European Commission

Study on Impacts on Resource Efficiency of Future EU Demand for Bioenergy

Task 2: Analysis of impacts of biomass production on natural resources and the global environment

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Table of Contents

1. Summary

Impacts of the energetic use of wood on natural resources and the global environment are manifold. While many studies have examined land use change emissions associated with biofuels, fewer studies can be found that assessed implications (mostly GHG emissions) of increasing the use of wood for biofuels and for heat and power compared to alternative uses of the wood.

The aim of the literature review is to provide an in-depth analysis of the potential impacts of the energetic use of wood, and its possible increase, on natural resources and the global environment, namely biodiversity, soils, water bodies, greenhouse gas emissions and indirect land use effects.

The literature review for <u>environmental and economic impacts</u> (both positive and negative) covers the impacts on biodiversity, soil, water, GHG-emissions, land use and indirect effects and economic impacts. A set of 40 references was considered relevant after categorization from an initial list of 202 references. Furthermore, nine references have been reviewed regarding measures and instruments related to the cascading use of biomass.

The main results from the literature review are:

- From a **biodiversity** perspective the review showed that two aspects are of high relevance: a) the protection of areas with high biodiversity value and b) sustainable extraction rates of dead wood, residues, stumps and old trees.
- The review showed that most **soil** impacts are very site specific and require respective soil conservation measures (e.g. restriction on residue and stump extraction)
- The identified impacts on **water** are of lower relevance compared to e.g. impacts on biodiversity and soil (focus on rain-fed systems).
- Strong impacts on **greenhouse gas emissions** from biomass production occur when areas of high carbon stock are converted to bioenergy plantations of low carbon stock, but also an increase of wood extraction, including whole tree harvest and residue extraction, can lower the carbon stock of forests.
- **Indirect effects** and also **economic impacts** are mainly related to competition between different biomass uses (energy, material) and occur for biomass resources that can potentially be deployed for different uses e.g. stem wood. Such effects are limited for the use of branches, stumps and residues.
- The most central issues and proposed methods for increasing cascading are the need for clear definitions of **cascading use** over the whole biomass lifecycle; imposition of taxes, subsidies and legal measures to promote cascading use; and cross-disciplinary dialogue for developing more efficient logistical and technological solutions in different cascading stages.

2. Introduction

The 'Roadmap to a Resource Efficient Europe'[1] and 'Roadmap for moving to a competitive low carbon economy in 2050'[2] of the European Commission identify land use and the food sector, beside the housing and mobility sectors, as key domains for effective restructuring and climate change mitigation. Relevant for the land use sector, the Resource Efficiency Roadmap requests e.g. the restoration of ecosystems and of biodiversity, an increase of soil carbon contents, and prevention of soil erosion. Also, the Resource Efficiency Roadmap refers indirectly to the land use sector by encouraging the substitution of carbon intensive materials e.g. in chemistry and construction by bio-products.

However, there is a challenge in regard of the overall outcome regarding net GHG emissions and efficient use of resources if individual policies and strategies impacting on land use, biomass production, trade and use are not integrated. Furthermore, impacts on other ecosystem services, competing sectors and triggered feedback mechanisms across sectors and economic actors is not appropriately quantified and understood. The poor understanding of these issues is due to the complex nature of global land use and due to the fact that the land use sector is closely connected to other sectors. Measures directly targeting this sector have implications on others and vice versa.

The impacts of biomass use on GHG emissions and associated land use and land use change are among the more researched biomass impacts. They were already studied in the 1990s (e.g., Leemans et al. 1996; Marland and Schlamadinger 1997) when direct land use change effects were also considered in life cycle assessments (LCA) studies. Most studies addressed land use change emissions associated with biofuels (e.g., Gibbs et al., 2008; Searchinger et al. 2008). However, some assessed also implications (mostly GHG emissions) of increasing the use of solid biomass for biofuels (Forströmm et al. 2012, Havlík et al 2011) and for heat and power (Cherubini 2010; Latta et al. 2013; Gerssen-Gondelach et al. 2014) compared to alternative uses of the wood (Böttcher et al. 2012; Matthews et al. 2014a). These impacts include trade-offs and synergies. The key challenge in the assessment of direct and indirect effects is the delineation of system boundaries and the development and application of appropriate methods and metrics to assess impacts within those.

Besides GHG emissions, other effects need to be considered when evaluating the impacts of biomass use and its expansion such as the potential loss of biodiversity and habitats or effects of cropland intensification and nutrient losses (IINAS/EFI/JR 2014). Some studies have explored the impact of biofuel production on biodiversity (Britz and Hertel 2009, Eggers et al. 2009, Hellmann and Verburg 2010). These impacts include trade-offs and synergies. There are many examples where existing land management is sub-optimal, resulting in various forms of desertification or degradation including wind and water erosion, sedimentation of rivers, rising groundwater levels, groundwater contamination, eutrophication of rivers and groundwater or loss of biodiversity. In several cases, the increased efficiency in biomass production may result in an improvement in overall land management (Smith et al. 2013).

The objective of this project ("Study on the Impacts on resource efficiency of future EU demand for bioenergy") is to investigate and assess the resource efficiency and implications of different future scenarios of increased use of bioenergy for electricity

[1] COM/2011/0571/final
[2] COM/2011/0112/final

and heat in the EU, including impacts on natural resources and on the environment and also indirect impacts of increased use. For the purpose of this study, "biomass" is defined as all kinds of cellulosic material from existing forestry operations, new plantations, short rotation coppice, dedicated crops, plus organic residues or waste used as a material or for energy.

2.1. Aim and methodology of Task 2

The aim of the literature review is to provide an in-depth analysis of the potential impacts of biomass production, and its possible increase, on natural resources and the global environment. The review focuses on quality, applied methodological approaches, and coherence between studies. Also shortcomings and limits of existing studies are subject to the review. This literature review is not a stand-alone product. A central aim is to provide a scientific balanced base for further work under Task 3 (modelling) and Task 4 (analysis of impacts).

The literature review for environmental and economic impacts (both positive and negative) covers the impacts on biodiversity, soil, water, GHG-emissions, land use and indirect effects and economic impacts. Each impact category is sub-divided in detailed impacts, e.g. soil erosion, soil carbon loss, soil compaction, soil nutrient loss and soil salinization for the category soil (see details in Appendix 1). Relevant references are selected from a list of potentially suitable references. Each selected reference is screened for the mentioned impact categories as well as the cause of impact and the suggested response. In total 40 references out of a list of 202 references have been covered.

Beside the analysis on the above mentioned impacts this literature review also covers a review of measures and instruments promoting the cascading use of biomass. For this topic much less references are available compared to environmental and economic aspects. In total nine references have been covered in the review. The references have been screened for measures and instruments related to the cascading use of biomass.

2.2. Use of the assessment within the project

The main outcome of the literature review is an evaluation of the (positive and negative) impacts most relevant to the scope of the study. Based on this, a set of impacts to be incorporated into the modelling work carried out under Task 3 have been proposed. These results will be further considered when developing the methodological framework of the modelling work e.g. as constrains in scenarios (Task 3.1).

Furthermore under task 3.1, the outcome of the literature review is used to develop sustainability indicators that can be linked with model output and thus be considered in the analysis of the impacts under Task 4. Here quantitative indicators directly calculated in the model framework, qualitative indicators derived from model outputs and from the literature review are used.

2.3. Overview of the structure of the report

Each environmental and economic impact as well as cascading use of biomass is covered in a single section. Following a short introduction, impacts from the use of biomass are reviewed for each topic separately to understand:

- impacts of biomass production and its increase;

- impacts of conversion, transport and use of biomass.

The review also includes responses to the impacts suggested in the reviewed references.

Following this review, conclusions are drawn about which identified impacts should be covered in the modelling framework. Furthermore we indicate how these impacts could be implemented and which datasets might be suitable for this work.

3. Biodiversity

Habitat loss as a result of land-use change is the major threat to biodiversity, with over 80% of globally threatened birds, mammals, and amphibians affected wholly or in part by habitat loss. Other prominent factors causing the decline of biodiversity are habitat fragmentation and isolation, land-use intensification and overexploitation, species invasions, and adverse climate-change impacts (see overview in Hennenberg et al. 2010).

The use of biomass for energy purposes can be one driver causing loss of biodiversity linked primarily to direct and indirect land-use change and increasing intensity of land use. The increasing use of biomass is likely to increase this pressure, with the exception that the increase of biomass extraction is embedded in biodiversity protection measures. In consequence, regulations and international agreements in the context of the energetic use of biomass (e.g. RED 2008, GBEP 2011) as well as voluntary certification systems (e.g. FSC, PEFC, RSB) address the protection of biodiversity.

The screening of literature carried out in this project focussed on the following detailed impacts: loss of species, loss of ecosystems, damage of flora and fauna and loss of ecosystem functions.

3.1. Impacts from the use of biomass on biodiversity

3.1.1. Impacts of biomass production and its increase

An overview of impacts addressed by studies and identified in the in-depth review is summarised in Table 3-1. First of all, the loss of areas with high biodiversity value is mentioned as an important impact that can follow unsustainable biomass production. In consequence, the protection of valuable areas is of high importance, including existing protected areas as well as valuable areas without a protection status (GBEP 2011, OEKO/IFEU/CI 2010, Berndes et al. 2013, Gove et al. 2010; see possible response in Table 3-1). These areas shall be completely excluded from biomass production or the land use shall be adopted in a manner that the protection goal can be achieved.

Beside protection of areas with a high biodiversity value, sustainable cultivation practices are needed that increase or at least preserve habitat quality, especially for rare, threatened and endangered species. A central negative impact on biodiversity from forest management is due to a low amount of dead wood in intensively managed forest ecosystems as habitat features for saproxylic organisms. Negative impacts can be further caused by the removal of logging residues (fine and course woody debris), whole tree harvest and the extraction of large dead wood (Müller and Bütler 2010, Abbas et al. 2011, Bouget et al. 2012, Fernholz et al. 2009, Tuomasjukka et al. 2014, Baral and Malins 2013, Verkerk et al. 2011, Hart et al. 2013). Regarding possible responses, Müller and Bütler (2010) stress the importance of heterogeneity of dead wood for the protection of biodiversity. From their literature review they derived threshold values to guarantee a sufficient amount of dead-wood and dying trees with respect to the protection of biodiversity including all dead wood fractions (peak-dead wood-values at 20–30 m^3 ha^{-1} for boreal coniferous forests; 30–40 m^3 ha^{-1} for mixed montane forests; 30–50 m^3 ha^{-1} for lowland oak–beech forests; see Müller and Bütler 2010). Furthermore the extraction of rare dead wood fractions like large dead wood should be avoided (Fernholz et al. 2009), residue harvesting in stands with high ecological values should be excluded and large scale extrapolation should be avoided (Bouget et al. 2012; see also Tuomasjukka et al. 2014). Such aspects should be included in site and resource specific management guidelines (Abbas et al. 2011, Hart et al. 2013, Baral and Malins 2013) or active measures against high biomass removal should be undertaken (Verkerk et al. 2011). Nevertheless, the production of forest biomass may affect the forest biodiversity positively (e.g. management of neglected forests; wood extraction to achieve nature protection goals).

The extraction of stumps can negatively impact biodiversity due to the loss of microhabitats found in stumps (Bouget et al. 2012, Moffat et al. 2011). In consequence, Bouget et al. (2012) advise as response to avoid large scale exportation of stumps as well a prohibition of stump extraction in areas with high ecological value. The identification of sensible areas should occur by a risk assessment on a site level (Moffat et al. 2011).

Old and dying trees show rare habitat features in managed forest (Bouget et al. 2012, Hart et al. 2013). Harvest of these trees should also be avoided, especially those of broad-leaved tree species (Bouget et al. 2012, see also Tuomasjukka et al. 2014).

Another aspect that was less prominent in the reviewed literature is the negative impact on biodiversity that can occur from invasive species, including tree species, cultivated for bioenergy use. These species should be avoided because they can spread out and can cause uncontrollable impacts outside of the production area (GBEP 2011).

The detailed impact "loss of ecosystem functions" was not explicitly mentioned in the reviewed references. However, it is well known that impacts like loss of species and ecosystems can directly result in a loss of ecosystem functions (e.g. Groom et al. 2006).

With regard to impacts of short rotation coppice (SRC) on biodiversity, the effects can be positive as well as negative. A differentiation among animal groups, previous land use, spatial structures and ecological conditions of SRCs is needed. For example, short rotation coppice, short-rotation forestry and Miscanthus appear to support a higher abundance and diversity of bird species than arable or improved grassland (Gove et al. 2010).

In addition, the respective landscape concerns need to be considered (Dimitriou et al. 2011). However, the cultivation of SRC on former intensively managed cropland is likely to show positive impacts on biodiversity while impacts tend to be negative on high biodiversity agricultural lands (Berndes et al. 2013).

Table 3-1 Cause of impact on biodiversity from biomass production and possible response found in literature

Cause of impact	Possible response
Loss of ecosystems – Valuable area (including areas with high biodiversity value)	
Degradation of valuable areas, protected areas, fragmentation, missing buffer zones, use of invasive species (OEKO/IFEU/CI 2010)	Scheme for mapping relevant areas, prior use of uncritical unused-land and making use of biodiversity friendly cropping methods (e.g. next to protected areas) (OEKO/IFEU/CI 2010)
Conversion of areas of high biodiversity value or critical ecosystems to areas of bioenergy production (GBEP 2011)	Not specified
Deforestation (Forestry Commission Scotland 2009)	Creation of forest habitat networks and new native woodlands (Forestry Commission Scotland 2009)

Replacement of native woodland or other biodiversity-rich habitats by energy crops (Gove et al. 2010)	Not specified
High volumes of timber and biomass harvested in more intensive forest management systems (Hart et al. 2013)	Not specified
Loss of biodiversity due to SRC cultivation if land already has a high biodiversity level (Berndes et al. 2013)	No SRC on high biodiversity agricultural lands (Berndes et al. 2013)
Short-rotation forestry and Miscanthus more likely to be colonized by species of disturbed or edge habitats, whereas woodland specialists are unlikely to establish without deliberate encouragement (Gove et al. 2010)	Re-introduction of traditional forestry management techniques, such as coppicing, and better use of our forestry resources (Gove et al. 2010)
Biomass crops such as SRC, short-rotation forestry and Miscanthus appear to support a higher abundance and diversity of bird species than arable or improved grassland (Gove et al. 2010)	No specification
Loss of species – Stumps	
Stump harvest as stumps show often microhabitats for rare species (Bouget et al. 2012);	No stump harvesting in stands with high ecological values, avoid large scale extrapolation (Bouget et al. 2012)
Loss of species that depend on dead wood and microhabitats in stumps (Moffat et al. 2011)	Careful assessment of risk at a site (Moffat et al. 2011)
Loss of species – Dead wood / Residues	
Absence of a sufficient amount of dead wood / dying trees as dead and dying trees have been shown to be a key habitat feature for a broad range of saproxylic organisms (Müller and Bütler 2010)	Guarantee an amount of dead-wood /dying trees above threshold value. (summary: peak-dead wood-values at 20–30 m^3 ha^{-1} for boreal coniferous forests, 30–40 m^3 ha^{-1} for mixed montane forests, and 30–50 m^3 ha^{-1} for lowland oak–beech forests. Beside the amount of dead wood its heterogeneity is of importance (Müller and Bütler 2010)
The removal of coarse and fine woody debris has an influence on maintaining ecosystem wildlife and biodiversity habitat resources (Abbas et al. 2011)	Site and resource specific management guidelines (Abbas et al. 2011)
Loss of habitats for deadwood specialists by removal of logging residues (fine and course woody debris) and whole tree harvest (Bouget et al. 2012)	No residue harvesting in stands with high ecological values, avoid large scale extrapolation (Bouget et al. 2012)
Loss of large dead wood (Fernholz et al. 2009)	No harvest of large dead trees (Fernholz et al. 2009)
The lack of dead and decaying wood is threatening many forest species and renewable energy targets are increasing that threat (negative effects on beetles, shrubs, structural diversity of tree, mosses, liverworts; positive effects on diversity of trees and small mammals) (Tuomasjukka et al. 2014)	Concentrate conservation efforts on areas where biodiversity still rich; care to be taken with energy wood harvesting near nature reserves, retain old living and dead trees especially deciduous oak, lime and aspen (Tuomasjukka et al. 2014)
Removal of forest residues (Baral and Malins 2013)	Adoption of best harvesting practices. A certain portion of residues should be left behind to ensure the adequate species abundance and diversity(Baral and Malins 2013)

Extracting forest biomass for energy production may result in loss of deadwood and hence biodiversity (Verkerk et al. 2011)	Undertaking active measures taken against high biomass removal (Verkerk et al. 2011)
Harvesting and extraction of forest residues and dead wood (Hart et al. 2013)	Protection or management of forest with the purpose of constraining harvesting activities (Hart et al. 2013)
Loss of species – Habitat trees	
Harvest of old / dead / dying trees that are habitats for deadwood specialists (Bouget et al. 2012);	No harvest of habitat trees, especially of broad leave trees (Bouget et al. 2012)
Selection and specialisation of forest tree species to fewer types (Hart et al. 2013)	Not specified
Biodiversity – Damage of flora and fauna	
Due to invasive species (GBEP 2011)	Not specified
Miscanthus crop plants provided less insect food than wheat crop plants (Bellamy et al. 2009)	Management for wildlife (Bellamy et al. 2009)
Modifications to stubble heights and straw management in-situ which could reduce cover for small farmland birds and increase their predation risk (IEEP et al. 2010)	Increased planting of cover crops as part of an optimised crop rotation that provide alternative winter fodder ground for birds (IEEP et al. 2010)

3.1.2. Impacts of conversion, transport and use of biomass

The selected references did not address impacts on biodiversity from the conversion, transport and use of biomass. This can be interpreted as the fact that such impacts are of minor importance compared to impacts occurring from biomass production. Impacts on biodiversity from conversion, transport and use of biomass often occur as "co-impacts" to other aspects like pollution of waterbodies or soil degradation.

3.2. Proposals to address biodiversity impacts in the modelling framework

From a biodiversity perspective the review showed that two aspects are of high relevance and it is proposed to cover them in in the modelling framework:

1. The protection of areas with high biodiversity value
2. Sustainable extraction rates of dead wood, residues, stumps and old trees

The first aspect could be implemented by the exclusion of already known valuable areas like protected areas (e.g. World Database on Protected Areas), primary forests (e.g. Forest Intact Landscape) and peatland areas (Harmonized World Soil Database, GLC 2000) from biomass production. Furthermore, the overlay of maps on the distribution of rare and threatened species from different species groups can be used to derive areas of high biodiversity value that are currently not protected (e.g. UNEP-WCMC biodiversity atlas; compare Table 3-2). These areas may also be excluded from biomass production. Mapping initiatives for rare and endangered species (e.g. Key Biodiversity Areas, Important Bird Areas, Important Plant Areas, Alliance for Zero Extinction), however, appear not to be easily usable in this project as they are not globally available and they are not freely available.

Sustainable extraction rates (point 2) for dead wood, residues, stumps and old trees should to be specific to forest types and regions. A differentiation between boreal, temperate, sub-tropical and tropical forests appears reasonable. The models applied by IIASA differentiate between stem wood, branches and stumps. Harvesting rates of these fractions should be set to a level as to assure a sufficient amount of dead wood. Given that adverse effects are clearly site and management specific in nature, these can be minimized through site-specific forest guidelines and best practices in forest management. These already exist in a number of EU Member States (as well as in third countries) and include for instance the type and amount of logging residues that should be left in the forest for biodiversity reasons (guidelines in Sweden suggest a 20% retention level, in Finland 30% and in the US state of Minnesota 20%).

The challenge is the selection of suitable thresholds that can be used in the model work. Thresholds for the extraction of dead wood could follow the results from Müller and Bütler (2010), e.g. leaving 30 m^3 ha^{-1} stem wood as dead wood and old trees in boreal coniferous forests. Less concrete responses found in the literature like the avoidance of large scale exportation of stumps (Bouget et al. 2012) need to be translated in reasonable thresholds, e.g. a maximum of 10% stump extraction.

Negative impacts from invasive species are difficult to address in models as the impacts will not occur on the production area. However, the yields implemented in IIASA models are based on native species for each region. This means that the models assume no cultivation of invasive species that may show higher productivity compared to native once.

Similarly, the cultivation of genetic modified organisms (GMO) may cause negative impacts on biodiversity outside of the cultivation area. GMO may show higher yields or may require less inputs compared to non-GMO that, e.g., may result in lower GHG-emissions in an LCA. However, this assessment is out of the scope of the applied models.

Table 3-2 List of dataset to address sustainability impacts on biodiversity*

Area type	Dataset to be used	SpecificationsStudy
Biodiversity - loss of ecosystems		
Protected areas	World database on protected area NATURA 2000	Category I-IV: No biomass extraction Category V-VI: Forestry allowed; normal land use on existing arable land and grassland
Primary forest	Intact forest landscape	No use and no conversion allowed of intact forest landscapes Link to corruption index for countries not respecting the rule?
Peat land	Harmonized world soil database GLC 2000	Category Histosol: no use
Area of high biodiversity value (including grassland and forests)	UNEP-UCMC biodiversity atlas	Selection depending on the number of endangered species from mammals, amphibians, birds, etc. on site; Restriction of site can be set like for protected areas, meaning no conversion, no use, use with yield restrictions.

*These proposals are based on results from OEKO/IFEU/CI (2010). The suitability of datasets will be evaluated in more detail under Task 3 of this project.

4. Soil

The fertility of soil plays a key role in the potential and capacity of land for agricultural and forestry use, and soil degradation is the main impact that threatens these opportunities (UNEP 2014). Furthermore, soil performs numerous environmental functions such as storing, filtering and transformation of substances (nutrients, contaminants and organic carbon) and serving as a habitat for species.

The use of biomass may affect the degradation status of the soil, positively (e.g. increase of soil carbon) or negatively (increase of soil erosion). The protection of soil is already embedded in legislation (e.g. cross compliance regulation within the EU) and is part of standards like Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC) and Roundtable on Sustainable Biofuels (RSB) as well as the Global Bioenergy Partnership (GBEP) indicator.

Soil degradation can be caused by inappropriate land management – that can be avoided by soil protection measures (e.g. WOCAT 2007) – or by natural disturbance. Main factors causing soil degradation are soil erosion, soil carbon loss, compaction, nutrient loss, salinization (OEKO/IFEU/CI 2010), and these are covered as detailed impact categories in this report.

4.1. Impacts from the use of biomass on soil

4.1.1. Impacts of biomass production and its increase

Most negative impacts on soil from biomass use mentioned in the reviewed references are a result of unsuitable land management during production or harvesting of biomass (see Table 4-1).

Soil erosion mainly occurs at unsuitable sites (e.g. steep slopes; OEKO/IFEU/CI 2010, Moffat et al. 2011) or after strong disturbance such as exposing bare soil to water and wind after deforestation (Forestry Commission Scotland 2009, Turbe et al. 2010), less surface cover after residue extraction (Alexopoulou et al. 2010, IEEP et al. 2010) and especially after deep tilling and stump harvest (Fernholz et al. 2009, Turbe et al. 2010).

Soil carbon and soil nutrient loss are often directly associated with the loss of upper soil layers by soil erosion. Furthermore, the loss and gain of soil carbon strongly depends on cultivation measures. Intensive soil treatments in general increase the mineralisation of soil carbon (OEKO/IFEU/CI 2010, Alexopoulos et al. 2010), and soil disturbance from stump extraction can have strong effects (Moffat et al. 2011). The extraction of forest or agricultural residues (OEKO/IFEU/CI 2010, Alexopoulos et al. 2010, Hart et al. 2013, GBEP 2011) reduces the rebuilding of soil carbon. However, the cultivation of short rotation coppice can increase C sequestration in the soil when grown on agricultural soils previously grown with annual crops (Dimitriou et al. 2011). This should also be the case for other perennial species.

Soil nutrient loss is mainly associated with the extraction rate of biomass and can reduce soil fertility mainly in case of pure soils (Bouget et al. 2012, Fernholz et al. 2009, Hart et al. 2013, Tuomasjukka et al. 2014, Aherne et al. 2011, Baral and Malins 2013). In forests the removal of wood parts containing high contents of nutrients, e.g. logging residues (fine and coarse woody debris) and whole tree harvest are of high importance (Bouget et al. 2012). Tuomasjukka et al. (2014) state that minor increases in harvesting of residues may causes major increase in nutrient loss from a site. Nutrient loss with stumps is of lower relevance, but the removal of nutrient-rich soil attached to the tree root plates can show strong impacts (Moffat et al. 2011). Furthermore nutrient load in run-off water can increase after root and stump extraction (Moffat et al. 2011).

Soil compaction is mainly caused by inappropriate use of machinery on vulnerable soils or under wet conditions (OEKO/IFEU/CI 2010, Hart et al. 2013, Turbe et al. 2010). Soil compaction can occur in a similar manner on forest or agricultural land. Salinization is mainly a result of inappropriate irrigation, often occurring in arid regions on arable land (OEKO/IFEU/CI 2010, Turbe et al. 2010). Most forest land is not irrigated and salinization is unlikely. Further impacts are the disturbance of soil structure by stump extraction (Moffat et al. 2011) and the reduction of soil functionality (including upper mentioned aspects) by the extraction of residues like straw on agricultural sites (IEEP et al. 2010).

The responses suggested in the reviewed references on impacts on soil erosion, nutrient loss and carbon loss are rather similar (see Table 4-1). Agricultural cultivation and harvest of tree and forest residues should be adapted to site conditions (categorising risk classes) and suitable soil protection measures should be applied according to a sound risk assessment. Appropriate soil protection measures will vary depending on the local and given soils character, but include, e.g., reduced tillage, cap on biomass and residue extraction rate, surface cover, green cover over the winter period, mulching, interception of rainfall and rooting systems. In many cases a soil protection measure addresses several impacts, e.g. mulching reduces the erosion risk, improves the soil carbon content and favours the nutrient cycle.

With regards to stumps and forest residues Fernholz et al. (2009) propose to forbid residue harvest on rocky, dry, poor soils and open swamps and stump harvest in addition on steep slopes and from riparian areas. On other harvest sites stumps with a diameter larger 15cm should not be extracted and no more than 30% of residues should be harvested (Fernholz et al. 2009).

Looking at soil nutrient loss, site-adapted extraction rates and avoiding of large-scale harvests are proposed (Bouget et al. (2012), and needles and leaves should stay on site (Aherne et al. 2011). However, intensive harvesting does not necessarily lead to reduced soil nutrient stocks as effects are site specific (Tuomasjukka et al. 2014). The application of wood ash may also compensate for the nutrient losses (Hart et al. 2013).

Table 4-1 Cause of impact on soil from biomass production and possible response found in literature

Cause of impact	Possible response
Soil erosion	
Insufficient land management (step slops, no soil protection measures applied) (OEKO/IFEU/CI 2010)	Soil protection measures, e.g. soil cover, perennial crops, row cultures, wind breaks and quota of residue use (OEKO/IFEU/CI 2010)
Increase of soil erosion on slopes due to soil disturbance (Moffat et al. 2011)	Careful assessment of risk at a site, categorizing soil types in risk classes (Moffat et al. 2011)
Soil disturbance due to stump harvest (Fernholz et al. 2009)	Stumps should not be harvested on steep slopes, from riparian areas and on rocky, dry, poor soils and open swamps. No extraction of stumps with a diameter larger than 15cm (Fernholz et al. 2009)
Unsuitable cropping management activities and crop characteristics, including residue extraction (Alexopoulou et al. 2010, IEEP et al. 2010)	Soil protection measures (interception of rainfall, surface cover, rooting system, particularly green cover over the winter period, leave residues on the soil) (Alexopoulou et al. 2010)

Deforestation (Forestry Commission Scotland 2009)	Creation of forest habitat networks and new native woodlands (Forestry Commission Scotland 2009)
Deforestation, exposing bare soil to water and wind, the use of deep tillage (Turbe et al. 2010)	No specification
Soil carbon loss	
Insufficient land management (high biomass extraction rate, intensive soil treatments) (OEKO/IFEU/CI 2010, Alexopoulos et al. 2010)	Soil protection measures, e.g. reduced tillage, cap on biomass and residue extraction rate, surface cover, mulching, interception of rainfall, rooting system (OEKO/IFEU/CI 2010)
Increase of carbon loss due to increased mineralisation of carbon after soil disturbance due to stump extraction (Moffat et al. 2011)	Careful assessment of risk at a site, e.g. categorizing soil types in risk classes (Moffat et al. 2011)
Negative or positive soil C balance of bioenergy feedstock (Don et al. 2012)	Plant and soil specifics should be compared to previous use of land (Don et al. 2012)
Loss of soil carbon due to intense biomass extraction and/or cultivation or missing of soil protection measures (GBEP 2011)	Application of soil conservation measures, depending on soil degradation risk (GBEP 2011)
Depletion of soil organic carbon because of extraction of forest residues on sites with shallow soils (Hart et al. 2013)	Not specified
An increased C sequestration can be expected when SRC is grown on agricultural soils previously grown with conventional crops. However, the initial soil properties are responsible for the extent of C storage (Dimitriou et al. 2011)	Not specified
Soil nutrient loss	
Removal of wood parts containing high contents of nutrients, e.g. logging residues (fine and coarse woody debris) and whole tree harvest (Bouget et al. 2012)	Site-adopted extraction rate, avoid large-scale harvest (categorizing soil types in risk classes) (Bouget et al. 2012)
Removal of nutrient-rich soil attached to the tree root plates; nutrient loss with stumps occurs, but is much lower compared to branches and steam wood; nutrient load in run-off water after root/stump extraction (Moffat et al. 2011)	Careful assessment of risk at a site (Moffat et al. 2011)
Extraction of nutrients by residue harvest (Fernholz et al. 2009)	No residue harvest on rocky, dry, poor soils and open swamps, and 30% of residues must be left on other harvest sites (Fernholz et al. 2009)
Depletion of nutrients because of extraction of forest residues on sites with shallow soils (Hart et al. 2013)	Application of wood ash to compensate for the nutrient losses (Hart et al. 2013)
Intensive harvesting will lead to decrease in soil nutrient status if not compensated for by management measures (Aherne et al. 2011)	Needles and leaves should stay on site, fertilisation of N and K and others as appropriate to ensure sustained forest growth (Aherne et al. 2011)
Removal of forest biomass decreases site nutrient stocks affecting e.g. the nitrogen cycling. Minor increase in harvesting residues may causes major increase in nutrient loss from a site (Tuomasjukka et al. 2014)	Intensive harvesting does not necessarily lead to reduced soil nutrient stocks. Effects are site specific (Tuomasjukka et al. 2014)
Loss of soil nutrients (removal of biomass) (Baral and Malins 2013)	Nitrogen fixation, atmospheric deposition or additional use of chemical fertilizers, organic manure, or ash (Baral and Malins 2013)

Soil compaction	
Inappropriate use of machinery depending on soil type and soil humidity (OEKO/IFEU/CI 2010)	soil protection measures, e.g. crop choice (yield mass, rooting system), adapted machinery (weight, tires), considering weather conditions (OEKO/IFEU/CI 2010)
Use of heavy machinery for extracting biomass or trampling (particularly in wet soil, e.g. caused by poor drainage) (Hart et al. 2013, Turbe et al. 2010)	Not specified
Soil salinisation	
Inappropriate irrigation (OEKO/IFEU/CI 2010, Turbe et al. 2010)	Irrigation measures, e.g. no irrigation on sensitive soils, use of water with low salt content for irrigation, use effective drainage systems (OEKO/IFEU/CI 2010, Turbe et al. 2010)
Other soil impacts	
Disturbance of soil structure by stump extraction (Moffat et al. 2011)	Careful assessment of risk at a site (Moffat et al. 2011)
Negative impacts from wood removal (Abbas et al. 2011)	Retaining or leaving tree foliage and leaving up to 30% of residues in the field (Abbas et al. 2011)
Reduction of soil functionality due to the extraction of straw from agricultural areas (IEEP et al. 2010)	Ploughing-in of cut straw following the cereal harvest to help maintain soil functionality (IEEP et al. 2010)

4.1.2. Conversion, transport and use of biomass

Impacts from conversion, transport and use of biomass on soil were not mentioned in the references covered in the literature review. However, soil contamination by pollutants from these processes may occur locally e.g. in case of non-routine operation.

4.2. Proposals to address soil impacts in the modelling framework

The review showed that most soil impacts are very site specific and require respective soil conservation measures. The amount of biomass extraction can be part of the soil conservation measure (e.g. mulching with straw, retaining nutrient cycle by leaving branches and leaves on site). Other soil conservation methods increase the possible extraction rate and create production costs (e.g. fertilisation with ash). Some soil conservation measures may only cause costs that are not directly visible in yields (e.g. adaption of machinery, windbreaks). Finally, specific soil conservation measures may lead to a lowering of the future yield developments (e.g. adoption of crop rotation to allow straw extraction).

From a modelling perspective the challenge is firstly to identify requirements that might be covered by area related restrictions in the model work:

1. Identification of exclusion areas where (i) no production is allowed at all and (ii) where no residue or stump extraction should occur (e.g. depending on steep slopes, poor soils (low soil organic content, low content of nutrients), wet soils)
2. Restriction of residue and stump extraction on all remaining areas
3. Lowering the development of yields (agriculture and intense forestry), i.e. assuming a lower annual yield-increase rate assuming stronger soil protection measures

A short overview of possible data sets that may be used for the implementation of soil restrictions in the model work are listed in Table 4-2.

Secondly, additional conservation measures of soils and their impact on production costs could be added and reflected upon in the economic model.

Table 4-2 List of dataset to address sustainability impacts on soil

Area type	Dataset to be used	SpecificationsStudy
Biodiversity - loss of ecosystems		
Steep slopes	Global evaluation data sets for slope classes "Global 30 Arc Second Elevation Data" as used by G4M for estimating forest growth.	No biomass extraction on slopes > 30%. No residue and stump extraction on slopes > 15%.
Soil restrictions	European soil database as harmonized for EU. Harmonized world soil database based on "Soil map of the world".	Maximum 30% extraction of residues and stump on all sites. For EU, no extraction of residues and stump on land with stones > 25% and Very fine texture. Globally, no extraction of residues and stump on land classified as stony.

5. Water and water pollution

The unsustainable management of freshwater resources is a key global environmental challenge to achieve human wellbeing (UN 2012, WWAP 2014) as well as the protection of ecosystems that depend on sufficient and clean water (CBD 2009). Freshwater is already scarce in some regions of the world, and existing freshwater resources are under heavy threat from overexploitation due to growing population and changing diets, pollution, energy demand and climate change. The agricultural sector in particular is responsible for about 70% of freshwater withdrawal worldwide (WWAP 2014).

The use of biomass for bioenergy can impact on freshwater resources mainly by an over-use of water resources, lowering of water table, and the pollution of water bodies (e.g. OEKO/IFEU/CI 2010).

5.1. Impacts from the use of biomass on water and water pollution

5.1.1. Impacts of biomass production and its increase

For biomass pathways under the focus of this study (solid biomass, short rotation coppice, lignocellulosic biomass, agricultural residues, etc.) impacts on freshwater are assessed to be much lower compared to impacts from arable crops for biofuels. Nevertheless, authors of the studies in this literature review highlight several impacts on water resources from the use of biomass that might be of interest within the model work.

The overuse of water resources and impacts on water tables (see Table 5-1) can occur from a high use of water for biomass cultivation (OEKO/IFEU/CI 2010, GBEP 2011), namely by irrigation in areas with water stress or by cultivating energy crops with high water demands (Alexopoulos et al. 2010). For example the evapotranspiration from short rotation coppice with willow and poplar is in most cases significantly higher than arable crops, but lower than conventional forests (Dimitriou et al. 2011, Don et al. 2012). In water scarce regions or regions with existing high water use a switchover to short rotation coppice may strengthen the water scarcity. To avoid such negative impacts of the cultivation of bioenergy crops on the local hydrological balance, authors of the reviewed reference suggest to consider plant species specifics when choosing species in arid and water scarce regions (Dimitriou et al. 2011) as well as mitigation options for irrigation (OEKO/IFEU/CI 2010). However, most bioenergy crops and especially forests grow under rainfed conditions and irrigation is of low relevance.

The main source of water pollution from agriculture and forestry is the use of fertiliser and pesticides (OEKO/IFEU/CI 2010, UNEP 2011, Alexopoulos et al. 2010, GBEP 2011, Baral and Malins 2013, Langeveld et al. 2012). Furthermore, high nutrient loads in run-off water can occur after stump extraction (Moffat et al. 2011), forest site preparation (Baral and Malins 2013) and intensive logging and residue extraction (Hart et al. 2013, Baral and Malins 2013). Possible responses include the reduced application of chemicals and adequate use of waste water from municipals and industries for irrigation (OEKO/IFEU/CI 2010) and innovative forms of integrated production (UNEP 2011) as well as careful assessment of risks at a site in case of stump extraction (Moffat et al. 2011).

Short rotation coppice is generally considered to improve the water quality relative to conventional agricultural crops due to the less intense management practices of SRC.

It is suggested to use short rotation coppice in intensively managed agricultural areas to improve the current water quality (Dimitriou et al. 2011).

An increased logging of forests can impact hydrological processes in a region (e.g. increased water run-off, retention and reduced water infiltration; Abbas et al. 2011, Tuomasjukka et al. 2014), and changes in lake water chemistry due to changes in water run-off chemistry can occur (Aherne et al. 2011). Tuomasjukka et al. (2014) reports a measurable and substantial negative response of intensive residue extraction in acid sensitive catchments in the boreal zone in medium term. Also high extraction rate of residues (e.g. straw removal) can decrease water filtration and increase evaporation (IEEP 2010). These impacts, however, may be addressed by management treatments considering local water cycle situations (Abbas et al. 2011) and by leaving a sufficient amount of leaves and residues in the forest (Aherne et al. 2011, IEEP 2010).

Table 5-1 Cause of impact on water from biomass production and possible response found in literature

Cause of impact	Possible **response**
Overuse of water resources and impact on water tables	
Irrigation in areas with water stress (OEKO/IFEU/CI 2010)	Mitigation options in case of overuse of water (e.g. upgrading of soil moisture capacity, improvement of irrigation and water use efficiency, reducing water demand at other locations, water storage)(OEKO/IFEU/CI 2010)
High use of water for bioenergy production (cultivation) (GBEP 2011)	No specification
High water demand of selected energy crops (Alexopoulos et al. 2010)	No specification
Surface runoff and impact on groundwater recharge (Langeveld et al. 2012)	No specification
Reduce downstream water availability (Berndes et al. 2013)	No specification
Evapotranspiration from SRC fields with willow and poplar is in most cases significantly higher than arable crops but lower than conventional forest (site-specific variation possible) (Dimitriou et al. 2011)	Plant species specifics should be considered when choosing species, especially in arid regions (Dimitriou et al. 2011)
Increased use of water in comparison to agricultural crops (e.g. a 5% and 10% higher water consumption for Miscanthus and willow compared with wheat and permanent grassland). SRC have deeper roots than agricultural crops that enables them to use and deplete deeper groundwater resources, although this could be a disadvantage by affecting the local hydrological balance (Don et al. 2012)	No specification
Water pollution – land use	
Washout/contamination from agrochemicals in case of high loads of nutrients and pesticides) (OEKO/IFEU/CI 2010)	Mitigation options, e.g. reduced application of chemicals and adequate use of waste water for irrigation (OEKO/IFEU/CI 2010)
Agricultural and forestry activities: The main sources of pollution are related to the use of pesticides and fertilizers (UNEP 2011)	Innovative forms of integrated production will prove the best way to avoid and mitigate impacts (UNEP 2011)

High loadings of nutrients (N, P, K) and pesticides in water bodies (Alexopoulos et al. 2010, GBEP 2011, Baral and Malins 2013, Langeveld et al. 2012)	Not specified
Nutrient load in run-off water after stump extraction can affect water bodies (Moffat et al. 2011)	Careful assessment of risk at a site (Moffat et al. 2011)
Forest management activities (site preparation, harvesting) (Baral and Malins 2013)	Not specified
Detrimental harvesting patterns (intensive logging, residue extraction) (Hart et al. 2013)	Not specified
SRC is generally considered to improve the water quality relative to conventional agricultural crops in a given area due to the management practices of SRC (weed control only during the establishment phase, tillage only before the establishment phase, and lower inorganic fertilization than other crops) (Dimitriou et al. 2011)	Several authors suggest the use of SRC in intensively managed agricultural areas to improve the current water quality and meet EU obligations in terms of water quality expressed in the Water Framework (Dimitriou et al. 2011)
Water – other aspects	
Hydrological process are impacted by tree removal: Reduced interception and reduced moisture storage results in more runoff in small streams and increased water yield; litter storage of water is impacted by changes in the amount of litter on-site; temporarily eliminating transpiration increases baseflow and soil moisture; reduced infiltration increases overland flow and storm flow, whereas increased infiltration decreases overland flow and increases base flow (Abbas et al. 2011)	A number of forest management guidelines have been developed to address these points. However, a number of them are very site specific and would be difficult to implement in a model. Furthermore, most hydrology guidelines recommend riparian areas, ditches, filter strips and water body protection. One though is that North American guidelines specify the avoidance of stump harvesting for utilization, except in woodland conversion sites (Abbas et al. 2011)
Increased demand for biomass for energy is increasing pressure on forests. Changes in harvesting levels has an influence on soil and lake water chemistry (Aherne et al. 2011)	Measures like: Needles and leaves to stay on site; fertilisation of N&K; ensure sustained forest growth (Aherne et al. 2011)
Decreasing water filtration and increasing evaporation due to high extraction rate of residues, e.g. straw removal (IEEP 2010)	Leaving cut residues on the surface of the soil (IEEP 2010)
Forest harvest influences interception, retention, cycling of water (delivery rates to surface waters and dynamics of aquatic systems) (Tuomasjukka et al. 2014)	Not specified
A measurable and substantial negative response of intensive residue extraction has been recorded in acid sensitive catchments in boreal zone in medium term (Tuomasjukka et al. 2014)	Not specified

5.1.2. Conversion, transport and use of biomass

Main impacts conversion, transport and use of biomass on water mentioned in the reviewed references refer to the pollution of waterbodies from processed waste water and non-routine operation (OEKO/IFEU/CI 2010, GBEP 2011, UNEP 2011). Technological improvements on waste water treatment and the selection of uncritical location of plants are proposed to response to these impacts (OEKO/IFEU/CI 2010, UNEP 2011). Furthermore, a high use of water for bioenergy production may cause an overuse of water resources (GBEP 2011).

Table 5-2 Cause of impact on water from conversion, transport and use of biomass and possible response found in literature

Cause of impact	Possible response
Overuse of water resources	
High use of water for bioenergy production (conversion) (GBEP 2011)	No specification
Water pollution – conversion	
Insufficient cleaning of process water / non-routine operation (OEKO/IFEU/CI 2010)	Mitigation options, e.g. improved waste water treatment and uncritical location of plants (OEKO/IFEU/CI 2010)
High loads of pollutants (manly organic substances) in waste water of bioenergy conversion plants (GBEP 2011)	Not specified
Agricultural and forestry activities: co-products (e.g. vinasse) from the industrial pathways of some feedstocks (UNEP 2011)	Future technologies, probably associated with bio-refineries, could incorporate better water quality management (UNEP 2011)

5.2. Proposals to address water impacts in the modelling framework

As mentioned above the identified impacts on water are of lower relevance under the scope of the project compared to e.g. impacts on biodiversity and soil, thus the implementation of impacts on water should be followed with lower priority.

Nevertheless, the most relevant impacts on water that might be considered in the model work are:

1. Avoid overuse of freshwater resources in water scarce regions
2. Avoid pollution of waterbodies from the application of fertilizer and pesticides
3. Avoid pollution of waterbodies from process waste water

The overuse of freshwater resources may be addressed by restrictions on irrigation for bioenergy crops in water scarce regions (see Table 5-3) as well as a cap on areas that could be used for short rotation coppice or other bioenergy crops characterised by high transpiration rates. Even regrowth of forests might be critical in such water scarce regions due to the even higher transpiration rate compared to short rotation coppice.

Table 5-3 List of dataset to address sustainability impacts on water

Area type	Dataset to be used	SpecificationsStudy
Biodiversity - loss of ecosystems		
Water scarcity	GLOBIOM endogenously estimated areas with high level of water scarcity.	In water scarce regions: - No irrigation (mainly agriculture) - Cap on the area used for short rotation copies

The pollution of water bodies caused by fertilizer and pesticides could be mitigated by the reduction of their application. This could partly be achieved by optimising e.g. fertiliser application, but also a reduction of yields is likely in case of the reduction of inputs. The latter could be implemented in the model work by lowering the assumed yield development. Furthermore the reduction of nutrient loads in run-off water could be addressed by mitigation options such as the restriction of residue and stump extraction rates already named for the protection of soil (see Section 4.2).

A reduction of the risk of water pollution from waste water would require higher investments in bioenergy conversion plants. However, in the modelling framework the demand of bioenergy is exogenously defined and the issue should as such be dealt with by POLES/PRIMES energy system models.

6. Greenhouse gas emissions

The reduction of greenhouse gas emissions (GHG) compared to fossil fuels is one important aim for the use of bioenergy (along with energy security and rural competitiveness and job creation), and GHG reductions from bioenergy compared to fossil fuels can be either positive or negative. Greenhouse gas emissions along bioenergy pathways are strongly dependent on each step along the production chain from land use to conversion, transport and use of biomass. Emissions from land use can be especially high in case of land use change (e.g. ploughing up grassland), and emissions from conversion, transport and use are influenced by parameters such as efficiency, transport distance and the avoidance of emission sources for methane and nitrous oxide in the process steps. Furthermore, the payback times when using forest products for bioenergy range from 0 to almost 500 years, depending on the reference (i.e. what is substituted e.g. coal), time horizon, site and species, etc. (Agostini et al. 2013). The review carried out focuses on three aspects: GHG emissions (incl. substitution effects compared to fossil fuels), change of carbon stock, and change of disturbance pattern.

6.1. Direct impacts from the use of biomass on greenhouse gas emissions

6.1.1. Impacts of biomass production and its increase

Significant negative impacts on greenhouse gas emissions from biomass production occur when areas of high carbon stock are converted to bioenergy plantations of low carbon stock (Hart et al. 2013, OEKO/IFEU/CI 2010, Forestry Commission Scotland 2009), but also an increase of wood extraction, including whole tree harvest and residue extraction, can lower the carbon stock of forests (Zanchi et al. 2012, Hart et al. 2013, Tuomasjukka et al. 2014, see Table 6-1). However, there are cases where long-term active forest management can increase biomass and timber production while still safeguarding the forest carbon stock at the landscape level (Berndes et al. 2013). Examples of such improvements range from the promotion of regeneration and silvicultural management to enhancing forest growth (through improved timing of pre-commercial cutting, thinning efforts, fertilization, etc.). Managing forests for products (energy and/or materials) can also determine higher GHG savings than suspending the management (Matthews et al 2014b), and an increase in woodfuel production may be occur after natural disturbances such as storms (Agostini et al. 2013).

Generation of bioenergy using stumps and roots may release more greenhouse gases into the atmosphere than are saved by their substitution for fossil fuels (Moffat et al. 2011). Also Vanhala et al. (2013) states that stump harvesting may decrease the soil carbon stock. However, empirical research on the magnitude of emissions from the use of stumps and roots in comparison to fossil fuels (positive or negative) is limited (Vanhala et al. 2013).

Furthermore, there is a debate concerning the timing of net GHG savings that occurs when biomass is used to replace fossil fuels. The core of this issue is that there is a time delay between emissions when woody biomass is burned and subsequent regrowth of the terrestrial C stock – the so-called "ecosystem carbon payback time". In particular when forests with long rotation periods are being used for energy purposes, there can be noted a strong temporal imbalance in the C dynamics between the time when the C is released into the atmosphere and later sequestrated again back into the forest (Zanchi et al. 2012, Berndes et al. 2013, EEA 2013a). However, under some forest use scenarios, the same argument applies when harvesting residues and stumps for energetic use, inducing a direct emission of carbon in comparison to the slow decomposition in the field (Vanhala et al. 2013). The implication of this issue varies significantly when looking at a stand level or landscape level, and if a short or a long term time scale is considered (Berndes et al. 2013).

For agricultural residues ADAS (2008) states that straw incorporation is an inefficient method of sequestering carbon and that the removal of straw for burning would have an adverse effect on greenhouse gas emissions.

The possible responses found in the reviewed references can be grouped into two main aspects. Firstly, areas of high carbon stock should not be converted to production areas with lower carbon stock (OEKO/IFEU/CI 2010, Forestry Commission Scotland 2009). Secondly, a GHG-accounting method along the full production chain for forestry products should also cover the carbon sequestration rate of forests and the carbon being released when the mass of fuel is burned (Zanchi et al. 2012, Berndes et al. 2013), including changes in soil carbon (Vanhala et al. 2013). Threshold values for the reduction of GHG emissions in comparison to fossil fuels are of importance for the implementation in regulations like the RED (OEKO/IFEU/CI 2010).

Table 6-1 Cause of impact on greenhouse-gas emissions from biomass production and possible response found in literature

Cause of impact	Possible response
GHG-emissions (incl. substitution effects compared to fossil fuels)	
High GHG-emissions along bioenergy-pathway (OEKO/IFEU/CI 2010)	Threashold for GHG-reduction of bioenergy, based on GHG-methodology (live-cycle analysis) including CO_2-fixation, substitution of fossils, emissions from farming (fertilizer, pesticides, fuel), emissions from direct and indirect land-use change (OEKO/IFEU/CI 2010)
UK example: (a) in a 40 year timeframe, CO_2 emissions are lower for suspended management forest than for forest managed for bioenergy only (b) managing the forest for products determines higher GHG savings than suspending the management (c) result depends on reference (what is substituted), time horizon, site and species, etc. (Matthews et al 2014b)	Not specified
Harvested material left in situ to decompose (including chipped wood) (ADAS 2008)	Not specified
Deforestation (Forestry Commission Scotland 2009)	Not specified
Removal of straw for burning would have an adverse effect on greenhouse gas emissions; straw incorporation is, however, an inefficient method of sequestering carbon (ADAS (2008))	Not specified
GHG – Change of carbon stock and carbon debth	
Loss of carbon due to conversion of land with high carbon stock (OEKO/IFEU/CI 2010)	Exclusion of areas of high carbon stock (OEKO/IFEU/CI 2010)
Conversion of high carbon stocks forests to bioenergy plantations of low carbon stock (Hart et al. 2013)	Not specified
Increased harvesting intensity can reduce the level of carbon sequestered in particular forest stands (Hart et al. 2013)	Not specified

Generation of bioenergy using stumps and roots may release more greenhouse gases into the atmosphere than are saved by their substitution for fossil fuels (Moffat et al. 2011)	Careful assessment of risk at a site, e.g. categorizing some soil types in risk classes (Moffat et al. 2011)
Stump harvesting may decrease the soil carbon stock. However, empirical research on the magnitude of these emissions are rare (Vanhala et al. 2012)	Consider emissions from soil when harvesting of stump takes place (Vanhala et al. 2012)
Harvesting of residues and stumps and using them directly for energy induces a direct emission of carbon in comparison to the slow decomposition in the field (Vanhala et al. 2012)	Timing of carbon from decomposition of harvesting residues could possibly be considered in terms of a slow change in the soil carbon pool (Vanhala et al. 2012)
Burning biomass for energy is not carbon neutral as: (a) there is a time delay between emissions and subsequent regrowth when woody biomass is burned; (b) current harvesting levels might result in lowering the forest C stock (Zanchi et al. 2012)	An accounting approach could possibly be used to cover the carbon sequestration rate of forests and the carbon being released when the mass of fuel is burned (Zanchi et al. 2012)
Whole tree harvesting reduces soil C compared to stem only. Effects seen more frequently on forest floor than in mineral soil (Tuomasjukka et al. 2014)	Considerable variation in the observed response to harvesting of logging residues in soil and tree C (Tuomasjukka et al. 2014)
Growth enhancing measures (e.g. fertilization) and site preparation may increase productivity but may also lead to faster decomposition of soil organic matter (Berndes et al. 2013)	Not specified
Intensification in forest management has shown that stand management can increase C stock and biomass and timber production (Berndes et al. 2013)	Not specified
GHG – Change of disturbance pattern	
An increase in woodfuel production may be attained with natural disturbances (Agostini et al. 2013)	Not specified

6.1.2. Conversion, transport and use of biomass

Single production steps along a bioenergy production chain may be responsible for high greenhouse gas emissions (OEKO/IFEU/CI 2010, see Table 6-2). For example, emissions of methane and nitrous oxide and other trace gases may occur during anaerobic digestion of bio-waste and use of biogas (EC JRC-IES 2011) as well as from manure management (FAO 2013). Water use in processing can also contribute to GHG emissions, for example in wastewater treatment in the palm oil industry (UNEP 2011).

GHG calculation methods need to cover all possible emissions. The challenge is then to identify critical process steps and to optimize them towards low GHG emissions. The sum of emissions should be compared with threshold values for the reduction of GHG emissions (OEKO/IFEU/CI 2010).

Table 6-2 Cause of impact on greenhouse-gas emissions from conversion, transport and use of biomass and possible response found in literature

Cause of impact	Possible response
GHG-emissions (incl. substitution effects)	
High GHG-emissions along bioenergy-pathway (OEKO/IFEU/CI 2010)	Threashold for GHG-reduction of bioeneregy, based on GHG-methodology (live-cycle analysis) including substitution of fossils, allocation of co-products, emissions from conversion, processing and transport (OEKO/IFEU/CI 2010)
Emission of CH_4, N_2O, and other trace gases during anaerobic digestion of bio-waste and use of biogas (EC JRC-IES 2011)	Minimise generation and emission of these gases, e.g. using biofilters (EC JRC-IES 2011)
Monogastric animals (pigs and poultry): feed provision is the first contributor to emissions, followed by manure management (production of methane) (FAO 2013)	Not specified
Water use in processing also contributes to GHG emissions, for example in wastewater treatment in the palm oil industry (UNEP 2011).	Not specified

6.2. Proposals to address impacts on greenhouse gas emissions in the modelling framework

From a greenhouse-gas emission perspective it is of high importance to address the following aspects:

- No conversion of areas of high carbon stock
- No overuse of forests, i.e. extraction rate is not above regrowth
- Time delay between emissions and subsequent regrowth, both for energy and materials
- Threshold for the supply chain GHG-emission reduction compared to fossil sources

The conversion of areas with high carbon stock needs to be addressed in the model work. Most relevant land categories are forests, wetlands and peatland. These categories are sufficiently covered in global datasets like GLC 2000, HWSD, GLWD and UNEP-WCMC carbon atlas (see Table 6-3).

Regarding an overuse of forests, the G4M model applied by IIASA for estimating the forest harvesting potential in consideration to site conditions such that the harvest rates, including stem wood, branches and stumps, are below the regrowth rate. Only sustainable forest harvest levels are considered within the modelling framework that will be applied. Also information concerning extraction rates as specified in Section 3.2 (biodiversity) may be considered.

The literature review highlights that time lags between growth and use of forest biomass can influence the GHG-balance of a bioenergy pathway. Here both are possible: (1) the CO_2-emission when burning wood occurs earlier than the CO_2-sequestration by the followed re-growth and (2) the material use of wood may fix CO_2 even longer than the re-growth would last (see also IPCC methodology on Harvested Wood Products, HWP). In the IIASA modelling framework, a landscape level approach is taken when it comes to CO_2-emissions related to harvest of wood, change in forest age structural dynamics, and change in forest rotation periods. This means that overall forest landscape changes does impact GHG-emissions, but individual harvests and associated pay-back times are not considered. IPCC methodology concerning HWP pools are also fully accounted for in terms of in the framework that will be applied.

Finally, a threshold on the reduction of GHG-emissions could possibly be implemented in the modelling work to enable the exclusion of bioenergy pathways that do not match the reduction goal of, e.g., 60%. This aspect could be implemented as exclusion rule in the economic tool of the model.

Table 6-3 List of dataset to address sustainability impacts on greenhouse gas emissions

Area type	Dataset to be used	SpecificationsStudy
Biodiversity - loss of ecosystems		
High carbon stock - forests	Global Land Cover 2010 (GLC 2010)	Land covered by forest types
High carbon stock - wetlands	Global lake and wetland database (GLWD) Global Land Cover 2010 (GLC 2010)	Location of wetlands
High carbon stock – peatland	Harmonized World Soil Database (HWSD)	Location of peatland (histosol)
High carbon stock	UNEP-WCMC carbon atlas	Location of area with high carbon stock

7. Indirect land use effects and economic impacts

Changes in land use are often the reason for impacts of the use of biomass on natural resources and the environment. Direct impacts from land-use change are already covered in the sections above, e.g. the conversion of areas of high biodiversity value (Chapter 3.1), increased soil erosion due to stump harvest (Chapter 4.1) and increased use of water by short rotation coppice in comparison to agricultural crops (Chapter 5.1). However, these direct land use impacts are in general under the control of the operator producing bioenergy and can be efficiently addressed by regulations and certification schemes.

In contrast, indirect effects and related impacts are mostly out of the control of bioenergy operators. Indirect effects occur mainly as consequence of the displacement of a former activity to fulfil a demand. In case that the former demand still exists, meeting this demand may case impacts elsewhere. The prominent example of indirect effects is indirect land use change (iLUC), i.e. impacts from land use change after displacing a former crop (including residues) by bioenergy production (see overview in Agostini et al. 2013). Though rarely reported indirect effects may also occur for the use of other resources like water and other activities like a reduced use of wood as materials due to an increased use for bioenergy.

Due to the interaction of global markets, the increased use of biomass resources can impact different biomass uses as well as other sectors. Such impacts are mainly driven by the competition for resources – that is often the driver for indirect effects mentioned above. Interaction takes place through, e.g., the supply and demand of biomass, costs and prices, trade pattern, technical development, changes in gross domestic product and environmental restrictions, and such aspects are typically covered in economic models. Within this project, economic aspects are already covered in-depth in the review of Task 1. Under this Task the covered references are in addition screened for the competition with other uses, increase of revenue, and supply cost at the power plant.

7.1. Impacts from the use of biomass

7.1.1. Impacts of biomass production and its increase

The main cause for indirect land-use change found in the reviewed references is the competition for land resulting in the displacement of a former land use, e.g. for food or feed production, by the production of biomass for bioenergy (OEKO/IFEU/CI 2010, Agostini et al. 2013, see Table 7-1). It is important to notice that displacement can not only occur for products (e.g. rape seed) and co-products (press cake of rape seed as feed), but also for residues if they are used for a specific purpose and the demand still exists (e.g. forest residues used for pulp and paper).

Furthermore the increased demand for land can result in a general intensification of land use – on bioenergy production areas as well as on other agricultural and forestry areas, for example the intensification of cereal cultivation (IEEP et al. 2010) or moving near natural forest towards intensive short rotation biomass production systems (Hart et al. 2013). Also an overuse of forest resources, i.e. increasing the wood-extraction rate above the wood regrowth rate (GBEP 2011), can be an indirect effect caused by an increased demand for bioenergy.

The overall reason for indirect land use change induced by the use of bioenergy is the increased biomass demand and the related production and competition for land resources. In consequence, the authors of the covered references suggest responses that release the pressure on the production of biomass and land already in use. This could be achieved by focussing biomass production on currently unused land (OEKO/IFEU/CI 2010), increase the use of unused wastes and residues (Hart et al. 2013), and the intensification of land use (e.g. increased and improved management, fertilization, suppression of natural disturbances like wild fires; Agostini et al. 2013) Furthermore, the iLUC effect should be visible in the calculation of greenhouse gas emissions from bioenergy, i.e. by including an iLUC factor (OEKO/IFEU/CI 2010).

Most economic impacts of biomass production identified in literature review are related to competition. The main driver is that the future increased use of wood for bio-energy and the bio-economy will put pressure on the use of wood in the EU, and even a gap between the supply and demand of wood can be expected (Indufor 2013). Already today about 10% of total traded wood chip volumes are allocated to bioenergy production (IEA 2012: Lamers, Junginger et al.). Furthermore, the growing demand of wood pellets in the EU is driving the pellet manufacturers to enlarge the feedstock base, adapting new logistics and transportation infrastructures, refining pellets (torrefaction; IEA 2011, see Table 7-1). This pressure is expected to result in the displacement of wood products from existing uses (materials and energy; Agostini et al. 2013). For example, the forest chip production can shift from the use of tops and branches towards an increasing use of stem wood and stumps (Diaz Yanez et al. 2013), and the optimisation of wood chip supply chains may lead to a shift from material use towards energy use (e.g. Spain; Anttila et al. 2011). Another economic impact is an intensification of forest management due to increased revenue for forest owners. This can be intensified by incentives for wood use (energy or other uses) (Agostini et al. 2013). Another relevant aspect might be the costs of land depending on the production pressure.

Table 7-1 Indirect effects and land-use impacts and economic impacts from biomass production and possible response found in literature

Cause of impact	Possible response
Indirect land-use change and competition with other land use	
Displacement of former land-use (OEKO/IFEU/CI 2010)	Utilisation of unused land for bioenergy and including iLUC factor in GHG-calculation are discussed (OEKO/IFEU/CI 2010)
Movement away from near natural forests towards intensive short rotation biomass production systems (Hart et al. 2013)	Use of wastes and residues as biomass to avoid land use change (Hart et al. 2013)
Expansion of production of straw (e.g. ploughing up of biodiversity-rich grasslands), but effect not likely (IEEP et al. 2010)	Not specified
Competition for land cases indirect land use change, iLUC) (Agostini et al. 2013)	Management intensification, e.g. increased and improved management, fertilization, natural disturbances suppression etc. (Agostini et al. 2013)
Potential intensification or expansion of cereal cultivation (IEEP et al. 2010)	Not specified

Overuse of forests	
Wood-extraction rate is above the wood regrowth rate, depending on forest type and site conditions (GBEP 2011)	Not specified
Competition with other uses	
Displacement of wood for products (or indirect Wood Use Change, iWUC) (Agostini et al. 2013)	Not specified
Displacement of wood from other energy sectors (or indirect Fuel Use Change, iFUC) (Agostini et al. 2013)	Not specified
Restriction for stump extraction (Abbas et al. 2011)	Not specified
The future increased use of wood for bio-energy and the bio-economy will put pressure on the use of wood in the EU. A gap between the supply and demand can be expected (Indufor 2013)	Not specified
Currently the bulk of the forest chips in the EU are produced from tops and branches, however shift towards increasing use of stem wood and stumps is expected as the demand grows (Diaz Yanez et al. 2013)	Not specified
In the global wood chip trade the current policies to reduce GHG emissions are driving the global trade of wood chips of pulp production to be replaced with chips to bioenergy production. It is estimated that app. 10% of total traded wood chip volumes are allocated to bioenergy production (IEA 2012: Lamers, Junginger et al.)	Not specified
Adopting Nordic forest chip supply chains to Spanish conditions can provide a feasible basis of utilizing the potential raw material in Spain to run heat energy business, whereas the local demand of wood for particle board production is declining (P. Anttila et al. 2011)	Not specified
Increase of revenue	
Increased revenue for forest owners due to incentives for wood use (energy or other uses) casing an intensification of forest management (Agostini et al. 2013)	Not specified
Increased demand	
Growing demand of wood pellets in EU are driving the pellet manufacturers to enlarge the feedstock base, adapting new logistics and transportation infrastructures, refining pellets (torrefaction) (IEA 2011)	Not specified

7.1.2. Conversion, transport and use of biomass

Along the production chain Asikainen et al. (2011) highlight that a high mechanization rate of wood harvesting (Scotland 90%, Poland 5%) lowers the supply costs, but small-scale heating systems and high wood chip quality requirements increase the supply costs (Scotland). In case that subsidies (feed in tariffs of market premiums) are only targeted for short span of time, delays to major investments in large wood pellet heating plants may occur since the investors do not have certainty of long term productivity of the projects (IEA 2013: Ikonen T., Asikainen A. et al.).

Table 7-2 Economic impacts on conversion, transport and use of biomass

Cause of impact	Suggested response
Supply cost at the Power plant	
High mechanization rate of wood harvesting (Scotland 90%, Poland 5%) lowers the supply costs. Small-scale heating systems and high wood chip quality requirement increases the costs (Scotland) (Asikainen et al. 2011)	Not specified
Delay in investments	
Subsidies (feed in tariffs of market premiums) are only targeted for short span of time. This has caused delays to major investments in large wood pellet heating plants since the investors do not have certainty of long term productivity of the projects (IEA 2013: Ikonen T., Asikainen A. et al.)	Not specified

7.2. Proposals to address indirect effects and other land-use impacts in the modelling framework

Indirect effects and also economic impacts are mainly related to competition between different biomass uses (energy, material) and occur for biomass resources that can potentially be deployed for different uses e.g. stem wood. Such effects are limited for the use of branches, stumps and residues. The construction of the model framework in combination with a suitable set of scenarios should address effects that occur from this circumstance.

In October 2012 the European Commission adopted a proposal[3] establishing an approach to minimize possible ILUC impacts of biofuels consumed in the EU. This includes a cap on the contribution that first generation food crops-based biofuels can make towards the national target of 10% renewable energy target in transport by 2020. The Commission proposal does, however, not include feedstock-specific ILUC factors due to the uncertainties associated to the modelling[4]. Such uncertainties also apply to biomass for heat and power. These points shall be reflected in the modelling framework.

The GLOBIOM modelling framework allows for assessing direct and indirect land use change impacts of increasing bioenergy demand. Baseline developments concerning land use for new plantations and development of agricultural land can be directly compared to scenarios with changed assumptions. Of relevance appear mainly the efficient use of residues and wastes (see also cascading use in Section 8) and an increase of yields higher than in the baseline. These points may be addressed in the used economic model (GLOBIOM).

Due to the situation that an increase of the pressure on the use of wood is likely, it is important to notice that the economic tool in the model framework (GLOBIOM) already covers competition between different uses of wood (energy use, material use including cascading; see Section 8). The approach that will be applied covers both competition for forest biomass types (steam, branches, and stumps) and potential uses (energy, different material) within the economic framework. In this manner, price induced shifts, including incentives, are possible as well as fully represented endogenously within the framework that will be applied. Also increasing land prices as well as price

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3 http://ec.europa.eu/energy/renewables/biofuels/doc/biofuels/com_2012_0595_en.pdf

4 Due to the lack of an agreed methodology, indirect land use change was also not included in the GHG calculation of the Product Environmental Footprint (PEF), under the Commission's Recommendation 2013/179/EU.

induced forestry intensification may be included within the model framework and the analysis.

8. Cascading use of biomass

Biomass is widely used in the EU in the forestry and agricultural sectors, most importantly for food, feed and material production. It is also an important renewable resource for heat and energy production. However, the growing demand for biomass calls for considerations so that resource competition does not lead to adverse negative impacts due to scarce available biomass resources. Potential competition risks can be addressed by sustainably increasing the mobilisation of forest and agriculture feedstock, or by implementing innovative ways to improve the efficient use of the biomass resources as available. Both approaches may potentially address and mitigate the above-mentioned risks. This section will focus on the second approach through improvements in the cascading use of biomass.

Cascading use of biomass refers to re-use and recycling of biomass products so that "biomass is processed into a bio-based final product and this final product is used at least once more either for materials or energy" (Essel et al. 2014). The cascading principles have long traditions of deployment especially in the forest industries, where the pulp and paper industries as well as sawmill industries have well-established chains of using the biomass for different purposes in different stages of its lifecycle. A typical example of a cascading chain is the use of roundwood in paper production, where the cellulose fibres can be used for paper recovered as recycled paper several times, and thereafter the paper sludge can be pressed into paper bricks and, finally, used as an energy feedstock.

Cascading, especially in the form of recycling and re-using, is already widely used within the biomass sector. However, examples of explicitly using cascading to reduce environmental impacts of industries, or improving the effectiveness of the cascading chain, are mostly limited to more theoretical research projects.

Political interest in cascading use of biomass has increased considerably in recent years at the EU level, given that it complements goals to increase resource efficiency and the increasing interest in the bioeconomy (COM 2012) and bioenergy (e.g. COM 2013).

In this literature review, the focus is on measures and instruments affecting prospects for cascading use in the EU. In order to specify aspects to take into account in the future scenario analysis, the literature is also scanned for possible indicators of cascading use and its environmental effects. Finally, the possible ways to implement policy measures into the scenario models are examined.

8.1. Defining cascading use

Comparing different studies on cascading use is complicated by the fact that there has not been a clear consensus on the definition of cascading use of biomass. A number of definitions of the term have been presented, focusing on various benefits for cascade use (e.g. economic, environmental, and industrial), various industrial sectors are involved (e.g. wood-processing, recycling, and energy sector), and aim of the study (e.g. theoretical evaluation or practical implementation). A short overview of the large range of definitions that have been provided will be given here.

Essel et al. (2014) offer the definition above, focusing on the material use of biomass at least at one point of the biomass life cycle. COM (2013) uses a more explicit definition for a cascading chain, with product-use being prioritized before re-use, recycling, bioenergy and disposal in a decreasing order of preference. While the concept of cascading overlaps with for example concepts of circular economy and the waste hierarchy, it is sometimes also used to refer to very complex systems of main and by-products (Essel et al. 2014).

Cascading use is referred to as single-stage if a product made of virgin wood is discarded and then directly used for energy (the biomass is used only for a single purpose, and then for energy). If there are two or more material uses for the biomass before its energy use (for example, discarded wooden furniture chipped and pressed into particleboards), cascading is said to be multi-stage (Essel et al. 2014). Odegard et al. (2012) differentiate biomass cascading chains also with respect to the dimensions in time, value and function – often all three elements are incorporated for the best environmental result. Cascading in time refers to increasing the lifespan of biomass by leaving as many future uses open as possible, as in paper recycling. Cascading in value refers to prioritizing the alternative uses of the biomass with respect to their value. Cascading in function refers to co-production of biomass products, so that the biomass stream is used for different types of products in order to promote as much functional use as possible.

Modelling cascading use first requires an understanding of the possible and existing biomass flows (Odegard et al. 2012, Mantau et al. 2010). In order to quantify the cascading use, indicators or proxys are needed. Mantau (2012) developed a detailed wood flow chart to calculate cascade factors for different cascading chains (Table 8-1). A cascade factor describes the relation between all wood resources (roundwood and other wood resources), and the resources from roundwood. This makes it is possible to calculate the input-output relation of wood for certain parts of the wood value chain (Mantau 2012), or for the whole chain of woody biomass use, as done by Indufor (2013). The cascade factor provides thus a useful indicator for comparisons of the extent of cascading between different value chains and also over time.

Table 8-1 An example of the calculation of cascade factors

	Utilization of wood biomass	Total volume (M m³)	Cascade factor	Calculation
A	Roundwood resources	577,1		
B	Residues in wood products	72,9	1,13	(A+B)/A
C	Residues in energy	103,4	1,18	(A+C)/A
D	Recycling in products	130,2	1,23	(A+D)/A
E	Recovery in energy	24,4	1,04	(A+E)/A
F	Residue cascades	176,3	1,31	(A+B+C)/A
G	Recycling + recovery cascades	154,6	1,27	(A+D+E)/A
H	**Cascades in products**	**203,0**	**1,35**	**(A+B+D)/A**
I	Residues + recycling in energy	127,9	1,22	(A+C+E)/A
J	**Total cascades**	**330,9**	**1,57**	**(A+H+I)/A**

Adopted from: Mantau (2012); the numerical values for total volume and cascade factors are illustrative only.

In the reviewed literature, central issues used for comparing the impacts of cascading use are land use, CO2 emission reductions, and costs and energy demand of production (Dornburg and Faaij 2005, Sathre and Gustavsson 2006). Usually the reference system is chosen so that it produces the same material or energy functions. However, if several different or alternative functions are produced through the cascading chain, the systems may become too complex to compare reliably. Therefore, Dornburg and Faaij (2005) emphasize the importance of comparing every single biomass chain with a single reference system.

Production costs and energy needed for production are relatively straightforward to calculate. The whole value chain needs to be taken into account: the different amounts of energy to produce, transport and process virgin and recovered wood, as well as the differences in by-product quantities (Sathre and Gustavsson 2006). The quantification of land use and CO2 emissions is not as easy, as these may occur at very different time points in alternative biomass production and cascading chains. For example, the rotation period – the time that the land is needed for one production cycle – in conventional forestry may be 100 years, whereas it in short rotation energy crops it is only a few years. On the material side, the time point when sequestrated carbon is released is also very different: for fuelwood it is almost directly after harvest, for paper maybe in a few weeks after production, and for building material possibly more than a hundred years after harvest. That is, the negative climate effects of CO2 emissions also occur at very different time points. One possibility to account for the different time horizons is to calculate the CO2 reductions of different land uses, and discount the monetary value of CO2 emissions at different points in time to the present day (Dornburg and Faaij 2005).

A clear definition of cascading use is of particular importance when aiming to increase cascading use through political instruments. Each of the definition as specified above has advantages and disadvantages in terms of the part of the system that they are able to cover and accurately represent. As expressed by AEBIOM et al. (2013) and Essel et al. (2014), narrowing the definition to multi-stage cascading implies hard restrictions on the biomass-using industries and may be impossible for many value chains. If single-stage cascading is also accepted within the term, more of the already existing product value chains may be counted in as utilizing the cascading principle.

8.2. Possible measures and instruments

There are several possible policy instruments that could be used to promote cascading use of biomass. Table 8-2 provides an overview of the instruments that have been suggested in the reviewed literature. The most central issues are the need for clear definitions of cascading use over the whole biomass lifecycle; imposition of taxes, subsidies and legal measures to promote cascading use; and cross-disciplinary and intergovernmental dialogue for developing more efficient logistical and technological solutions in different cascading stages. As noted by Haberl and Geissler (2000), notable gains in the total energy balance could be achieved by also utilizing the currently unused biomass residues in energy production. However, this is likely to require considerable investments in waste collection and treatment facilities.

Table 8-2 Possible ways to increase cascading use through policy tools

Measures	Instruments
New paradigm of resource value (Sirkin et al. 1994)	Taking total utility into account when assigning the product prices, also reflecting the resource quality and potential utility, and not solely market prices of the resources. This includes special valuation of vital resource qualities (qualities that cannot be replaced, such as food biomass quality), over non-vital (e.g. biomass for energy, where there are many alternatives)
Improvement of resource efficiency (Sirkin et al. 1994)	Policies for promoting product durability; effective re-collection and distribution systems for used and reclaimed materials; co-production and co-design

Balancing consumption with replenishment (Sirkin et al. 1994)	Policy measures encouraging the development of methods for efficient resource regeneration and replenishment; production methods and product design with exploit replenishable and renewable sources
Promoting cascadable design (Sirkin et al. 1994)	Formulating standard requirements for interchangeability; standard requirements for the utilisation of substances and materials; replacement equivalent deposit systems or introduction of resource compensation cost into the price of products; imposition of levies on products which cannot be cascaded or disassembled
Defining the criteria of the cascade (Keegan and Kretschmer 2013)	Taking entire life-cycles into account; water use efficiency and impacts on natural resources (including biodiversity); social considerations (supply security, and economic viability); waste prevention
Enhanced use of ecodesign to ensure technical feasibility of cascading use (Keegan and Kretschmer 2013)	Research and development.
Solving the logistical challenges of cascading use (Keegan and Kretschmer 2013)	Encouraging interdisciplinary research and strong links between sectors; strengthening the operation of waste collection and separation
Solving related policy challenges (Keegan and Kretschmer 2013)	Coordinated policies across government ministries (industry, agriculture, environment, research)
Financial measures (Keegan and Kretschmer 2013, Odegard et al. 2012)	Imposition of taxes on the use of virgin raw material, subsidizing energy sector for cascading use of biomass
Policy and/or legal measures (Odegard et al. 2012)	Recycling targets, landfill bans, adjusting laws that complicate the alternative uses of biogenic waste
Example from Austria: Utilizing the unused biomass residues for energy generation could contribute 6% (76 PJ) of the energy consumption (Haberl and Geissler 2000)	Account for combustion of woody wastes (from housing, agriculture) and straw from grain production; and utilizing wet municipal organic wastes, animal dung, organic residue from plant production as biogas
International agreement on limited biomass availability (IEA Bioenergy 2009)	Maximizing biomass conversion efficiency by minimizing raw material requirements while strengthening the economic position of agriculture, forestry, chemical and energy sectors.
Develop multi-disciplinary partnerships to foster R&D and deployment of new technologies (IEA Bioenergy 2009)	Bring together key stakeholders from different market sectors (agriculture and forestry, transportation fuels, chemicals, energy…)

8.3. Proposals to address cascading use in the modelling framework

Within this project, we propose first to analyse the extent of cascading in the different bioenergy scenarios using cascade factors presented in Table 8-2 (Mantau 2012, Indufor 2013). At this first stage, we will assess the potential use of the above-mentioned indicators within the modelling framework and how they could be applied to provide insight to the model development over time. The indicators will then be monitored to show how cascading evolves over time, both in total and in different parts of the value chain. The indicators will at first strictly be used as a monitoring tool to analyse and inform how change in cascading may occur over time, and how different scenarios may impact the applied indicators. This in turn allows also an analysis of the differences between the scenarios in overall land use change and related CO_2 emissions in relation to cascading use.

Within a second stage, policy measures identified in this review as particularly important for increasing cascade use will be assessed in terms of their potential impact on the cascade indicators developed in the first stage. The policy measures for cascading use touch on different aspects of the wood cascade chain, and are expected to affect the cascade indicators differently. The main underlying storylines may focus on (i) improved waste recovery through policy targets, i.e. maximise recycling of solid wood and (ii) imposing taxes on the energy use of virgin raw material. These envisioned policies measured are of particular interest as they are expected to have direct implications for the cascade indicators to be used and on the other environmental and economy indicators that are to be monitored.

9. Conclusions

Impacts of biomass use on natural resources and the global environment are manifold. The project attempts to cover the most relevant impacts in the model framework (Task 3) and assesses them in the subsequent analysis of impacts (Task 4). The literature review carried out in the project gives a comprehensive overview of the current knowledge on possible impacts on biodiversity, soil, water bodies, greenhouse gas emissions and indirect effects and other land-use impacts, including some aspects on economic impacts. Each impact category was divided into detailed impacts, e.g. soil erosion, soil carbon loss, soil compaction, soil nutrient loss and soil salinization for the category soil. A set of 40 references was considered relevant after categorization from an initial list of 202 references. The selected references were then analyzed for detailed impacts that were reported, as well as the causes of impacts and the responses suggested by the literature. Despite the complexity of the issue, the project tried to also identify important aspects regarding responses to impacts reported in the reviewed literature that have the potential to help reduce negative impacts (see summary in Table 9-1).

The use of biomass for energy purposes can potentially be a driver of loss of **biodiversity**, linked primarily to direct and indirect land-use change and increasing intensity of land use. The increasing use of biomass is likely to increase this pressure. The screening of literature carried out in this project focused on the following detailed impacts: loss of species, loss of ecosystems, damage of flora and fauna and loss of ecosystem functions. From a biodiversity perspective the review showed that two aspects are of high relevance: a) the protection of areas with high biodiversity value and b) sustainable extraction rates of dead wood, residues, stumps and old trees.

The review showed that most **soil** impacts are very site specific and require respective soil conservation measures. For sensitive areas measures may include the exclusion of areas from production and the restriction of residue and stump extraction (Table 9-1). However, the amount of biomass extraction can be part of the soil conservation measure (e.g. mulching with straw, retaining nutrient cycle by leaving branches and leaves on site) and lead to win-win situations. Other soil conservation methods increase the possible extraction rate but entail higher production costs (e.g. fertilization with ash). Some soil conservation measures may also only cause costs and not necessarily contribute to improved yields (e.g. adaption of machinery, windbreaks). Finally, specific soil conservation measures may lead to a lowering of yields compared to the option without measures (e.g. adoption of crop rotation to allow straw extraction). It is therefore necessary to favour win-win measures that contribute to soil conservation while positively impacting biomass production.

The identified impacts on **water** are of lower relevance compared to e.g. impacts on biodiversity and soil. This is due to the focus of the literature review on systems producing solid biomass that are largely rain-fed systems. The most relevant potential negative impacts on water are a) overuse of freshwater resources in water scarce regions, b) pollution of waterbodies from the application of fertilizer and pesticides, and c) pollution of waterbodies from process waste water (Table 9-1). However, there can also be positive impacts of biomass production systems, e.g. on ground water supply.

Strong impacts on **greenhouse gas emissions** from biomass production occur when areas of high carbon stock are converted to bioenergy plantations of low carbon stock, but also an increase of wood extraction, including whole tree harvest and residue extraction, can lower the carbon stock of forests (Table 9-1). However, there are cases where long-term active forest management can increase biomass and timber production while still safeguarding the forest carbon stock at the landscape level. Examples of such improvements range from the promotion of regeneration and silvicultural management to enhancing forest growth (through improved timing of pre-commercial cutting, thinning efforts, fertilization, etc.). When including substitution effects on GHG emissions within the energy and industry sector, managing forests for products and services (energy and/or materials) can also determine higher GHG savings than suspending the management.

Table 9-1 Important points identified from the reviewed literature to reduce negative impacts from biomass use on the environment

Environmental aspect
Biodiversity
▪ The protection of areas with high biodiversity value ▪ Sustainable extraction rates of dead wood, residues, stumps and old trees
Soil
▪ Identification of exclusion areas where (i) no production at all is allowed at all and (ii) where no residue or stump extraction should occur (e.g. depending on steep slopes, poor soils, wet soils) ▪ Restriction of residue and stump extraction on all remaining areas ▪ Lowering the development of yields, i.e. assuming a lower annual yield-increase rate assuming stronger soil protection measures
Waterbodies
▪ Avoid overuse of freshwater resources in water scarce regions ▪ Avoid pollution of waterbodies from the application of fertilizer and pesticides ▪ Avoid pollution of waterbodies from process waste water
Greenhouse gas emissions
▪ No conversion of areas of high carbon stock ▪ No overuse of forests ▪ Time lag of forest growth and wood use, both for energy and materials ▪ Threshold for the GHG-emission reduction compared to fossil sources

Indirect effects (for all environmental impacts) occur mainly as a consequence of the displacement of a former activity to fulfil a demand. In case that the former demand still exists, meeting this demand may case impacts elsewhere, especially as further biomass production will tend to extend into less fertile soils (hence requiring more inputs such as fertilizers and/or water) and/or into areas with higher ecological value. Results from the literature review on indirect effects and on economic impacts showed that both aspects are mainly related to competition between different biomass uses (energy, material) for biomass resources such as stem, branches, stumps and residues.

Finally a literature review was carried out for the **cascading use** of biomass, focusing on measures and instruments to incentivize it. The most central issues and proposed methods for increasing cascading mentioned in the covered studies are the need for clear definitions of cascading use over the whole biomass lifecycle; imposition of taxes, subsidies and legal measures to promote cascading use; and cross-disciplinary dialogue for developing more efficient logistical and technological solutions in different cascading stages.

10. References

Please note that the references are split in two reference lists (see details in Appendix 1):

- References that are cited in the text of this study and/or used in the in-depth literature review (Section 10.1)
- Further references that have been considered in the pre-selection of the literature review (Section 10.2)

10.1. References cited in the report and used in the in-depth literature review

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11. Appendix 1: Methodology

11.1. Impact on the environment

During the last two decades a vast number of scientific studies addressing the sustainability of bioenergy have been published. The challenge of this literature review is to identify those studies that are of relevance for the modelling under Task 3 and the impact assessment under Task 4. We developed a three-step approach to fulfil this challenge:

Step 1: List of available studies
Based on the knowledge of the involved project partners on existing literature we generated a list of references that address impacts of biomass production and conversion on natural resources and the global environment. In total we covered more than 202 references with a specific focus on review studies. All references are listed in the Appendix. General information on the references, e.g. focus of the study, geographical range and type of land use, is collected in an Excel file that will be delivered as appendix of this report.

Step 2: Pre-selection
Due to time constraints we carried out a pre-selection of those references to be considered in an in-depth review. Studies were selected for in-depth review if they fulfilled the following requirement: *"Are concrete indicators covered within the study (not only principles, e.g. soil protection is needed, but information on how soil protection shall be addressed, e.g. listing soil conservation measures)"*. In total, 40 studies were selected for an in-depth review that provided information on more concrete indicators. The list in the Appendix identifies studies selected for in-depth review.

Step 3: In-depth review
For the selected studies an in-depth review was carried out. We categorised the studies to make results of the review more comparable across studies and to make sure the review is sufficiently representative (see Table 11-1). The following categories were covered in all reviews to achieve a systematic analysis across all selected references:

- **Type of biomass.** Describes the tye of biomass feedstock regarding its origin (agricuture or forestry) and cultivation method.
- **Type of ecosystem.** Describes the type of ecosystem used for and natural conditions of biomass production differentiating tropical, sub-tropical, temperate and boreal forest and agriculture ecosystems.
- **Type of study.** Describes the type of research undertaken leading to the results presented by the study. Types of studies under review are: Model; Empirical; Review /Synthesis
- **Pressure / driver.** Describes the pressures and drivers of impacts addressed by the study. Categories are: (increase of) biomass production; conversion /transport /use of biomass; (general)
- **Impact.** Describes the impact of biomass production or use analysed in the study. We differentiate between: Biodiversity; Soil; Water and water pollution; GHG-emissions; Land-use impacts; Economic impacts; Others

- **Impact detail.** Describes the impact in detail regarding concrete indicators affected by biomass use and production:
    - **Biodiversity.** Loss of species; Loss of ecosystems; Damage of flora and fauna; Loss of ecosystem functions; Others
    - **Soil.** Soil errosion; Soil carbon loss; Soil compaction; Soil nutrient loss; Soil salinization; Others
    - **Water.** Over-use of water resources; Impact on water table; Water pollution; Others
    - **GHG emissions (incl. substitution effects).** Change of carbon stock; Change of disturbance pattern; Others
    - **Land-use impacts.** Indirect land-use change; Competition with other land use; Ploughing of grasslands; Overuse of forests; Others
    - **Economic impacts.** Increase of revenue; Competition with other uses; Supply cost at the Power plant; Others

Table 11-1 Cause of impact on biodiversity and suggested response

Category name	Description
Type of biomass	
agr_all	All agricultural systems
agr_short rotation	Agricultural systems providing lignocellulosic biomass from Short Rotation Coppice systems
agr_grasses	Agricultural systems providing grasses
agr_lignocellulosic species	Agricultural systems providing lignocellulosic biomass
agr-animal byproducts	Agricultural systems providing biomass as a by-product of animal production
agr_residues	Agricultural systems providing biomass as residue of agricultural crop production
for_all	All forestry systems
for_round wood	Forestry systems providing biomass from round wood
for_residues_all	Forestry systems providing biomass from primary and secondary residues
for_residues_stumps	Forestry systems providing biomass from primary residues based on stump extraction
for_residues_branches	Forestry systems providing biomass from primary residues based on branch extraction
for_dead wood	Forestry systems providing biomass from primary residues based on dead wood extraction
waste_all	All waste categories
waste_food waste	Biomass from food waste
waste_biological fraction MSW	Biomass from the biological fraction of Municipal Solid Waste (i.e. households)

The relevant references were further screened for information describing:

- **Cause of impact** (e.g., inappropriate management, degradation etc.)
- **Suggested response** (e.g., thresholds, default values, measures etc.)

- **Suggestions on incorporating impact in modeling** (e.g. datasets, procedures, etc.)

In case that a reference covered different categories, a new entry was produced to cover this specific information. This means that a single reference may occur several times in the in-depth review list for different aspects.
The information gathered from selected studies is presented in a summary table and further described in the text.

11.2. Cascading use

Similar to the review on impacts on the environment relevant references are collected for the topic of cascade use. The selected references were screened for information on measures and instruments addressing explicitly the cascade use of biomass. On purpose a wide definition of cascade use was adopted include in the beginning as many studies as possible. This definition describes cascade use of biomass products that are at least once recycled, reused or recovered for either material, chemical or energy use. Due to the fact that publications on cascade use are rare, no pre-selection procedure was needed and all found references were covered in the review. In total nine studies were selected for an analysis.