

## **Sustainability criteria and indicators of bioenergy systems from steering, research and Finnish bioenergy business operators' perspectives**

Rimppi Heli, Uusitalo Ville, Väisänen Sanni, Soukka Risto

This is a Author's accepted manuscript (AAM) version of a publication

published by Elsevier

in Ecological Indicators

**DOI:** 10.1016/j.ecolind.2016.02.005

**Copyright of the original publication:** © Elsevier 2016

### **Please cite the publication as follows:**

Rimppi, H., Uusitalo, V., Väisänen, S., Soukka, R. (2016). Sustainability criteria and indicators of bioenergy systems from steering, research and Finnish bioenergy business operators' perspectives. *Ecological Indicators*, Vol 66, Issue July. p. 357-368. DOI: 10.1016/j.ecolind.2016.02.005

**This is a parallel published version of an original publication.  
This version can differ from the original published article.**

*Ecological Indicators*, 2016, Vol., 66, pp. 357–368.

<https://doi.org/10.1016/j.ecolind.2016.02.005>

**Sustainability criteria and indicators of bioenergy systems from steering, research and Finnish bioenergy business operators' perspectives**

Heli Rimppi<sup>a\*</sup>, Ville Uusitalo<sup>a</sup>, Sanni Väisänen<sup>a</sup>, Risto Soukka<sup>a</sup>

<sup>a</sup> Lappeenranta University of Technology, LUT School of Energy Systems, P.O. Box 20, 53851 Lappeenranta, Finland

\* Corresponding author E-mail address: [heli.rimppi@lut.fi](mailto:heli.rimppi@lut.fi), Telephone: +358 50 439 3984

**Abstract**

This paper addresses the interface of steering, research, and business operators' perspectives to bioenergy sustainability. Although bioenergy business operators are essential for sustainable development of bioenergy systems through implementation of sustainability criteria, their perspective to sustainability is rarely studied. We systematically studied the relevant sustainability criteria and indicators from the three perspectives in different stages of a general bioenergy life cycle and in different sustainability dimensions, and evaluated bioenergy operators' sustainability principles, criteria and indicators simultaneously with respect to the steering and research data and a business sustainability maturity framework. We collected data from literature and a workshop for Finnish bioenergy experts. The results show a similar division of steering and operators' sustainability criteria and indicators to life cycle stages and sustainability dimensions with a slight emphasis on business economic sustainability from operators' perspective. The acceptability principle could provide bioenergy operators a meaningful way of identifying the role of sustainability criteria and indicators from steering and research sources in advancing their business sustainability maturity.

**Keywords**

bioenergy; sustainability; life cycle; system analysis; Finnish business

# 1 Introduction

In 2010, 10% of the global primary energy demand was met by bioenergy production. One third of bioenergy was consumed by the industry, energy, or transportation sector. (IEA, 2012.) According to a scenario by the IEA (2012), the global primary energy demand for bioenergy, excluding traditional uses, could more than double by 2035. Currently, the markets of energy biomass are increasing and internationalizing rapidly (Vakkilainen et al., 2013).

Greenhouse gas emission reduction and renewable energy promotion targets, such as the EU 20-20-20 policy (2009/28/EC) and resulting political mandates and subsidies (FAO, 2008; ICTSD, 2009) for biomass-based solutions as part of the energy infrastructure affect the production of bioenergy. Renewable energy production, including bioenergy, is generally recognized as a promising solution to replace fossil fuels in an attempt to cover the rapidly growing energy demand, triggered by drastic population and economic growth, especially in the developing areas of the world.

The bioenergy growth should be managed so that the bioenergy systems develop sustainably. The sustainability of human operations presumes that the planetary boundaries or local environmental ceiling are not exceeded and the quality of life is maintained by respecting the social foundation of human well-being (Griggs et al., 2013; Heijungs et al., 2014; Raworth, 2012; Rockström et al., 2009).

Scientists stress the importance of a holistic vision and integrated approach to bioenergy system sustainability assessing the environmental, social, and economic impacts together (Buchholz et al., 2007; Dale et al., 2013; Purba et al., 2009; Sheehan, 2009). Several authors have found interactions and interdependencies between the sustainability dimensions (Brose et al., 2010; Dale et al., 2013; ISO 13065 draft; Püzl et al., 2012) resulting in both synergies and conflicts between the environmental and socioeconomic impacts (Diaz-Chavez, 2014). For example, Rettenmaier and Hienz (2014) found links between the environmental and socioeconomic indicators, for instance the land use impacts on food security, ecosystem services, biodiversity, water, and soil.

However, bioenergy sustainability studies have tended to concentrate on the environmental sustainability and especially on two issues: greenhouse gas and energy balance (Buchholz et al., 2009; Cherubini and Strømman, 2011), which are necessary but not sufficient sustainability indicators because they fail to include a variety of other relevant environmental aspects. (Liao et al., 2011; Maes and Van Passel, 2014). Furthermore, Diaz-Chavez (2014) states that in the context of sustainability emphasis has been put on economic and environmental dimensions, whereas social dimensions have been less vigorously addressed, until recently. The same trend is visible in the currently applicable sustainability criteria for biofuels and bioliquids in the legislation (EU Directive 2009/28/EC (RED)) on the promotion of the use of energy from renewable sources) and standard series EN 16214 (1, 3 and 4), the criteria of which are in accordance with the RED criteria. Rettenmaier and Hienz (2014) state that the RED mandatory criteria currently concentrate exclusively on greenhouse gas and biodiversity effects, whereas criteria (on e.g. soil, water, and air protection) strongly linked to the ecosystem services would cover the social impacts better. However, new standards (such as ISO 13065) and certification schemes for bioenergy sustainability are under development creating a new potential for covering the sustainability more holistically from the steering perspective.

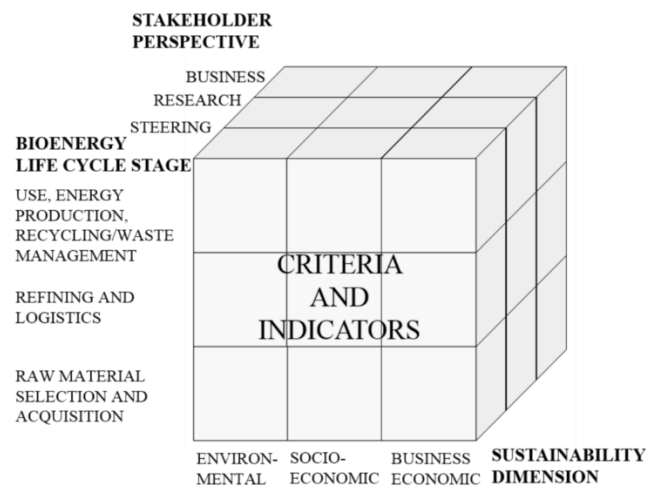
Bioenergy systems can be described as adaptive systems (Buchholz et al., 2007) where the bioenergy life cycle processes and their practical implementers, that is, bioenergy operators, constantly interact with different levels of their operational environment: business, micro-, and macro-environment (Ketola, 2005). A prerequisite for the sustainable development of bioenergy systems is that the bioenergy operators are aware of the sustainability aspects in the bioenergy life cycle stages adopting sustainability thinking and criteria in practice (Borghesi and Vercelli, 2008). In the research literature, the interface of bioenergy operators', steering, and research perspectives on the sustainability criteria and indicators of bioenergy life cycles has yet received little attention.

This paper aims to build a view of the bioenergy operators' perspective of the sustainability criteria and indicators in bioenergy systems and compare them with the current bioenergy sustainability criteria and indicators in the bioenergy legislation in the EU, international and European standards, and research literature. The operators' perspective is studied in a workshop for Finnish bioenergy experts and steering and research perspectives from the literature. Sustainability is considered holistically from the environmental, social, and economic perspectives, and the criteria and indicators are systematically categorized utilizing life cycle thinking. Workshop sustainability aspects, including criteria and indicators, are evaluated with respect to a business sustainability maturity framework. The results provide information on the extent to which bioenergy operators, steering and research currently consider different sustainability criteria and indicators with regard to life cycle stages and sustainability dimensions, on the current maturity of bioenergy sustainability thinking in Finnish bioenergy companies, and on possibilities to develop bioenergy systems towards a better state of sustainability through interactions between steering, research and bioenergy operators in the development of sustainability principles, criteria and indicators.

## 2 Theory

### 2.1 Systematic and holistic approach to sustainability

Figure 1 shows how we structured our systematic approach to sustainability. Bautista et al. (2016) have previously applied a similar multidimensional sustainability framework with different sustainability principles, criteria and indicators and sustainability dimensions to biodiesel supply chain.



**Figure 1.** Systematic approach: the perspectives to sustainability, life cycle stages and sustainability dimensions in which sustainability criteria and indicators were divided (the cube)

#### 2.1.1 The sustainability dimensions

Sustainability is considered to comprise four dimensions: environmental, social, economic, and institutional (Herva et al., 2011). As stated in the introduction, this paper focuses on the environmental, social, and economic dimension of sustainability. Pülzl et al. (2012) have concluded that although artificial and suggestive at best, the categorization of sustainability aspects according to sustainability dimensions can be a useful attempt to manage the complexity of sustainability. To enhance the systematic structuring of our data, we utilized the sustainability dimension approach in our analysis. The socioeconomic dimension was considered to include aspects related to macroeconomy and microeconomy (i.e., the economy of the external operational environment of a company), human well-being, culture, and work. Although business economic sustainability aspects (i.e., company internal economy) have traditionally not been separately discussed and may be integrated into the socioeconomic sustainability dimension, we distinguished the business economic dimension to highlight the bioenergy operators' perspective and to compare its emphasis in the workshop versus literature.

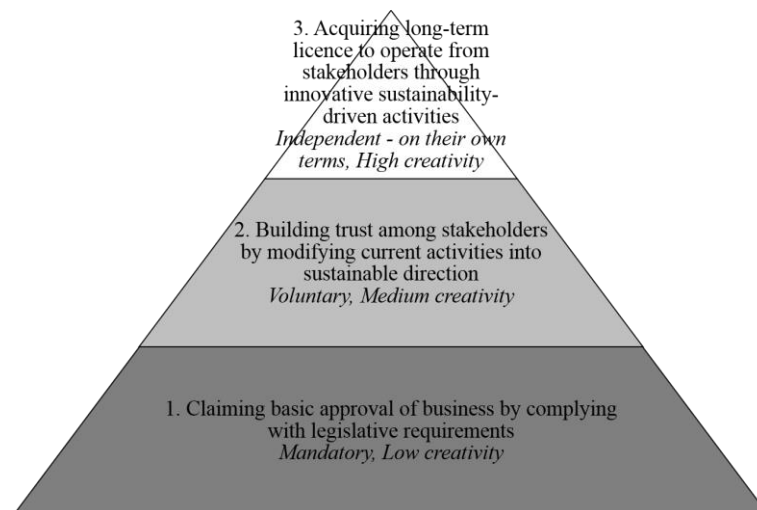
#### 2.1.2 The bioenergy life cycle stages

Life cycle approach was selected as the basis for the research because LCA is a generally accepted method for the environmental impact assessment of products (Cherubini and Strømman, 2011; ISO 14040, 2006), social impacts can be related either directly to the life cycle processes or to the supply chain and the conduct of companies performing the processes (Dale et al., 2013; Jørgensen et al., 2008), and the costs can be related to the life cycle (e.g.

Klöppfer and Ciroth, 2011). Thus, this paper relates to the life cycle-based sustainability thinking as suggested by Klöppfer (2008), Guinée et al. (2011) and Klöppfer and Grahl (2014).

### 2.1.3 The stakeholder perspective

The three different stakeholders (steering, research and business) of bioenergy systems, have fundamentally different sustainability-related objectives. Steering aims to protect human health and the environment and ensure fair and equal treatment and well-being of humans, whereas research aims to produce new knowledge about bioenergy sustainability. The difference in the time span of the steering and research is remarkable: where research produces new knowledge, steering incorporates this knowledge into, for example, legislative acts after legislative processes that could take several years (Kapanen, 2014; The Federation of Finnish Technology Industries, 2010) – thus, the risk of outdated knowledge may hinder the implementation of the protection objectives through regulation. Business operators have various objectives ranging from short to long term, however, the common objective is the continuity of business. Figure 2 is a simple depiction of business approaches to sustainability, applied from theories and ideas by (Ansoff, 1987, 1984; Fava, 2014; Heikkurinen, 2013; Heikkurinen and Ketola, 2012; Schumpeter, 2014).



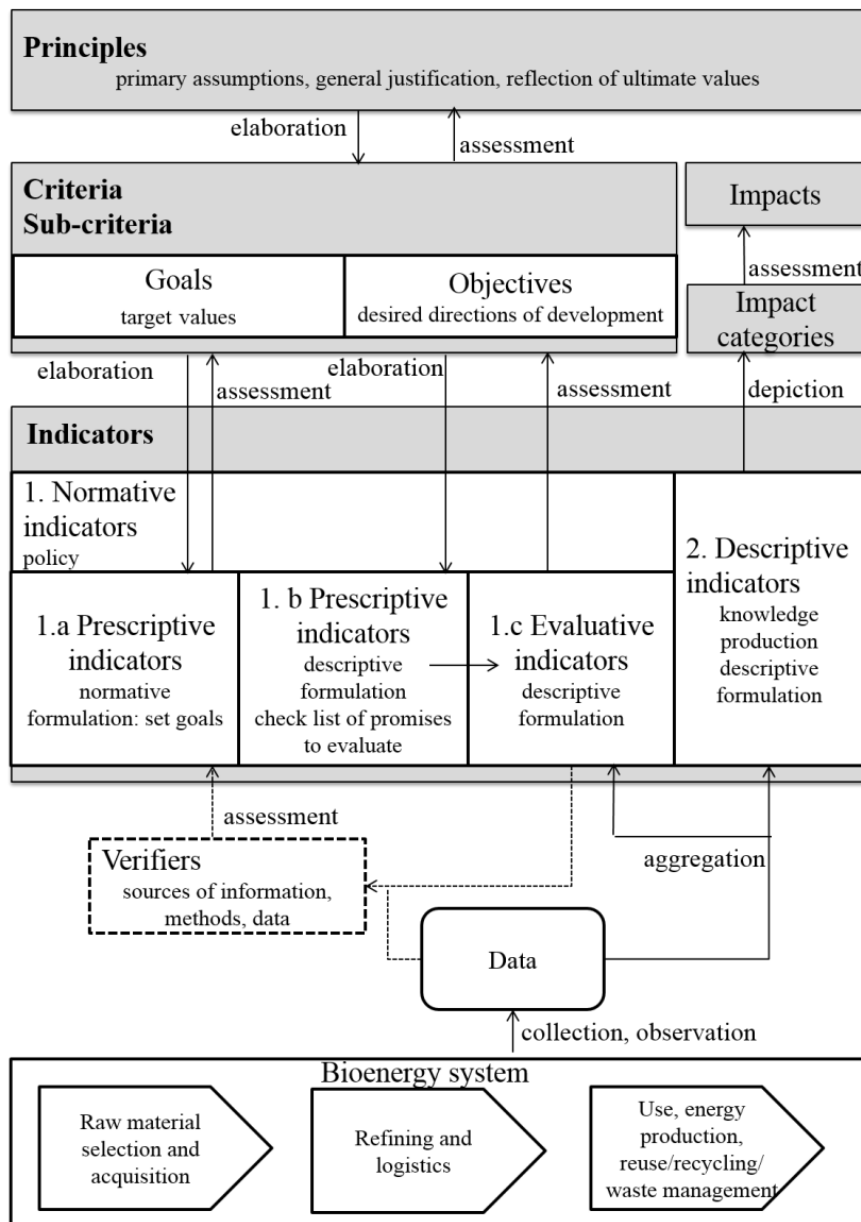
**Figure 2.** Development of the maturity of business approaches to sustainability (the triangle)

In figure 2, constant compliance with mandatory legislative requirements is the basis for building sustainable business and trust among stakeholders at level 1. The role of steering by standards and certification systems may be more significant at level 2 where the focus is on modifying operations towards a sustainable direction and building trust of among stakeholders. In the upper levels, creativity and voluntariness related to sustainability activities increase. Activities on these two upper levels, aiming to acquire long-term license to operate from stakeholders, are clearly more dependent on the novel knowledge provided by research.

### 2.1.4 Criteria and indicators

In this paper, criteria and indicators form the basis for the comparison of the bioenergy operator's perspective, bioenergy legislation, international standards, and research literature. As a general concept, sustainable development is ambiguous and vague, and therefore, indicators that provide metrics for action level are needed (Herva et al., 2011; Tibbs 1999, Johnston et al., 2007). Indicators are quantitative or qualitative indicative measures or

components, and they are used for the assessment of fulfilment of criteria, which are principles operationalized by elaborating their goals and objectives, or for the depiction of impact categories and thus assessment of impacts (Chang, 2011; Cramer et al., 2007; Heink and Kowarick, 2010). Figure 3 depicts the relation of principles, criteria, different types of indicators and related concepts. Figure 3 has been constructed based on theories and ideas by (Chang, 2011; Christen and Schmidt, 2012; Corbière-Nicollier et al., 2011; Cramer et al., 2007; Diaz-Chavez, 2014; Heink and Kowarick, 2010; Ibáñez-Forés et al., 2014; Kaario and Peltola, 2008; Mendoza and Prabhu, 2000; Rametsteiner et al., 2011; Rempel et al., 2004; SFS-EN 16214-1: 2012; SFS-EN-ISO 14040, 2006; Wu and Wu in Madu and Kuei (eds.), 2012).



**Figure 3.** Relations of principles, criteria, indicators, verifiers and data

Figure 3 incorporates practical process management, monitoring and development, knowledge production (Kaario and Peltola, 2008) and steering perspectives, thus including one or more of bioenergy operators', researchers' and policy-makers' interests. In the best case, the different actors cooperate to produce profound understanding (wisdom) of the state of sustainability and sustainable development of the specific bioenergy system. Thus, both normative and



descriptive (Heink and Kowarick, 2010) dimensions of sustainability are included in the analysis.

The steering perspective on one hand represents a normative approach through mandatory sustainability criteria and on the other, gives guidance on verification of compliance through evaluative or descriptive indicators. Figure 3 includes the depiction of knowledge production. Data is aggregated to indicators, and an indicator unit gives a meaning to the indicator, producing information, which through further interpretation transforms into knowledge and further to wisdom (Kaario and Peltola, 2008) in a larger context, for example of the role of bioenergy in sustainable energy production. Research is important, on one hand, in knowledge production bottom-up from the data, and on the other, development of criteria through the acquired knowledge. Bioenergy operators can reactively apply the given criteria in their bioenergy system processes and produce required information of their processes (as in level one of figure 2). Bioenergy operators could also actively assess impacts of their current of planned bioenergy chain operations, develop indicators, and aim to set the industry standards as well as lobbying new sustainability criteria into legislation – simultaneously striving towards a better state of sustainability (as in levels 2–3 in figure 2).

In this paper, we classify indicators with descriptive formulation as indicators and prescriptive indicators with normative formulation as criteria. Verifiers only have a rather vague definition in EN 16214-1. Thus, verifiers are not included in further analysis.

## **3 Methods**

### **3.1 Data collection**

A twofold approach was chosen for data collection to get a comprehensive view of sustainability criteria and indicators from steering, research, and business perspectives. Data on sustainability criteria and indicators were collected from literature sources and in a workshop organized for Finnish bioenergy experts.

#### **3.1.1 Literature review: steering and research perspectives**

Recent and central references (see Table 1 and Table 2) that contained lists of relevant sustainability criteria and indicators for bioenergy systems in general or parts of general bioenergy systems were selected for review. Literature concentrating exclusively on the sustainability aspects of certain biomass sources instead of bioenergy systems was excluded from the review. The aim of the literature review was to emphasize the research and steering perspectives to the sustainability of bioenergy systems.

Legislation, standards, and the certification scheme represent the steering perspective to bioenergy production. The EU legislation and European standards that are a central basis for the operations of the Finnish bioenergy operators were selected for review. The preparation of the proposal for a directive on sustainability criteria for solid and gaseous biomass has been canceled; however, the draft proposal was included in the analysis because it addresses important sustainability aspects of those biomasses, although Gamborg et al. (2014) predict that possible future sustainability criteria for solid and gaseous biomass fuels would likely be similar to the criteria of the RED. The European requirements apply to bioenergy life cycles globally. The draft international standard ISO 13065 and the standard and certification scheme by the Roundtable on Sustainable Biomaterials (RSB) represent the globally accepted approach to bioenergy sustainability. The RSB certification scheme is in accordance with the EU RED (RSB, 2013).

**Table 1.** Steering literature for review: five references

Reference	Type of reference	Title, <u>scope</u>
Directive 2009/28/EC (RED)	Legislation	Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance) <u>Scope: energy from biofuels and bioliquids irrespective of whether the raw materials were cultivated inside or outside the EU</u>
Draft proposal for a directive on sustainability criteria for solid and gaseous biomass (dropped)	Legislation	Proposal for a Directive of the European Parliament and of the Council on sustainability criteria for <u>solid and gaseous biomass used in electricity and/or heating and cooling and biomethane injected into the natural gas network</u> (Text with EEA relevance)
EN 16214-3:2012	Standard	Sustainability criteria for the <u>production of biofuels and bioliquids for energy applications</u> . Principles, criteria, indicators and verifiers. Part 3: biodiversity and environmental aspects related to nature protection purposes
ISO/DIS 13065 (draft)	Standard	Sustainability criteria for bioenergy. Scope: <u>Whole bioenergy supply chain, parts of a supply chain or a single process in the supply chain. All forms of bioenergy, irrespective of raw material, geographical location, technology or end use.</u>
RSB 2013	Certification scheme	Consolidated RSB EU RED principles & criteria for sustainable <u>biofuel production</u>

Articles published in scientific journals and other research reports represent the research perspective. Research about environmental, social, and economic sustainability criteria and indicators was reviewed equally. The research article by Buchholz et al. (2009) presents a relevance, practicality, reliability, and importance rating of central environmental, social, and economic sustainability criteria of bioenergy systems based on an international bioenergy expert survey. Due to the similarities in the approach with the workshop, the article was chosen for review. The research articles by Dale et al. (2013) and McBride et al. (2011) emphasize the practicality of sustainability indicators introducing a set of central socioeconomic sustainability indicators (Dale et al., 2013) and environmental sustainability indicators (McBride et al., 2011). Since the perspective of these two articles is similar to the objectives of the workshop (practical or business perspective and recognizing key sustainability indicators), these articles were selected for review. Although they concentrate on the costs of criteria, Smeets and Faaij (2010) select areas of concern and define sustainability criteria, and thus qualify for our review. Though the report by Cramer et al. (2007) has been initiated by the Dutch government, it is applicable in the EU area. The two articles in Rutz and Janssen (2014) were selected for review to balance the number of references related to different sustainability dimensions: they, together with Dale et al. (2013) represent the socioeconomic sustainability indicators of bioenergy, whereas McBride et al. (2011) and Cherubini and Strømman (2011) concentrate on environmental sustainability. The Global Bioenergy Partnership (GBEP) indicators have raised interest among researchers (e.g. Hayashi et al., 2014). Thus, the GBEP indicators were assumed central and selected for review.

**Table 2.** Scientific/grey literature for review: nine references

Reference	Type of reference	Title, <u>scope</u>
Buchholz et al., 2009	Research article in a scientific journal	Sustainability criteria for <u>bioenergy systems</u> : results from an expert survey
Cherubini and Strömman, 2011	Research article in a scientific journal	Life cycle assessment of <u>bioenergy systems</u> : State of the art and future challenges
Dale et al., 2013	Research article in a scientific journal	Indicators for assessing socioeconomic sustainability of <u>bioenergy systems</u> : A short list of practical measures
McBride et al., 2011	Research article in a scientific journal	Indicators to support environmental sustainability of <u>bioenergy systems</u>
Smeets and Faaij, 2010	Research article in a scientific journal	The impact of sustainability criteria on the costs and potentials of <u>bioenergy production</u> – Applied for case studies in Brazil and Ukraine
Cramer et al., 2007	Other research report	Testing framework for sustainable <u>biomass</u>
Diaz-Chavez, 2014	Other research report	Indicators for Socio-Economic Sustainability Assessment, Scope: <u>biofuel production</u>
van Eijck and Faaij, 2014	Other research report	Analysis of Socio-Economic Indicators on Different Bioenergy Case Studies, Scope: <u>bioenergy chains with different geographical locations, feedstock sources, conversion technologies and products</u>
GBEP, 2011	Other research report	The Global Bioenergy Partnership sustainability indicators for <u>bioenergy</u>

### 3.1.2 Workshop: bioenergy operators' perspective

Bioenergy sustainability aspects were collected in a one-day workshop, which was organized in Finland in November 2013. Previous research has shown that the use or understanding of indicators has not been consistent in research literature (see for example Heink and Kowarick, 2010). Thus, to avoid confusion among the participants due to these definitional issues, the workshop concentrated on collecting any sustainability aspects which were categorized later in detail. The workshop emphasized the business perspective to the sustainability of bioenergy systems and aimed at giving profound insights on the sustainability aspects through group discussions. In total, 28 Finnish bioenergy and/or sustainability experts representing 17 different organizations participated. Eight researchers from two research organizations were steering the work while the remaining 20 people (seven researchers, 11 company representatives, and two research program managers) from 15 organizations produced the data.

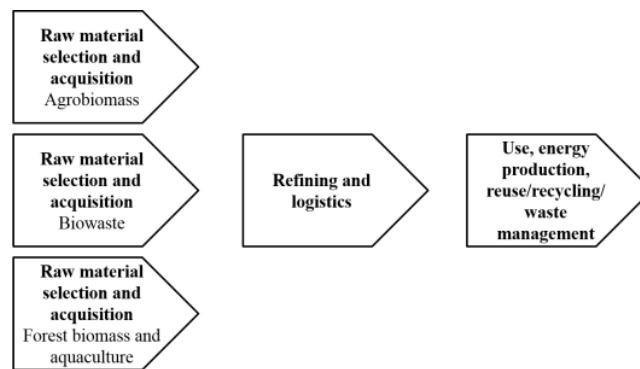
In literature, bioenergy operators are further classified: RSB (2013) divides operators in the biofuel chain into feedstock producers, feedstock processors, biofuel producers, and biofuel blenders, whereas Dale et al. (2013) mention growers and suppliers as the major actors in the feedstock production stage, biorefineries in the conversion stage, and fuel users in the end-user stage of biofuels. Following the preceding examples of biofuel chain operator categorizations, Table 3 presents the categorization of the workshop participants. Biofuel producers, technology providers, and bioenergy producers (seven companies) in the workshop were large enterprises not defined as micro, small or medium-sized enterprises according to the EU Commission recommendation C(2003) 1422.

**Table 3.** Categorization of workshop participants

Participant organization	End-product	Number of participant organizations (number of people)
Research organization	Research/scientific knowledge (related to bioenergy systems)	8 (15)
Biofuel producer	Biofuel	3 (3)
Technology provider	Technology and related services, such as maintenance and design	1 (1)
Bioenergy producer	Biomass-based energy, e.g. heating, cooling, electricity	3 (7)
Other		2 (2)
<b>Total</b>		<b>17 (28)</b>

In the workshop, participants were divided into five working groups, which consisted of both researchers and different types of bioenergy operators. Each working group considered the environmental, social, and economic sustainability aspects of one stage of the bioenergy life cycle (see Fig. 4) at a time. The standard EN 16214-4 gives an example of a generic biofuel production chain that was used as a basis for the selection of three life cycle stages.

The raw material selection and acquisition stage was further divided into three alternative phases according to the biomass resource. Agrobiomass, biowaste, forest biomass, and aquaculture were included because these biomass categories are common in bioenergy production. Since the use of biomass from aquaculture for energy production is yet marginal, aquaculture was grouped together with forest biomass. Definitions of RED 2009/28/EC and EN 16214-1 are applicable for all these biomasses. The bioenergy system is considered to include all conversion routes and technologies, biofuel products, energy production technologies, and end uses (heating/cooling, electricity, and transportation).



**Figure 4.** The bioenergy system life cycle stages considered in the workshop.

### 3.2 Data analysis

#### 3.2.1 Categorization of literature and workshop data for the production of quantitative results (the cube)

Literature data were categorized into three life cycle stages and three sustainability dimensions. Table 4 and Table 5 show what information on the categorization of sustainability criteria and indicators into life cycle stages and sustainability dimensions (literature used a division to environmental, social, economic, and socioeconomic dimensions) the literature sources provided and could be utilized in further categorization. Furthermore, the tables show that the

categorization of bioenergy sustainability criteria and indicators into life cycle stages or sustainability dimensions (most often optionally) is a common practice.

**Table 4.** Categorization of sustainability criteria and indicators in the steering literature sources according to life cycle stages and sustainability dimensions

<b>Reference</b>	<b>Type of reference</b>	<b>Criteria and indicators categorized according to life cycle stages</b>	<b>Criteria and indicators categorized according to sustainability dimensions</b>
Directive 2009/28/EC (RED)	Legislation	Yes (Could unambiguously be interpreted from the data)	No
Draft proposal for a directive on sustainability criteria for solid and gaseous biomass (dropped)	Legislation	Yes (Could unambiguously be interpreted from the data)	No
SFS-EN 16214-3: 2012	Standard	No (Could partly be interpreted from the data)	Yes
ISO/DIS 13065 (draft)	Standard	No	Yes
RSB 2013	Certification scheme	No (Could be interpreted from scope: biofuel production = raw material selection and acquisition + refining and logistics)	No

**Table 5.** Categorization of sustainability criteria and indicators in the research literature sources according to life cycle stages and sustainability dimensions

Reference	Type of reference	Criteria and indicators categorized according to life cycle stages	Criteria and indicators categorized according to sustainability dimensions
Buchholz et al., 2009	Research article in a scientific journal	No	Yes
Cherubini and Strømman, 2011	Research article in a scientific journal	Yes (Scope = the whole life cycle: all issues in all life cycle stages)	Yes
Dale et al., 2013	Research article in a scientific journal	No	Yes
McBride et al., 2011	Research article in a scientific journal	No	Yes
Smeets and Faaij, 2010	Research article in a scientific journal	Yes (Scope = one life cycle stage)	No
Cramer et al., 2007	Other research report	Yes	No (Could partly be interpreted from the data)
Diaz-Chavez, 2014	Other research report	No (Could be interpreted from scope: biofuel production = raw material selection and acquisition + refining and logistics)	Yes
van Eijck and Faaij, 2014	Other research report	No (Could partly be interpreted from the data)	Yes
GBEP, 2011	Other research report	No (Could partly be interpreted from the data)	Yes

The workshop produced 25 data sets (five sets per life cycle stage) on the sustainability aspects. These data sets were combined into one data set per life cycle stage; duplicate data was removed, and the data was translated from Finnish into English. Thereafter, all data were combined into one table and classified into three life cycle stages regarding the information at which life cycle stage each datum was collected in the workshop. However, the categorization of data based solely on this information would have been insufficient since many data related to more than one life cycle stage or were misplaced in the original data set. Thus, three researchers who were familiar with the data expressed their views on which life cycle stage each datum would directly relate to. Accordingly, a common categorization was established: when two or more researchers (the majority) agreed on a direct link between a datum and a life cycle stage, the link was considered relevant. Similar categorization was done for the literature data to complement the categorization provided by the literature sources. Respectively, both workshop and literature data on the sustainability criteria and indicators were categorized into three dimensions of sustainability: environmental, socioeconomic, and business economic.

The workshop data was further categorized into criteria, indicators and other categories that table 6 shows. The division of sustainability aspects into principles, criteria, indicators, indicator units and verifiers was based on the indicator theory explained in Section 2.1.4. Workshop data included data that were categorized as impacts that need to be indicated, decision-making questions that, for example, included multi-(sustainability) criteria process-optimization problems or assessment of alternatives, in which case a sustainability impact assessment may be necessary, and observations – a broad range of different notions of bioenergy in general or certain bioenergy processes, for example sustainability challenges and

opportunities. The formulation of each category indicates differences between the categories. Furthermore, table 6 shows the presence of respective categories in literature. For comparability of the results from different sources, only sustainability aspects that were defined as criteria or indicators, were taken into account in the calculations, and thus, production of the quantitative results. In quantitative results, criteria and indicators were not further separated.

**Table 6.** Categorization of sustainability aspects from workshop, steering literature and research literature

Category of sustainability aspect	Number of sustainability aspects		Formulation
	Workshop	Literature	
Principles	8	62	Normative
Criteria	83	161	Normative
Indicators	162	74	Descriptive
Indicator units	1	61	SI unit
Verifiers	N/A	42	Descriptive
Impacts to be indicated	29	N/A	Descriptive
Decision-making questions, options	31	N/A	Descriptive/interrogatory
Observations	96	N/A	Descriptive/normative/interrogatory

### 3.2.2 Production of qualitative results based on business approaches (the triangle)

In qualitative comparison of data from different sources, sustainability aspects of different categories (principles, criteria, indicators etc., see table 6) were studied more broadly than in quantitative analysis, with focus on content. Most importantly, principles, criteria and indicators in workshop and literature data were compared. Additionally, impacts to be indicated from workshop data were included in the comparison because of their close relation to criteria and indicators. Decision-making questions and observations from workshop data were utilized in the comparison as sources of additional information on bioenergy operators' awareness of different sustainability themes. Indicator units and verifiers were not considered in the comparison due to their absence in workshop data.

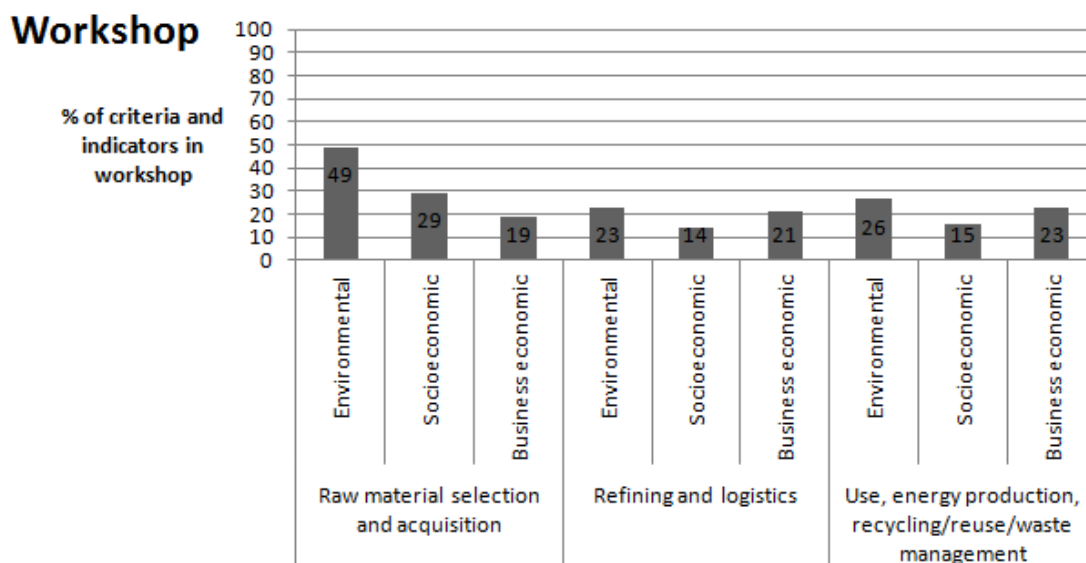
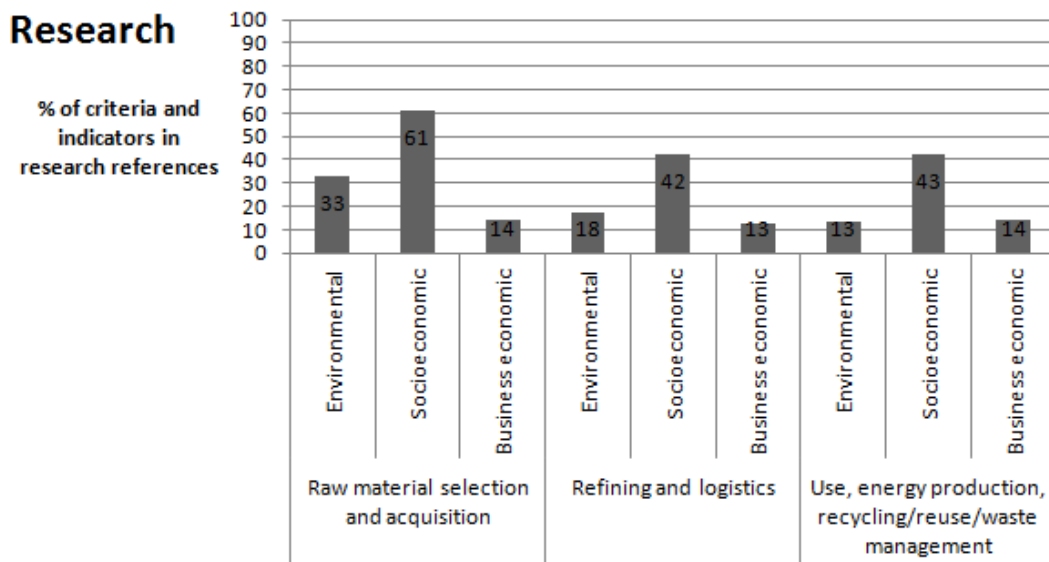
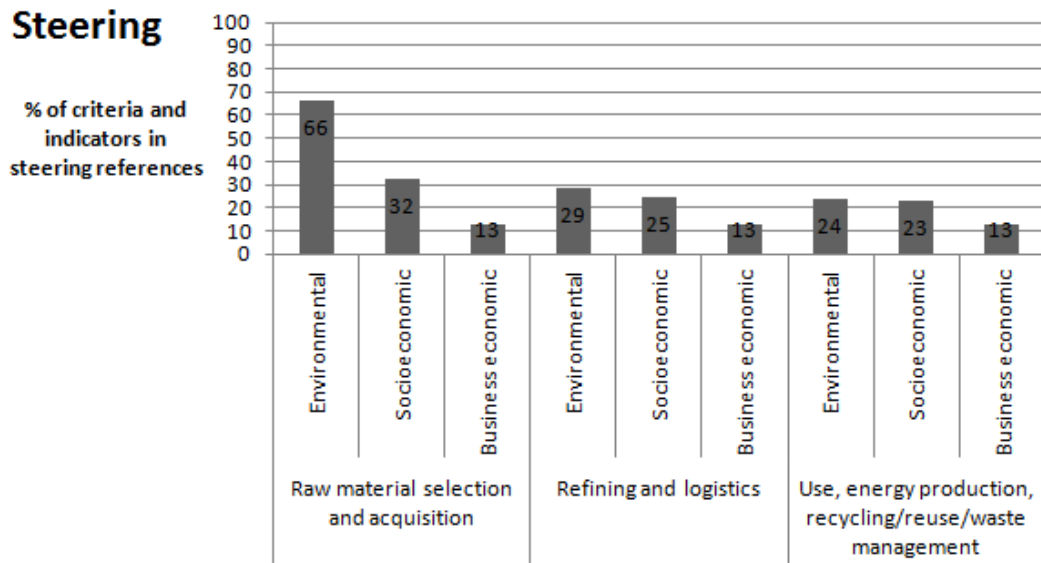
The aims of the qualitative analysis were to compare the coverage of sustainability themes from steering, research and business operators' perspectives and to evaluate what sustainability maturity levels (figure 2) bioenergy business operators can reach through compliance with criteria and utilization of indicators from different stakeholders related to different sustainability themes. Sustainability principles, criteria and indicators from steering and research literature were grouped theme-by-theme, and thereafter, the sustainability aspects expressed by bioenergy operators (those discussed in the workshop) were located in the groups based on whether they were at the level of legislative steering, current standards, the future standard (ISO 13065), certification or research literature content-wise. The initial assumption was, based on the hypothesis on in Section 2.1.3, that principles, criteria and indicators in legislative steering would belong to level 1 of sustainability maturity (mandatory activities), in standards and certification systems to level 2 (voluntary development to sustainable direction and building trust among stakeholders) and in research literature to level 3 (active, creative sustainability-driven activities and acquiring long-term licence to operate).



## **4 Results and discussion**

### **4.1 Quantitative results: aspects of different stakeholders in different dimensions of sustainability and life cycle stages (the cube)**

Figure 5 shows how the sustainability criteria and indicators of different stakeholders are divided into three different sustainability dimensions in three different life cycle stages. Some criteria and indicators directly link to more than one life cycle stage and more than one sustainability dimension. For example, in the steering literature, 19% of sustainability aspects were divided to more than one sustainability dimension, and respectively in the research literature 18% and in the workshop 34%. This multiplicity explains percentages over 100.



**Figure 5.** Sustainability criteria and indicators of different stakeholders (workshop represents business perspective) directly linked to different sustainability dimensions in different life cycle stages

The results show that the steering literature mainly concentrates on environmental sustainability, whereas socioeconomic sustainability is highlighted over other sustainability aspects in every life cycle stage in the research literature. The selection of the research literature sources for review and a small number of references, however, affects the distribution of the sustainability aspects between sustainability dimensions, and does not provide an all-encompassing picture of the research situation. As stated in the introduction, bioenergy sustainability research by far has had the tendency to focus on greenhouse gas emissions and energy balance – both issues generally perceived as environmental. Finnish bioenergy business seems to have adopted thinking that is closer to the steering literature than the research literature. The main differences between the steering literature and the workshop material are that steering literature concentrates more on environmental sustainability (especially in the first life cycle stage) while business economic sustainability has more importance in the workshop material in every life cycle stage. The business operators' focus on the feasibility of business might explain this variation. In all cases, the majority of the sustainability aspects can be directly linked to the raw material selection and acquisition.

In the steering literature 60% of the criteria and indicators directly linked to the environmental sustainability dimension, 29% to the socioeconomic dimension and 11% to the business economic dimension. The respective percentages were 30%, 57% and 13% for research literature and 46%, 25% and 29% for the workshop. Bautista et al. (2016) studied 103 documents that included certification and initiatives of sustainability criteria of biofuels, biofuel standards and policies, research papers and biofuel testing frameworks and scorecards. They concluded that 43% of the documents related to the environmental, 29% to the social and 16% to the economic sustainability dimension (Bautista et al., 2016). Our workshop results are most in line with these previous results, especially the raw material selection and acquisition stage, though the slight differences in the division of socioeconomic and business economic dimension. This study does not and could not suggest, whether the percentages should be equal, however, research might have some more socioeconomic issues to add to the steering and bioenergy operators' perspective.

#### **4.2 Qualitative results: principles, criteria, indicators and other aspects at different levels of business sustainability maturity (the triangle)**

The literature highlighted legality and compliance with legislation as a separate sustainability theme. Respectively, business operators have to follow steering literature to comply with the legislative sustainability criteria and optimize the bioenergy chain within the boundaries set by legislation. The requirement of compliance may explain the similar profiles of steering literature and workshop material in the previous section. According to the workshop discussions, bioenergy operators can choose their level of effort with regard to legislative sustainability requirements: for example, whether it is beneficial to be notably under maximum emission limits or to achieve minimum compliance.

Currently, sustainable development of bioenergy systems largely depends on the active striving of bioenergy operators towards sustainability through creative, voluntary actions, because the influence of legislative requirements is so far quite sub-optimal due to limited sustainability themes of legislation (greenhouse gas emissions, carbon balance, peatland drainage, biodiversity and farmers), limited coverage of bioenergy life cycle (mainly raw material cultivation) and restricted scope (biofuels and bioliquids). Solid and gaseous biomass based fuels are unregulated by sustainability legislation. Given the interest of research towards

biodiversity, it seems a rising issue of concern in more extent. Furthermore, steering might focus more on socioeconomic aspects in the future as highlighted by research and via steering, business operators will apply socioeconomic aspects.

Our analysis of legislative requirements that affect bioenergy operations is narrow and concentrates on bioenergy sustainability criteria. A large variety of legislative acts, for example, local laws set very specific requirements for each operator, such as environmental permits (cf. Environmental Protection Act 527/2014 in Finland). Internationally harmonized sustainability criteria are few, though, and thus, the role of local steering is emphasized. At some locations, sustainable actions may depend on the business operators' ethics and voluntary activity.

As legislative steering forms the basis of acceptable business, as in level 1 of the sustainability maturity triangle (figure 2), standards and certification systems significantly broaden the scope of bioenergy steering systems with regard to sustainability themes. Demonstrating compliance with the criteria of standards and certification systems through utilization of their indicators is not mandatory from legal perspective, and thus the level of voluntariness and creativity is higher for those companies that add standards and certification systems to their compliance list in comparison to those companies merely striving to legislative compliance. Bioenergy operators stated that compliance with the sustainability criteria in standards and certification systems could be important tools for bioenergy operators to gain further long-term acceptance from customers and other stakeholders.

Although the workshop discussion was not at a detailed level, it covered the sustainability themes of the literature. Thus, the workshop participants were well aware of the literature that we selected for review, or the themes are currently generally discussed regarding bioenergy. Furthermore, the workshop highlighted some themes that were not present in the steering or research literature, and may, thus, best represent the bioenergy operators' own perspective to sustainability. Inclusion of these themes, addressed more in-depth in the following chapters, into holistic bioenergy sustainability assessments in research could be important.

Resource efficiency and related sub-topics, such as nutrient balance, fertilizer use, and optimization of raw material use, were discussed in the workshop, not in literature. A focus of discussions on the sustainability of energy from biowaste might have contributed to this emphasis. Furthermore, resource efficiency is currently at high level on the EU environmental policy agenda (European Commission, 2015). According to Schumpeter (2014), aiming at reduced costs through resource efficiency measures is a traditional business approach to sustainability.

Bioenergy operators pondered the advantages of or value added through bioenergy in comparison to other energy production options to justify bioenergy production. They highlighted opportunities of emission savings to air, soil and water. Furthermore, they found optimization of bioenergy production important, therefore emphasizing operational aspects more than the literature: reliability of operation that includes at least criteria on uninterrupted biomass/fuel supply to the power plant, raw material and fuel quality influenced by transportation, storage and terminal conditions, choices related to the scale of production, for example centralized vs decentralized bioenergy production guided by economy of scale, and alternative energy production technologies. The criterion on reliable and secure, good-quality raw material sources may at least partly originate from the traceability requirement of the RED. Indicators of infrastructure and logistics capacity were discussed in research literature, not at

the steering level. However, bioenergy operators were equally able to find challenges and criticism related to bioenergy production, such as the impacts of subsidies on the true sustainability of bioenergy. According to Sala et al. (2013), the sustainability assessments currently tend to concentrate on avoiding negative impacts, whereas enhancing positive impacts is a rising trend. Whether bioenergy operators perceive sustainability aspects as challenges or opportunities and whether these two mindsets enhance or decrease creativity on sustainability activities, could be an interesting topic for further research, for example utilizing the SWOT analysis.

Resources relevant for bioenergy production – land, water and employees – seemed to include different sustainability maturity perspectives. Research and the workshop discussions included indicators on land-use change, which further leads to questions on land rights and land availability. Land rights are a legislative issue related to property rights as well as human rights, whereas land availability is a value for the local community. ISO 13056 and the RSB (2013) certification as well as research include criteria and indicators on land rights, whereas land availability indicators are discussed exclusively in research literature, and are at a higher level in the triangle. The same applies to water quality and quantity, water rights and water availability. Water rights are discussed in RSB (2013) and ISO 13065, whereas research, GBEP (2011), discusses the availability. In land and water availability issues, research leads the sustainability thinking, and bioenergy operators have adopted the availability idea. However, regardless of bioenergy, the water footprint standard ISO 14046 will probably contribute to the water availability thinking. Labour rights are, again, more legislative issues, included in the ISO 13065, whereas working conditions could be improved limitlessly, thus, improving the well-being of employees and creating value to them. The working conditions and added value to employees were discussed mainly in research (not steering), and seem to be of great interest to the bioenergy operators. The division presented in this chapter is somewhat analogous to what Schumpeter (2014) has suggested about two business approaches to sustainability: the traditional approach focused on efficiency improvements and the new approach based on value creation to various stakeholders.

Further sustainability criteria and indicators that were not discussed in steering literature, and are driven by research or bioenergy operators, were included in themes that are of significance to the well-being of local communities. Research literature included indicators and few criteria on contribution to local or regional economy, macroeconomic sustainability, employment and energy security. Business operators touched these themes and added new ideas of characteristics of the market area and their influence business economic sustainability: demand of green electricity, market for and competitiveness of the end-product, and competitive price of the end-product for consumers. Food security, however, was included both in the certification system RSB (2013) that presented two principles and criteria for food security and in research, which mainly included indicators and few criteria.

Another theme of value to local communities discussed merely by Buchholz et al. (2009) and bioenergy operators was local environmental quality and attractiveness related to visual impacts and noise. Bioenergy operators added odour impacts to the discussion – both as an important indicator of public acceptance of bioenergy operations and as an indicator of process functionality. Environmental quality aspects, such as soil and water quality seemed to be, measured by the number of indicators and criteria related to these themes in literature, important, possibly rising sustainability themes together with biodiversity that was discussed above. Bioenergy operators recognized soil quality indicators, such as erosion, carbon balance and loss of nutrients, as well as sufficiency and quality of water resources. Although the EU

has extensive product-related chemical legislation (for example the REACH regulation (EC) No 1907/2006 and CLP regulation (EC) No 1272/2008), health hazards caused by chemical pollution were not found from steering literature concerning sustainability of bioenergy processes. The chemical regulations, however, apply to the end-products, such as biofuels. In our data set, three researchers, Buchholz et al. (2009), Cherubini and Strømman (2011) and Smeets and Faaij (2010), addressed chemical pollution, as did bioenergy operators. Literature discussed responsible use of chemicals, pesticides, insecticides and herbicides, toxicity through heavy metals and carcinogens (Buchholz et al., 2009; Cherubini and Strømman, 2011). Bioenergy operators add to the list emissions of drug residues and germs, especially in the energy from biowaste chain.

Our results suggest that gaining acceptance from stakeholders is essential for business operators, analogously to the triangle (figure 2) thinking in Section 2.1.3. Similarly, Dale et al. (2013) consider social acceptability as a major social sustainability category. As we suggested above, the prerequisite for acceptability is compliance with legislation. However, acceptability is a complex concept, which according to our workshop discussions, further requires ethical business, commitment of local community, and open communications between the business operator and different stakeholders. The findings of Dale et al. (2013) support this observation.

The concept of acceptability comprises different stakeholders' subjective and possibly value-based perspectives to sustainability and views of which sustainability aspects are relevant. This advances context-specific and local sustainability thinking. Buchholz et al. (2007) and Sala et al. (2013) have suggested a participatory approach in decision-making to create solutions for multiobjective sustainability questions. Thus, bioenergy operators developing the sustainability of their business or creating new sustainable bioenergy solutions could benefit from application of acceptability thinking and the sustainability maturity approach, which have similarities. Levels 2 and 3 require certain freedom for companies to offer their sustainable solutions, unrestricted by legislation and steered by stakeholder acceptance or abandonment. Whether or not this freedom without expanding legislative requirements is beneficial for sustainable development of bioenergy systems, depends on the willingness and ability of the bioenergy operators to voluntarily, creatively and broadly approach the sustainability challenges and opportunities. The difficulty with giving mandatory requirements for sustainability themes currently at higher levels of the sustainability maturity triangle, based on for example answering different stakeholders' value-based needs such as attractive environment, may be the formulation of clearly quantifiable or otherwise demonstrable indicators.

In summary, we found that content-wise the division of standards and certification systems and research into the two more creative levels 2 and 3 is not as unambiguous as first presented in Section 2.1.3 and assumed in Section 2.3.2. All the three data sources include criteria and indicators on the basic legislative level and on more creative levels. Distinguishing levels 2 and 3 is neither unambiguous. It must be noted that the triangle generalizes business approaches, although its justification lies in numerous previous research efforts. Using the maturity approach to understand the relationship, differences and interactions between research, steering and bioenergy operators could, however, be useful in the modelling and in the sustainability assessment of adaptive bioenergy systems, as defined by Buchholz et al. (2007).

### **4.3 Sensitivity analysis**

In quantitative analysis, we based the comparability of the three different data sources on sustainability criteria and indicators. Differences in the definitions of criteria and indicators

and understanding of their mutual relation in different sources, however, add uncertainty to our results. Steering and research literature could divide data to principles, criteria and indicators differently. In the workshop data, information on correlative and causal relationships, through which the indicators indicate (Heink and Kowarick, 2010), was missing. Thus, more information about the context would have been necessary to unambiguously identify indicators in the data.

Requirements in the legislation and standards impact the implementation of bioenergy processes, and thus, affect the perspective of bioenergy operators on the most important sustainability questions and vice versa: company views impact the legislation. Thus the question arises whether the bioenergy business operators' perspective can be distinguished from the steering or research perspectives, and which part of the workshop data represents solely bioenergy operators' view, is somewhat uncertain. The aim of the workshop, however, was to concentrate on the bioenergy operators' perspective to sustainability, and thus, the participation of the researchers in the workshop was not considered problematic with regard to the emphasis of the results. Furthermore, a strict division of people into company representatives and researchers is hardly possible due to for example different job descriptions, work experiences, personal interests, and personalities. The atmosphere of open discussion in the workshop aimed at releasing participants from their company or research organization representative roles while bringing participants' best expertise into use. Uncertainty about the perspective from which workshop participants expressed their views is however inevitable.

In a workshop, group dynamics evidently affect the outcome (cf. Bell and Morse, 2013), although all participants were given the opportunity to express their opinions before common discussion on the ideas. On one hand, the researchers introducing the workshop and steering the work might have influenced the themes under discussion for instance by prompting discussion on their own areas of interest. On the other hand, proper steering helps participants to concentrate on the topic and produce more relevant results. Slight differences between the results of different life cycle stages may occur due to the conduct of workshop steering.

Our research was lacking grounds for assessing and comparing the relative importance of different sustainability criteria and indicators due to possible bias originating from the selection of themes for discussion in the workshop, removal of duplicates from the workshop data, and different approaches in literature sources. The weighting of environmental sustainability themes is, however, assessed in other literature sources: cf. Buchholz et al. (2009) and Cherubini and Strømman (2011).

## 5 Conclusions

Including whole life cycles and multiple, interlinked dimensions of sustainability is essential in studying and assessing the sustainability of bioenergy systems. Using a systematic approach, we recognized various sustainability criteria and indicators in all dimensions of sustainability, in all bioenergy life cycle stages from steering, research and Finnish bioenergy operators' perspective. Finnish large bioenergy business operators are aware of different sustainability aspects and are able to divide the sustainability aspects to different life cycle stages. This mindset would enable them to operate at the more mature business sustainability levels provided that they have the resources and a systematic strategy.

The business operators and steering literature have similar distribution of sustainability criteria and indicators in bioenergy life cycle stages and sustainability dimensions. Bioenergy operators and steering literature emphasize especially environmental sustainability, and bioenergy operators emphasize business economic sustainability criteria and indicators slightly more than the steering and research literature. Legislative bioenergy sustainability criteria and indicators currently lack the power to influence the holistically sustainable development of bioenergy systems, and thus, the role of creating new research knowledge and voluntary activity of bioenergy operators in advancing sustainability is significant. To achieve greater sustainability maturity, bioenergy operators need to be aware of possible reactive reliance on legislative sustainability criteria development, if reactive reliance is what the similar distributions of sustainability criteria and indicators suggest, and aim for more creative and more broadly stakeholder-inclusive sustainability approaches.

The acceptability concept was present as an important theme through the whole data set and the business sustainability maturity approach. Acceptability covered major, partly overlapping sustainability themes, such as legislative compliance, justification of bioenergy, human, labour and property rights, resource availability, local environmental quality and attractiveness, biodiversity and productivity, economic development, and human health and well-being. Consequently, we suggest that acceptability could be raised as a sustainability principle of bioenergy systems and begin the development of respective criteria and indicators from that starting point. The acceptability principle could provide bioenergy operators a meaningful way of identifying the role of sustainability criteria and indicators from steering and research sources in advancing their business sustainability maturity. The acceptability and sustainability maturity approach could also be applicable for large, and possibly also smaller, bioenergy operators globally and to other fields of industry.

### **Acknowledgements**

This work was carried out in the Sustainable Bioenergy Solutions for Tomorrow (BEST) research program coordinated by FIBIC Ltd. and CLEEN Ltd. with funding from the Finnish Funding Agency for Innovation, Tekes. The corresponding author would like to thank the staff of the Energy Biosciences Institute at the University of California, Berkeley for encouragement during the writing process. The authors wish to acknowledge D.Sc. (Tech.) Mika Luoranen from Lappeenranta University of Technology for participation in the data collection. In addition, the authors would like to thank M.Sc. (Tech.), M.A. Sari Silventoinen for language advice and two anonymous reviewers for valuable comments.



## References

Ansoff I. 1984. *Implanting Strategic Management*. USA: Prentice/Hall International. 510 p. ISBN 0-13-451808-X.

Ansoff I. 1987. *Corporate strategy*. Revised edition. UK: Penguin Books. 284 p. ISBN 0-14-009112-2.

Bautista S, Narvaeza P, Camargob M, Cheryb O, Morel L. 2016. Biodiesel-TBL+: A new hierarchical sustainability assessment framework of PC&I for biodiesel production – Part I. *Ecol Indic* 60: 84–107. DOI: 10.1016/j.ecolind.2015.06.020

Bell S, Morse S. 2013. Towards an understanding of how policy making groups use indicators. *Ecol Indic* 35: 13–23. DOI: 10.1016/j.ecolind.2012.12.023

Borghesi S, Vercelli A. 2008. *Global Sustainability: Social and Environmental Conditions*. USA: Palgrave Macmillan. 272 p. ISBN 978-0-230-54696-7.

Brose I, Van Stappen F, Castiaux A. 2010. Articulation of environmental and socio-economic externalities from bioenergy. *Manag Environ Qual: Int J* 21: 812–829. DOI: 10.1108/14777831011077664

Buchholz TS, Volk TA, Luzadis VA. 2007. A participatory systems approach to modeling social, economic, and ecological components of bioenergy. *Energy Policy* 35: 6084–6094. DOI:10.1016/j.enpol.2007.08.020

Buchholz T, Luzadis VA, Volk TA. 2009. Sustainability criteria for bioenergy systems: results from an expert survey. *J Clean Prod* 17: S86–S98. DOI:10.1016/j.jclepro.2009.04.015

Chang N. 2011. *Systems Analysis for Sustainable Engineering: Theory and Applications* [e-book]. McGraw-Hill. 688 p. ISBN 978-0-07-163006-1.

Cherubini F, Strømman AH. 2011. Life cycle assessment of bioenergy systems: State of the art and future challenges. *Bioresour Technol* 102: 437–451. DOI:10.1016/j.biortech.2010.08.010

Christen M, Schmidt S. 2012. A Formal Framework for Conceptions of Sustainability – a Theoretical Contribution to the Discourse in Sustainable Development. *Sustain Dev Development* 20: 400–410. DOI: 10.1002/sd.518

Corbière-Nicollier T, Blanc I, Erkman S. 2011. Towards a global criteria based framework for the sustainability assessment of bioethanol supply chains – Application to the Swiss di-lemma: Is local produced bioethanol more sustainable than bioethanol imported from Brazil? *Ecol Indic* 11: 1447–1458. DOI: 10.1016/j.ecolind.2011.03.018

Cramer J, Wissema E, de Bruijne M, Lammers E, Dijk Daan, Jager H, van Bennekom S, Breunese E, Horster R, van Leenders C, Wonink S, Wolters W, Kip H, Stam H, Faaij A, Kwant K. 2007. Testing framework for sustainable biomass Final report from the project group “Sustainable production of biomass” [e-document]. [Retrieved January 16, 2014]. 60 p. From: [http://www.lowcvp.org.uk/assets/reports/070427-Cramer-FinalReport\\_EN.pdf](http://www.lowcvp.org.uk/assets/reports/070427-Cramer-FinalReport_EN.pdf)

C(2003) 1422. Commission recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises (notified under document number C(2003) 1422) (Text with EEA relevance).

Dale VH, Efroymsen R, Kline KL, Langholtz MH, Leiby PN, Oladosu GA, Davis MR, Downing ME, Hilliard MR. 2013. Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. *Ecol Indic* 26: 87–102. DOI:10.1016/j.ecolind.2012.10.014

Diaz-Chavez R. 2014. Chapter 2. Indicators for socio-economic sustainability assessment. In: Rutz D, Janssen R (eds.) *Socio-Economic Impacts of Bioenergy Production*: pp. 17-37. Springer.

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance) (aka RES Directive aka RED)

Draft Proposal for a Directive of the European Parliament and of the Council on sustainability criteria for solid and gaseous biomass used in electricity and/or heating and cooling and biomethane injected into the natural gas network (Text with EEA relevance) From: <http://www.endseurope.com/docs/130819a.pdf>

van Eijck J, Faaij APC. 2014. Chapter 16. Analysis of Socio-Economic Indicators on Different Bioenergy Case Studies. In: Rutz D, Janssen R (eds.) *Socio-Economic Impacts of Bioenergy Production*: pp. 267-284. Springer.

Environmental Protection Act 27.6.2014/527

European Commission. 2015. The Roadmap to a Resource Efficient Europe [web page]. Updated 27 August 2015. [Retrieved 17 September 2015]. From: [http://ec.europa.eu/environment/resource\\_efficiency/about/roadmap/index\\_en.htm](http://ec.europa.eu/environment/resource_efficiency/about/roadmap/index_en.htm)

FAO. 2008. The state of food and agriculture—Biofuels: prospects, risks and opportunities [e-document]. [Retrieved April 16, 2014]. 128 p. ISSN 0081-4539. From: <ftp://ftp.fao.org/docrep/fao/011/i0100e/i0100e.pdf>

Fava J. 2014. The sustainability maturity curve [web page]. Updated 6 November 2014. [Retrieved 20 May 2015]. Thinkstep. From: <http://www.thinkstep.com/blog/blog-sustainability-maturity-curve>

Gamborg, C., Anker, H.T., Sandøe, P. 2014. Ethical and legal challenges in bioenergy governance: Coping with value disagreement and regulatory complexity. *Energy Policy* 69: 326–333. DOI: 10.1016/j.enpol.2014.02.013

GBEP. 2011. The Global Bioenergy Partnership sustainability indicators for bioenergy, first edition. [Retrieved November 16, 2013]. 211 p. From: [http://www.cleanenergyministerial.org/Portals/2/pdfs/The\\_GBEP\\_Sustainability\\_Indicators\\_f or\\_Bioenergy\\_FINAL.pdf](http://www.cleanenergyministerial.org/Portals/2/pdfs/The_GBEP_Sustainability_Indicators_f or_Bioenergy_FINAL.pdf)

Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman MC, Shyamsundar P, Steffen W, Glaser G, Kanie N, Noble I. 2013. Sustainable development goals for people and planet. *Nature* 495: 305–307. DOI: 10.1038/495305a

Guinée JB, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonamici R, Ekvall T, Rydberg T. 2011. Life cycle assessment: past, present and future. *Environ Sci Technol* 45: 90–96. DOI: 10.1021/es101316v

Hayashi T, van Ierland EC, Zhu X. 2014. A holistic sustainability assessment tool for bioenergy using the Global Bioenergy Partnership (GBEP) sustainability indicators. *Biomass Bioenergy* 66: 70–80. DOI:10.1016/j.biombioe.2014.01.040

Heijungs R, de Koning A, Guinée JB. 2014. Maximizing affluence within the planetary boundaries. *Int J LCA* 19: 1331–1335. DOI: 10.1007/s11367-014-0729-y

Heikkurinen P. 2013. Reframing strategic corporate responsibility: From economic instrumentalism and stakeholder thinking to awareness and sustainable development. Doctoral dissertation. Aalto University, School of Business, Department of Management and International Business. Helsinki, Finland. 173 p.

Heikkurinen P, Ketola T. 2012. Corporate responsibility and identity: from a stakeholder to an awareness approach. *Bus Strategy Environ* 21: 326–337. ISSN 1099-0836. DOI: 10.1002/bse.744

Heink U, Kowarik I. 2010. What are indicators? On the definition of indicators in ecology and environmental planning. *Ecol Indic* 10: 584–593. DOI: 10.1016/j.ecolind.2009.09.009

Herva M, Franco A, Carrasco E, Roca E. 2011. Review of corporate environmental indicators. *J Clean Prod* 19: 1687-1699. DOI: 10.1016/j.jclepro.2011.05.019

Ibáñez-Forés V, Bovea M, Pérez-Belis V. 2014. A holistic review of applied methodologies for assessing and selecting the optimal technological alternative from a sustainability perspective. *J Clean Prod* 70: 259–281. DOI: 10.1016/j.jclepro.2014.01.082

ICTSD. 2009. Biofuels subsidies and the law of the WTO [e-document]. [Retrieved April 16, 2014]. 37 p. International Centre for Trade and Sustainable Development Issue Paper No. 20. From: <http://ictsd.org/downloads/2012/03/biofuels-subsidies-and-the-law-of-the-wto.pdf>

IEA. 2012. World Energy Outlook 2012 [e-document]. [Retrieved April 19, 2014]. 668 p. From: [http://www.iea.org/publications/freepublications/publication/WEO2012\\_free.pdf](http://www.iea.org/publications/freepublications/publication/WEO2012_free.pdf)

ISO. 2014. ISO 13065 draft. Sustainability criteria for bioenergy (draft version). [Retrieved September 6, 2014].

Jørgensen A, Le Bocq A, Nazarkina L, Hauschild M. 2008. Methodologies for Social Life Cycle Assessment. *Int J LCA* 13: 96–103. DOI: 10.1065/lca2007.11.367

Kaario K, Peltola T. 2008. Tiedonhallinta: Avain tietotyön tuottavuuteen (Information management: Key to the productivity of information work). First edition. Porvoo: WS Bookwell. 164 p. In Finnish. ISBN 978-951-0-34793-5.

Kapanen M. 2014. Legislative measures in managing environmental impacts of product chains. Lecture of the Basic Course in Environmental Technology, Lappeenranta University of Technology October 29, 2014.

Ketola T. 2005. Vastuullinen liiketoiminta—Sanoista teoksi [Responsible business—From words to deeds]. Helsinki: Edita Prima Oy. 212 p. In Finnish. ISBN 951-37-4466-3.

Klöppfer W. 2008. Life cycle sustainability assessment of products. *Int J LCA* 13: 89–95. DOI: 10.1065/lca2008.02.376

Klöppfer W, Ciroth A. 2011. Is LCC relevant in a sustainability assessment? *Int J LCA* 16: 99–101. DOI: 10.1007/s11367-011-0249-y

Klöppfer W, Grahl B. 2014. *Life Cycle Assessment (LCA)*. Wiley. 412 p. ISBN 9783527655656.

Liao W, Heijungs R, Huppes G. 2011. Is bioethanol a sustainable energy source? An energy-, exergy- and emergy-based thermodynamic system analysis. *Renew Energy* 36: 3479–3487. DOI: 10.1016/j.renene.2011.05.030

Madu C, Kuei C-H (eds). 2012. *Handbook of sustainability management*. Singapore: World Scientific. 899 p. ISBN 978-981-4354-81-3.

Maes D, Van Passel S. 2014. Advantages and limitations of exergy indicators to assess sustainability of bioenergy and biobased materials. *Environ Impact Assess Rev* 45: 19–29. DOI: 10.1016/j.eiar.2013.11.002

McBride AC, Dale VH, Baskaran LM, Downing ME, Eaton LM, Efroymson RA, Garten Jr CT, Kline KL, Jager HI, Mulholland PJ, Parish ES, Schweizer PE, Storey JM. 2011. Indicators to support environmental sustainability of bioenergy systems. *Ecol Indic* 11: 1277–1289. DOI: 10.1016/j.ecolind.2011.01.010

Mendoza Guillermo A, Prabhu R. 2000. Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: a case study. *For Ecol Manag* 131: 107–126. DOI: 10.1016/S0378-1127(99)00204-2

Pülzl H, Prokofieva I, Berg S, Rametsteiner E, Aggestam F, Wolfslehner B. 2012. Indicator development in sustainability impact assessment: balancing theory and practice. *Eur J For Res* 131: 35–46. DOI: 10.1007/s10342-011-0547-8

Purba R, Singh AK, la O'Castillo O, Intal Jr PS, Sajid A. 2009. A metric for corporate environmental indicators... for small and medium enterprises in the Philippines. *Bus Strategy Environ* 18: 14–31. DOI: 10.1002/bse.555.

Rametsteiner E, Pülzl H, Alkan-Olsson J, Frederiksen P. 2011. Sustainability indicator development—Science or political negotiation? *Ecol Indic* 11: 61–70. DOI: 10.1016/j.ecolind.2009.06.009

Raworth K. 2012. A safe and just space for humanity: can we live within the doughnut? [e-document]. [Retrieved October 24]. 22 p. Oxfam discussion paper, February 2012. From: <http://www.oxfam.org/sites/www.oxfam.org/files/dp-a-safe-and-just-space-for-humanity-130212-en.pdf>

Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (Text with EEA relevance)

Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC

Rempel RS, Andison DW, Hannon SJ. 2004. Guiding principles for developing an indicator and monitoring framework. *The Forestry Chronicle* 80: Issue 1. DOI: 10.5558/tfc80082-1

Rettenmaier N, Hienz G. 2014. Chapter 4. Linkages Between Socio-Economic and Environmental Impacts of Bioenergy. In: Rutz D, Janssen R (eds.) *Socio-Economic Impacts of Bioenergy Production*: pp. 59-80. Springer.

Rockström J, Steffen W, Noone K, Persson Å, Chapin FS, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Livermen D, Richardson K, Crutzen P, Foley JA. 2009. A safe operating space for humanity. *Nature* 461: 472–475. DOI: 10.1038/461472a

RSB Roundtable of Sustainable Biomaterials. 2013. Consolidated RSB EU RED Principles & Criteria for Sustainable Biofuel Production [e-document]. Version 2.0, 10 May 2011. [Retrieved February 28, 2014]. 30 p. From: <http://rsb.org/pdfs/standards/RSB-EU-RED-Standards/11-05-10-RSB-STD-11-001-01-001%20vers%20%201%20Consolidated%20RSB%20EU%20RED%20PCs.pdf>

Rutz D, Janssen R (eds.). 2014. *Socio-Economic Impacts of Bioenergy Production*. 297 p. Springer International Publishing Switzerland. ISBN 978-3-319-03829-2 (eBook).

Sala S, Farioli F, Zamagni A. 2013. Life cycle sustainability assessment in the context of sustainability science progress (part 2). *Int J LCA* 18: 1686–1697. DOI: 10.1007/s11367-012-0509-5

Schumpeter. 2014. A new green wave. *The Economist* 30 August 2014. From: <http://www.economist.com/news/business/21614152-few-pioneering-businesses-are-developing-sustainability-policies-worthy-name-new>

SFS-EN-ISO 14040. 2006. Environmental management. Life cycle assessment. Principles and framework. Finnish Standards Association SFS. 2nd edition. Helsinki: Finnish Standards Association SFS. 48 p.

SFS-EN 16214-1. 2012. Sustainability criteria for the production of biofuels and bioliquids for energy applications. Principles, criteria, indicators and verifiers. Part 1: Terminology. Finnish Standards Association SFS. 1st edition. Helsinki: Finnish Standards Association SFS. 27 p.

SFS-EN 16214-3. 2012. Sustainability criteria for the production of biofuels and bioliquids for energy applications. Part 3: Biodiversity and environmental aspects related to nature protection purposes. Finnish Standards Association SFS. 1st edition. Helsinki: Finnish Standards Association SFS. 22 p.

SFS-EN 16214-4. 2013. Sustainability criteria for the production of biofuels and bioliquids for energy applications. Finnish Standards Association SFS. 1st edition. Helsinki: Finnish Standards Association SFS. Part 4: Calculation methods of the greenhouse gas emission balance using a life cycle analysis approach. 41 p.

SFS-ISO 14046. 2014. Environmental management. Water footprint. Principles, requirements and guidelines. Finnish Standards Association SFS. 1st edition. Helsinki: Finnish Standards Association SFS. 76 p.

Sheehan JJ. 2009. Biofuels and the conundrum of sustainability. *Curr Opin Biotechnol* 20: 255–380. DOI: 10.1016/j.copbio.2009.05.010

Smeets EMW, Faaij APC 2010. The impact of sustainability criteria on the costs and potentials of bioenergy production—Applied for case studies in Brazil and Ukraine. *Biomass Bioenergy* 34: 319–333. DOI: 10.1016/j.biombioe.2009.11.003

The Federation of Finnish Technology Industries. 2010. Ympäristölainsäädäntö: Seuranta ja vaikuttaminen (Environmental legislation: Monitoring and influencing) [e-document]. August 2010. [Retrieved September 14, 2015]. 72 p. In Finnish. From: [http://teknologiateollisuus.fi/sites/default/files/file\\_attachments/elinkeinopolitiikka\\_kestava\\_kehitys\\_julkaisut\\_ymparistolainsaadanto\\_verkkoversio\\_20092010.pdf](http://teknologiateollisuus.fi/sites/default/files/file_attachments/elinkeinopolitiikka_kestava_kehitys_julkaisut_ymparistolainsaadanto_verkkoversio_20092010.pdf)

Vakkilainen E, Kuparinen K, Heinimö J. 2013. Large industrial users of energy biomass [e-document]. Published September 12, 2013. [Retrieved April 15, 2014]. 55 p. IEA Bioenergy Task 40: Sustainable International Bioenergy Trade. From: <http://www.bioenergytrade.org/downloads/t40-large-industrial-biomass-users.pdf>