A Global Assessment of the Environmental and Social Impacts Caused by the Production and Use of Biofuels

A report by the IUCN Commission on Environmental, Economic and Social Policy Biofuels Task Force

International Union for Conservation of Nature

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Cover photo credit: ©CIFOR – Growing jatropha can benefit smallholders.

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Foreword

One of the International Union for Conservation of Nature's (IUCN's) key tools to promote conservation of biodiversity and more sustainable practices are the resolutions and recommendations issued by its members at its World Conservation Congresses. These define IUCN's policy and also help distil common messages and practices to be promoted and adopted by the various stakeholders. With regards to sources of renewable energy and in particular biofuels, IUCN has issued numerous resolutions, all aiming at improving the outcomes of the use of biofuel on nature and people.

At IUCN's 5th World Conservation Congress, held in the Republic of South Korea in 2012, IUCN members adopted Resolution 88, « Responsible renewable energy sources ». This resolution expressed members' concerns that industrial biofuel production causes serious deforestation and degradation of forests; forces people to leave their lands; removes their capacity to produce food for their livelihoods; and, is responsible for increases in greenhouse gas emissions during different phases of the production cycle.

In adopting Resolution 88, IUCN members requested IUCN's Director General to lead the compilation of a report including an assessment of the environmental and social impacts caused by the production and use of biofuels on a global scale. To respond to this request, IUCN's Commission on Environmental, Economic and Social Policy (CEESP) Biofuels Task Force and IUCN's Secretariat, represented by its Global Business and Biodiversity Programme (BBP), commissioned a literature review of articles about biofuels which identified both global trends and existing information gaps: A "Scoping analysis of biofuels literature". With their help this was conducted by László Máthé and Dr. Fiona Borthwick, with the help of CEESP and BBP.

IUCN began its work on the issue of biofuels over 10 years ago, addressing it from different perspectives, including supporting the development of the first sustainability standards, now known as the Roundtable on Sustainable Biomaterials; working with leading businesses interested in exploring more closely the trade-offs between the opportunities and threats to biodiversity generated by this type of energy source; and bringing the discussion to its diverse membership. From the outset, the claim that biofuels, the liquid fuels derived from biomass, could be sustainable substitutes for petroleum based fuels has been challenged from many perspectives. Are these renewable fuels part of the energy challenge solution? Or are they part of the problem? What are their benefits? What are their limits?

The jury is still out. As it often is the case when issues “hit the ground”, the answer is not that simple and it often depends on many variables. The development of biofuel projects demonstrated that current biofuels policies and practices run the risk of undermining food security while degrading ecosystems through deforestation, agrochemical pollution, the introduction of invasive species and the use of genetically-modified feedstock. However, well-planned and managed biofuels production can conceivably contribute to a more sustainable energy future while providing opportunities for improved landscape management, conservation farming practices, climate change adaptation, and rural livelihoods development.

A Global Assessment of the Environmental and Social Impacts Caused by the Production and Use of Biofuels found that producing biofuels has caused harmful, often unanticipated impacts on people and the environment. There is continuing concern about the social impacts such as food security, land grabs and human rights abuses. A major finding is that there is little information available about the impacts of biofuels production on biodiversity. This is attributed to the lack of criteria for monitoring of these impacts in voluntary certification systems, a problem that we recommend be addressed. Though commitments may be made to protect biodiversity, definitions of this are vague and continuous monitoring is not required.

The available literature has provided little documentation of the positive impacts of biofuels production. More studies are definitely needed because there are emerging models for how smallholders can benefit financially and protect the environment at the same time.

On the positive side, recognition of the problems it has caused is spurring the development of more sustainable alternative fuels and practices. These innovations could ultimately help mitigate climate change and contribute to improved livelihoods for rural communities. For example, the use of wastes as feedstock can reduce land demands and impacts of food supplies. The “Next Steps” section of this Global Assessment provides suggestions for action and research. It is hoped that activists and scientists will see them as opportunities to be more engaged in this issue.

Doris Cellarius
Co-Chair, IUCN Cross-Theme Biofuels Task Force (CEESP)

Giulia Carbone
Deputy Director, IUCN Global Business and Biodiversity Programme

1. Introduction

This report offers a review of literature from various sources on the impacts of the production and use of liquid biofuels, which are used mainly in the transport sector. Liquid biofuel is one of the two main types of bioenergy, along with solid biomass, used mainly to generate heat and electricity. In many cases, the evidence reviewed for this report discussed both kinds of bioenergy. The sustainability of both types continues to be a controversial topic, particularly because more information is now available about indirect impacts.

In recent years, investments in bioenergy have slowed due to policy uncertainties, as well as the economic crisis. Nevertheless, a number of organizations predict that the role of bioenergy will continue to grow in the coming decades, driven by climate change mitigation needs, rural development and other policies.

The potential climate mitigation role of bioenergy, including liquid biofuels, is also acknowledged by the latest International Panel on Climate Change (IPCC) report. If feedstock production does not lead to the conversion of high carbon stocks and biodiverse areas, and if best land and water management practices are implemented, bioenergy could play a critical role in climate change mitigation (IPCC, 2014).

In 2009, Campbell and Doswald (2009) published a review similar to this one, focusing on the biodiversity impacts of biofuels, on behalf of UNEP–WCMC. This report reflects on the progress made since that review.

While most evidence referred to in this report focuses on modern bioenergy applications, it is important to remember that traditional bioenergy (fuelwood, charcoal use, etc.) accounts for approximately one-half of the wood currently removed from forests, leading to deforestation, ecosystem degradation, human health problems and other social implications when extracted unsustainably. For modern bioenergy to contribute substantially to future energy systems, it is imperative to address these challenges associated with the traditional use of biomass.

2. Objectives of this report

This report has three main objectives:

- identify key gaps in the existing literature about the social and environmental impacts of biofuels, with a special focus on biodiversity impacts;
- develop a synopsis of the existing literature related to the sustainability of biofuel production; and
- develop recommendations to address the gaps, in collaboration with IUCN.

3. Methodology

3.1 Scope

Based on initial discussions with IUCN, this report includes reviews of literature related not just to the production of liquid biofuels (1st generation, 2nd generation and advanced), but also solid biomass used for heat and electricity. While most of the evidence cited in this report relates to impacts associated with liquid biofuel production, it is often difficult and not always helpful to separate the two main types of bioenergy.

This report focuses mainly on feedstock production; impacts related to processing or transport of various feedstocks were not included. Additionally, traditional bioenergy use (fuelwood, charcoal use in developing countries) is also excluded, because of the very different nature of impacts, users and markets.

The literature reviewed for this report includes evidence focusing on existing impacts related to modern bioenergy feedstock production, as well as various models and scenarios that attempt to predict future environmental and social impacts. The geographic coverage is diverse, and there has been no preference for certain regions.

3.2 Indicators

In order to carry out a comprehensive review of social and environmental impacts related to biofuel production, indicators developed for lifecycle analysis, social analysis and biodiversity assessments were combined into a single set of indicators. This set of indicators was then used to assess the extent to which they are represented in the literature, rather than to assess performance.

To identify the gaps in the existing literature, a set of indicators was compiled from guidance on lifecycle assessment (Koellner and Geyer, 2013; EU, 2010; Hass, Wetterich and Geier, 2000), with additional guidance on social aspects of lifecycle assessment from a UNEP document (2009). It is acknowledged that biodiversity is not well-represented in lifecycle analysis indicators, so an additional set of indicators was compiled from the Biodiversity Indicators Partnership (2010) and the European Environment Agency (2012).

These indicators were selected to give a comprehensive overview of the literature and evidence relating to the environmental impacts of biofuel production. The indicators were then either scoped in or out of the survey, depending on their relevance. The list of indicators is presented in Annex 1.

3.3 Selection of literature

The environmental and social impacts of large-scale production of biofuels have received increasing attention from various groups of stakeholders. A Science Direct search was conducted in December 2013, using the search term 'biofuel, impact'. A total of 17,606 peer-reviewed papers were returned.

Subsequent searches included 'biofuel, biodiversity' (3,022 papers) and 'biofuel, conservation' (6,156). Of the journal articles captured by the search, this report reviewed all that contained biodiversity in the title and as a key term.

The majority of these articles have been published since 2008. A similar methodology has been implemented by Savilaakso, et al. (2014) for an article synthesising the biodiversity impacts of oil palm production, based on existing literature.

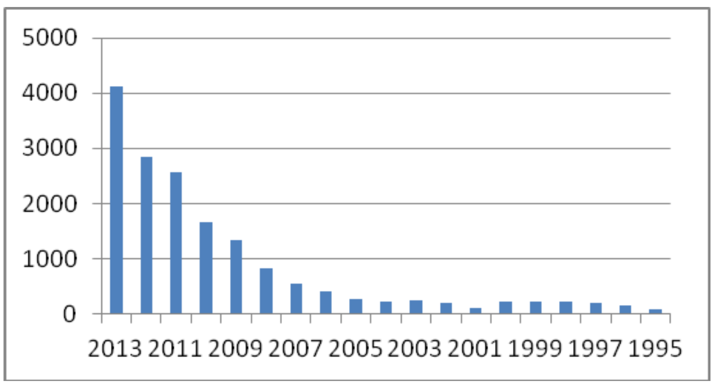


Figure 1: Total number of papers held in Science Direct under search term 'biofuel, impact'

Figure 1 was generated using information provided by Science Direct, which analyses the top themes in the papers within the search. This indicates that the main key theme of the current literature is greenhouse gases and climate change-related evidence. Countries that are specifically covered to a large extent include China, Brazil and India. Sustainable development is included in this breakdown, but not as one of the most significant themes. Papers focusing on technical aspects of biofuels were not included in this analysis, but, as shown in Figure 2, these are also key themes.

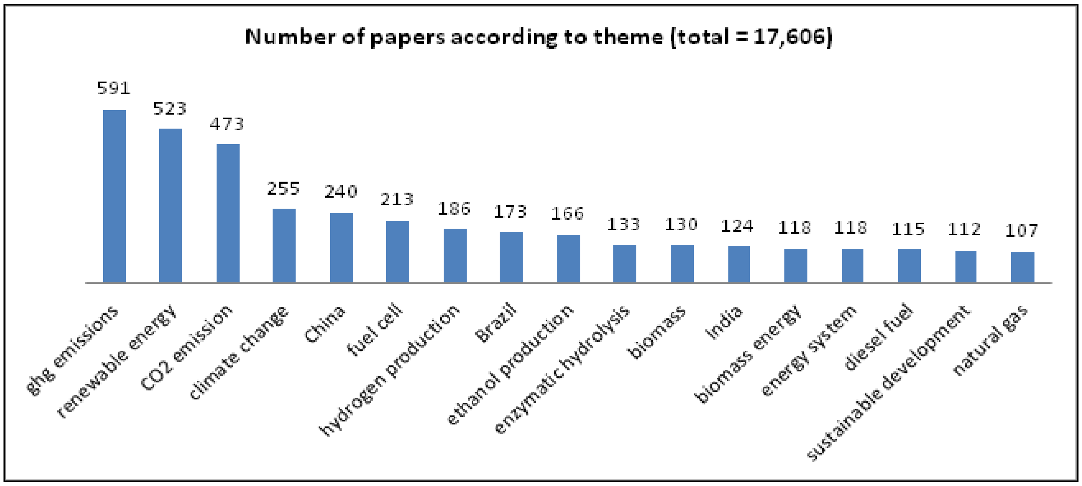


Figure 2: Number of papers held by Science Direct according to theme (biofuel impacts search term)

Four main sources of literature have been used for analysis as a basis of this report:

- **Doris Cellarius, Sierra Club** and the **IUCN Cross-Theme Biofuels Task Force (CEESP)** provided a significant share of the papers.
- **Science Direct:** The selection was limited to 2008-2014, and also to papers that contained biodiversity as a key term**;** the authors then randomly chose a small sample of the search term returns. Additionally, the key journals producing articles on this subject were selected, and a number of articles sampled from these, including: *Biomass and Bioenergy*, *Bioresource Technology*, *Global Food Security*, *Food Policy*, *Land Use Policy*, *Renewable and Sustainable Energy Reviews* and *Journal of Cleaner Production*.
- Furthermore, a selection of reports from the **Global Bioenergy Partnership virtual library was also included**, focusing on bioenergy and climate change, bioenergy and sustainability, and bioenergy and food security.
- Finally, based on the **authors' expertise, additional papers** were added to the list.

While the sample size (95) is small in relation to the total number of articles and reports available, it is a representative selection that focuses on the most current publications, the presence of search terms within the title and main body, and expert opinion. It is therefore possible to draw general conclusions about the knowledge available relating to the indicators selected.

3.4 General overview of literature

Geographic scope: Of the 95 papers reviewed, a high proportion had either a global or national scope; a regional (multi-national) focus was less relevant in the literature sample. The distribution of papers focusing on a region is dominated by the EU. The United States, Brazil and India dominate the papers with a national scope.

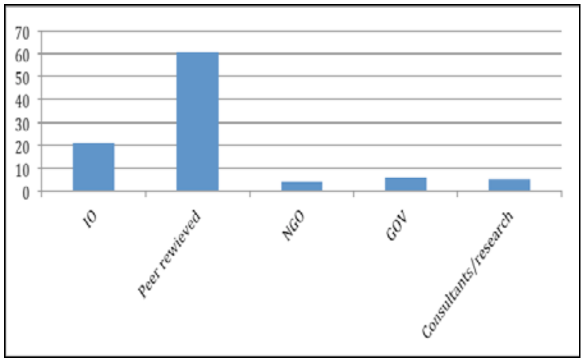


Figure 3: Type of paper reviewed

Given that there is a significant amount of the total literature focused on Brazil and India, this is expected; however papers on China are not as evident, indicating either that the selection of papers did not represent this theme or that papers discussing China and biofuels are not found in the past six years as frequently, or present a technical processing focus.

Peer review vs. grey literature: The type of papers reviewed is presented in Figure 3. The majority of papers were peer-reviewed journal articles. A number of papers considered 'grey literature' from International Organizations (IO), such as the United Nations and World Bank, were also reviewed.

Existing vs. future impacts: The review process also recorded the temporal nature of the impacts discussed (see Figure 4). In some cases, the papers discussed the development of impact assessment of modeling tools and so were related neither to existing nor future impacts. These categories are not exclusive; some papers discussed both existing and future impacts. While more papers discussing existing impacts were reviewed, the split is fairly even, suggesting that both are well-represented in the existing evidence.

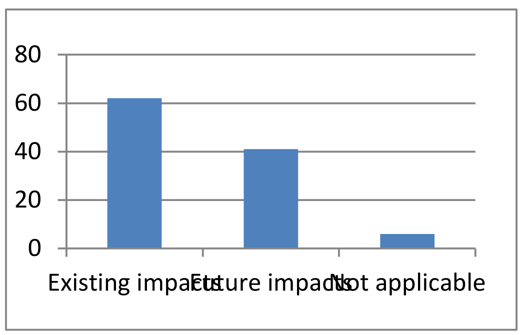


Figure 4: Existing vs future impacts in the reviewed literature

Bioenergy feedstock and technologies: The papers reviewed covered a broad range of feedstocks and technologies, including both 1st and 2nd generation technologies, as well as biomass for heat end electricity. However, as shown in Figure 5, these were not covered equally. Many of the papers were feedstock neutral and could only make broad generalisations. When specific feedstocks were covered, the most common types were wheat, corn, soybean, switch grass, canola/rape seed and jatropha (see Figure 6).

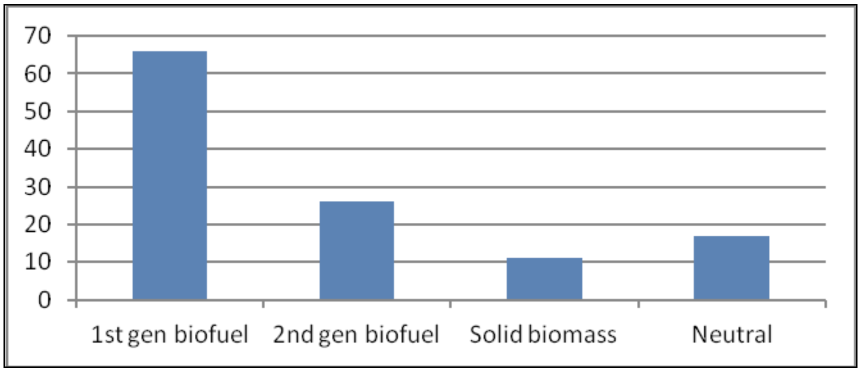


Figure 5: Bioenergy technologies in the papers included in the analysis (nr)

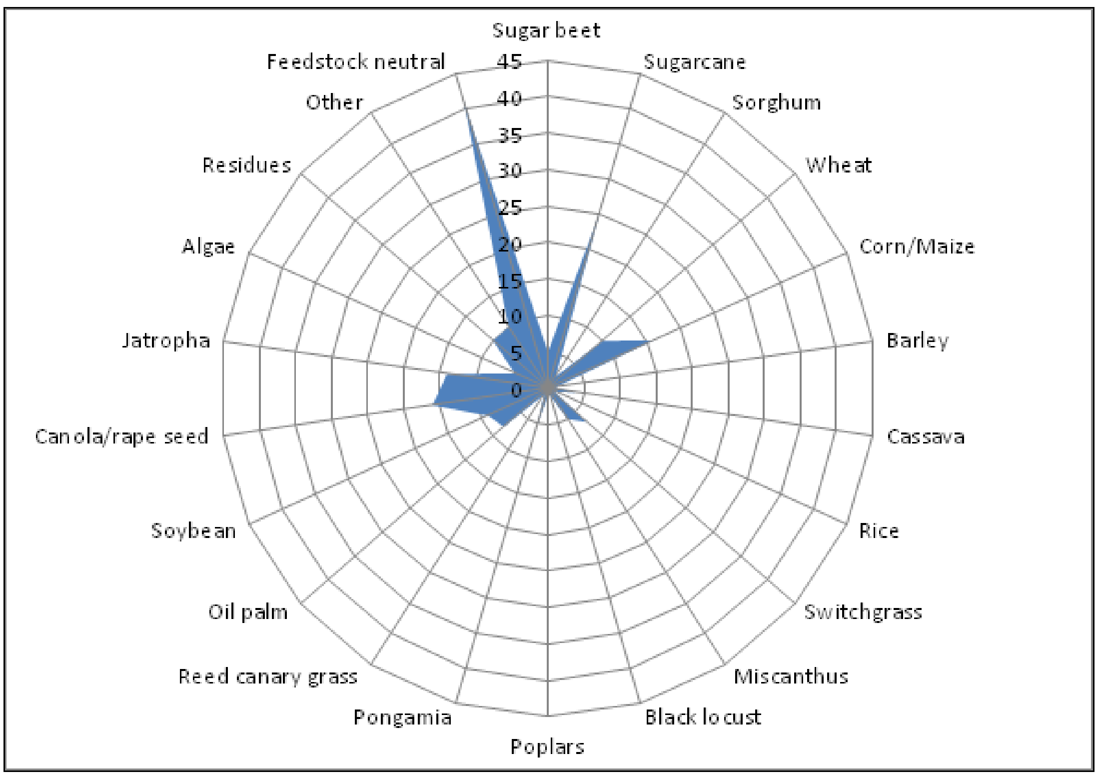


Figure 6: Feedstocks mentioned in the papers included in the analysis

4. Findings – environment and biodiversity

Evidence related to the biodiversity impacts of bioenergy expansion is fragmented and insufficient in most cases to support decision making by governments or biofuel feedstock producers. Annex 2 provides a detailed overview for each indicator that was used for this analysis.

Biodiversity impacts: Looking just at the indicators related to environment and biodiversity (see Figure 8), it becomes obvious that the biodiversity impacts of bioenergy feedstock production need further attention in a number of research areas. The relatively high score on natural environment is a result of a high occurrence of information related to land-use change. However, in most cases these are general references to land-use change, often based on modeling work.

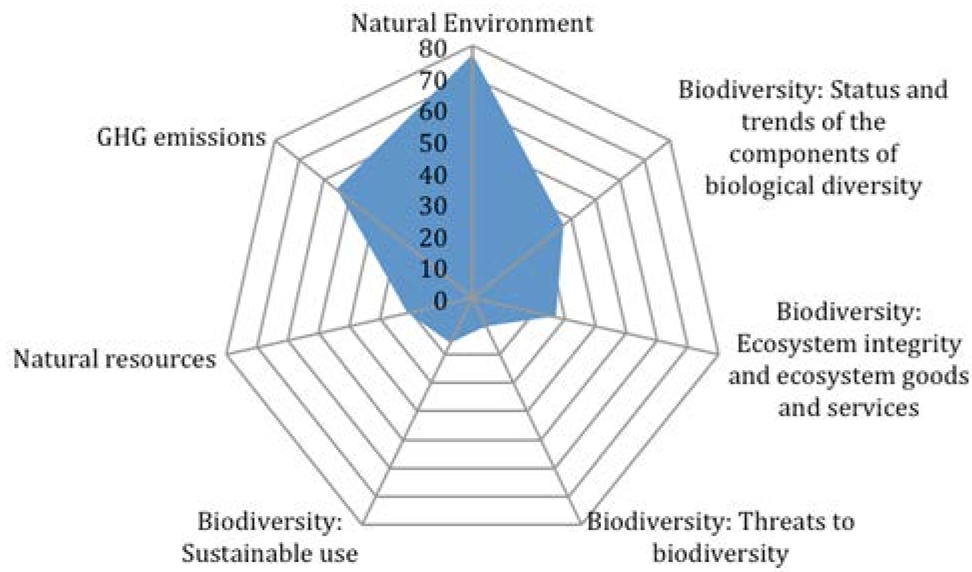


Figure 7: Number of papers reviewed covering environmental indicators

While modeling is a useful tool in predicting impacts, the examples that were reviewed for this report can only provide general findings, for example on the extent and nature of likely land-use patterns. There are only a handful of examples of systematic assessment of biodiversity impacts related to biofuel feedstock production expansion in a certain region. German, et al. (2011) has carried out one such assessment, based on case studies from Brazil, Ghana, Mexico, Indonesia and Zambia. One of the key conclusions of this assessment is that between 16 and 99 per cent of the crop expansion (used as a biofuel feedstock) has taken place at the expense of forests; the highest share is from oil palm in Indonesia.

However, the paper notes that the major drivers of deforestation are multi-purpose crops that are mainly used in the food or feed sectors, with biofuels being a relatively small contributor. Changes in land use are useful to predict the likely scale of impacts, but they have significant limitations when it comes to predicting biodiversity loss. Not all forests, grasslands etc. harbor the same biodiversity values, and without detailed field observations it is difficult to use land-use change as a proxy for estimating biodiversity loss.

Additionally, not all land-use change results in negative biodiversity impacts. In the case of degraded landscapes, certain types of land-use change can actually result in positive biodiversity outcomes. Savilaakso, et al. (2014) have produced a synthesis report linking oil palm with notable reductions in biodiversity. They also noted that there was insufficient information on two other commodities used for biofuel production that were investigated (soybean and jatropha).

A recent report added further complexity to this topic by calculating the ‘land footprint’ of EU bioenergy targets (Schutter and Giljum, 2014). The report concludes that, by 2030, the EU bioenergy targets will have a land footprint of more than 70 million hectares, a significant share of which would be forest lands. Nonetheless, without an indication of the scale and intensity of forest management in these areas, it is difficult to draw any sort of conclusion. Low-intensity forest management has been shown to have certain positive biodiversity impacts, and Europe has extensive unprotected forests that are not managed.

Recommendation: While evidence concerning biodiversity impacts does exist, there are areas where more knowledge is needed, particularly ‘trends in genetic diversity’, ‘coverage of protected areas’, ‘connectivity and fragmentation of ecosystems’, ‘trends in invasive alien species’, and ‘ecological footprints’. While one could argue that some of these topics, such as trends in genetic diversity are less relevant for the purposes of this analysis, they are important for a thorough understanding of the impacts of biofuel production on biodiversity. Several key areas, such as connectivity and fragmentation of ecosystems or changes in the status of protected species, are very clearly under-researched and will require further work. These topics were only covered by a couple of papers included in the analysis.

Product- or end-use-specific approaches are not always efficient: Using certain crops for bioenergy often represents just one of the possible end uses. Advocating sustainability for one of the end uses without considering all the possible users leads to leakage and ultimately a failure to deliver on sustainability. This is reinforced by the conclusions of a recent UNEP (2014) report focusing on consumption of various land-based commodities and sustainable supply. The UNEP report also predicts that, under business as usual scenarios, sectors such as biomaterials will require more raw materials (and as a result potentially more land) than bioenergy by 2050.

Recommendation: Policies related to the bioeconomy need to take into account land and resource availability and the demand from competing sectors. Considering that sustainable biomass will be a limited resource, focus should be given to the most resource-efficient pathway. Additionally, all end uses should comply with sustainability criteria to avoid leakage and indirect impacts.

Positive vs. negative biodiversity impacts: Overwhelmingly, both the academic and grey literature focus on negative impacts, with very few detailing positive examples. The ones that refer to positive impacts are fairly narrowly focused. For example, Hedenec (2014) discusses the impacts of native and introduced biofuel crops in the Czech Republic and concludes that native species contribute to a more diverse soil biota.

Recommendation: Biofuel feedstock production, depending on the feedstocks, nature of the production system and previous land use can lead to significant negative impacts. There are some well-documented examples, especially for feedstocks that are the major land-use-change drivers, such as oil palm and soy, which in recent years have also been used in the bioenergy sector. Nonetheless, there is very limited knowledge about how bioenergy could play a positive role in biodiversity conservation or contribute positively to local communities. It is difficult to estimate how significant such production models could be, although at the local level the benefits could be important enough to try and promote them. Examples could include: removal of invasive species, restoration of landscapes and low-intensity harvesting. The bioenergy market could provide incentives for such projects. A systematic overview of such positive examples would be extremely useful, especially if these are linked to various incentives established by legislation or voluntary standards.

Sustainable production: An important finding that should be highlighted based on Figure 7 is the fact there is very little evidence available about the extent of sustainable production, as outlined by some of the best management practices included in this assessment. Additionally, there is not adequate evidence about the biodiversity implications of better management practices. For example, there is very limited information available with regards to the positive implications of various voluntary standards and certification schemes. Voluntary standards are mentioned in several papers as a key strategy to reduce impacts, but little is actually known about their on-the-ground impacts. The Roundtable on Sustainable Biomaterials (formerly Roundtable on Sustainable Biofuels) is cited by a couple of papers; however, there is currently no field evidence related to the implementation of its standards.

Recommendation: Research projects should be developed to better understand the biodiversity benefits of better management practices proposed by the literature. Field research should also focus on identifying to what extent various voluntary standards provide adequate safeguards for biodiversity, especially because there is quite significant variability between various instruments.

Biofuel potentials that are compatible with biodiversity targets: None of the papers reviewed for this report contained estimates of the global or regional potential for sustainable bioenergy production, considering various biodiversity targets. A number of assessments use various proxies to estimate sustainable potentials, especially land-use change. Nonetheless, these proxies are not precise enough in predicting compatibility with various biodiversity targets at a global or local scale.

A recent UNEP (2014) report highlights that productive land is a limited resource and suggests that halving biofuel targets (among other measures targeting all sectors) would result in land-use dynamics considered to be in the 'safe operating space'. Current global biofuel production could cover nearly all of the fuel needs of today's aviation sector, so depending on the economics of biofuels, the demand could be significantly larger. At least two other sectors are dependent on liquid fuels as a low-carbon option: shipping and long-haul trucking. Reducing biofuel mandates will ultimately mean that these sectors are locked in fossil pathways.

Recommendation: Research projects should be developed, preferably at a regional level, to determine biofuel potentials that are compatible with local, national or regional biodiversity conservation targets.

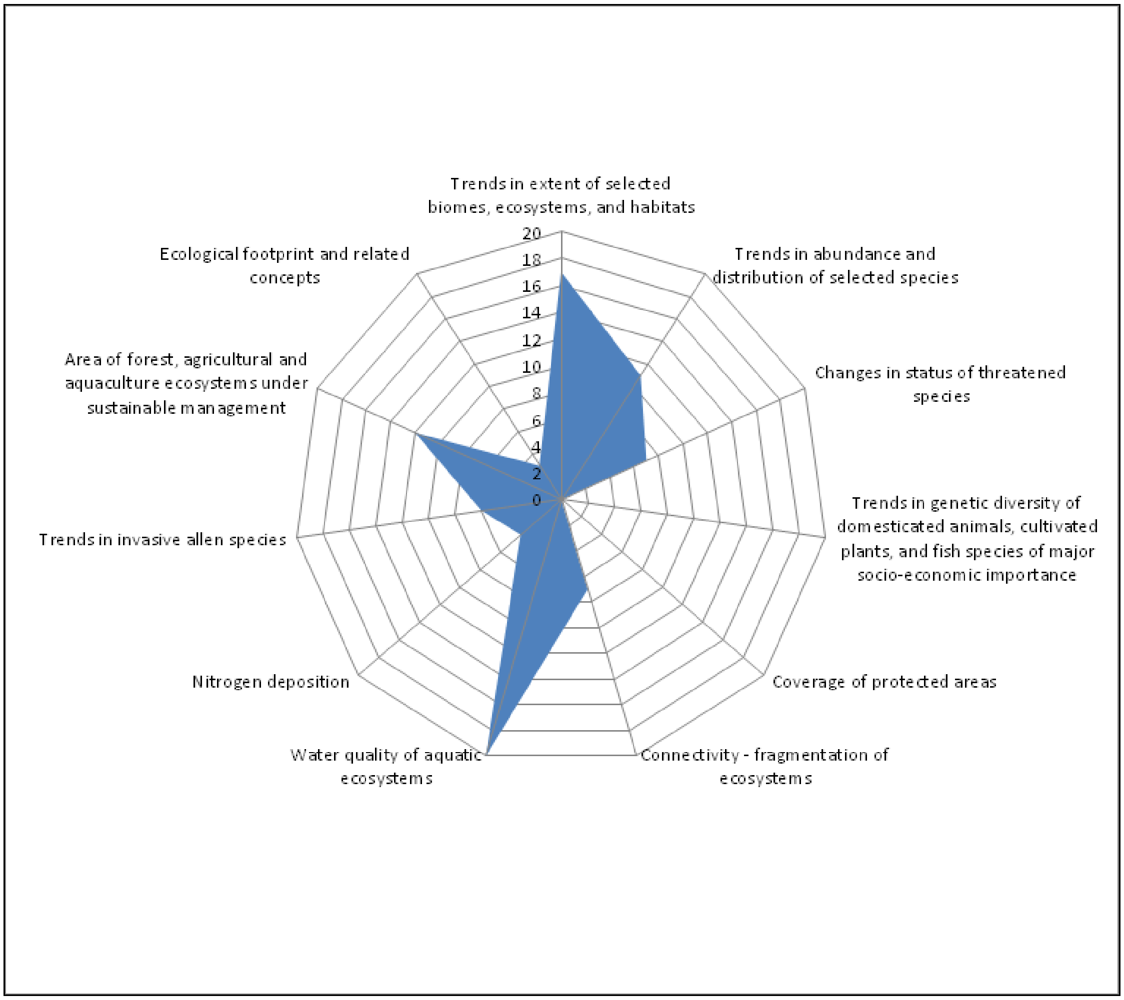


Figure 8: Occurrence of biodiversity-related indicators in the reviewed literature.

Focus on less important feedstocks: Figure 4 illustrates a bias toward some feedstocks that have very small or no contribution to the current bioenergy supply. Jatropha is a good example. Current jatropha-oil-based biodiesel production is insignificant, yet in the papers reviewed for this report, jatropha has the same or similar weight as some of the main feedstocks, including corn, soy or sugarcane. Gasparators, et. al (2010) list jatropha as one of the most 'prevalent feedstocks'. A number of arguments might be listed to support this: Jatropha is a relatively 'new' crop, so little is known about it, while corn, soy and sugarcane production have all been extensively researched. In addition, jatropha is planted in sensitive areas, so even a small expansion will have significant impacts. While it is difficult to find reliable numbers on the extent of jatropha plantations, they are relatively modest.

Strictly from a biodiversity point of view, the choice of feedstock in many cases is less relevant; rather, it is more important where and how the feedstocks are produced (Stromberg, et al., 2010; Berndes, et al., 2011; Taylor, 2012). A similar bias can be observed when it comes to the countries included in the research.

For example, while India has good technical potential to develop a domestic biofuel industry based on sugarcane and molasses, its biofuel industry is in its infancy. Yet it is mentioned in the sampled papers nearly as many times as the biggest global biofuel players, including Brazil and the United States. Gasparatos, et. al (2010) note: "Currently there is also considerable attention in the production of biodiesel from jatropha in India, China and several sub-Saharan nations." The biofuel production based on jatropha in all of these regions is insignificant.

Recommendation: Future research should be focused either on geographic regions that are likely to witness expansion of bioenergy feedstock production, regardless of the feedstocks, or on existing mainstream bioenergy feedstocks (corn, soy, rapeseed, sugarcane) and their impacts.

Capacity: It emerged from this review that there is a clear issue of capacity. More sophisticated modeling studies tended to be from the European Union or United States, with very few in Asia, Africa or South America – areas where biofuel production has the potential to both expand in future years and have significant social and environmental impacts. The majority of papers discussing impacts of biofuel production in the United States use a modeling approach – either spatial or economic (Ziolkowska, 2013; Wu and Liu, 2012; Wu, Demissie and Yan, 2012; Kim and Dale, 2011; Piroli, Ciaian and Kancs, 2012; Thompson and Meyer, 2013; Kwon, et al., 2013). These use existing data and a set of scenarios to make predictions about impacts in the future, including land use.

If we compare this with papers on Africa, we have lifecycle analysis (Melanu and Blottnitz, 2010), a policy paper on local and national adaptation (Symons, 2013), a study on gender (Arndt, Benfica and Thurlow, 2012), a household survey study (Negash and Swinnen, 2013), a biofuel scoping study (Roberntz, et al., 2009) and a study of community-level production of jatropha (Shumba, et al., 2011). This juxtaposition of modeling scenario-based studies that can offer predictions about the impacts of increased biofuel production in the United States to the small-scale assessments in Africa does suggest a capacity gap.

This capacity gap is evident in other areas of research, and is illustrated by data from the World Bank on research and development expenditure (as a percentage of GDP) by countries globally (World Bank, 2014). The picture is mixed, but between 2009 and 2013, South Africa, Morocco and Tunisia spent the greatest, at 0.8 per cent, 0.7 per cent, and 1.1 per cent respectively, with the remaining African countries spending significantly less. This trend is reflected in the number of researchers employed in these countries. There are some modeling studies focusing on the African context, particularly in relation to climate change. Webber, Gaiser and Ewert, (2014) provide a good overview, and capacity is improving, however it is a significant barrier to understanding the impacts discussed in this review in the African context.

Recommendation: A key recommendation would be to look further into this issue, and if indeed there is a capacity gap, to apply the models created in different regions – a suggestion made in a number of the modeling papers. A meta-analysis of modeling studies relating to various aspects of bioenergy production would be useful for understanding the current situation and identifying potential areas where models could be applied.

Impact assessment with broad scope: Most of the literature has a broad geographic focus, or covers a wide range of feedstocks and has less specific evidence. It is noted in some papers that it is vital to understand the impacts of the production of specific feedstocks in specific ecological systems, as impacts vary greatly (Ziolkowska, 2013; Li, Guan and Merchant, 2012; Duvenage, et al., 2014; Wu, Demissie and Yan, 2012; Ariza-Montobbio and Lele, 2010).

Nearly half of the evidence that is included in this review focuses on impacts at the global level. While global assessments are useful to inform debate and international processes, decisions related to land use and natural resource management are made at the national and local levels.

WWF's (2011) recent report on forests and bioenergy concludes that bioenergy will have a significant impact on forest management, by potentially doubling demand for timber and significant expansion of fast-growing tree plantations. However, there is little detailed information provided on where such expansion will happen, which reduces the usefulness of the findings.

Recommendation: While global impact assessments are useful to inform international processes and debate, these should be improved by national and local assessments based on actual field data to enable decision making by governments and corporations. Regional and local assessments are required, focusing on specific challenges and conditions and relating to feedstocks likely to be used in that area.

Biodiversity impact assessments are based on diverse assessment methodologies: This makes comparisons or reviews difficult. While it is unlikely that a ‘one size fits all’ solution will be found, maybe it is not necessarily desirable. However, in the literature referring to greenhouse gas emissions as well as land-use-change modeling, attempts are made to harmonize methodologies and assumptions to improve the quality of their assessments and develop comparable results. The study finds little evidence of this taking place in the literature related to biodiversity impacts of bioenergy expansion. The scale of the studies, the timelines and the methodologies related to biodiversity impact assessment are very different, and this makes a comparative analysis difficult.

Additionally, there is no evidence on how field observations are used to improve the models and scenarios developed to predict biodiversity impacts. A number of reports tackle the issue of future land-use change, and attempts are made to predict land-use-change patterns in certain priority regions. The models for this purpose could benefit from research focused on identifying actual land-use patterns.

Recommendation: It would be desirable to develop guidance for assessing biodiversity impacts related to bioenergy feedstock production. Such guidance should focus on improving the quality of assessments, ensuring that results are comparable and, if desirable, the assessments replicable. Additionally, attempts should be made to improve the impact assessments based on modeling, by using the results of actual field assessments.

5. Findings – social aspects

The key themes covered by the papers reviewed were food security, energy security, socio-economic repercussions, governance, changes in welfare and changes in health (See Figure 9). Given the concerns over the increased use of biofuel crops and the impact on food availability and commodity prices, it is understandable that a large proportion of the evidence considers this topic. It is also not surprising that energy security is extensively addressed because of the nature of biofuel and potential energy security impacts. It is a concern that a number of key social indicators related to production systems, especially in developing countries, including working conditions, health and safety, and human rights, are not more prevalent in the literature.

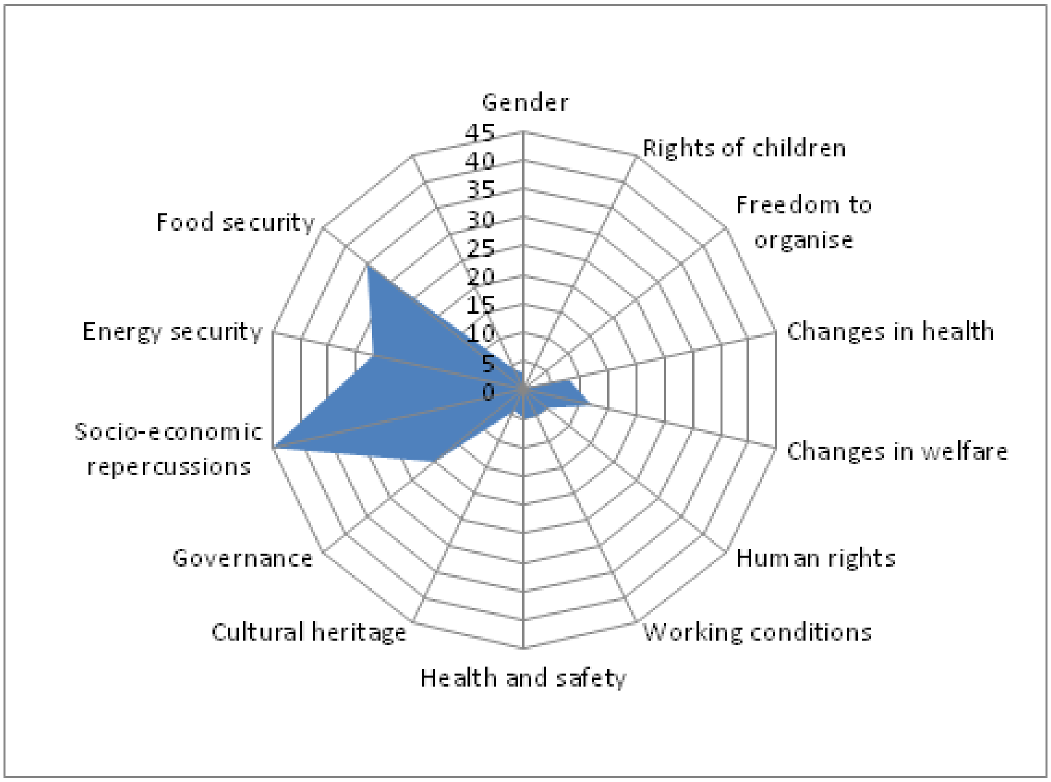


Figure 9: Social Indicators used for the purpose of this analysis

Some of the key findings from the review were that biofuel production can have significant positive social impacts, such as improved air quality, but also negative ones, the most significant of which might be food price increases (Scovronick and Wilkinson, 2013; Seck Kim, et al., 2013). One study raised the concern that social capacity in relation to small-scale biofuel production has not been explored, and that this, coupled with local environmental constraints, may have negative impacts on communities where biofuel production is targeted (Ariza-Montobbio and Lele 2010).

A number of papers reviewing social lifecycle analysis of biofuels conclude that more evidence is required in order to fully understand these interactions (Ribeiro 2013, Macombe, et al., 2013, German and Schoneveld, 2012). The issue of smallholder production has been explored in some regions, for example in Ejigu (2008), which offers a range of recommendations, including the need for further research.

In addition to the emphasis on local context, there is also a recommendation that small-scale producers are included in the social context of biofuel production (Florin, van de Ven and van Ittersum, 2013). A synthesis report by German, Schoneveld and Pacheco (2011) presents the findings of a number of studies focusing on social impacts on local communities in Brazil, Ghana, Indonesia, Malaysia, Mexico and Zambia – all biofuel-producing countries. This important paper notes that negative socio-economic impacts in the case study countries are concentrated on customary land users, with significant landholdings being lost by these groups to biofuel production. On the other hand, employment for customary land users and for small-scale producers improved in the case study areas. The findings emphasize the need for improved governance and market-based instruments, to ensure that the needs of small-scale producers and local communities are met and that the positive aspects of biofuel production for rural development can be achieved.

Recommendation: There needs to be a greater understanding of social impacts relating to the rights of various groups in relation to biofuel production, particularly local communities, workers, children and women.

6. Findings - biofuels and waste

There is a growing interest in promoting waste-based biofuels. The recent IPCC Fifth Assessment Report (2014) states that the land implications and impacts on livelihoods from bioenergy will largely depend on four factors, one of which is the share of bioenergy derived from waste. In theory, using waste products will reduce the impacts on lands rich in biodiversity or those that are needed for food production but used to produce biofuels.

A number of studies included in this analysis reach similar conclusions with regard to uncertainties in estimating global or even regional potentials. Though they centre on biodiversity impacts, their conclusions are particularly relevant to biofuel production, where there are competing uses for residues and agricultural waste, especially locally. The studies call for more research on these environmental impacts.

In an overview of the sustainability of bioenergy crops, Muller (2014) points to a lack of research on the issue of bioenergy from crop residues and the impact on soil health and agricultural sustainability. Areas Muller highlights that require further empirical evidence include the impact of residue use on crop yields and increases in inputs such as chemical fertilizers. These findings are also confirmed by a recent report published by Malins et. al (2014), which concluded: “Unfortunately, there have been relatively few experimental studies in the EU on the impact of removing residues, and a review of those studies that have been undertaken found significant variation.”

Other authors also highlight the need for further studies in the area of crop residues for biomass. In a macro analysis of crop residue use in Africa, Cooper and Laing (2007) point out that empirical evidence on the current residue uses by communities, as well as social data on practices is required, particularly in Africa, where the potential for energy from crop residues is high. There are a number of studies of the potential for use of crop residue in Africa, such as Iye and Bilsborrow’s (2013) assessment in Nigeria. This study emphasizes the importance of competing uses for residues and agricultural waste, such as feed, fodder, traditional fuel and industrial fuel.

Iye and Bilsborrow also highlight the variation in potential for energy between crops, regions and seasons. These findings are reflected in Petersen, Elbersen and Fritsche (2014), which analyses resource efficiency in the 27 EU states.

Waste-based bioenergy, if produced from sustainably sourced feedstocks using advanced technologies, can lead to significant GHG savings, as noted by Malins (2014). It is also a key strategy in avoiding indirect impacts, which is recognized by the Low Indirect Impacts Methodology developed by Ecofys, WWF and RSB (2012).

Due to their low energy densities and large volumes required for waste-based bioenergy technologies, it is more likely that these resources will be used locally. This is confirmed by the assessment authored by Ros, et. al (2012), which also states that, at least in the European context, waste will not play a predominant role in the bioeconomy of the EU by 2020.

Recommendations: More studies are needed on indirect impacts, particularly relating to competing uses for residues and agricultural waste. Furthermore, for some of the feedstocks, a better understanding is required on the biodiversity and carbon impacts of removing residues. These assessments should have a local and regional focus.

7. Progress since 2009

At the end of 2009, Campbell and Doswald (2009) published a similar review, focusing on biodiversity, on behalf of UNEP–WCMC. The topics and the conclusions of their report are similar to the issues and findings detailed in this report, suggesting that more research effort is required to inform the debate around biofuel sustainability and specifically its biodiversity impacts. As this report focuses on publications between 2008 and 2014, there is limited overlap between the two studies. Annex 3 provides a comparison of the findings presented in the earlier report and the results of this analysis.

8. Conclusions

As noted in the IPCC Fifth Assessment Report, bioenergy can contribute significantly to climate change mitigation. This contribution will depend to a large extent on where and how the feedstocks are produced, as well as on the type of feedstock.

This report has focused on synthesizing the biodiversity and social impacts of bioenergy production, mainly relying on literature related to liquid biofuels. The analysis has concluded that, although the volume and quality of research evidence related to the topic of this report has grown significantly in the past years, gaps remain. Some of these gaps are geographical, while others relate to certain feedstocks.

Conclusions drawn from the analysis:

- Sustainable biofuels remain a key climate change mitigation strategy; for parts of the transport sector biofuels are the only low-carbon option.
- Information about the actual biodiversity impact of biofuel production is fragmented, geographically unbalanced and in some cases focused on niche feedstocks.
- The impact of biofuels on protected areas is especially under-researched, with no systematic research available on this topic. A handful of reports, mainly produced by NGOs, suggest that some projects encroach on protected areas.
- As biofuels are, in most cases, just one of the possible end uses of agriculture or forestry management, impact mitigation strategies will need to ensure that all possible users of the commodities in question adhere to the same sustainability requirements as the bioenergy sector.
- At the moment, there is limited information available on the effectiveness and/or potential of certain mitigation strategies, such as product certification or use of waste and byproducts.
- While in the case of GHG lifecycle emissions, efforts are being made to harmonize methodologies, no such attempts are being observed for biodiversity impact assessments, and as a result, the outcomes are often not comparable.
- In certain regions, especially Sub-Saharan Africa, there seems to be little capacity for developing models that could predict land-use dynamics.
- The overwhelming majority of the literature focuses on negative impacts; when positive impacts are discussed, they are related to either climate change mitigation or socio-economic indicators.

9. Next steps

One of the top priorities should be the development of a biodiversity and social impacts assessment tool for biofuel production. This should be a simple guidance tool enabling capacity development and the collection of comparable data in a wide range of regions. This tool should consider the additional following research priorities:

Micro assessments – Local context is key to understanding environmental and social impacts. It is suggested that micro-level studies are conducted in areas identified as already experiencing rapid increases in biofuel production, or likely to in the near future.

Land-use change – A focus on modeling and scenarios should be supplemented by further empirical studies considering the impacts at the biodiversity and social level.

Biodiversity impacts – Further detailed literature reviews are needed to identify specific studies on trends in genetic diversity, coverage of protected areas, connectivity and fragmentation of ecosystems, trends in invasive alien species, and ecological footprints. Papers reviewed in this study indicate that these topics are not covered by evidence collected on the ground. This is vital in order to understand the biodiversity impacts of biofuel production.

Positive impacts of biofuels – The environmental and social positive impacts of biofuel production are not fully understood. In order to enhance these positives, more must be understood about them, including a better understanding of sustainable production processes. These studies should consider the potential for increases in sustainable biofuel production that take into account regional and national biodiversity conservation strategies.

Feedstocks – Studies should focus on regions that are predicted to see significant growth in biofuel production, as well as the most significant potential feedstocks in those regions, rather than niche commodities.

Capacity gap – Use existing modeling approaches applied in North America and Europe in regions and countries that have been identified as likely to experience a significant increase in biofuel production.

Glossary

Biofuels – fuel comprised of or produced from biological material; in the case of this report, biofuel refers to liquid.

Biofuel feedstocks – dedicated crops, waste and byproducts used to produce bioenergy.

Bioenergy – energy contained within living or recently living biological material, used to describe both liquid fuels used by the transport sector and solid biomass used for heat and electricity consumption.

Biomass – biological material from living or recently living organisms, generally used to describe solid biomass used in heat and electricity production, such as wood chips.

Biomaterials – products, such as bioplastics, that are produced from crops or waste and byproducts.

Indicators – identifiable and measurable attributes that are used to assess performance.

Indirect impacts – impacts that are removed temporally and/or spatially from an activity, but are reasonably foreseeable.

Indirect Land-Use Change (ILUC) – bioenergy deployment triggering the conversion to cropland of lands somewhere on the globe, to replace some portion of the displaced crops.

Lifecycle analysis – the measurement of the impacts of all stages of a product, from cradle to grave.

RSB – Roundtable on Sustainable Biomaterials.

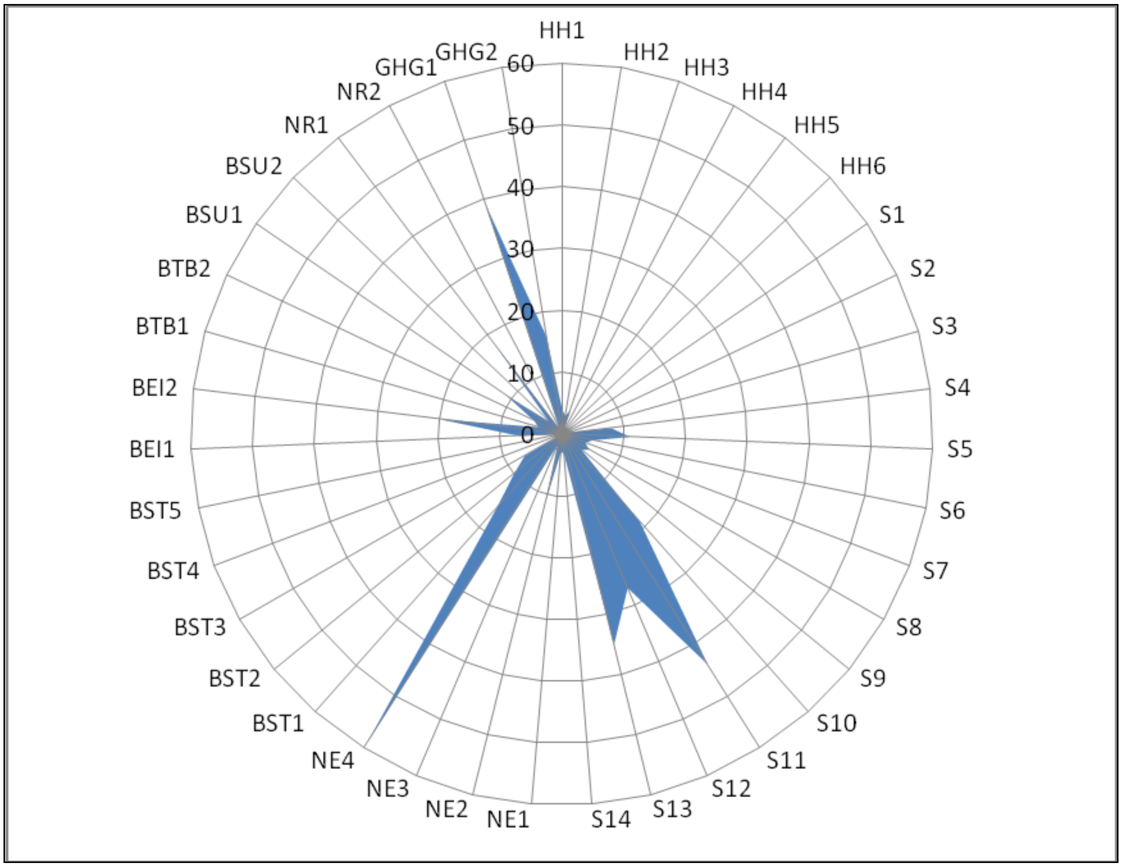
Sustainable biofuels – biofuels that meet social, economic and environmental criteria; for the purpose of this report, the authors considered the RSB as a framework for sustainable biofuels.

Annex 1 – List of indicators with scoping decision

Topics	Indicators	Scoped IN/OUT
Human Health	Climate change	IN
	Ozone depletion	OUT
	Human toxicity	IN
	Respiratory inorganics	IN
	Ionising radiation	OUT
	Noise	IN
	Accidents	IN
	Photochemical ozone formation	IN
Social	Gender	IN
	Rights of children	IN
	Freedom to organize	IN
	Changes in health	IN
	Changes in welfare	IN
	Human rights	IN
	Working conditions	IN
	Health and safety	IN
	Cultural heritage	IN
	Governance	IN
	Socio-economic repercussions	IN
	Energy security	IN
	Food security	IN
	Traditional knowledge, practices	IN
Natural environment	Acidification	IN

	Eutrophication	IN
	Ecotoxicity	IN
	Land use	IN
Biodiversity	**Status and trends of the components of biological diversity**	
	Trends in extent of selected biomes, ecosystems and habitats	IN
	Trends in abundance and distribution of selected species	IN
	Changes in status of threatened species	IN
	Trends in genetic diversity of domesticated animals, cultivated plants and fish species of major socio-economic importance	IN
	Coverage of protected areas	IN
	Ecosystem integrity and ecosystem goods and services	
	Marine trophic index	OUT
	Connectivity - fragmentation of ecosystems	IN
	Water quality of aquatic ecosystems	IN
	Threats to biodiversity	
	Nitrogen deposition	IN
	Trends in invasive alien species	IN
	Impact of climate change on biodiversity	OUT
	Sustainable use	
	Area of forest, agricultural and aquaculture ecosystems under sustainable management	IN
	Ecological footprint and related concepts	IN
Natural resources	Resource depletion	IN
	Desiccation, salinization	IN
GHG emissions	Direct emissions	IN
	Indirect emissions	IN

Annex 2 - Distribution of literature based on the indicators



This figure shows the specific indicators that are well covered by the selected papers (S11, S12, S13,NE4, BEI2, and GHG1), as well as the gaps in evidence, particularly related to the biodiversity indicators and human health.

Headline Indicator	Indicator	Code	Headline indicator	Indicator	Code
Human Health	Climate change	HH1	**Biodiversity**	Trends in extent of selected biomes, ecosystems and habitats	BST1
	Human toxicity	HH2		Trends in abundance and distribution of selected species	BST2
	Respiratory inorganics	HH3		Changes in status of threatened species	BST3
	Noise	HH4		Trends in genetic diversity of domesticated animals, cultivated plants and fish species of major socio-economic importance	BST4
	Accidents	HH5		Coverage of protected areas	BST5
	Photochemical ozone formation	HH6		Connectivity - fragmentation of ecosystems	BEI1
Social	Gender	S1		Water quality of aquatic ecosystems	BEI2
	Rights of children	S2		Nitrogen deposition	BTB1
	Freedom to organize	S3		Trends in invasive alien species	BTB2
	Changes in health	S4		Area of forest, agricultural and aquaculture ecosystems under sustainable management	BSU1
	Changes in welfare	S5		Ecological footprint and related concepts	BSU2
	Human rights	S6	**Natural Resources**	Resource depletion	NR1
	Working conditions	S7		Desiccation, salinization	NR2
	Health and safety	S8	**Green House Gas Emissions**	Direct emissions	GHG1
	Cultural heritage	S9		Indirect emissions	GHG2
	Governance	S10	**Natural Environment**	Acidification	NE1
	Socio-economic repercussions	S11		Eutrophication	NE2
	Energy security	S12		Ecotoxicity	NE3
	Food security	S13		Land use	NE4
	Traditional knowledge, practices	S14			

Annex 3 – Progress since 2009

At the end of 2009, Campbell and Doswald (2009) published a similar review, focusing on biodiversity, on behalf of UNEP–WCMC. The topics and conclusions of their report are similar to the issues and findings detailed in this report, suggesting that more research effort is required to inform the debate around biofuel sustainability, specifically related to biodiversity impacts.

The following table includes a comparison of the findings presented in the earlier report and the results of this analysis.

Campbell and Doswald (2009)	**Current report**
"The production of liquid biofuels is rapidly increasing."	According to the global energy statistics collected by BP[1] and the US Energy Information Administration,[2] global biofuel production and consumption has been actually stagnating and, in some areas, decreasing since 2010, for a number of reasons. The biggest growth was in the United States, followed by (relatively modest) increases in Asia, while South And Central America have seen the biggest decrease, followed by Europe. Africa and the rest of the world continue to be a minor biofuel producer. How much and where production growth takes place is a key part of any attempt to assess biodiversity impacts.
"The impacts on biodiversity will depend upon the biofuel feedstocks, previous land use, and agricultural practices employed, and can be positive where well-managed plantations are established in suitable areas."	This conclusion is confirmed by the findings of this report.
"…the limited literature available suggests that biodiversity will continue to be negatively impacted"	Both elements of this conclusion are supported by findings of this report. First, there is limited research available; second, the research does document or suggests negative impacts.

[1] http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy-2013/review-by-energy-type/renewable-energy/biofuels.html

[2] http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1

"...the potential impacts of large-scale production [of next generation biofuels] are largely unknown, and there is some skepticism over their ability to reduce land use requirements."	This conclusion is also supported by the findings of this report. Additionally, based on the analysis for this paper, the authors would argue that this is true not just for next generation biofuels, but in some cases first generation mainstream biofuels, too.
"Given that biofuel production is increasing, a comprehensive assessment of the environmental impacts of biofuel production, and the identification of measures to reduce these impacts, is required at local to regional scales."	This conclusion is also supported by the findings of this report; however, in the view of the authors, research should be targeted to provide more information either about specific bioenergy diversity impacts or specific geographies.
"Sustainability standards for biofuel production may help to reduce adverse impacts on biodiversity, and a number of these are currently under development, or in the early stages of implementation. However, they will need to overcome a number of issues surrounding definitions of key terms, and address the issue of indirect land use change if they are to be successfully implemented. In addition, it is likely that sustainability standards will only be part of the solution, and will need to be combined with improved land use planning."	Since 2009, there have been significant developments in the landscape of biofuel standards. Driven by the implementation of the EU legislation, a number of new standards were made available to the market. ISCC, a standard that originates in Germany, has recently announced that it has passed 5,000 certificates and experienced 135-percent growth since last year. However, as highlighted by recent reports from IUCN[3] and WWF,[4] there are significant differences in the requirements and the robustness of the implementation. This confirms the findings from 2009. As some of these standards become mainstream, it would be important to ensure that definitions and terms referring to biodiversity values are harmonized as much as possible.
"Biofuels have the potential to contribute to climate change mitigation. However, this may need to be balanced against the negative impacts on biodiversity. The impacts on biodiversity are not always obvious (e.g. from indirect land use change), and more research is needed, especially at the local level since much of the current literature reviewed focuses on global overviews."	This conclusion is also strongly supported by the findings of this report. Much of the focus in the last years has been dedicated to indirect land-use change, sometimes neglecting the fact that direct impacts are not adequately addressed at this stage.

[3] https://cmsdata.iucn.org/downloads/betting_on_best_quality.pdf

[4] http://assets.panda.org/downloads/wwf_searching_for_sustainability_2013.pdf

Annex 4 – Literature reviewed

Arndt, C., Benfica, R. and Thurlow, J. (2013). *Gender Implications of Biofuels Expansion in Africa: The Case of Mozambique*.

Bastos, M.B. (2013). *Lima Adjusting Biofuel Policies to Meet Social and Rural Development Needs: Analysing the Experiences of Brazil, India and Indonesia*.

Bauen, A., Hudziak, C., Vad, K. and Watson, P. (2010). *A causal descriptive approach to modelling the GHG emissions associated with the indirect land use impacts of biofuels*. E4TECH.

Berndes, G., Bird, N., and Cowie, A. (2010). *Bioenergy, Land Use Change and Climate Change Mitigation*. IEA.

Biodiversity Indicators Partnership. (2010). *Biodiversity indicators and the 2010 target: experiences and lessons learnt from the 2010 biodiversity indicators partnership*. Montreal, Canada: Secretariat of the Convention on Biological Diversity.

Bird, N., Cowie, A., Cherubini, F. and Jungmeier, G. (2011). *Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy*.

Campbell, A. and Doswald, N. (2009). *The impacts of biofuel production on biodiversity: A review of the current literature*. Cambridge, UK: UNEP-WCMC.

Carriquiry, M.A., Xiaodong Du and Timilsina, G.R. (2010). *Second generation biofuels*.

Cooper, C.J. and Laing, C.A. (2007). 'A macro analysis of crop residue and animal wastes as a potential energy source in Africa'. *Journal of Energy in Southern Africa* 18(1).

Crosti, R. (2009). 'Invasiveness of biofuel crops and potential harm to natural habitats and native species'. Council of Europe. Paper prepared for the Convention on the Conservation of European Wildlife and Natural Habitats Standing Committee.

Dehue, B., Cornelissen, S. and Peters, D. (2010). *Indirect effects of biofuels*. A review for GBEP. Ecofys.

De Vries, S.C., van de Ven, G.W.J. and Ittersum, M.K. (2014). 'First of second generation biofuel crops in Brandenburg, Germany? A model-based comparison of their production-ecological sustainability'. *European Journal of Agronomy* 52:166-179.

De Vries, S.C., van de Ven, G.W.J., van Ittersum, M.K. and Giller, K.E. (2010). 'Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques'. *Biomass and Bioenergy* 34:588-601.

Duvenage, I., Langston, C., Stringer, L.C., Dunstan, K. 2014. 'Grappling with biofuels in Zimbabwe: depriving or sustaining societal and environmental integrity?' Journal of Cleaner Production. 42: 132-140.

Edwards, R., Mulligan, D. and Marelli, L. (2010). *Indirect Land Use Change from Increased Biofuels Demand*.

EEA. (2012). *Streamlining European biodiversity indicators w2020: building a future on lessons learnt from the SEBI 2010 process*. European Environment Agency technical report No. 11

Eisentrout, A. (2010). *Sustainable production of second-generation biofuels*. IEA.

Ejigu, M. (2008). 'Toward energy and livelihoods security in Africa: Smallholder production and processing of bioenergy as a strategy'. *Natural Resources Forum* 32: 152-162.

EU. (2010). *Framework and requirements for life cycle impact assessment models and indicators*. JRC European commission. Institute for environment and sustainability.

Florin, M.J., van de Ven, G.W.J. and van Ittersum, M.K. (2013). 'What drives sustainable biofuels? A review of indicator assessments of biofuel production systems involving smallholder farmers'. *Environmental science and policy*. 37: 142-157

Food security and climate change. (2012). HLPE.

Fortin, E. (2013). 'Transnational multi-stakeholder sustainability standards and biofuels: understanding standards processes'. *The journal of peasant studies* 40(3): 563-587.

Fritsche, U.R., Hennenberg, K. and Hünecke, K. (2010). *The "iLUC Factor" as a Means to Hedge Risks of GHG Emissions from Indirect Land Use Change*.

Gamba, L. and Toop, G. 2013. *Lessons learned in testing the Global Bio-Energy Partnership sustainability indicators*. Ecofys

Gasparatos, A., Stromberg, P. and Takeuchi, K. (2011). 'Biofuels, ecosystem services and human wellbeing: putting biofuels in the ecosystem services narrative'. *Agriculture, Ecosystems and Environment* 142:111-128.

German, L. and Schoneveld, G. (2012). 'A review of social sustainability considerations among EU-approved voluntary schemes for biofuel, with implications for rural livelihood'. *Energy Policy* 51:765-778.

German, L., Schoneveld, G.C. and Pacheco, P. (2011). 'Local Social and Environmental Impacts of Biofuels: Global Comparative Assessment and Implications for Governance'. *Ecology and Society* 16 (4):29.

GNESD (2011). *Bioenergy: The potential for rural development and poverty alleviation*.

Global Network on Energy for Sustainable Development (GNESD). Summary for policy-makers. GNESD-SPM-BET-11/2011.

Gonzales, J. (2006). *An Assessment of the Biofuels Industry in India*.

'Grappling with biofuels in Zimbabwe: depriving or sustaining societal and environmental integrity?' *Journal of Cleaner Production* 42:132-140.

Gunatilake, H., Roland-Holst, D., Sugiyarto, G. and Baka, J. (2011). *Energy Security and Economics of Indian Biofuel Strategy in a Global Context*. ADB.

Gunatilake, H. (2011). *Financial and Economic Assessment of Biodiesel Production and Use in India*. ADB.

Haas, G., Wetterich, F. and Geier, U. (2000). 'Life Cycle Assessment Framework in Agriculture on the Farm Level'. *International Journal of LCA* 6:345-348.

Hart Energy (2010). *Land Use Change: Science and Policy Review*. Hart Energy.

Hennenberg, K. J., Dragisic, C., Haye, S., Hewson, J., Semroc, B., Savy, C., Wiegmann, K., Fehrenbach, H. and Fritsche, U. R. (2010). 'The Power Of Bioenergy-Related Standards to Protect Biodiversity'. *Conservation Biology*, 24:412–423. doi: 10.1111/j.1523-1739.2009.01380.x

Hertel, T.W. and Tyner, W. (2013). 'Market-mediated environmental impacts of biofuels'. *Global Food Security*. 2: 131-137.

Hiederer, R., Ramos, F., Capitani, C., Koeble, R., Blujdea, V., Gomez, O., Mulligan, D. and Marelli, L. (2010). *Biofuels: a New Methodology to Estimate GHG Emissions from Global Land Use Change*. JRC.

IPCC (2014). Chapter 11: Agriculture, Forestry and Other Land Use (AFOLU) http://report.mitigation2014.org/drafts/final-draft-postplenary/ipcc_wg3_ar5_final-draft_postplenary_chapter11.pdf

Iye, E.L. and Bilsborrow, P.E. (2013). 'Assessment of the availability of agricultural residues on a zonal basis for medium- to large-scale bioenergy production in Nigeria'. *Biomass and Bioenergy* 48.: 66-74.

Jaleta, M., Kassie, M. and Shiferaw, B. (2013). 'Trade-offs in crop residue utilization in mixed crop-livestock systems and implications for conservation agricultural'. *Agricultural Systems* 121.: 96-105.

Killeen, T.J., Schroth, G., Turner, W., Harvey, C.A., Steininger, M.K., Dragisic, C. and Mittermeier, R.A. (2011). 'Stabilizing the agricultural frontier: leveraging REDD with biofuels for sustainable development'. *Biomass and Bioenergy* 35:4815-4823.

Kim, S. and Dale, B.E. (2011). ‘Indirect land use change for biofuels: testing predictions and improving analytical methodologies’. *Biomass and bioenergy* 35:3235-3240.

Koellner, T. and Geyer, R. (2013). ‘Global land use impact assessment on biodiversity and ecosystem services in LCA’. *International Journal of Life Cycle Assessment* 18:1185-1187.

Koh, L.P. and Ghazoul, J. (2008). ‘Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities’. *Biological Conservation* 141:2450-2460.

Kraxner, F., Nordström, E., Havlík, P., Gusti, M., Mosnier, A., Frank, S., Valin, H., Fritz, S., Fuss, S., Kindermann, G., McCallum, I., Khabarov, N., Böttcher, H., See, L., Aoki, K., Schmid, E., Máthé, L. and Obersteiner, M. (2013). ‘Global bioenergy scenarios – Future forest development, land-use implications, and trade-offs’. *Biomass and Bioenergy*, 57: 86-96, ISSN 0961-9534.

Kretschmer, B., Bowyer, C. and Buckwell, A. (2012). *EU biofuel use and agricultural commodity process: a review of the evidence base*. Action Aid. Institute for European Environmental Policy.

Kwon, H-Y., Mueller, S., Dunn, J.B. and Wander, M.M. (2013). ‘Modelling state-level soil carbon emission factors under various scenarios for direct land use change associated with United States biofuel feedstock production’. *Biomass and Bioenergy* 55:299-310.

Larsen, L.E., Jepsen, M.R. and Frederriksen, P. (2013). ‘Scenarios for biofuel demands, biomass production and land use – the case of Denmark’. *Biomass and Bioenergy* 55:27-40.

Li, R., Guan, Q. and Merchant, J. (2012). ‘A geospatial modelling framework for assessing biofuels-related land-use and land-cover change’. *Agriculture, Ecosystems and Environment* 161:17-26.

Liang, S., Lui, Z., Xu, M. and Zhang, T. (2013). ‘Waste oil derived biofuels in China bring brightness for global GHG mitigation’. *Bioresource Technology* 131:139-145.

Liang, S., Xu, M. and Zhang, T. (2012). ‘Unintended consequences of bioethanol feedstock choice in China’. *Bioresource Technology* 125:312-317.

Lucia, L.D. (2013). ‘Too difficult to govern? An assessment of the governability of transport biofuels in the EU’. *Energy Policy* 63:81-88.

Macombe, C., Leskinene, P., Feschet, P. and Antikainen, R. (2013). ‘Social life cycle assessment of biodiesel production at three levels: a literature review and development needs’. *Journal of Cleaner Production* 52:205-216.

Malins, C., (2014). *Wasted: An Assessment of Advanced Biofuels from Wastes & Residues*. http://europeanclimate.org/wp-content/uploads/2014/02/WASTED-final.pdf

McKone, T.E., Nazaroff, W.W., Berck, P., Auffhammer, M., Lipman, T., Torn, M.S., Masanet, E., Lobscheid, A., Santer. N., Mishra, U., Barett, A., Bomberg, M., Fingerman, K., Scown, C., Strogen, B. and Horvath, A. (2011). 'Grand challenges for Life-Cycle Assessment of Biofuels'. *Environmental Science and Technology*.

Møller. F., Slentø, E. and Frederiksen, P. (2014). 'Integrated well-to-wheel assessment of biofuels combining energy and emission LCA and welfare economic cost-benefit analysis'. *Biomass and Bioenergy* 60:41-49.

Muller, A. (2014). *Sustainable Farming of Bioenergy Crops. Bioenergy Research: Advances and Applications*.

Oberling, D.F., Rovere, E.L. and de Oliveira Silva, H.V. (2013). 'SEA making inroads in land-use planning in Brazil: The case of the extreme south of Bahia with forestry and biofuels'. *Land Use Policy* 35:341-358.

Petersen, J.-E., Elbersen, B. and Fritshe, U.R. (2014). 'Applying resource efficiency principles to the analysis of EU-27 bioenergy options by 2020 – findings from a recent study for the European Environment Agency'. *Biomass and Bioenergy* 65: 170-182.

Piroli, G., Ciaian, P. and Kancs, D. (2012). 'Land use change impacts of biofuels: near-VAR evidence from the US'. *Ecological Economics* 84:98-109.

PISCES Consortium (2011). *Bioenergy research status in India*.

Pleininger, T. (2008). 'How the emergence of biofuels challenges environmental conservation'. *Environmental Conservation* 34:273-275.

Rajagopal, D. and Zilberman, D. (2007). *Review of Environmental, Economic and Policy Aspects of Biofuels.* The World Bank.

Raju, S.S., Parappurathu, S., Chand, R., Kumar,P. and Msangi, S. (2012). *Biofuels in India: Potential, Policy and Emerging Paradigms*. National Centre for Agricultural Economics and Policy Research.

Ravindranath, N.H., Lakshmi, C.S., Manuvie, R. and Balachandra, P. (2011). 'Biofuel production and implications for land use, food production and environment in India'. *Energy Policy* 39:5737-5745.

Ribeiro, B.E. (2013). 'Beyond commonplace biofuels: social aspects of ethanol'. *Energy Policy* 57:355-362.

Ros, et al. (2012). *Sustainability of biomass in a bio-based economy. A quick-scan analysis of the biomass demand of a bio-based economy in 2030 compared to the sustainable supply.*

Rossi, A., ed. (2012). *Good Environmental Practices in Bioenergy Feedstock Production*. FAO.

Savilaakso, S., Garcia, C., Garcia-Ulloa, J., Ghazoul, J., Groom, M., Guariguata, M.R., Laumonier, Y., Nasi, R., Petrokokfsky, G., Snaddon, J. and Zrust, M. (2014). 'Systematic review of effects on biodiversity from oil palm production'. *Environmental Evidence* 3:4.

Schutter, L. and Giljum, S. (2014). *A calculation of the EU Bioenergy Land Footprint*.

Scovronick, N. and Wilkinson, P. (2013). 'Health impacts of liquid biofuel production and use: a review'. *Global Environmental Change*. 24: 155-164.

SDC (2007). *Biofuels, Opportunity Or Threat To The Poor?*

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D. and Yu, T. (2008). *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change*.

Seck Kim, J., Binfield, J., Patton, M., Zhang, L. and Moss, J. (2013). 'Impact of increasing liquid biofuel usage on EU and UK agriculture'. *Food Policy* 38:59-69.

Shumba, E., Robertnz, P. and Mawire, B. (2011). *Community level production and utilisation of jatropha feedstock in Malawi, Zambia and Zimbabwe*. WWF.

Simons, K. (2013). *How Bioenergy Can Help Local Communities Adapt to Climate Change: Lessons from Nyanza Province, Kenya*. Pisces. University of Edinburgh.

Stromberg, P.M., Gasparatos, A., Lee, J.S.H., Garcia-Ulloa, J., Koh. L.P. and Takeuchi, K. (2010). *Impacts of Liquid Biofuels on Ecosystem Services and Biodiversity*. UNU-IAS.

Taylor, R., ed. (2011). *The Living Forest Report: Bioenergy and forests*. WWF.

Thompson, W. and Meyer, S. (2013). 'Second generation biofuels and food crops: co-products or competitors?' *Global Food Security* 2: 89-96

UNEP (2014). *Assessing Global Land Use: Balancing Consumption with Sustainable Supply*
http://www.unep.org/resourcepanel/Publications/AreasofAssessment/AssessingGlobalLandUseBalancingConsumptionw/tabid/132063/Default.aspx

UNEP (2011). *The bioenergy and water nexus*. United Nations Environment Programme, Oeko-Institut and IEA Bioenergy Task 43.

UNEP (2009). *Guidelines for social life cycle assessment of products*. United Nations Environment Programme

USDA Gain report. (2012).

Valencia, M.J. and Cardona, C.A. (2014). 'The Colombian biofuel supply chains: the assessment of current and promising scenarios based on environmental goals'. *Energy Policy*.67:232-242.

Van der Horst, D. and Vermeylen, S. (2011). 'Spatial scale and social impacts of biofuel production'. *Biomass and Bioenergy* 35:2435-2443.

Van der Staij, et al. (2012). *Low Indirect Impact Biofuels*. www.liib.org.

Webber, H., Gaiser, T. and Ewert, F. (2014). 'What role can crop models play in supporting climate change adaptation decisions to enhance food security in Sub-Saharan Africa?' *Agricultural Systems*. 127: 161-177.

World Bank. (2014). *Research and Development Expenditure (as a % of GDP)*. Available online at http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS/countries?display=default {last viewed 18.03.2014]

Wu, M., Demissie, Y. and Yan, E. (2012). 'Simulated impact of future biofuel production on water quality and water cycle dynamics in the Upper Mississippi river basin'. *Biomass and Bioenergy* 41:44-56.

Wu, Y. and Liu, S. (2012). 'Impacts of biofuels production alternatives on water quantity and quality in Iowa river basin'. *Biomass and Bioenergy* 36:182-191.

Zhang, W., Yu, E.A., Rozelle, S., Yang, J. and Msangi, S. (2013). 'The impact of biofuel growth on agriculture: why is the range of estimates so wide?' *Food policy* 38:227-239.

Ziolkowska, J.R. (2013). 'Evaluating sustainability of biofuels feedstock: a multi-objective framework for supporting decision making'. *Biomass and Bioenergy* 59:425-440

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