Methods and tools to assess the sustainability of biomass and bioenergy supply chains

Summary of findings under Objective 1 of the IEA Bioenergy inter-Task project "Measuring, governing and gaining support for sustainable bioenergy supply chains"

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Measuring, governing and gaining support for sustainable bioenergy supply chains

Methods and tools to assess the sustainability of biomass and bioenergy supply chains

Authors

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This summary and synthesis report is based on work in Objective 1 of the inter-Task project "Measuring, governing and gaining support for sustainable bioenergy supply chains", involving the following contributors:

Pereira, L.G., Cavalett, O., Bonomi, A., Zhang, Y., Warner, E., Chum, H.L. (Comparison of tools for assessing biofuels)

Durocher, C., Thiffault, E., Achim, A., Auty, D., Barrette, J. (The carbon balance of bioenergy systems using residues and low-value stems, or "unloved wood"),

Cintas, O., Berndes, G., Bergh, J., Egnell, G., Hansson, J., Lundmark, T., Nordin A., Poudel, B. (The use of residues and roundwood for energy and the influence of forest management on the resulting carbon balance)

Englund, O., Berndes, G., Cederberg, C., Börjesson, P. (Methods for analyzing and mapping ecosystem services in landscapes).

Langeveld, H., Brandao, M., Cowie, A., Dale, V., Fritsche., U., Kline, K., Koponen, K., Oladosu, A., (Indirect effects and baselines).

Simmons, A., Cowie, A., Waters, C. (The use of biomass from woodland clearing for bioenergy and biochar compared with in-field burning in Australia).

Published by IEA Bioenergy

Contents

1. Introduction

Several systems to monitor progress toward sustainability of bioenergy have been developed and implemented (e.g. GBEP 2011; McBride et al. 2012; RSB 2015; ISO 2015; ASTM 2016; Dale et al. 2015). While much has been achieved, there are still challenges associated with understanding, defining, measuring, and gaining trust in assessing sustainability of bioenergy (IEA Roadmap 2017).

In light of these challenges, the IEA Bioenergy inter-Task project on "Measuring, governing and gaining support for sustainable bioenergy supply chains" was formed to synthesise works of a number of IEA Bioenergy Tasks including Task 37, 38, 39, 40, 42 and 43. The project aimed at addressing the following questions:

1. How to measure and quantify progress towards more sustainable practices?

2. How to improve the input and output legitimacy of existing and proposed governance systems?

3. How to engage more successfully with the broad range of stakeholders so that policies and sustainability governance are perceived as legitimate and help build-up social capital, trust, and support among all stakeholders?

The project was started in 2016 and was completed at the end of 2018. A multitude of studies were initiated focusing largely on the agricultural and forestry sectors, and on biogas systems. The aim of this summary is to share final project results from the work carried out under the first question (Objective 1). This summary presents highlights from several of the studies undertaken in Objective 1, and provides recommendations based on a synthesis of the work carried out in this Objective. The work in Objective 1 was coordinated by Annette Cowie (Task 38 – Climate change effects of biomass and bioenergy systems) and Göran Berndes (Task 43 – Biomass feedstocks for energy markets).

1.1 METHODS AND TOOLS TO ASSESS THE SUSTAINABILITY OF BIOMASS AND BIOENERGY SUPPLY CHAINS (OBJECTIVE 1)

The sustainability performance of biomass and bioenergy supply chains is debated, both within the scientific community and in society. Sometimes conflicting views are put forward even for very similar bioenergy and biofuel production chains. One reason behind conflicting views is that underlying assessments arrive at different conclusions due to differences in methodological approaches.

Objective 1 addressed calculation methods and tools to assess the sustainability of biomass and bioenergy supply chains. The focus is placed on greenhouse gas (GHG) balances, but we have also addressed assessments of ecosystem services, which are made to clarify how land use and biomass production systems may affect the capacity of ecosystems to support different ecosystem services. In this regard, we have assessed the efficacy and utility of various sustainability indicators, including those proposed and/or implemented by voluntary certification systems, set by national and supra-national governments and international bodies, or proposed by researchers.

Within the frame of Objective 1, case studies were carried out within the following themes:

- Challenges for LCA and other assessment tools supporting governance 1: Comparison of tools for assessing biofuels

- Challenges for LCA and other assessment tools supporting governance 2: Methods for analyzing and mapping ecosystem services in landscapes, to promote co-benefits from bioenergy

- Challenges for LCA and other assessment tools supporting governance 3: Indirect effects and baselines
- Methodological aspects of assessing forest bioenergy systems 1: Canadian case study on biorefinery using either only residues or residues together with low-value stems, or "unloved wood")
- Methodological aspects of assessing forest bioenergy systems 2: Swedish case study on the use of residues and roundwood for energy and the influence of forest management on the resulting carbon balance.
- Methodological aspects of assessing forest bioenergy systems 3: Australian case study on the use of cleared scrub for bioenergy or biochar compared with in-field burning

While all case studies were linked to this inter-Task project, most studies also received funding from other sources and, therefore, addressed also questions that are outside the scope of Objective 1 (e.g., the Canadian case study also addressed social acceptability of forest bioenergy in Canada). However, all studies provide important insights concerning methods and tools to assess the sustainability of biomass and bioenergy supply chains.

Below, main findings from Objective 1 are summarized and selected case study results are highlighted, with special emphasis on:

- Reasons behind differences between tools for assessing GHG emissions of biofuels
- Methods for analyzing and mapping ecosystem services in landscapes, to promote co-benefits from bioenergy
- Carbon balances and climate impacts of forest bioenergy systems

2. Challenges for LCA and other assessment tools supporting governance

2.1 REASONS BEHIND DIFFERENCES BETWEEN TOOLS FOR ASSESSING GHG EMISSIONS OF BIOFUELS

Many models and tools have been developed to quantify life-cycle GHG emissions of biofuels and their reference fuels (typically petroleum gasoline, diesel, and jet fuels). Some models were designed to comply with regulatory requirements, whereas others were adopted and/or modified from existing research and development tools investigating multiple pathways for fuels coupled to vehicle life-cycle systems. **Discrepancies between results obtained by using different tools have challenged the credibility of the individual assessments**, and as result, the progress towards or compliance with GHG mitigation targets.

This study examined the basis for differences between tools commonly used to assess GHG emissions from biofuels. The objective was to identify the main differences and common features in methodological structures, calculation procedures, and assumptions for the major commercial biofuel, ethanol, across three public LCA tools, BioGrace (EU), GHGenius (Canada), and GREET (U.S.), and a research-oriented fourth tool, the Virtual Sugarcane Biorefinery (VSB), a Brazilian platform for sugarcane ethanol assessments. Use of the Brazilian model VSB enabled harmonization of the three public models that are used in support of, or designed for compliance with, legislative requirements or government directives.

Figure 1 shows the range of emissions calculated by the tools. Harmonizing the three public tools using VSB assumptions for sugarcane ethanol produced in Brazil, the range was reduced from 16-45 to 16-17 g CO2eq MJ-1. Thus, **the models vary, using their base assumptions, but converge when the assumptions are harmonised**. Agricultural production (e.g., N2O emissions from fertilizers; energy and fuel use; straw field-burning; and limestone application) and ethanol shipping were found to be the major causes for differences between the tools' estimates of emissions for sugarcane ethanol. Harmonizing BioGrace and GHGenius calculations using GREET assumptions for U.S. corn ethanol generated nearly identical results (models varied within a 3% range). The method used to handle co-products was found to be the most influential parameter in the variations calculated for both corn and wheat ethanol.

The application of specific tools for GHG emissions accounting is often defined via regulations, and differences and/or conflicting assumptions set forth in these models lead to most differences observed. The study provides recommendations for **promoting transparency in LCA calculations and assumptions** across the tools used in research and development of biofuels, and for regulatory purposes.

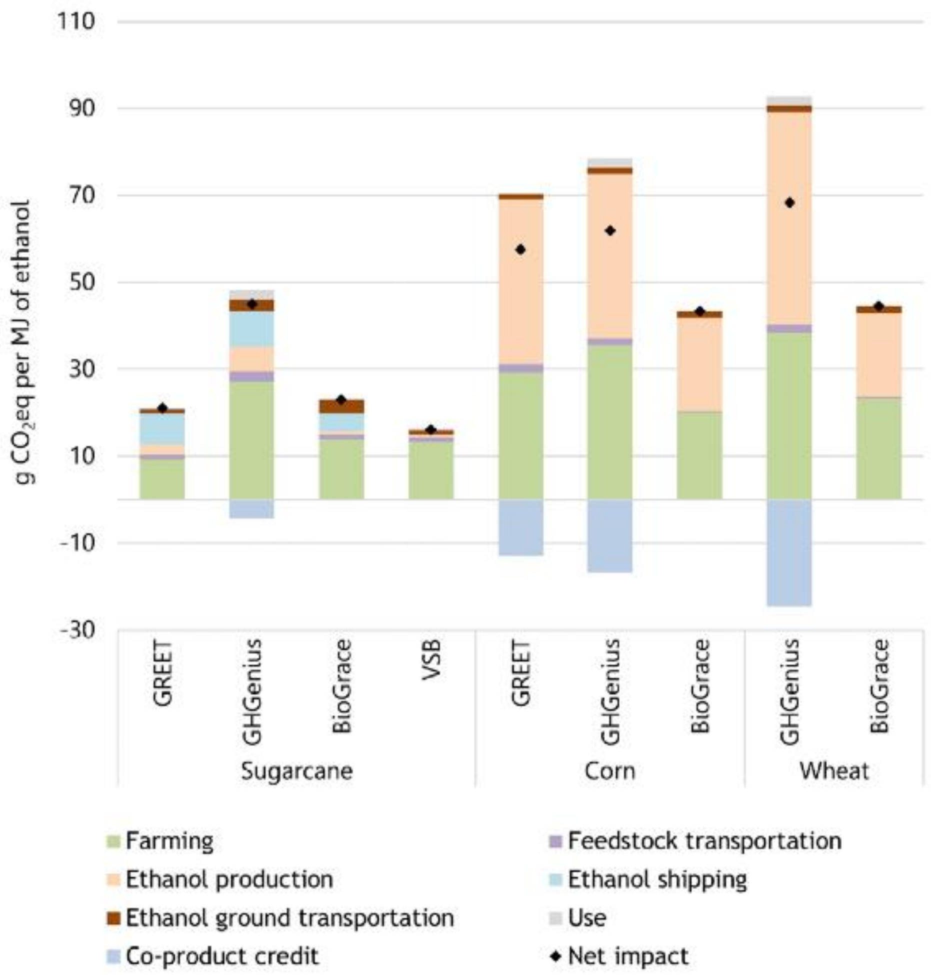

Figure 1. Greenhouse gas emissions impacts of ethanol produced from sugarcane, corn, and wheat in g CO2eq per MJ of ethanol calculated by GREET, GHGenius, BioGrace, and VSB tools.

2.2 METHODS FOR ANALYZING AND MAPPING ECOSYSTEM SERVICES IN LANDSCAPES, TO PROMOTE CO-BENEFITS FROM BIOENERGY

Besides climate effects, biomass production for bioenergy and the bioeconomy can influence a range of environmental and other values, not the least through associated land use change (LUC) and resulting effects on nature's capacity to supply ecosystem services. Society benefits in a multitude of ways from a range of ecosystem services. Some of these are recognized as essential (e.g., food and wood supply), but several are often not valued unless diminishing; the provisioning of clean drinking water and the decomposition of wastes are today commonly recognized as essential, but at the same time may be taken for granted when available. It can also be difficult to identify causes behind diminishing ecosystem services, the pollination of crops by insects being one example.

While LUC is commonly perceived as a negative aspect of bioenergy development, **there are many examples of how the integration of new biomass supply systems into agriculture landscapes can support essential ecosystem services and help mitigate adverse impacts of existing land use.** Recognition of such opportunities to promote co-benefits from bioenergy is important, considering that society faces the double challenge of addressing negative impacts of current land use while increasing biomass production for food, materials and energy.

Strategic placement, design and management of perennial grasses and short-rotation coppice and trees can provide biomass for bioenergy and other purposes while enhancing landscape diversity and improving conditions for a multitude of ecosystem services including enhanced retention of nutrients and sediment, erosion control, climate regulation, pollination, pest and disease control, and flood regulation. To illustrate, Figure 2 indicates those areas in Europe in which the establishment of new perennial biomass production systems can contribute to mitigating impacts caused by erosion, recurring floods, nitrogen emissions to water, and soil carbon losses.

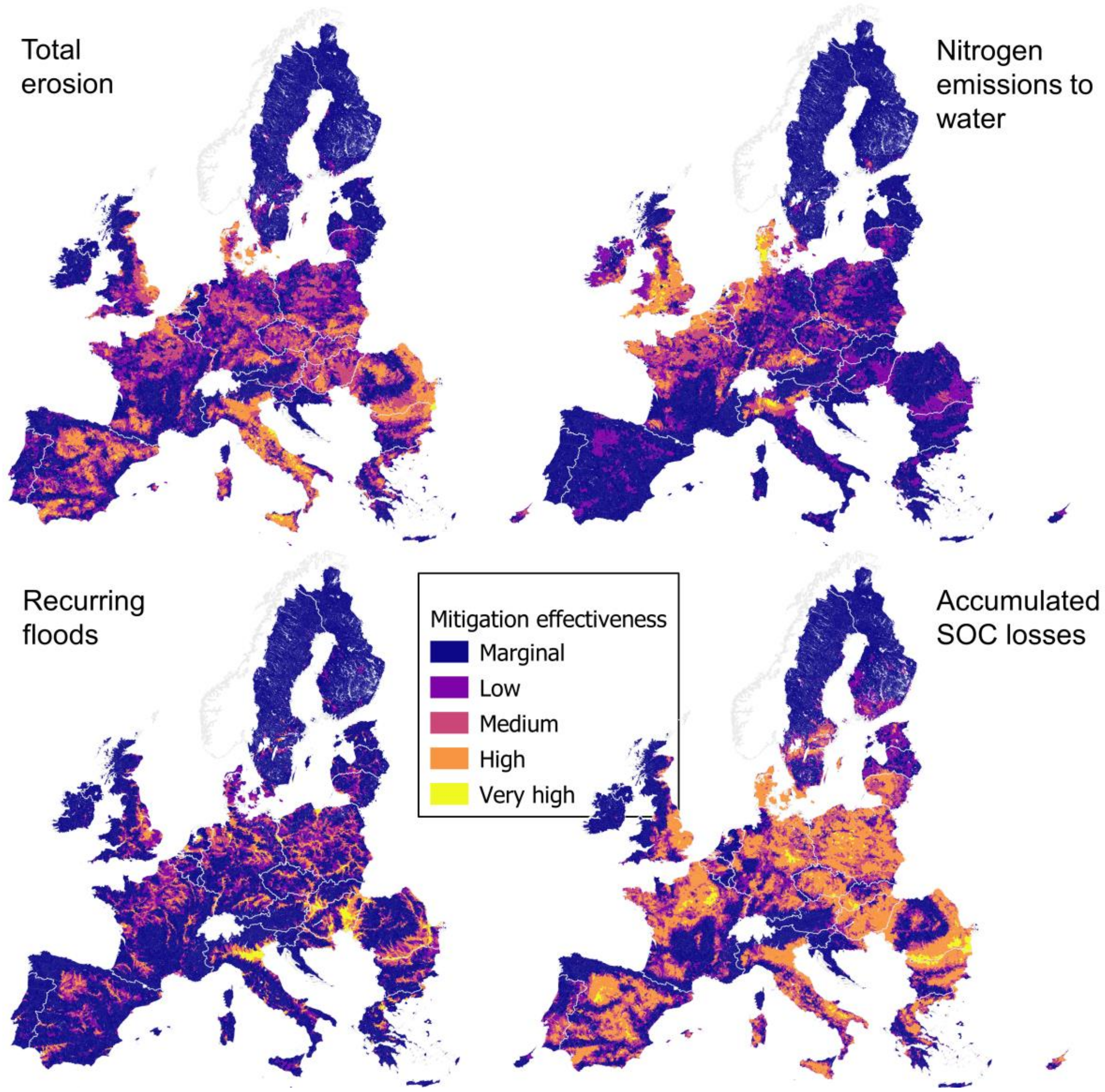

Figure 2. Effectiveness of introducing perennial biomass cultivations to mitigate selected impacts of annual crop production (sub-watershed scale). Source: Englund et al. (in review)

The promotion of environmental co-benefits from bioenergy deployment requires spatially explicit assessment methods that incorporate site-specific characteristics at high resolution and differentiate between land management practices. To support the development of such assessment methods, a systematic review was carried out of methods for analyzing and mapping ecosystem services in landscapes (Englund et al., 2017). Regulating and maintenance services were most commonly mapped (165 cases) in the reviewed studies, followed by cultural (85 cases), and provisioning services (73 cases). For individual ecosystem services, a large variation in number of mapping cases was found. This may reflect the perceived importance of the ecosystem services, and/or that different ecosystem services can be more or less easily mapped.

One important finding was that only twelve percent of all cases were validated with empirical data. As unconfirmed results can be difficult to evaluate and thus be of limited use in, e.g., landscape planning, validation should be prioritized in future mapping studies. It is preferable to focus on those ecosystem services that can be studied using meaningful indicators, and adequately validated. Text box 1 below further summarizes related findings from the review study.

In parallel with the Objective 1 activities, IEA Bioenergy Task 43 has organized workshops and coordinated studies addressing landscape management and design for bioenergy and the bioeconomy. Resulting publications and workshop documents can be found at http://task43.ieabioenergy.com/. A webinar was also arranged to disseminate Objective 1 work on this topic, see https://www.ieabioenergy.com/publications/biomass-production-in-sustainably-managed-landscapes/.

Findings from a review of methods for analysing and mapping ecosystem services in landscapes

Sustainability assessment relies on easily-measured indicators. Proxy-based methods are appealing because they are much less complex than, for example, direct mapping with survey and census approaches, or empirical production function models. But there are disadvantages, such as the risk of generalization error, which makes them unsuitable for landscape scale studies.

Practitioners with advanced GIS skills may benefit from creating their own models. However, some existing models have been applied many times and with validated and acceptably accurate results. When using third-party models, it is imperative that these are properly evaluated on their suitability for the specific project beforehand, and also calibrated and validated using empirical data.

Given the importance of high resolution and need for more complex methods and validation, most ecosystem services assessments with a landscape scope will need to limit the number of ecosystem services included in the study. To ensure that the most relevant ecosystem services are included, it is essential to involve stakeholders in the selection process, recognising that the key variables and indicators are context-dependent.

There is significant diversity in methodological approaches and inconsistent terminology. But there are also harmonization initiatives, such as the International Classification of Ecosystem Services (CICES) classification system, developed by the European Environment Agency (www.cices.eu). Translation of ecosystem services into the CICES classification system is in most cases relatively straightforward. Further development of CICES should consider whether to only include ecosystem services associated with direct benefits to humans.

The comprehensiveness and use of more technical terms in CICES may create a barrier for communication and interaction with those that lack in-depth understanding of ecosystem services. Given the importance of stakeholder involvement in assessments of ecosystem services, this is a clear disadvantage.

It may therefore be beneficial to review the wording or to complement the typology with alternative, less technical, descriptions. This can preferably be coordinated with other initiatives that aim to inform policies and everyday practices, such as the "Nature's contributions to people" (NCP) concept developed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

3. Carbon balances and climate impacts of forest bioenergy systems

In recent years, there has been considerable debate about climate effects of bioenergy products that are produced from forest biomass. There is no clear consensus among scientists on the issue and their messages may even appear contradictory to decision-makers and citizens. The divergence in views arises because scientists address the issue from different points of view, which can all be valid. The varying context of the analysis and policy objectives have a strong influence on the formulation of research questions, as well as the methods and assumptions about critical parameters that are then applied, which in turn have a strong impact on the results and conclusions.

Objective 1 provides important inputs to the debate by showing that **the climate effects of bioenergy systems need to be assessed in the specific context where bioenergy policies are applied and bioenergy is produced and used.** For forest bioenergy, this often means that studies should analyze bioenergy systems as components in value chains or production processes that also produce material products, such as sawn wood, pulp, paper and chemicals. Below, three case studies are summarized that are illustrative of the varying context for implementation of bioenergy systems.

3.1 THE CARBON BALANCE OF BIOENERGY SYSTEMS USING UNLOVED WOODS IN QUEBEC

The study from Quebec shows how the sustainability of forest bioenergy needs to be considered as an integral part of larger forest management systems. The most recent Sustainable Forest Development Act in Quebec (in force since 2013 and applied to all public forest lands), relies on the concept of ecosystem-based forest management, which aims to reduce the differences between managed forests and the natural forest in order to create landscapes that contain all the diversity of the natural forest. This type of management maintains a high level of naturalness in forest landscapes but also results in a large variability in the quality of wood supply. The forest industrial network needs to adapt to this variability, which can create difficulties for sawmills and pulp mills as they usually have strict standards and requirements in terms of wood fibre quality. When trees with undesirable fibre characteristics (i.e., "unloved woods", such as defoliated or dead trees and uncommercial hardwood species) are abundant in a landscape, clear-cut operations tend to either: create extremely large loads of residues on harvested areas, or leave whole stands untouched where low proportion of high-quality timber makes harvesting unprofitable.

Polyvalent fibre-takers such as **the bioenergy industry can facilitate forest management by using unloved woods**. In some instances, biomass procurement can serve as an important silvicultural practice by (i) reducing residue loads on clear-cut areas and accelerating the establishment and growth of the regenerating stand; or (ii) allowing profitable harvesting of stands that were previously left untouched because of their high proportion of undesirable trees, and thus unlocking the portion of higher-quality timber that these stands contain. In those cases, bioenergy can both displace fossil fuels and deliver additional benefits. This should be taken into account in evaluations of the GHG balance of such forest bioenergy systems. Additional benefits can arise in the form of (i) increased carbon sequestration on forest sites (Figure 3a); or (ii) increased displacement effects associated with the newly mobilized volumes of sawn timber products reaching the markets (Figure 3b).

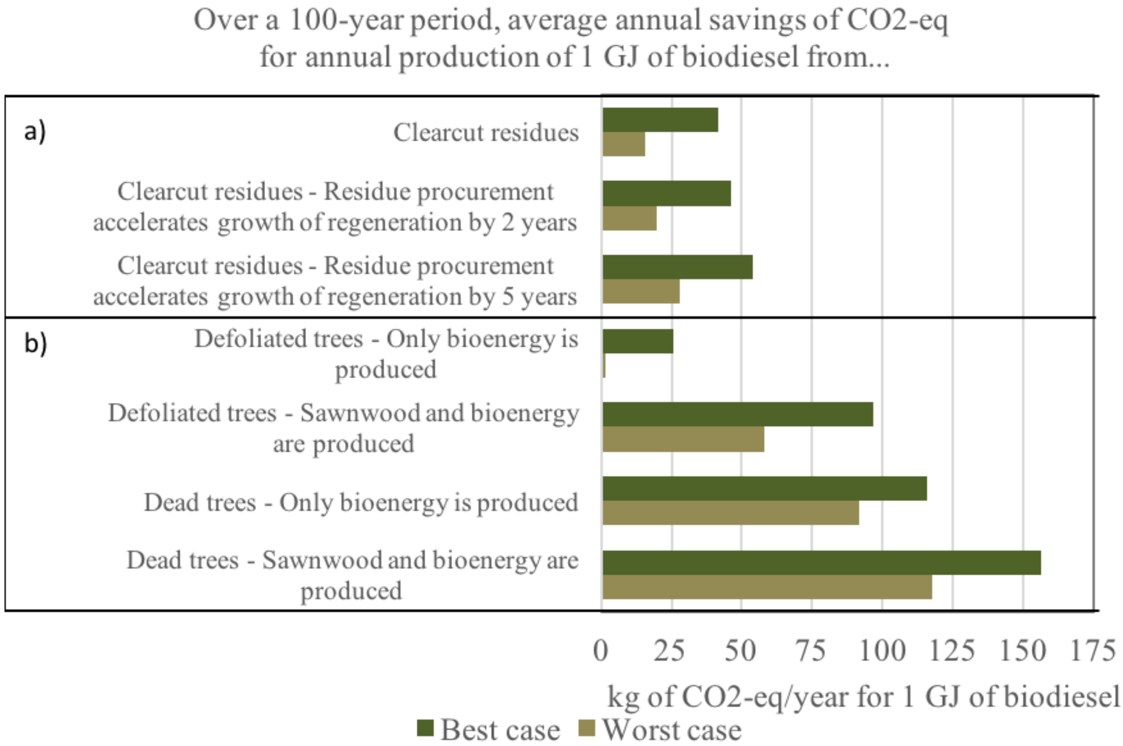

Figure 3. Example of calculation of CO_2-eq balance of forest bioenergy systems producing biodiesel using forest biomass from boreal balsam fir stands, relative to a reference system based on fossil diesel. a) In the reference fossil fuel scenario, clearcut residues would be left to decay on site. b) In the reference fossil fuel scenario, the stand would be left unharvested. Best/Worst case: Estimates of maximum/minimum savings based on variability of input parameters.

3.2 THE USE OF BIOMASS FROM WOODLAND CLEARING FOR BIOENERGY AND BIOCHAR COMPARED WITH IN-FIELD BURNING IN AUSTRALIA

Invasive native scrub (INS) is native woodland vegetation of, generally, low ecological value that invades grasslands and reduces livestock production. Legislation allows landholders to strategically clear INS to return an area to production, a practice associated with GHG emissions due to the field burning of residues. The Australian government has created an incentive for landholders to retain INS, to mitigate the climate impacts of clearing practices through a scheme that gives credit for avoided clearing of INS.

This study used LCA to estimate the cumulative radiative forcing of two management strategies relative to the business-as-usual (BAU) strategy of clearing INS and burning residues in the field: 1) pyrolysing INS residues, co-producing electricity from syngas and then applying biochar to croplands and 2) retaining INS, as incentivised by the Australian government. The climate change mitigation potential of these strategies was assessed using both an attributional and consequential approach.

Results indicate that the INS pyrolysis strategy had greater climate change mitigation potential than both the INS retention strategy and BAU. When the INS pyrolysis strategy was assessed using an attributional approach, the greatest contributor to mitigation was avoided field burning emissions. When a consequential approach was used, electricity production avoided due to the electricity generated as a co-product of pyrolysis was the greatest contributor to mitigation. Sensitivity analysis indicated that – across a range of INS biomass yields at clearing – the INS pyrolysis strategy consistently provided greater climate change mitigation than did INS retention or BAU. More broadly, the research indicates that **bioenergy sourced from vegetation with a relatively low ecological value that invades agricultural land may provide climate mitigation whilst returning the land to production and improving the economic viability of the agricultural enterprise.**

Figure 4. In western NSW, invasive native scrub (left) is cleared for grazing (right). Usually the cleared biomass is burned in the field. Source: Cathy Waters

3.3 THE USE OF RESIDUES AND ROUNDWOOD FOR ENERGY IN SWEDEN AND THE INFLUENCE OF FOREST MANAGEMENT ON THE RESULTING CARBON BALANCE AT THE NATIONAL LEVEL

This study investigated the potential role of forest management and wood use in Sweden, in scenarios aiming towards climate neutrality by mid-century. It combined two scenarios for energy use in Sweden with four forest scenarios and quantified GHG balances associated with energy-use for heat, electricity, and road transport, and with forest management and production, use, and end-of-life management of various forest products, including products for export. The production of biofuels in the agriculture sector was also considered but not analyzed in detail. The aggregated national GHG balances were evaluated in relation to an allocated Swedish CO_2 budget derived from a global CO_2 budget corresponding to a 66% chance of staying below 2-degree warming. This evaluation perspective was put forward in previous publications from IEA Bioenergy[1] but until now not implemented on a national scale.

The GHG emissions mitigation associated with forests is already today very significant in the Swedish GHG balance. As shown in Fig. 5, **measures to increase forest growth and biomass output can further strengthen the contribution to climate change mitigation by supplying forest fuels and other products while maintaining or enhancing carbon storage in vegetation, soils, and forest products.** The forest sector can in this way contribute to a development where Sweden does not use its allocated CO_2 budget. Instead, by transforming the energy, industry and transport sectors, and by investing in forest management to produce forest fuels and a range of other forest products, Sweden as a country becomes a net carbon sink during this century. Not shown in Fig. 5, the additional mitigation effect of carbon storage and GHG savings abroad, associated with exported forest products, is similar in size as the mitigation effect in Sweden.

[1] Berndes, G., Cowie, A., Bird, N. (2010). Bioenergy, land use change and climate change mitigation. Report for policy advisors and policy makers. IEA Bioenergy: ExCo:2010:03; Cowie, A., Berndes, G., Smith, T. (2013). On the Timing of Greenhouse Gas Mitigation Benefits of Forest-Based Bioenergy. IEA Bioenergy ExCo:2013:04

While the result in this Swedish study is also supported by other studies[2], it is emphasized that the Swedish situation should not be understood as globally representative for varying conditions. Changes in forest management to produce forest fuels can also lead to decreases in forest carbon stocks. An important conclusion of this study is that the development of strategies and policies for forest-based mitigation needs to consider *both* how the displacement of fossil fuels and other GHG-intensive products can help avoiding GHG emissions *and* how forest management, and the production and use of forest products, affect the strength of the forest carbon sink and the amount of carbon that is stored in forests and in forest products over time. This was evident in the Swedish study: the climate neutrality goal is not met in any of the scenarios without factoring in carbon sequestration in forests and forest products.

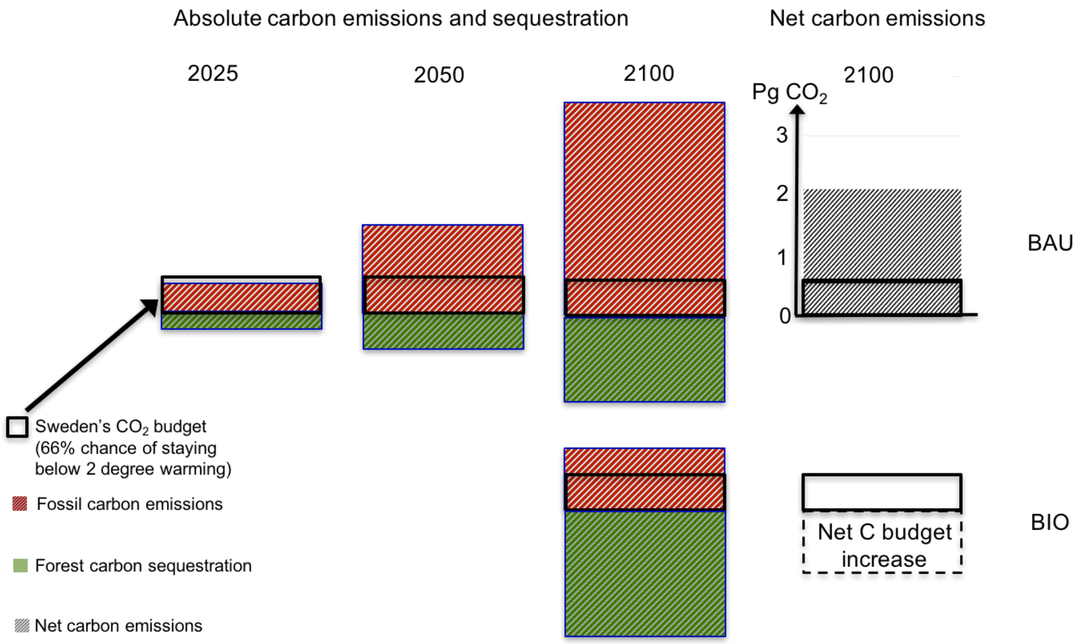

Figure 5. The cumulative net CO_2 emissions in Sweden (fossil C emissions minus forest C sequestration) compared with an allocated Swedish CO_2 budget (66% chance of staying below 2-degree warming). The upper bars show the absolute emissions and sequestrations (left three columns), as well as net carbon emissions (right column), for a business-as-usual (BAU) scenario 2025-2100. The lower bars show the situation in 2100 in a scenario with active forest management to increase forest growth and biomass output (BIO). The Swedish CO_2 budget is represented by the black rectangle overlaid on each bar. Source: Cintas et al. (2017).

[2] Nilsson, U., Fahlvik, N., Johansson, U., Lundström, A., Rosvall, O., (2011). Simulation of the effect of intensive forest management on forest production in Sweden. Forests 2, 373–393; Poudel, B.C., Sathre, R., Bergh, J., Gustavsson, L., Lundström, A., Hyvönen, R., (2012). Potential effects of intensive forestry on biomass production and total carbon balance in north-central Sweden. Environ. Sci. Policy 15, 106–124.; Sathre, R., Gustavsson, L., Bergh, J., (2010). Primary energy and greenhouse gas implications of increasing biomass production through forest fertilization. Biomass Bioenergy 34, 572–581.

4. Summary of main findings, recommendations and way forward

Based on the combined portfolio of studies undertaken in Objective 1, an overall conclusion is that **assessment approaches need to reflect that existing and emerging bioenergy systems are commonly integrated with other bio-based systems and associated land use. Several complementary methodologies may need to be combined to address relevant aspects along all sustainability dimensions** and to facilitate efficient utilization of biomass resources and improved sustainability performance**.** The methodologies addressed in this summary report are among those that are suitable for assessing bioenergy and other bio-based systems.

Several of the included studies investigated how assessment approaches can influence results as well as conclusions of studies. The varying biophysical, social and economic context of analyses and policy objectives influence the formulation of research questions as well as the methodology approach (e.g. spatial and temporal scales) and parameter assumptions, e.g., which (fossil) fuels are substituted and what reference scenarios are chosen to compare with bioenergy scenarios. It has been shown that the methodology approach is in itself a critical factor behind results and conclusions across different case studies (see, e.g., Cintas et al. 2017 and Bentsen et al. 2017). Sometimes disagreement among studies can be explained by differences in assumptions about the values of uncertain parameters (Pereira et al., in review). It is important to involve policy makers and stakeholders in defining policy-relevant research questions (e.g., in defining objectives, scope and selecting reference scenarios). This would increase the likelihood that results are relevant, interpreted correctly and useful in the policy development process.

Climate effects

Concerning forest bioenergy systems, our work shows that **the climate effects of forest-based bioenergy systems need to be assessed in the specific context where bioenergy policies are applied and bioenergy is produced.** Studies that assess bioenergy systems as single entities, in isolation from the context where bioenergy and other bio-based products are produced and used, do not capture the full climate effect of implementing such systems. For example, studies that analyse carbon flows at individual forest stand level may provide useful information within the limited boundaries of the studies, e.g., allowing benchmarking of different pathways on a common scale. But their limited scope reduces their usefulness for informing policy making.

A specific drawback of stand-level assessments is also that the forest system is represented by a prescribed sequence of events (e.g., site preparation, planting or natural regeneration, forest thinning and other silvicultural operations, final felling) despite that these events in reality occur simultaneously across the forest landscape. Due to this, **studies that apply stand level assessments can be misleading as a model for the forest sector and its overall impact on climate**.

It is also influential when the modelling of the carbon impact is started. For example, if the carbon accounting is started at the time when biomass is extracted from a stand and used for bioenergy, i.e., commencing with a pulse emission followed by a phase of sequestration, there will be – by design – often an initial net GHG emission. Conversely, if the carbon accounting is started at the time when a stand has recently been planted with new trees, the forest system will be characterized by a period of net carbon sequestration which ends when the stand is harvested and the sequestered carbon is "returned" to the atmosphere (Berndes et al., 2016; Koponen et al., 2018). Landscape level assessments that capture all carbon flows in the landscape throughout the accounting period avoid such system boundary effects (Cintas et al., 2017).

Land management decisions reflect the balancing of economic, ecological, and social objectives. **In relation to the objective to mitigate climate change, the management of forests needs to consider the contributions from forest carbon sinks, carbon storage in forests**

and forest products, and wood harvesting to produce forest products that substitute for fossil fuels and other products such as cement. Thus assessments should ideally consider the full product portfolio, take full account of all the types of forest management operations that occur across the landscape, and include realistic representations of the age-dependence of forest growth rates so that it is considered that carbon accumulation rates diminish as forests age.

Landscape level studies can consider how forest management operations, and the production and use of forest products, affect the strength of forest carbon sinks and the amount of carbon that is stored in forests and in forest products over time, i.e. the biophysical dynamics of the landscape. Integrated modelling approaches that also capture economic dynamics and interactions with the biophysical environment can be used to study how forest management will vary depending on the characteristics of demand, forest structure, climate, forest industry profile, forest owners' views about emerging bioenergy markets, and the outlook for other forest product markets. Such studies can reveal how adjustments across affected systems (including the forest, product uses, markets and processing technologies) influence the development of forest carbon stocks and GHG emissions.

Ecosystem services

The study of methods for assessing and mapping ecosystem services in the landscape revealed a significant diversity in methodological approaches and an inconsistent terminology. But we also found harmonization initiatives, such as the new International Classification of Ecosystem Services (CICES) classification system, developed by the European Environment Agency (www.cices.eu). In summary, it was found that methods that use readily-measured proxies to represent key variables have the advantage that they are much less complex than, for example, direct mapping with survey and census approaches, or empirical production function models. But there are disadvantages, such as the risk of generalization error, so they may be unsuitable for landscape scale studies, and should be validated with empirical data to confirm their suitability before use. **Given the importance of high resolution and need for more complex methods and validation, most ecosystem services assessments with a landscape scope will need to limit the number of ecosystem services included in the study. To ensure that the most relevant ecosystem services are included, it is essential to involve stakeholders in the selection process.**

Translation of ecosystem services into the CICES classification system is in most cases relatively straight-forward. But the comprehensiveness and use of more technical terms in CICES may create a barrier for communication and interaction with those that lack in-depth understanding of ecosystem services. Given the importance of stakeholder involvement in assessments of ecosystem services, this is a clear disadvantage. It may therefore be beneficial to review the wording or to complement the typology with alternative, less technical, descriptions. This can preferably be coordinated with other initiatives that aim to inform policies and everyday practices, such as the Nature's contributions to people (NCP) concept within the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[3].

Based on Objective 1 studies, we recommend the following:

1) Involve relevant policy makers and stakeholders in defining policy-relevant research questions, e.g., in defining objectives, scope and selecting reference scenarios, and in reflexive processes during the research itself ("transdisciplinarity"). This will increase the likelihood that there is agreement about the assessment framework, and that results are relevant, correctly

[3] Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M., Baste, I.A., Brauman, K.A. and Polasky, S., 2018. Assessing nature's contributions to people. *Science*, *359*(6373), pp.270-272.

interpreted and become useful in the policy development process.

2) Ensure that the design of the assessment framework and assumptions about parameter values are transparent and are open for discussion. It should be clear which spatial and temporal scales are applied and why these are appropriate for the purpose.

3) Use indicators that inform about the effects of bioenergy systems on global warming on different time scales. Further, it is desirable that methods are developed to consider non-GHG climate forcers (e.g., albedo and aerosols) as these can be as important as GHGs.

4) Use integrated modelling to get more realistic assessments, considering that the climate impacts of forestry depend also on the dynamics of the economic system and industrial structure.

5) For assessment of impacts on ecosystem services, involve stakeholders in the selection process to ensure that the most relevant ecosystem services are included.

6) Translate technical descriptions of assessment frameworks into plain language, to properly inform a broader audience.

7) Validate proxy-based methods for assessing ecosystem services using local empirical data, and recognise that they have limitations that can make them unsuitable for landscape-scale studies.

8) If third-party models are used, evaluate their suitability for the specific project beforehand, and also calibrate and validate them using local empirical data.

The new IEA Bioenergy Task 45 – Climate and sustainability effects of bioenergy within the broader bioeconomy – will build further on Objective 1 results during the 2019-2021 triennium. One key goal of the Task is to increase understanding of the environmental, social and economic effects of producing and using biomass for bioenergy, within the broader bioeconomy. A central aspect concerns the development and application of science-based methodologies and tools for assessing the effects of bio-based systems. More information about Task 45 can be found at http://task45.ieabioenergy.com/.

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5. Outputs of Objective 1

Bentsen, Niclas Scott. Carbon debt and payback time – Lost in the forest? Renewable and Sustainable Energy Reviews. Renewable and Sustainable Energy Reviews 73 (2017) 1211–1217.

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