergy – but intensity of management may change. Likewise, the substitution of intensively cultivated crops to perennials may have positive impacts on both above ground and soil biodiversity. In the other end, abandoned land may benefit from being kept in production, if use is not intensive.

Larger and serious threats are related to the areas, which are today high in biodiversity, and under low and extensive management. These will almost certainly deteriorate in terms of biodiversity. Mowing and cutting for bioenergy purposes are in general not very likely to take place, unless it is creates an obvious and cost effective option of combining bioenergy raw material provision and biodiversity management. This is due to the low hay productivity of these areas, and the often fragmented character of small landscape elements, which poses technological and economic challenges.

Different trends can be observed across Europe. In this study we see that some countries move faster forward than others – Sweden demonstrating 8% growth in share of consumption from 2005 to 2010, while for The Netherlands only a 1.2% growth is observed. Also, some countries import larger shares than others (Denmark imported 23% of the bioenergy feedstock in 2010). However, across the different ways countries use their biomass for bioenergy, potential for improvement seems to be available, e.g. in a large unused resource in agricultural waste.

5.3. Further research needs for optimal land-based biomass use

Firstly it should be considered that very drastic changes like shifts from the most extensively used land to intensive arable uses, are not very likely to occur from an economic and technical point of view. Research on the effects of conversions of land and management should therefore be prioritised towards most likely shifts and should not only focus on the environmental and ecological effects, but also on the economic and technical aspects.

It is clear that there is much need for more empirically based research on the biodiversity effects of biomass cropping and harvesting. Although a range of circumstances is covered by the countries studied, they can evidently not represent the whole spectrum of EU countries, especially not the Mediterranean and Alpine countries.

From the above it is clear that most mechanisms discussed are expert based and build on research results in relation to wider agricultural and forest management practices and developments not specifically linked to biomass cropping [58]. Little research has specifically investigated the effects of novel biomass crops such as short rotation coppice and perennial biomass grasses, on biodiversity, although the number of publications in this field has shown a gradual increase in the last years [29,34,59]. The problem, however, is that experimental research is still limited, involving very small samples only in the first few years after establishment. Since these plantations exist for 15–20 years, long term observations are needed but practically not available yet. Other research needs are related to identifying and field testing of farm management practices for biomass cropping at different scales within the wide variation of European agro-ecosystems. There is a need to explore win–win options for energy cropping in combination with nature conservation and with climate adaptation (e.g. promoting agroforestry or buffer strips). Eventually landscape planning methods for introducing dedicated biomass crops in the landscape are needed, that integrate productivity objectives with reduced environmental and biodiversity impacts.

On the longer term biomass cropping is assumed to alleviate climate change, which theoretically should be beneficial for biodiversity. No empirical evidence is available thus far to determine how much biomass should be produced to reach these effects in a measurable way. However, the IPCC findings give a clear indication that warming beyond 2–3 degrees will lead to a significant risk of biodiversity loss [60]. Several scenarios surveyed in the IPCC and published since (see e.g. [61], and the annual World Energy Outlooks by the International Energy Agency IEA) offer indications on the scale of biomass input required to avoiding a temperature increase above 2 °C. All of these scenarios have limitations and are subject to uncertainty but any prediction up to 2100 is poised to have these limitations.

Acknowledgements

Research for this paper was undertaken within the cooperative framework of the EU FP 6 Network of excellence ALTER-Net (A *Long-Term Biodiversity, Ecosystem and Awareness Research Network* (http://www.alter-net.info/)).

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Please cite this article in press as: Pedroli B, et al., Is energy cropping in Europe compatible with biodiversity? – Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes, Biomass and Bioenergy (2012), http://dx.doi.org/10.1016/j.biombioe.2012.09.054