Editorial

Governing sustainability of bioenergy, biomaterial and bioproduct supply chains from forest and agricultural landscapes

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Introduction

Agriculture and forestry produce a range of goods that are critical to human survival and welfare, including food and timber, and biomass feedstock for bioenergy, biochemicals, and biomaterials. The associated management activities span over large portions of the world’s productive land and generate some of the largest human impacts on nature and the environment at scales that range from local to global. As the global population, its wealth, and interactions increase, the challenge to find an acceptable balance between human acquisition of food and raw materials and the impacts of such production on climate, nature, environment and people also increases.

Countries that increased their use of domestic biomass to substitute fossil fuels in modern bioenergy production after the oil embargo in the 1970s have also often adopted national recommendations for biomass harvesting in forests due to public concerns over the potential impacts of intensified management practices [1]. A booming international trade with bioenergy products since the 2000s [2] has led to creation of transnational sustainability regulation, often as a combination of national legal requirements and non-state certification to show compliance [3, 4]. The adopted and applied systems have been under public scrutiny from the beginning, but governance1 is likely still one of the most useful tools available for finding agreement among stakeholders, or voters, on sustainability goals and criteria and indicators for measuring progress towards these goals [5].

The overall question addressed by this thematic article collection is how the choice of design of the sustainability governance system affects people's granting of legitimacy to the system. A high level of legitimacy is a precondition for building trust that the system leads to acceptable and beneficial outcomes. The question sits in the nexus

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1 For the purpose of this article collection, we understand governance broadly as a range of public and private regulatory mechanisms. Public regulatory regimes include, for example, governmental regulation, ordinances, guidelines, BMPs, educational programmes, and public awareness campaigns, as well as international agreements and conventions with nations as signatories. Private regulatory regimes include non-state certification systems, standardisation, company policies such as Corporate Social Responsibility, organisations’ or communities’ BMPs and education programmes [1].
of science, policy and governance, and public acceptance [5–7] (Fig. 1). There is evidence that people are more likely to perceive a governance system as legitimate when rigorous science underpins its design, when the science is seen as credible, and when the system’s exertion of power is seen to be fair and appropriate [5].

The model provided in Fig. 1 depicts the conceptual framework that underlies this article collection on sustainability governance of bioenergy and the bioeconomy. The included papers are part of a larger body of literature and knowledge generated from collaborative activities in research networks and projects funded by International Energy Agency (IEA) Bioenergy and the Nordic Council of Ministers, with contributions from the participating researchers’ home organisations. The outputs include scientific articles, reports, workshops, and excursions that all have sought to increase the level of integration between science, policy and governance in relation to sustainability governance for bioenergy.

**International collaboration**

The IEA Bioenergy research collaboration on forest resource mobilisation through intensive logging residue and whole-tree harvesting started in the early 1970s, with associated investigations of how it affects site fertility and other ecological values. Several countries needed such knowledge when interest in the use of domestic forest biomass for energy increased after the oil embargo in 1973 [1, 5]. The collaboration on the topic continued in a dynamic research and knowledge exchange environment created by workshops and projects under various IEA Bioenergy Tasks with national research in participating member states as a basis. As the body of scientific literature grew, books, articles and reports synthesised knowledge to inform forest management and policy. Major works include the books Dyck et al. (1994) “Impacts of Forest Harvesting on Long-Term Site Productivity” [8] and Richardson et al. (2002) “Bioenergy from Sustainable Forestry—Guiding Principles and Practice” [9]. A European Union R&D project also produced a book within the same topic area: Röser et al. (2008) “Sustainable Use of Forest Biomass for Energy—A Synthesis with Focus on the Baltic and Nordic Region” [10]. Articles developed from these collaborations during the period 2007–2013 also proposed and reviewed criteria and indicators for sustainable wood fuel production from forests [11–15], and the IEA Bioenergy strategic study “Monitoring Sustainability Certification of Bioenergy” (2012–2013) examined the potential role of voluntary certification schemes in the governance of bioenergy sustainability, how these schemes affect supply chain actors [16], and perceptions if existing systems are adequate [17].

The boom in the transatlantic wood pellet trade in the early 2010s, especially from North America to Europe [2], created a sense of urgency to improve communication through dialogues around the scientific basis for regulation and governance of the sustainability of forest bioenergy. Workshops in Quebec, Canada, 2012 [18] and in Arona, Italy, 2013 [19] discussed, for example, the application of the term “primary forest” in sustainability requirements of the European Union Renewable Energy Directive from 2009 [20] (Fig. 2). It had become a significant concern that such terminology does not easily translate into a North American context.

The increasing volumes of internationally traded wood pellets also gave rise to new concerns about whether forest bioenergy is truly leading to climate benefits. This motivated another workshop in Savannah, Georgia, USA, in 2013 [21], which provided a platform for discussions on methodology and assumptions for calculation of greenhouse gas emission savings from forest bioenergy. This debate is still energetically ongoing today [5] and continues to give rise to new studies on greenhouse gas emission savings, also in this article collection.

The international trade with bioenergy products further stimulated interest in broader bioenergy sustainability criteria, potentially covering a range of supply chains and feedstocks. A tour across the landscapes of southeastern North America in 2016 to discuss a range of bioenergy production systems [22] provided inspiration for the newly started IEA Bioenergy project “Measuring, governing and gaining support for sustainable bioenergy supply chains” [23]. The project had three objectives
under which it commissioned a number of studies relating to measuring, governing, and gaining support for sustainable bioenergy supply chains, respectively, corresponding to the three components of the model in Fig. 1. Preliminary results were presented during a workshop in Gothenburg, Sweden, in 2017 [24].

In 2018, IEA Bioenergy Task participants joined forces with the Nordic–Baltic networks “Effect of bioenergy production from forests and agriculture on ecosystem services in the Nordic and Baltic landscapes” and “Centre of Advanced Research on Environmental Services from Nordic Forest Ecosystems”, funded by Nordic Forest Research and The Nordic Joint Committee for Agricultural and Food Research, to arrange a conference in Copenhagen, Denmark, titled “Governing sustainability of bioenergy, biomaterial and bioproduct supply chains from forest and agricultural landscapes” [25]. The conference focussed on questions around design of effective and legitimate science-based sustainability governance for bioenergy and the bioeconomy, with the ultimate criterion for a “good” design being high levels of public trust that bioenergy production only takes place when and where it is sustainable. Long-term and new collaborators presented analyses of governance systems, impacts, and stakeholder perceptions in relation to bioenergy supply chains based on forest or agriculture biomass, or manure for biogas, as during the IEA Bioenergy inter-Task project. Some main conclusions were synthesised and presented to larger audiences the same year at the European Biomass and Exhibition (EUBCE) in Copenhagen, Denmark [26], and at the IEA Bioenergy Triennial Summit in San Francisco, California, USA [27].

It became clear that it is not possible to satisfy the demand for certified biomass only with systems based on management unit-level certification [4]. This increased the interest in sourcing area and regional risk-based approaches to document compliance with sustainability criteria. A workshop in Athens, Georgia, USA, focused on advanced spatial data and their usefulness for conducting risk assessments for sustainable wood sourcing practices in the USA [28], and a workshop in Richmond, Virginia, USA, discussed the application of risk-based approaches especially in sensitive forests in the USA [29].

This article collection mainly contains a sub-set of articles produced under the inter-Task project and/or presented at the conference in Copenhagen in 2018 (see Table 1). However, other publications produced in the same context have also been included for the overview provided in the next section (see Table 2).
Overview of articles and future perspectives

Studies conducted within the context of the above collaborations generally focussed on one of the three research areas (Table 3), corresponding to the components of the model in Fig. 1: “Governance system design”, “the underpinning science”, and “stakeholder perceptions and engagement”, combined with one of three generalised types of bioenergy supply chains. The generalised supply chains were defined by their dominant type of feedstock and typical energy end-use, where feedstock types included forest biomass, agricultural crop residues and perennial crops, and animal manure for biogas (Table 3). Other studies more broadly addressed conceptual understandings, all bioenergy sectors together, or the bioeconomy as a whole, but most studies could be categorised as addressing one of the three research focuses for one of the three types of supply chains (Table 3).

The studies provide an opportunity to deduce and compare lessons learned from each of the three supply chain types, across a range of domestic and international supply chains that involve different geographical regions for both feedstock production and bioenergy end-use (Table 3). Positive experiences from one supply chain may be applicable for the two other supply chain types. A detailed analysis and synthesis is beyond the scope of this editorial, but Stupak et al. [5] present a research...
framework for conducting such an analysis, and a model for adaptive governance that builds on the collective sum of experiences and understanding gained from the individual studies (Table 3), the broader research network collaborations, and other literature on the topic.

The model suggests that a well-designed adaptive approach to governance will positively affect the quality of the stakeholder participation ("input legitimacy") as well as the ability of the system to achieve environmental, social, economic or cultural sustainability goals and avoid undesired impacts ("output legitimacy"). Both issues have been shown to be critical for gaining support for governance (Fig. 3). An additional critical element is the efficiency in implementation and enforcement, as well as the efficient, fair, truthful, and transparent conduct of system affairs generally ("throughput legitimacy").

The adaptive governance cycle comprises steps to identify sustainability concerns, design policy and standards to address them, and design implementation and enforcement systems, as well as monitoring-and-evaluation systems. Finally, lessons learned and recommendations are deduced for system revision, and the cycle starts again with identification of new concerns or dissatisfactions, needs to correct unintended impacts, and adaptations to new technologies or framework conditions. The monitoring-and-evaluation system is thus a critical element of the adaptive cycle, as it tracks progress towards the intended goals and facilitates the development and improvement of the quality of the governance system processes.

While governance is a beneficial tool for resolving disagreement, we assert that value-based political and public discourses will continue to influence political decisions and public opinion, and these may at times overrule the
outcomes of monitoring and research. This is an important condition in democratically governed societies. To this end, it is also important to recognise that research does not take place in an entirely value-free, objective, and neutral space. This means that transparency around funding, topic selection, chosen methodology, etc., becomes crucial to avoid suspicion about scientific results, especially when there are value-based disagreements. We venture to hope that the articles in this collection fulfil the transparency criterion, especially, but also that the presented work may inform and inspire the development of sustainability governance systems in the future.

Table 3  Overview of papers of this article collection (see Table 1) as well as those written within the same context but published elsewhere (see Table 2), categorised according to the addressed type of supply chain and type of research focus

| Supply chains component | Type of supply chain | Forest | Agriculture | Biogas |
|-------------------------|----------------------|--------|-------------|--------|
| Feedstock               | Primary, secondary and tertiary woody biomass | Crop residues, perennial energy crops | Manure, energy crops, agricultural residues |
| End-use                 | Heat and power       | Transportation fuels, heat and power | Heat and power, transportation |

| Type of research focus | Type of supply chain | Forest | Agriculture | Biogas |
|------------------------|----------------------|--------|-------------|--------|
| Conceptual basis, theory | General              | A3. Stupak et al. (2021). Conceptual framework |
| Governance system design | North America         | A4. Kittler et al. (2020). Southeastern USA |
|                        | B3. Cheung et al. (2019). Ontario, Canada |
|                        | A2. Titus et al. (2021). Northern hemisphere |
|                        | B9. Stupak and Smith (2018). SE USA and Baltic states |
|                        | Europe                | A13. Larsen et al. (2019). Denmark |
|                        | A1. Hansen et al. (2021). Fennoscandia |
|                        | General              | A5. Moosmann et al. (2020). The EU |
|                        | B5. Diaz-Chavez and van Dam (2020) |
| The underpinning science | North America         | B6. Kline et al. (2018). SE USA. Greenhouse gas emissions |
|                        | Europe                | A1. Hansen et al. (2021). Fennoscandia. Sustainability |
|                        | A10. Varnagiryte-Kabalińska et al. (2019). Lithuania. Environmental issues |
| Perceptions and stakeholder engagement | North America         | B4. Dale et al. (2018). Iowa, USA |
|                        | Europe                | A12. Pestalozzi et al. (2019). Germany |

The topic is indicated for papers listed under “The underpinning science”
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Authors’ contributions
All authors jointly conceived the ideas behind the editorial. IS compiled it with continued feedback and suggestions from CTS and NC. All authors read and approved the final manuscript.

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Availability of data and materials
Not applicable.

Fig. 3 Model for adaptive sustainability governance with proposed linkages with the principles and open-ended criteria for “good” sustainability governance, organised under three legitimacy principles: input, output, and throughput legitimacy.

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The authors declare that they have no competing interests.

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