1 **Use of a participatory approach to develop a regional assessment tool**
2 **for bioenergy production**

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11 ***Abstract***

12

13 Recent years have witnessed an upsurge in certification schemes and sustainability
14 assessment tools for bioenergy, however these mechanisms are often too generic,
15 numerous and too broad for regional or local level implementation. Furthermore, these
16 assessments are often weighted toward economic and environmental sustainability with
17 less focus on social, cultural and institutional factors. This study was intended to
18 overcome these limitations. We developed a community-driven regional assessment tool
19 for forest-based bioenergy production in the Upper Peninsula of Michigan (USA).
20 Stakeholders representing local landowners, farmers, township supervisors, timberland
21 management companies, venture capitalists, government organizations and local interest
22 groups generated a preliminary list of criteria and indicators (C&I) in a series of focus
23 groups and interviews, and narrowed the list using multiple criteria analysis (MCA) in a
24 workshop. Participants ranked environmental protection as the most important and
25 relevant sustainability criteria, although policy and governance, and institutional capacity
26 were also weighted highly. The final set of C&I consisted of 17 criteria and 31 indicators
27 (in parentheses): Economic (6), Environmental (7), Social (8), Policy and regulations (4)
28 and Institutional capacity (6). This set reflected the general balance across sustainability
29 principles valued by the stakeholders. While expert-developed sustainability assessments
30 are routinely biased toward easily quantifiable indicators, the indicators that were
31 considered important and relevant by our participants included both quantitative as well
32 as qualitative indicators, in almost equal proportions. This participatory MCA method
33 identified criteria and indicators that reflect the regional context and the concerns of local
34 stakeholders, and data for many of these indicators are readily available.

35

36 **Keywords:** bioenergy, participatory, multiple criteria analysis, sustainability, sustainable
37 assessment

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41 **1. Introduction**

42 Growing interest of countries in the production and use of renewable energy,
43 particularly since the early 2000s (e.g. US Energy Independence and Security Act of
44 2007; EU Renewable Energy Directive 2009) has generated a rapid expansion of
45 biomass-based bioenergy production. In response, there has been a sharp increase in the
46 number of initiatives to monitor and standardize the production of bioenergy products
47 and their sustainability-related impacts [1]. These initiatives are generally motivated by
48 the need for international trade obligations and other considerations [2], with little regard
49 to local contexts [3].

50 Sustainability is an integrative function of environmental protection, economic
51 viability and social equity [4-8]. Sustainable bioenergy development entails context-
52 driven policy, regulations and institutional capacity [9, 10]. Nevertheless, most
53 sustainability assessment frameworks for bioenergy neglect issues such as governance,
54 social impacts, and the linkages among global, national and local contexts [3, 10, 11].
55 Van Dam et al. (2010) suggested that bioenergy assessments of developing countries are
56 generally motivated by socio-economic concerns while assessments in developed
57 countries focus more on economic and environmental principles of bioenergy production
58 [11]. Similarly, assessment tools used for micro and meso-scale assessments (e.g., Life
59 Cycle Assessments, Cost-Benefit Analysis, and Environmental Impact Assessment)
60 mostly focus on techno-economic and environmental aspects of bioenergy development,
61 largely failing to reflect socio-economic and other community concerns and contexts
62 [12]. A few global-scale sustainability assessments address these shortcomings and
63 incorporate all sustainability principles (such as Roundtable on Sustainable Biomaterials
64 (RSB), Roundtable on Sustainable Palm Oil (RSPO), Global Bioenergy Partnership
65 (GBEP), and International Organization for Standardization (ISO) etc.). However, the
66 variety of feedstocks, geographical regions, cultural contexts, logistic requirements, and
67 production processes make existing generic frameworks too broad and ambiguous for
68 practitioners to use at the grassroots level [3, 13-16]. This suggests the need for a
69 comprehensive framework for building sustainability assessments to address
70 sustainability goals at a variety of scales [3, 11, 13, 15].

71 Bioenergy production is a complex system with multiple interconnected
72 components. An indicators-based sustainability assessment for bioenergy should be
73 holistic and systemic, incorporating the participation of experts and actors from all
74 components of the system [16, 17]. This is possible only through an inductive,
75 collaborative and reflexive approach that involves all key stakeholders in the
76 development of the framework [13, 18]. Participation in decision-making processes by
77 key stakeholders and local experts can also enhance credibility, ownership, and context-
78 specificity of the interventions, which are all imperative in the pursuit of sustainable
79 bioenergy development [13].

80 This paper discusses the participatory development of a regional bioenergy
81 sustainability assessment, involving stakeholders from all key components of a potential
82 bioenergy production system. In the earlier phase of this study, we identified the interests
83 and values of key stakeholders in relation to regional bioenergy development. These
84 concerns and values were then translated into an extensive list of sustainability criteria
85 and indicators (C&I) using an expert-assisted approach¹ for a bioenergy production
86 system [10]. The main objective of this paper is to report the results from a stakeholder
87 workshop and Multiple Criteria Analysis (MCA) methods to narrow down the long list of
88 C&I from the earlier phase into a comprehensive yet manageable set of sustainability
89 C&I. In Section 2, we briefly discuss the different phases of the research, and techniques
90 used to collect and analyze data over the course of this study. In Section 3, we discuss our
91 research outcomes and present the final sustainability assessment framework. In Section
92 4, we discuss the conclusions and limitations of our study.

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95 **2. Methods**

96 Our study was conducted in the Western Upper Peninsula (WUP) of Michigan.
97 The immense exploitation of the forestlands in the late 1800s and the early 1900s by the
98 logging and mining industries had once left this region almost completely deforested
99 [20]. Following the rapid downsizing of these industries by the 1960s, the subsequent

¹ An expert-assisted approach is a participatory approach, which involves the elicitation of local knowledge to understand the local socio-ecological context. In this approach, experts only facilitate the process and avoid using pre-defined criteria and indicators to generate a sustainability framework [19].

100 outmigration had a tremendous impact on the regional economy. In the intervening
101 decades the forests have regenerated, and currently more than 80% of the WUP land is
102 forested [21]. The forest industry remains as an important part of the local economy and
103 culture in the WUP. However, the youth population has continued to decline and the
104 WUP remains an aging population [22].

105 We divided the study into three distinct phases: I) stakeholder selection; II)
106 qualitative development of C&I; and III) preference elicitation using MCA techniques.
107 We accomplished stakeholder selection through stakeholder analysis [23]. We collected
108 data using a combination of three different participatory techniques for the latter two
109 phases: focus groups and interviews for phase II [10] and one workshop to accomplish
110 phase III. Here we will limit our discussion to phases I and III of this study. The main
111 purpose of the workshop was to solicit feedback using MCA techniques on the
112 importance and relevance of C&I generated from phase II, to generate a manageable,
113 representative set of C&I to be used as a sustainability assessment tool as the bioenergy
114 industry develops in the WUP.

115

116 **2.1. Stakeholder selection**

117 We identified stakeholders using a number of sources, including professional
118 networks, snowballing and Internet searches. We invited potential participants through
119 physical mail and/or email, which conveyed a brief description about the project, their
120 role in the study, time commitments required of them, and incentives for their
121 participation in the project.

122 A total of 31 stakeholders participated in the study, representing four major
123 stakeholder groups as illustrated in Fig 1.

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Fig 1. Distribution of participants over different stakeholder groups: Participants were categorized into different stakeholder groups (representing different components of bioenergy production system) depending upon their affiliations. Some participants have been counted in more than one category, depending upon the number of stakeholder groups they represented.

2.2. Qualitative development of C&Is

This phase identified the concerns of the stakeholders and their information needs. In addition to data collected through focus group meetings and interviews, a literature review on sustainability assessments also contributed to the development of the preliminary list of C&I. The literature review allowed us to partially validate our results from the focus groups and interviews, and highlighted the influence of the regional context on the sustainability goals of the community. Subsequently, we developed an extensive list of sustainability principles and criteria (and sub-criteria and indicators for some criteria) based on the framework described in [24] (see Appendix A).

2.3. Preference elicitation: Stakeholder workshop

Criteria that are widely used in the evaluation of sustainability indicators are: importance, relevance, practicality, reliability and their sensitivity to the changes caused by the system of concern [17, 25-27]. In our study, participants evaluated the preliminary set of sustainability criteria for their importance (to the participants) and relevance (to the wood-based bioenergy production in the WUP) at the stakeholder workshop. The evaluation of C&I based on their sensitivity and practicality was beyond the scope of this study.

166 Prior to the preference elicitation, we gave a PowerPoint presentation to
167 participants about the research activities conducted up to that point, expected outcomes of
168 the workshop, and the MCA techniques that participants would use to evaluate the
169 criteria and indicators. The presentation also included a brief introduction about the
170 project, objectives of the workshop agenda, purpose of the workshop, and the project as a
171 whole. The stakeholder workshop was held to accomplish this task. The workshop
172 followed three steps:

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174 *2.3.1. Preparation*

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176 *2.3.1.1. Criteria and indicators:* Not all criteria and indicators in the preliminary list were
177 bioenergy-specific, and many of them reflected the general concerns of the participants as
178 a community. On the other hand, some of the bioenergy-specific criteria and indicators
179 were relevant to one group of stakeholders with little relevance to another group. For
180 instance, ‘land management opportunities for landowners’ and ‘professional consulting
181 services for landowners and farmers’ are clearly relevant to feedstock producers, while
182 they are of little relevance to the bioenergy producers or potential consumers of the
183 bioenergy products. Therefore, in order to make the assessments comprehensive and easy
184 to work with for all participants, we rearranged the criteria and indicators in the
185 preliminary list into two broad categories: general (for criteria that reflected the concerns
186 of the stakeholders as a community) and bioenergy-specific (for criteria that were
187 reflective of participants’ concerns as stakeholders of the bioenergy system). We further
188 subdivided the categories based on specific concern areas (as shown in Fig 2) and
189 assessed in different group structures (as discussed in Section 2.3.3)

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Fig 2. Rearrangement of criteria and indicators: Criteria and indicators in the preliminary list were rearranged so as to make it easier for participants to evaluate them using different assessment techniques at the workshop.

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201 *2.3.1.2. Participants:* We invited all study participants (36 in total) who had participated
 202 in phase II to the half-day workshop. The invitation included a workshop agenda with a
 203 timeline and a list of activities planned for the workshop. Only 17 participants could
 204 attend the workshop, and were accompanied at the workshop by five researchers (new
 205 participants) working on different components of forest-based bioenergy development in
 206 the WUP. Fifteen of the invited participants expressed interest in participating in the
 207 workshop but could not due to time conflicts. We sent a survey package to record their
 208 preferences. The data collection package contained four key materials: a handout that
 209 explained MCA techniques, an assessment worksheet, and a glossary that briefly
 210 described all the criteria listed in the assessment sheet (see Appendix B for an example of
 211 data collection worksheet). Out of those 15 participants, nine returned the worksheet.
 212 Altogether 31 stakeholders participated in this phase.

213

214 2.3.2. *Preference elicitation tools*

215 Multiple Criteria Analysis (MCA) was used to identify the most relevant and
216 important C&I for the sustainability assessment of bioenergy production in the WUP.
217 MCA is a decision-making tool used when an evaluation process involves multiple,
218 competing interests and objectives among diverse stakeholders. It has been used
219 extensively as a decision-making tool in a wide range of resource management and
220 planning projects [28, 29, 30], including sustainable energy development and planning
221 [17, 31-34]. MCA has also been used for a variety of other purposes, many of which
222 include choosing between management alternatives or technology options against a set of
223 pre-defined criteria [35-37]. In some cases it has been used to identify the optimal criteria
224 or indicators to assess an emerging intervention or technology [17, 37, 38].

225 In our study, we used three different MCA techniques to elicit preferences from
226 the stakeholders: Analytical Hierarchy Process or pairwise comparison²; ranking; and
227 rating (for procedural details about these methods, refer to [28, 39]). We used these
228 simple MCA techniques for preference elicitation over other more popular software-
229 based MCA techniques [40], because: i) no special skill or technology is required to use
230 them and they are easy to learn and understand, which was important in our case as it
231 involved participants (or ‘decision-makers’) from diverse backgrounds (i.e. both
232 scientific and non-scientific); ii) it can be used to evaluate both quantitative and
233 qualitative criteria and indicators, and iii) these methods require relatively less time for
234 decision-making [28, 30, 40, 41] Since pairwise comparison, outranking and rating are
235 relatively easier to use than other software-based techniques, it can encourage a greater
236 participation of stakeholders from a wide range of backgrounds to aid decision-making
237 processes. For this reason, MCA is often associated with transparency and credibility [28,
238 39, 42].

239 Participants used pairwise comparison to make one-on-one comparisons between
240 criteria [28]. We calculated pairwise ranks, and aggregate weights using Microsoft Excel
241 and Analytical Hierarchy Process formulae adapted from [28, 39, 43]. Participants
242 evaluated different options at three different levels or hierarchies: principles, criteria and
243 sub-criteria/indicators. However, pairwise comparison was used only at principles and

² Where the scoring or ranking is derived from a one-to-one comparison between criteria.

criteria level because of the implicit requirement for more information to make comparison between indicators. In pairwise ranking, only the comparisons that had a consistency ratio (CR) ≤ 0.1 were included in the calculation of the average ranks. For weighted averages, n (total number of samples) was between 10-13 for each set of pairwise comparison, after eliminating the matrices with CR > 0.1. Participants used rating and ranking methods for all bioenergy-specific criteria and indicators. Multiple techniques were used to assess criteria and indicators whenever possible, in order to examine consistency in decision-making. Criteria and sub-criteria with the highest aggregate weights were listed in the final set.

2.3.3. Assessment of C&I

We divided the workshop exercise into three segments: individual assessment, stakeholders' group assessment, and mixed-group assessment. We encouraged participants to write down notes on terms and phrases that they found difficult to understand, and to note C&I that they felt were redundant or missing from the list.

2.3.3.1. Individual assessment: First, on their own, participants ranked and rated sustainability principles (i.e. environmental protection, social justice and equity, economic benefits, policy and regulations, and institutional capacity), and a list of environmental and socio-economic criteria and indicators. Participants evaluated these principles and C&Is based on their relative importance and relevance to the forest-based bioenergy industry in the context of the WUP, using pairwise comparison and rating methods. To make the assessment less time-intensive for the participants, use of pairwise comparison (which usually takes longer than the other two MCA techniques) was limited to general criteria under three primary sustainability principles: environmental, economic and social. Participants also used a rating method to evaluate the criteria based on their relevance and importance. They rated indicators for social, economic and environmental sustainability that were validated through a literature review. We designed this assessment based on the assumption that local stakeholders' knowledge and perceptions would lead to C&I that are more reflective of the local context and interests of the community. We used individual assessment for general socio-economic and

275 environmental C&I because of their (large) numbers and relevance to all stakeholders.
276 Running them through group assessments may have entailed longer discussion times,
277 which in turn could have affected the effectiveness and efficiency of the process. Despite
278 the willingness shown by our participants to contribute to this study, conflicting
279 schedules and travel distance to the workshop made time one of our limiting factors.

280

281 *2.3.3.2. Mixed group assessment:* Next, we sorted all participants to create four
282 heterogeneous groups of stakeholders. This group evaluated criteria and indicators under
283 ‘Consumers’ concerns’ and ‘Policy and institutional concerns’ under the ‘General
284 criteria’ category in Fig 2. All groups used ranking as well as rating systems to evaluate
285 the given list of C&Is for their relevance and importance. We structured the group
286 assessment based on the assumption that ‘Consumers’ concerns’ and ‘General policy and
287 institutional concerns’ were relevant to all stakeholders, because everyone plays the role
288 of consumer and occasionally a decision-maker.

289

290 *2.3.3.3. Stakeholder group assessment:* Finally, we categorized our participants into three
291 homogenous³ stakeholders’ groups (feedstock production, biofuel production, decision
292 makers) depending on the components of the bioenergy production system that they
293 represented. They worked with the criteria that were specific to the components for their
294 group. For example, the ‘feedstock production’ group evaluated criteria such as ‘location
295 of the plantation’, ‘land management opportunities for landowners’, ‘professional
296 consulting services for landowners and farmers’, and ‘long-term contracts between
297 buyers of feedstock and the growers of feedstock’.

298

299

300 **3. Results and Discussion**

301

302 Although C&I were evaluated using different methods and in different group
303 structures by our participants at the workshop, the results from all assessments have been

³ ‘Homogeneity’ has been stressed in the structuring of the groups because a homogenous group is more likely to encourage unhindered communication and smooth exchange of information [44].

combined and rearranged in the final set under five different sustainability principles: economic, environmental, social, governance, and institutional capacity. While most sustainability discourse is primarily focused on social, environmental and economic dimensions, our participants also assessed ‘Policy & regulations’ and ‘Institutional capacity’ as important and relevant sustainability principles (see Fig. 3). They were rated and ranked similarly (in terms of both importance and relevance) to social and economic principles.

Fig 3. Individual assessment using pairwise ranking and rating methods for broad sustainability principles⁴

3.1. Sustainability assessment tool

Tables 1-4 introduce the final set of C&I for a regional bioenergy industry, based on the preference elicitation exercises (for results from each individual and stakeholder group assessment, please refer to the Supplemental Material). Criteria with the highest aggregate rankings and their highest-ranking indicators were listed in the final set. For each sub-criterion/indicator, we identified relevant aspects of the bioenergy production

⁴ For pairwise ranking: 1= implies the most important among all choices, and higher numbers indicate lower relative importance. For rating: 1= weakly important; 3= less important; 5= moderately important; 7= strongly important; 9= extremely important. Even numbers denote intermediate scales between two adjacent judgments

system (indicated by shaded boxes in the following tables) and the potential source/s of data for them (also included in tables below).

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328 3.1.1. *Economic criteria*

329 Most of the economic indicators chosen as the most important and relevant by our
330 participants have been widely used in the literature [12, 38, 45]. However, the use of
331 local resources for local consumption was heavily emphasized by most of our
332 stakeholders (Table 1).

333

334

335 **Table 1. Final set of economic C&I⁵**

Criteria	Sub-criteria/Indicators	Direction to sustainability	Potential data sources
Local economy	Unemployment rate	< baseline (e.g. 5.4% ⁶)	US Bureau of Labor Statistics (US BLS)
	Local revenue (per capita personal income in USD)	> baseline (e.g. 34,685 ⁷)	US Bureau of Economic Analysis (US BEA)
Resource efficiency	Wood biomass availability/price	= baseline	US Department of Agriculture (USDA)- Forest Inventory and Analysis, MI-Department of Natural Resources
	Fossil energy return on investment (EROI)	> baseline (e.g. 1 ⁸)	Michigan Forest Biofuels Research, US Department of Energy (USDoE)-Biomass Program
	Use of local resources	↑	Survey of bioenergy plant
Profitability	Return over investment	↑	Survey of energy plants and feedstock producers, Techno-economic assessments (Ongoing researches)

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337

338 3.1.2. *Environmental criteria*

339 Although our participants rated environmental sustainability as the most
340 important of all criteria, they were not able to identify, recommend, or rate environmental
341 indicators easily. Many participants expressed difficulty in understanding scientific
342 terminologies related to these indicators, and some environmental indicators were not
343 rated. Under such circumstances, non-responses were not counted into the calculation of

⁵ When data were not available, the relationship has been indicated as ↑ or ↓ or = signs to indicate whether they should increase/improve, decrease/decline or remain intact/balanced, as compared to the baseline. For qualitative indicators, relationships have been indicated as √ (for 'Yes' or affirmative) and X (for 'No' or negative) measurements.

⁶ Estimate for WUP from September [46].

⁷ Estimate from [47].

⁸ Estimate varies depending on boundaries, subsidies, externalities, and production system [48].

average ratings. Therefore, most of the environmental indicators presented in the table have been validated further using the sustainable bioenergy literature (Table 2).

Table 2. Final set of environmental C&I

Criteria	Sub-criteria /Indicators	Direction to sustainability	Potential sources of data
Water quality	Nutrient concentration (N, P)	↓	United States Geological Survey (USGS), MSU Extension
	Herbicide/pesticide concentration	↓	United States Geological Survey (USGS), MSU Extension
Air quality	Particulate matters (PM), CO, SOx, NOx	↓	United States Environmental Protection Agency (US-EPA), EPA (National Emissions Inventory, Monitoring services)
	Greenhouse gases	↓	EPA (National Emissions Inventory, Monitoring services)
Soil quality	Soil erosion/soil compaction	↓	USGS, United States Department of Agriculture (USDA)
	Nutrient	= baseline	USGS, USDA
Ecosystem	Avoid invasive species/ Use native species	√	Michigan Department of Natural Resources (MI-DNR), USDA

3.1.3. Social criteria

The social criteria had a balance of quantitative and qualitative indicators (Table 3). Although social indicators in general have been overlooked in sustainability assessments, social indicators for criteria such as food security, transparency and participation are increasingly popular in sustainability assessments for energy systems [3, 12, 38]. Indicators related to participation and transparency were also weighted highly in our study; however, food security was not weighted as highly for relevance.

Table 3. Final set of social C&Is

Criteria	Sub-criteria /Indicators	Direction to sustainability	Potential sources of data
Participation	Key stakeholders' participation in decision making	√	Stakeholder survey
Transparency	Public availability of management plan	√	Stakeholder survey, Monitoring reports
	Communication of research outcomes and long-term impacts	√	Stakeholder survey
Work condition	Workers safety	√	Survey, Project plan
Recreational values	Recreational activities/areas	=	DNR, WUPPDR, Survey

Educational/capacity building	Skill transfer and training opportunities	↑	Survey, Project plan
Consumer concerns	Reliability/consistent supply of the product	√	Market survey
	Environment-friendly	↑	Market survey, Techno-economic assessments

3.1.4. Criteria for governance and institutional capacity

This set represents policy, institutional building and management concerns of the participants (Table 4). All indicators in this set are qualitative.

Table 4. Final set of governance, and institutional capacity related C&Is

Sustainability Principles	Criteria	Sub-criteria /Indicators	Direction to sustainability	Potential sources of data
Governance	Regulatory policies	Pay all legally prescribed fees/royalties/taxes	√	<i>Ex post</i> stakeholder survey
		Compliance to state standards and regulations	√	Monitoring agencies
	Precautionary policies and support mechanisms	Compliance to sustainable harvesting practices	√	<i>Ex post</i> stakeholder survey, Government monitoring agency
		Protection of landowners' rights	√	<i>Ex post</i> landowner survey
Institutional capacity	Logistics	Water source	√	Baseline study
		Technical expertise	√	Baseline study
		Consistent supply of feedstock/products	√	Baseline study, <i>ex post</i> market survey
	Management & monitoring	Regular monitoring	√	Monitoring agencies
		Residue management and utilization	√	Project plan, Monitoring reports
		Colocation of biorefineries in existing facilities	√	Project plan, Monitoring reports

3.2. Measurable sub-criteria/indicators and eliminations

From the final list of C&Is, the indicators that were rated lower were eliminated, particularly if the variance for the calculated means were also smaller [28]. For indicators with no available data, we chose the indicator rated and/or ranked next highest with available data.

376 While some C&Is preferred by the stakeholders are clearly measurable and are
377 supported by existing databases, others (mostly concerning social, policy and
378 management issues) were inherently qualitative and their measurement would require
379 additional data collection through qualitative research methods. For such criteria rated
380 and ranked highly important and relevant (such as ‘Compliance to sustainable harvesting
381 practice’, ‘Pay all applicable and legally prescribed fees/royalties/taxes’), existing
382 databases were not helpful. For these, routine monitoring and evaluation by the state
383 agencies will be necessary.

384

385 **3.3. *Interesting criteria/indicators***

386 Interestingly, some of the sustainability indicators (‘benefits from external trade’,
387 ‘infrastructure development in the region’, ‘youth population in the region’ and indicators
388 related to food security) that were frequently discussed in focus groups and interviews
389 were rated lower than others in the workshop. For example, ‘food security’ was rated as
390 important and relevant at the criteria-level (see Supplemental Material), but its indicators
391 (i.e. food price, change in local agricultural land area, restrict use of agricultural land for
392 biofuel production, availability of agricultural land) received low ratings for their
393 relevance to wood-based bioenergy production. During the focus group and interviews,
394 participants associated forest-based bioenergy more with residues and wastes from forest-
395 based industries, than with plantations and food crops.

396 External trade was brought up as an important concern by venture capitalists in
397 focus groups and interviews. However, at the workshop it received the lowest aggregate
398 weighting for relevance and importance as an economic criterion. Indicators related to
399 employment, energy security, resource efficiency and use of local resources were rated
400 and ranked higher in the assessment (in both criteria as well as indicator level
401 assessments) than those related to external trade. This may suggest that stakeholders were
402 more concerned about ensuring economic benefits to the community through self-reliance
403 in energy and local employment, than through expansion of external trade.

404 Similarly, in focus groups and interviews, the loss of the youth population for jobs
405 elsewhere was frequently cited as a negative effect of the shrinking economy. However,
406 relative weightings suggested that participants on average considered youth population to

407 be the least relevant indicator of ‘local economy’. The fact that ‘employment’ was rated
408 the highest in the given criteria suggests that participants may have viewed ‘youth
409 population’ as redundant indicator in the list, hence rated lower.

410

411 **3.4. *Difficult indicators***

412 A few participants expressed confusion in understanding terms such as
413 ‘Institutional capacity’, ‘Transparency’ and ‘Compliance’. Participants particularly
414 struggled with rating indicators under environmental criteria; at least 6 workshop
415 participants expressed difficulty in understanding or assessing the environmental
416 indicators, despite the assistance of the facilitators and the glossary provided to each
417 participant at the workshop. Environmental indicators are the most extensively used
418 sustainability indicators in the literature for assessing sustainability of bioenergy
419 production [11]. At the focus groups and interviews, however, most participants hesitated
420 to provide specific indicators for environmental criteria that they perceived as important,
421 citing their lack of awareness about the potential impacts of bioenergy production on the
422 environment. The difficulty among the participants in evaluating environmental
423 indicators may be due to these indicators being expert-driven, and laden with technical
424 terminologies.

425 In a similar study for sustainable development indicators for Marine Protected
426 Areas, Marques et al. (2013) attributed unanswered questions in their survey by
427 stakeholders to either a lack of knowledge about the matter, or a lack of interest in the
428 given issue [49]. Our interaction with participants at the workshop suggested that the
429 former might be the case in this study.

430

431 **3.5. *Variability in judgments***

432 Participants were allowed to choose their own methods to reach consensus and
433 provide a collective judgment in the given worksheet. These methods either involved
434 averaging out the individually assigned rankings and ratings within the group, or making
435 collective decisions preceded by intense discussions.

436 The large variance (standard error) across almost all criteria and indicators could
437 originate from two sources. First, some of the participants struggled with the data

collection tool, and the large standard errors could reflect some confusion over the tool itself. Based on the consistency index, participants were found to be less comfortable and consistent in making judgments using pairwise comparison methods. Our results also suggest that on the whole, our participants saw little difference between importance and relevance, and perhaps one of the two can be omitted in the future. Second, there could be wide disagreement among stakeholders (or even within stakeholder groups) regarding the relative utility of criteria and indicators; in this case, the standard error provides a measure of the diversity within our sample group.

Finally, in the case of a few criteria and indicators (such as ‘Subsidies and taxes’), the high priority may reflect a diversity of opinion and possible interpretations; in these cases, one must go back to the conversations in the focus groups and interviews. ‘Subsidies/tax incentives’ was one of the most contentious issues: some participants expressed that bioenergy production would need to be subsidized in order to be successful, while others felt that a bioenergy industry should not receive subsidies to be considered ‘sustainable’ (in the sense of persisting in the long term). Still other participants considered subsidies to the fossil industry to be an important issue in bioenergy sustainability, but were arguing for the elimination of all subsidies. All of these positions consider subsidies to be an important issue, but for different reasons. Therefore, the high priority of “subsidies and taxes” should not be interpreted as uniform support for subsidizing the bioenergy industry, for example. This indicator was omitted from the final list of C&Is due to a lack of consistency in the relevant judgments.

3.6. *Threshold and directions*

Sustainability assessment is a tool which should contribute to a better understanding of contextual details, and influence actions that can contribute to meeting sustainability objectives of the key stakeholders [16]. A common limitation of many generic sustainability assessments is that they fail to provide direction and thresholds that are imperative for the measurement and interpretation of sustainability indicators [13]. Efroymson et al. (2013; p. 302) argue that general sustainability assessments should be treated as a starting point, but local concerns and objectives should guide the ‘selection, measurement and interpretation’ of sustainability indicators for biofuel systems [15]. We

469 selected sustainability indicators based on local concerns and stakeholders' values, and
470 we are able to provide a direction for improvement based on the characteristics and
471 function of each indicator (Table 1-4). However, setting thresholds (which is key to the
472 interpretation of sustainability indicators) is beyond the scope of this study.

473

474 **3.7. *Sustainability assessment and its policy implications***

475 The Michigan Public Act 295 (2008) stipulated that electric providers in the state
476 have ten percent of electricity produced from qualified renewable energy sources by 2015
477 [50]. Until 2012, wood-based biomass was the primary contributor to the Michigan
478 renewable energy portfolio (RPS). In 2014, biomass contributed 35% of the Michigan
479 RPS compliance target [51]. However, of the three renewable energy projects under the
480 Michigan RPS in the UP, only one project uses biomass as a source of renewable energy
481 [50]. The only biomass-driven energy plant in the WUP (in L'Anse, MI) has recently
482 come under public scrutiny for the use of environmentally hazardous feedstock [52].
483 Similarly, a demonstration facility located in Northeast Michigan halted its wood-based
484 ethanol production due to "the low ethanol price environment, the small size of the pre-
485 commercial facility, and the limited feedstock supply" (see
486 <http://www.alpenabiorefinery.com/>). Although the utility companies with renewable
487 energy contracts in Michigan claim that they have met the 2015 compliance target, they
488 have supported removing the mandates [53]. The Renewable Energy Amendment (2012)
489 that proposed an increased renewable energy target of 25% to be met by 2025 (Proposal
490 3) was defeated at the state's electorate. Nevertheless, Li et al. (2014) suggest that
491 renewable energy is widely supported by the Michigan public and the defeat of Proposal
492 3 does not reflect public opinion regarding renewable energy [54].

493 Most of our participants were interested in local energy production using
494 renewable resources and in learning about the potential for wood-based bioenergy. Our
495 stakeholders were very keen on participation and transparency, expressing a desire for
496 more communication about research progress and policy interventions. With reference to
497 bioenergy production, Becker et al. (2009) suggest that not only benefits and promises,
498 but tradeoffs and local constraints should also be effectively communicated [55].
499 Conversely, public outreach and research are generally the least-used policy interventions

500 by states for the development of bioenergy industries [56]. A stakeholder-driven regional
501 sustainability assessment tool can play an important role in informing policy-makers
502 about the key areas that may require intervention for the sustainable development of this
503 industry.

504

505

506 **4. Conclusion**

507

508 Finally, stakeholders' participation was the keystone of this study; it provided
509 multiple opportunities to the researchers involved to interact with stakeholders and to
510 define sustainability in relation to bioenergy production. Although the C&I were derived
511 from stakeholders' concerns and perceptions, allowing participants to provide feedback
512 was important to further ensure the credibility and validity of our study findings. The
513 workshop provided an opportunity for researchers to share research outcomes and
514 progress with the participants.

515 Involving stakeholders and local experts in the project (from planning and design
516 to evaluation of the C&I) also allowed us (the researchers) to familiarize ourselves with
517 the local terms, contexts and, stakeholders' interests and values. This is important to
518 improve the likelihood that the framework is adopted and implemented by local
519 practitioners and policy makers as the bioenergy industry develops in the region.
520 However, it may be difficult to collect data for the qualitative indicators that we
521 recommend, particularly those related to governance and institutional capacity. Further
522 work may be necessary to identify methodological requirements for the collection of
523 relevant data. Furthermore, it may be difficult to monitor these qualitative data over time
524 if no one agency is responsible for collecting and monitoring these data.

525

526

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- 703

704 **Appendix A: Criteria and indicators derived from focus group and interview data.**
705 **Italics font indicates criteria and indicators, which were modified**
706 **(reworded/rephrased) for the stakeholder workshop in Phase III.**
707

Sustainability Principles	Criteria	Sub-criteria/Indicators
<i>Economic</i>	Contribution to local economy	<i>Employment</i>
		Use of local resources
		Value-addition to forest products
		<i>Infrastructure development (roadways, railways, hospitals, training institutes)</i>
		<i>Benefit from external trade</i>
		Youth population in the region
	Energy security	<i>Net energy import dependency</i>
		Consistent/Reliable supply of energy products
		Competitive cost of biofuel
	Economic viability	Cost of production/operation
		Energy return over investment (EROI)
		<i>Energy from forest-based biomass compared to energy from fossil fuels; British Thermal unit (BTU) per volume</i>
		<i>Travel distance between production and distribution points; Withinkm</i>
		Return over investment; Net investment/ initial investment
		<i>Resource efficiency of the process; Fuel production per volume of feedstock or hectare</i>
		Scale of production: Local/Regional
	Market acceptance & adaptability	Ability to use diverse feedstock
		Ability to produce diverse products/co-products
		Return rate; Payback time in years
		Cost of returning to previous land use
		Comparative gain over other investments
	Competition for resources	<i>Technology, infrastructure, machineries and equipment; Production of energy, use of energy</i>
		Availability of forest biomass; Price and availability of forest products
		Availability of lands for other purposes; Land price; land availability
<i>Environmental</i>	Air quality	GHG emissions; <i>CO₂ equivalent emissions, change in carbon sequestration properties</i>
		Particulate matter, NOx, SOx, CO
	<i>Ecosystem and wildlife habitat</i>	Biodiversity
		<i>Controlled use of agrochemicals</i>
		<i>Avoid any disturbance to high conservation value areas</i>
	Invasiveness	<i>Controlled use of forestland for bioenergy operations</i>
		<i>Use of non-native species/genetically engineered species for bioenergy production</i>
	<i>Water quality and quantity</i>	<i>Prevent water contamination (Herbicide concentrations in water, pH, eutrophication)</i>
	<i>Land/Soil quality</i>	<i>Productivity/yield, soil organic compounds, soil nutrient, pH, soil compaction</i>
		Land (soil) conservation/management
	Waste management	Residue management and utilization
		Waste management; Waste volume; Management plan
<i>Social</i>	Cultural value	<i>Access to recreational activities in public lands</i>
		<i>Protection of local/tribal heritage and sites</i>
		<i>Access to forest products for local inhabitants</i>
		<i>Aesthetics, change in forest cover, general cover type of the region</i>
	<i>Ethical concern</i>	<i>Avoid any disturbance in the livelihood of the local residents, Improved neighborhood: Noise, smell, traffic</i>
		Protection of land rights and access for local residents
		Work conditions; Income (fair wage/benefits); Safety
	Food security	Availability of agricultural land; change in agricultural land area
		Food and feed (for livestock) price
	<i>Transparency/ Participation</i>	Involve public and citizen advisory panel in decision-making
		Public availability of management plans
		<i>Involvement of local organization, institutions or companies in the monitoring and control process</i>

<i>Governance</i>	Precautionary and support mechanisms	<i>Sustainable harvesting guidelines</i>
		Inventory of accessible forest resources
		Compliance to best management practices
		Subscription to certification schemes
		Subsidies and tax incentives
	Compliance with laws and regulations	Policies to protect the local industry from impact of fluctuating oil prices and foreign competition
		Payment of legally prescribed fees, taxes, royalties
		Compliance with local standards, laws and regulations
	Regulatory policies	Compliance with national and international standards
		Restrict use of agricultural land
Restrict use of forest and high conservation value areas		
Traffic controls		
<i>Institutional capacity</i>	<i>Integration and colocation</i>	Pollution control mechanisms
		Mechanism to integrate bioenergy projects into existing developmental projects and programs (e.g. carbon projects, community development)
		Co-location of bioenergy production on or near existing facilities such as paper and pulp industries
	<i>Administration and Management</i>	<i>Education and training facilities to produce skilled workforce</i>
		Research and development programs for new technologies and processes
		Communication and reporting of management and operation plans
		Regular monitoring and evaluation of operational and management systems by a third party
		Legal documentation of clearly stated tenure and contracts
	<i>Communication and outreach</i>	Events and workshops for mutual learning and information sharing among key stakeholders
		Communication of research outcomes and long-term impacts
A unit to facilitate communication between different stakeholders		

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Appendix B: Data collection worksheet

Session A

1. Research updates: Potential list of sustainability criteria and indicators (C&I) derived from focus group discussions and telephone interviews.
2. Hands-on overview on Pairwise comparison, ranking, and rating methods for decision-making.

Session B

I. Individual Assessment (pairwise comparison and rated for relevance and importance): Criteria level

<i>Broad sustainability concerns</i>
Economic benefits
Environmental protection
Socio-economic benefits
Policy and regulations
Institutional capacity and strength
<i>Social criteria</i>
Improved neighborhood
Aesthetics
Recreational values (hunting, hiking, snow mobiling etc)
Cultural products (herbs, fruits, firewood etc)
Food security
Educational/capacity building
<i>Environmental criteria</i>
Ecosystem services
Biodiversity
Air Quality
Water quality and quantity
Soil quality
Climate change
Land productivity
<i>Economic criteria</i>
Employment
Infrastructure development
Energy security
Benefit from external trade
Resource efficiency

II. Individual Assessment (rated for relevance): Criteria level

<i>Environmental criteria</i>	<i>Potential indicators</i>
Ecosystem	Native forest cover
	Land fragmentation
	Natural grasslands area
	State of areas with high conservation value
	No. of wetlands/Peatlands
	Population and habitat changes of species of concern
	Wildlife population
	Invasiveness of species being used or introduced as feedstock
Air Quality	Tropospheric ozone
	CO emissions
	SO2 emissions
	Particulate matter (PM2.5, PM10)
	Nitrogen Oxides emission
	Odor
Water Quality & Quantity	Biological Oxygen Demand level (eutrophication)
	Dissolved Oxygen (DO)
	Total suspended solids
	Nutrient level in water sources
	Herbicide concentration
	pH (Acidification)
	Depth of water table
Soil Quality	pH
	Bulk density of the soil (Soil moisture)
	Total organic carbon
	Nitrate and phosphate concentration
	Total exchangeable cations (causes change in pH)
	Amount of soil washed away
	Soil compaction
Climate change	GHG emissions
<i>Economic criteria</i>	<i>Potential indicators</i>
Resource efficiency & use	Price of wood (\$)
	Availability of wood
	Land price
	Land availability
	Stress on water resource
	Availability of agricultural land
	Use of local resources versus imports
Local economy	Employment rate (Number of full time equivalent jobs)
	Displacement of existing jobs
	Job types (direct versus indirect, service type versus other etc)
	Youth population in the region
	State revenue (Local economy)
	Diverse local economy
	Expansion of road networks
	New industries
	Infrastructures for public services (hospital, educational institutions)

Energy security	Fossil Energy Return On Investment (Fossil EROI)
	Local distribution of energy
	External input/total input
Benefit from external trade	Terms of trade (Price of exports/price of imports)
	Trade volume (in terms of income)
	Consumption of resources versus production
<i>Social criteria</i>	<i>Potential indicators</i>
Work conditions	Gender-based discrimination at work
	Safety of workers
	Health condition of workers
	Fair wage conditions
Food security	Change in local agricultural land area
	Food and feed (livestock) price
Education/Capacity building of the community	Skill transfer and training opportunities
	No. of educational resources, and presence of information resources
Improved neighborhood	Traffic volumes
	Access to roadways
	Crime rate
	Odor
	Noise

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724 Session C

725 I. Stakeholder group (Feedstock production) assessment: rated and ranked for
726 relevance and importance

<i>Participation and acceptance</i>
Key stakeholders participation in decision-making
Professional consulting services for landowners
Presence of landowners cooperatives
Protect landowners rights
Ability to be integrated into current use of lands
Low cost of returning to previous land use
Long-term contracts with the buyers of feedstock
<i>Profitability and benefits</i>
Return over investment
Return over time
Financial incentives/government incentives
Maintain land productivity
Comparative gain over other investment
Carbon emission reduction
Resource conservation
Land management opportunity
Infrastructure development
<i>Logistics</i>
Location of the plantation
Transportation facilities
Machineries and equipment (harvesting, collection, hauling)
Infrastructure (storage, processing)
Water source
Expertise in feedstock production
<i>Management and Monitoring</i>
Avoid use of chemical herbicides and fertilizers
Avoid clear-cutting
Avoid using heavy equipment for harvesting and collection
Avoid plantations in agricultural land
Protect ethical and cultural concerns of the local inhabitants
Residue management and utilization
Third party audit or assessment program (e.g., certification)

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729 **II. Stakeholder group (Biofuel production) assessment: rated and ranked for relevance**
730 **and importance)**

<i>Acceptability</i>
Adaptability to changing market
Distance between plant and the market
Ability to use diverse feedstock
Ability to produce diverse products/co-products
Competitive price
Use of local resource
Cost of setting up a supply chain
<i>Profitability and benefits</i>
Return over investment
Return over time
Value addition to the wood products
Upfront cost requirement
Scale of production/operation (local versus regional)
Cost of production /operation
<i>Logistics</i>
Location of the plant
Expertise (training facilities)
Energy balance
Consistent supply of feedstock/products
Technology for efficient production
Transportation for distribution
<i>Management and Monitoring</i>
Pollution control mechanisms
Residue management and utilization plan
Waste management plans
Continuous research and pilot projects
Transparency about management and operation plans
Collaboration with existing forest-based industries
Local third party institutions' involvement in audit or assessment program
Local stakeholders' participation in decision-making

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735 **III. Stakeholder group (Decision makers) assessment (rated and ranked for relevance**
736 **and importance)**

<i>Regulatory policies</i>
Pay all applicable and legally prescribed fees, royalties, taxes should be paid
Compliance with state standards and regulations
Compliance with national and international standards and regulations
Restrict use of agricultural land
Restrict use of forests, wetlands and water courses
Restrict use of high conservation value areas
Protection of unique and significant tribal sites
<i>Transparency</i>
Involve citizen advisory panel in decision making
Public availability of management plan
A unit to facilitate communication between different stakeholders
Involvement of local organization/institutions/companies in the management/control processes
Communication of research outcomes and long-term impacts
<i>Precautionary policies and support mechanisms</i>
Management prescription for sustainable harvesting
Compliance to best management practices
Subsidies/tax incentives
Subscription to certification schemes
Policies to protect the local industry from impact of falling oil prices/foreign competitions
Integration of bioenergy projects into existing developmental projects & programs
<i>Management and Monitoring</i>
Reporting of management and operational activities.
Events and workshops for mutual learning/information sharing
Regular revision of management/operation decisions
Legal documentation of clearly stated tenure and use rights
Colocation of biorefineries on or near existing sites such as paper and pulp mills
Comprehensive R&D programs for new technologies/processes

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743 **Session D**

744 **Mixed group assessment (rated and ranked for relevance and importance)**

<i>Policy and institutional framework for wood-based bioenergy industry</i>
Subsidies/tax incentives
Public participation in decision-making
Compliance with sustainable harvesting practices
Compliance with state and national regulations
Communication and reporting of management and operational decisions and plans
Continuous research
Regular monitoring
Maintain transparency in management/operation decisions
Collaborative learning, education, public awareness
<i>Consumers' concerns regarding bioenergy products</i>
Competitive cost
Compatibility with existing vehicle/technology
Convenience
Reliability (consistent supply of product)
Environment friendly
Efficiency
Renewable energy alternative

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