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A systematic literature review on indicators to assess local sustainability of forest energy production

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ABSTRACT

Bioenergy production is considered the single most significant contributor to the climate change mitigation within the forest sector. In addition, the production of forest-based bioenergy may also positively affect social welfare, local development and forest economy. In environmental markets the role of forests and the challenge of combining international, national and local needs related to their sustainable use for bioenergy and social livelihood is increasing. These global ecological and socio-economic changes pose new challenges for ecologically, economically, socially and culturally sustainable utilization of forest resources. The purpose of this literature review is to map the existing indicator sets introduced in scientific literature suitable for evaluating the sustainability of forest-based bioenergy production systems from a local perspective. In addition, also the challenges in assessing ecological, economic, social and cultural sustainability by using different types of indicators are discussed. According to the results of this study, there are plenty of indicators suitable for assessing either the ecological, economic, social and cultural sustainability of forest-based bioenergy production at a local level. In contrast, information on appropriate procedures for taking into account local development goals abreast with the objectives of sustainable development at general global level are lacking. Additionally, in order to analyze trade-offs in different sustainability dimensions caused by optional decisions regarding forest-based energy production, methodological development would be required. The comprehensive indicators lists presented in this study can employed as background information to define the measures that are especially relevant in enhancing the local sustainability goals from the perspective of different stakeholders in specific localities.

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1. Introduction

Bioenergy production is considered the single most significant contributor to the climate change mitigation within the forest sector [1]. In addition, utilization of forest resources for bioenergy production may positively affect social welfare, local development and forest economy especially in rural areas [2]. Combining international, national and local needs related to the sustainable use of forests for bioenergy production [3] and supporting social wellbeing, for example, are expected to be major themes in environmental markets in the future [4]. These global ecological, socio-economic and cultural changes [4,6] also pose new challenges and conflicts of interests for ecologically, economically, socially and culturally (i.e., multi-dimensionally) sustainable utilization of forest resources both at national and global level [7].

International bioenergy trade is growing rapidly due to policy incentives (e.g., linked to climate change mitigation), large resource potentials, relatively low production costs, and objectives aiming at increasing the stability of national and regional fuel markets by reducing the dependency on crude oil imports [8,9]. Industrial forest-based bioenergy products comprise different types of biofuels (processed in biorefineries), heat and electricity (produced in combined heat and power, CHP plants), heat (produced in district heating plants), and pellets (manufactured in pellet factories). The characteristics of forest-based bioenergy products, for example, vary considerably depending on the infrastructure needed in processing, the scale of operations, competitive environment, and impacts in the local communities [10]. In addition to balancing the multiple needs related to using forest resources in primary production [11], enhancing the ecological and socio-economic sustainability of forest-based bioenergy and its markets also requires paying attention to the sustainability effects caused by different phases of the production [12]. Abreast with the ecological, economic and social issues, the importance of recognizing cultural sustainability as an independent dimension of sustainability has gained more attention since the 1990s [13–17].

Compared to social sustainability, cultural sustainability is more context-dependent, describing particular opinions, values and character of a group of people living at a specific time and place [18,17]. For example, forest landscapes do not only have ecological value, but also crucial value in expressing the interactions between society and local livelihood, thus supporting the cultural integration of the local people in the society [19,20]. Especially in the era of industrial globalization, urbanization, and international pressures on using local natural resources in geographical regions rich in natural resources, incorporating culturally acceptable landscape management to secure local cultural systems is becoming more and more important to decrease the threats on the existence of valuable cultural landscapes [21,22,19]. Thus, cultural sustainability does not comprise only places of spiritual importance for some groups of people, for example, but also local traditions in developed countries of using forest resources and acquiring livelihood as workers in the forest sector, for example [17,6,46]. Additionally, from the perspective of climate change, recognizing local cultures of different regions related to their traditions and knowledge on natural resource usage is crucial issue in seeking for global climate change adaptation and mitigation strategies [23].

There is no unambiguous definition for the concept of sustainability, which causes challenges for the empirical assessment of the overall sustainability impacts of natural resource usage decisions [24,25]. In the report of Brundtland [26], for example, sustainability is defined in general as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Similar to the concept of sustainability, the definition of sustainable development is also a complex entity including ecological, economic, technological, social, political and human dimensions of the development [27,28].

Sustainable development may be approached from macro-regional (e.g., continents), national, and micro-level (i.e., communities, firms and households) perspectives [29]. In forestry, the sustainable use of forest resources at macro-level presumes taking into account the monetary and non-monetary benefits of forests in general, while at a national and micro-level the sustainable use of forests requires concrete steps towards supporting the socio-economic development enhancing both the conservation of the key features of the ecosystems and the contribution to the fulfilment of human needs in a broad scope [30].

Indicators are tools for aggregating and condensing information used for defining and understanding multi-dimensional relationships between the ecological, economic, social and cultural sustainability dimensions and the different scopes of sustainable development [27]. Ready-made indicators and indicator systems developed for particular assessment situations are usually not suitable for all measurement contexts and therefore require modification in order to serve other/new situations of sustainability evaluation [27,31,32]. The indicator definition and modification may be based either on top-down or bottom-up approaches: top-down indicators are created via political processes [33] and they are applicable especially to macro-level and national decision-making, while the definition of indicators in a bottom-up approach is grounded on local participation for taking into account the micro-level diversity of local circumstances [34,35].

The purpose of this literature review is to map the existing indicator sets introduced in scientific literature suitable for assessing the ecological, economic, social and cultural sustainability of forest-based bioenergy production systems. The focus of this study is especially on literature including local, i.e., micro-level, perspective on sustainability indicators that could be employed in developing bottom-up multi-dimensional sustainability assessment in communities and firms/businesses involved in forest-based bioenergy production. In addition to examining the contents of indicator sets, also the challenges and critical areas in assessing ecological, economic, social and cultural sustainability by using different types of indicators are evaluated.

2. Theoretical background

Principles, criteria, indicators and verifiers are *conceptual tools* for sustainability assessments [36]. Principles are "a fundamental truth" or "a law" used as a basis for a reasoning or action that provides justification for the criteria and indicators. As an example, a principle for using biomass for energy sources could be: "Sustainable bioenergy production has a notable potential for creating environmental, economic and social benefits both at local and global level" [37].

Criteria add meaning and operationality to a principle without being a direct measure of performance, while indicators are variables or components of a system expressing the status of a particular criterion [36]. According to Bossel [38], indicators are linkages to a real world by condensing the enormous amount of meaningful information into a manageable quantity of data usable in decision-making. Indicator sets to be developed for a certain system are determined by two distinct requirements: they must provide vital information of the state of the system and they must provide sufficient information for decision-makers to intervene and correct the system in relation to the given objectives. The state indicators provide information of the current state of the system, while the rate indicators express the speed of change in the system. Verifiers are data, which provide specific details of the

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