ABSTRACT

RADICS, ROBERT ISTVAN. Forest Bioenergy: Social, Environmental and Economic Perspectives. (Under the direction of Dr. Stephen Kelley and Dr. Sudipta Dasmohapatra.)

The goal of this paper is to examine sustainability impacts of forest bioenergy by determining social perspectives, and combining that with the economic and environmental impacts to evaluate tools that optimize these impacts. Public perceptions about bioenergy is used in this paper to understand how society perceives bioenergy impacts and a qualitative and a quantitative tool have been compared to optimize bioenergy sustainability.

A systematic literature review on stakeholders' perception of bioenergy resulted in 44 published articles between 2000 and 2013. Among stakeholder groups, the majority of studies (79%) focused on the general public's opinion about bioenergy. Overall findings show that the stakeholder groups show low to moderate support for the bioenergy industry. The results of the systematic review introduced in Chapter 1.

Based on the systematic review, an extensive survey of the general public was conducted in NC and TN in Fall 2013 and Spring 2014. The results from this study are presented in Chapter 2. Approximately, 586 consumers completed the electronic survey (376 NC, 210 TN). Solar and wind energy sources were mostly recognized as renewable compared to all other energy sources. The findings from this study highlight not only educational needs and outreach efforts but also reflect the need for trustworthy channels of communication, helpful policy, market, and institutional support for bioenergy success.

Chapter 3 includes an assessment of a qualitative tool to examine the social, economic and environmental impacts of bioenergy for a wood-to-pellet production case. A Multi-Attribute Decision Support System (MADSS) was used to analyze woody feedstock alternatives – naturally regenerated hardwood, plantation pine, and plantation poplar - for pellet production. Plantation pine were found the most sustainable, closely followed by natural hardwood. When analyzing economic criteria alone plantation pine and plantation poplar were found to have advantages over natural hardwood, due in large part to their higher growth rates. On both environmental and social indicators, natural hardwood was found to have a better footprint compared to the other two feedstocks.

A quantitative tool – linear programming - was used to optimize of forest biomass supply chain for bioenergy production. Two feedstocks (roundwood and wood residues), two products (white pellet, torrefied pellet), two markets (domestic, international), and two kinds of end use (power generating, heating) were optimized. The objective of this case study was to optimize the monetized social, environmental, and economic impacts of different alternatives, and analyze the trade-offs. The economic optimization resulted that the best solution was to use 1104 GBtu Roundwood and 474 GBtu forest residue feedstock for producing black pellet to the EU, for heating. The higher bioenergy prices in the EU and using the maximum capacity of the pellet mill resulted in $5.4 million profit/year. The economic and social impacts optimization differs from the economic in the achievable profit and rank of the scenarios. Although, roundwood costed more than forest residue, this payment was a social benefit for the local community, so the higher feedstock cost resulted in higher benefits together. Also, the higher feedstock demand for black pellet production made it more advantageous from socio-economic perspective. The economic and social optimization resulted in $19.8 million a year, what was almost four times higher than the economic benefit alone. Both socio-economic and the tri-objective (economic, social, and environmental) optimization found that black pellet production from roundwood to the EU market for heating is the most beneficial. Black pellet became even more advantageous because the higher energy density decreased ocean transportation costs, but also reduced the emission by transportation of energy.

Forest Bioenergy: Social, Environmental and Economic Perspectives

by
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DEDICATION

To my wife Beatrix, and our children - Reka, Barnabas, and Mate - who supported me patiently and understandingly in pursuing a Ph.D.

BIOGRAPHY

Robert Istvan Radics has specialized in sustainability, environmental protection and economics during his career.

He received an MS in Forest Engineering in 1994 and an MS in Environmental Engineering in 1996, both from the University of West Hungary. In 1998, he earned an MS in Economics from Budapest Business School.

His first job was an environmental expert in the largest mining plant of MOL Group from 1994-1999. From 1999-2006, he led the health, safety, and environmental protection department of MOL Group. MOL Group is an S&P 500 multinational petrochemical company. He was the chief executive officer of Geohidroterv Group from 2006-2011. He managed the turnover of the business, and he governed the company to the leading position of the Hungarian environmental remediation market. He has been a research and teaching assistant at North Carolina State University since 2012. His interest is a sustainable bioenergy industry, industry, and sustainable forestry.

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

LIST OF FIGURES

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

INTRODUCTION

Bioenergy had a leading role in energy till fossil energy sources took over this role in the 19th century. In the last decades, the advantages, opportunities, and possible negative impacts of growing bioenergy industry indicated an abundant research. The 2007 Energy Independence and Security Act (EISA) mandates the production and use of 36 billion gallons of bioethanol using renewable feedstocks by 2022. Of this, 21 billion gallons is required to be produced from a non-corn feedstock. The U.S. Department of Energy has also highlighted the potential for production of other types of bioproducts (e.g., chemicals) for a greener, low-carbon society (U.S. Department of Energy 2011). The One example of the rapid changes is US pellet production which has increased from 8.5 to 120 PJ (from ~380,000 metric ton to 5,345,000 metric ton) between 2000 and to 2010 (Lamers et al. 2012), and the trend expected to continue in the next decade. Clearly, biomass as a feedstock for bioenergy has a complex array of potential benefits and cost for the economy, environment and society (Scott et al. 2012).

Cambero and Sowlati (2014) conducted a literature review of the environmental, social, and economic optimization studies of the forest biomass supply chain by analyzing 54 assessment studies. They found that while there are a number of studies looking at the economic and environmental impacts and interactions of different bioenergy systems, the social impacts of forest biomass supply chain were not studied or optimized (Figure 21).

The successful growth of any new technology and its acceptance in the marketplace is not solely dependent on its technical and economic advantages, but also requires environmental and social acceptance. This is also true for new products such as bio-ethanol/diesel, wood pellets or other bio-products, where societal acceptance and cultural dimensions play an important role in a product's success in the marketplace (Miller and Lewis 1991, Rochracher et al. 2004, Dwivedi and Alavalapati 2009, Pacini and Silveria 2010, Halder et al. 2011).

This work looks at different levels public perception for bioenergy, and then uses qualitative and quantitative multi-attribute decision support tools to evaluate specific bioenergy production systems.

Chapter 1 is a systematic review of bioenergy perception studies and in Chapter 2consumers' perception of bioenergy in North Carolina and Tennessee is explored to define the perceived social impacts of bioenergy.

In Chapter 3, a qualitative tool, the Multi-Attribute Decision Supporting System (MADSS) is used to analyze social, environmental, and economic impacts of different feedstocks for bioenergy production.

In the last chapter (Chapter 4), a quantitative linear programming approach was used to optimize pellet production with consideration of social, environmental and economic benefits and costs.

CHAPTER 1

SYSTEMATIC REVIEW OF BIOENERGY PERCEPTION STUDIES

Robert Radics, Sudipta Dasmohapatra, and Stephen S. Kelley

This paper presents the results of a structured review of published articles that discuss stakeholders' perceptions of bioenergy, including both biofuels and biopower. An electronic search process using numerous key terms identified 44 peer-reviewed publications from 2000 to 2013 that focused on stakeholders' perceptions, understanding, and acceptance of bioenergy. These findings indicate that in the last decade the research community has been more active in publications focused on the societal and public perceptions of the bioenergy industry compared to prior years. Among the reviewed studies, most (84%) are based in the US and Europe, and only a few recent studies have focused on stakeholders in Asia and other parts of the world. This review revealed no standardized methods for evaluation of stakeholder perception, for data collection, or statistical analysis of the data. Among stakeholder groups, the majority of studies focused on the general public or the consumer's opinion about bioenergy (79% of studies). Overall findings show that the stakeholder groups show low to moderate support for the bioenergy industry. As anticipated, the stakeholder groups had varied views about the opportunities and risks associated with bioenergy industry, and these views varied based on their experiences.

Keywords: Systematic-review; Bioenergy; Perception; Stakeholders

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INTRODUCTION

In the last decade, societal acceptance and perceptions of bioenergy has become a significant area of research. This is evidenced by marked increases in publications in this area as seen in several journals focused on biomass and bioenergy as well as in grant proposals where social impacts are one of the key areas of focus. In addition to the traditional focus on technical, economic, and environmental aspects of bioenergy production, the knowledge and perception of the society and the social impacts are also the focus of many discussions as an integral part of successful diffusion of bioenergy in today's economy (Miller and Lewis 1991; Dwivedi and Alavalapati 2009; Halder *et al.* 2010; Pacini and Silveria 2010; McCormick 2010). Public perceptions about the opportunities and risks from the introduction of any new product in the marketplace are considered to be a key factor in avoiding market failures (Fry and Polonsky 2004; Rohracher *et al.* 2004; Verbeke 2007; Wegener and Kelley 2008).

While interest in the area of societal perceptions in bioenergy is evident, it is clear that in measuring public perceptions, the knowledge, opinion, and attitude of each of the dynamic stakeholder groups who may be directly or indirectly impacted by the industry need to be taken into account (Dwivedi and Alavalapati 2009; McCormick 2010; Johnston *et al.* 2013). In addition to the consumers (final users) and the landowners (feedstock suppliers), there are other stakeholder groups including industry personnel, investment groups, government, academia, non-profit organizations, policy makers, and other users (utilities and other industries) who may have an impact on the acceptance of bioenergy products in the marketplace. These stakeholder groups may have different, sometimes conflicting values and goals based on their involvement or level of interaction with the product, which should also be considered by the industry when investing in a facility or product commercialization (Johnston *et al.* 2013). For example, the landowners may be interested in a long-term contract for feedstock supply to bioenergy industry for economic stability, whereas the general public may be interested in the environmental impact more than the financial return to investors. Thus, each stakeholder group should be carefully identified to understand their level of understanding and risk perceptions.

To help understand how different stakeholder groups perceive the bioenergy industry, the present article presents a synthesis of publications on bioenergy using a systematic review approach. There are many excellent studies published in this area, although many studies have distinct conceptual and methodological limitations and do not report adequate detail to allow for a complete assessment of their reliability. Thus, a systematic review and synthesis of results is useful to better understand the commonalities, and differences, between the studies and to gain more complete insight into the relevant and reliable research rather than focus on a few individual studies or a small group of studies (Gough *et al.* 2012). As yet, there does not appear to be a review that has considered the bioenergy perception area from a broader perspective comparing different stakeholder groups and examining the range of research methodologies. The results of the synthesis will not only provide a summary of the current work on this topic in one place, but also present a more complete picture for investors and policymakers to make informed decisions.

We examine perception in this paper as a means of understanding behavioral intentions based on Fishbein and Ajzen's (1975) theory of reasoned action. The theory of reasoned action models intentions and behaviors as consequences of perception measured as attitudes and subjective norms. Attitude is defined as the evaluation of how favorable or unfavorable performing a particular behavior will be and perceived norm is the social pressure one expects regarding performing the behavior. In a recent publication (Fishbein and Ajzen 2010), the authors consider another type of perception "self-efficacy" that influences intention in addition to attitude and subjective norm. Self-efficacy is defined as the extent to which a person feels capable of performing a particular behavior.

Gibson (1969) was one of the first researchers to publish about the theory of perception learning and development by defining perception as the ability to extract information from a stimulus array. According to the author, perception guides action and is one of the important ways to understand behavior. Hemholtz (1971), another early leader of perception research, argued that perception is not direct registration of senses or stimuli but there are intermediate processes (such as inferential thinking) that allows for one to develop their perception. Using experiments, the author shows that the more perceivers have experience (engage in the activities), the more knowledgeable they are, and experience helps one to choose between two belief sets. The literature shows that perception is affected by a number of variables through the intermediate processes including a person's expectations (Vernon 1955), their emotion (Kunst-Wilson and Zajonc 1980), their motivation (Allport 1955), and culture

(Deregowski *et al.* 1972). The bioenergy perception analysis of stakeholders in this study includes some reflection on differences in demographics that may be impacted by the aforementioned factors.

OBJECTIVES

The goal of this article is to synthesize the results and findings from past studies focused on the perceptions of stakeholder groups about bioenergy using a structured systematic review. The specific objectives of this research include:

- Identifying experiments and methods used in the perception literature across papers;
- Examining the level of acceptance (positive or negative) toward bioenergy by the stakeholder groups;
- Identifying the perceived risks and opportunities in four specific subcategories (economic, environmental, social, and technological);
- Recognizing the challenges faced by researchers in conducting perception studies including the identification of areas that require further research.

METHODOLOGY

A systematic review was undertaken to analyze the literature on stakeholders' perception of bioenergy along salient dimensions of the research methodologies. The results from this review were then used to generate a meta-analysis of the knowledge that could be used to guide future perception research on bioenergy. Reviewing research systematically involves three key activities, including 1) identifying and describing the relevant research, 2) critically appraising research reports in a systematic manner, and 3) bringing the findings together to form coherent statements or themes, a process also called synthesis (Gough *et al.* 2012).

In order to find the available relevant literature on the perceptions of bioenergy stakeholders, pre-searches were run with various keywords in several different search engines (Internet Explorer, Google Chrome, Safari) to find relevant studies. Based on the methodology proposed by Moher *et al*. (2009), the steps for searching, extracting and including articles in our systematic review, is shown in Fig. 1.

Three methods were used for the article search including Google Scholar search motor for peer-reviewed studies, Web of Science, and two databases - CAB Abstracts and Summon Database (both databases contain records of books, articles, conference proceedings, thesis and dissertations, videos, *etc*.) Over 100 articles and documents were found that were focused on stakeholder perceptions of bioenergy using the keywords indicated in Figure 1 and based on the two criteria for inclusion of articles. Peer-reviewed articles published in English;

- Published articles between 2000 and 2013 (search was done mid-year in 2014).

The following criteria were used as additional filters for the inclusion of articles and publications found by the systematic literature review:

- Articles that include primary data collected;
- Articles are covering or discussing at least one stakeholder group.

The above criteria narrowed the focus to 52 articles, and a further examination of the articles led to the exclusion of articles focused on renewable energy other than biomass-based energy (solar, wind, tidal, hydrology) and those articles that did not allow for summarization of data. The final count of included articles was 44. The present findings are discussed based on the articles using the above methodology and focus on factors that are most significant for the bioenergy industry success in the marketplace. In doing so, ideas are systematically presented indicating that the bioenergy industry may or may not utilize them based on past literature without introducing any author bias.

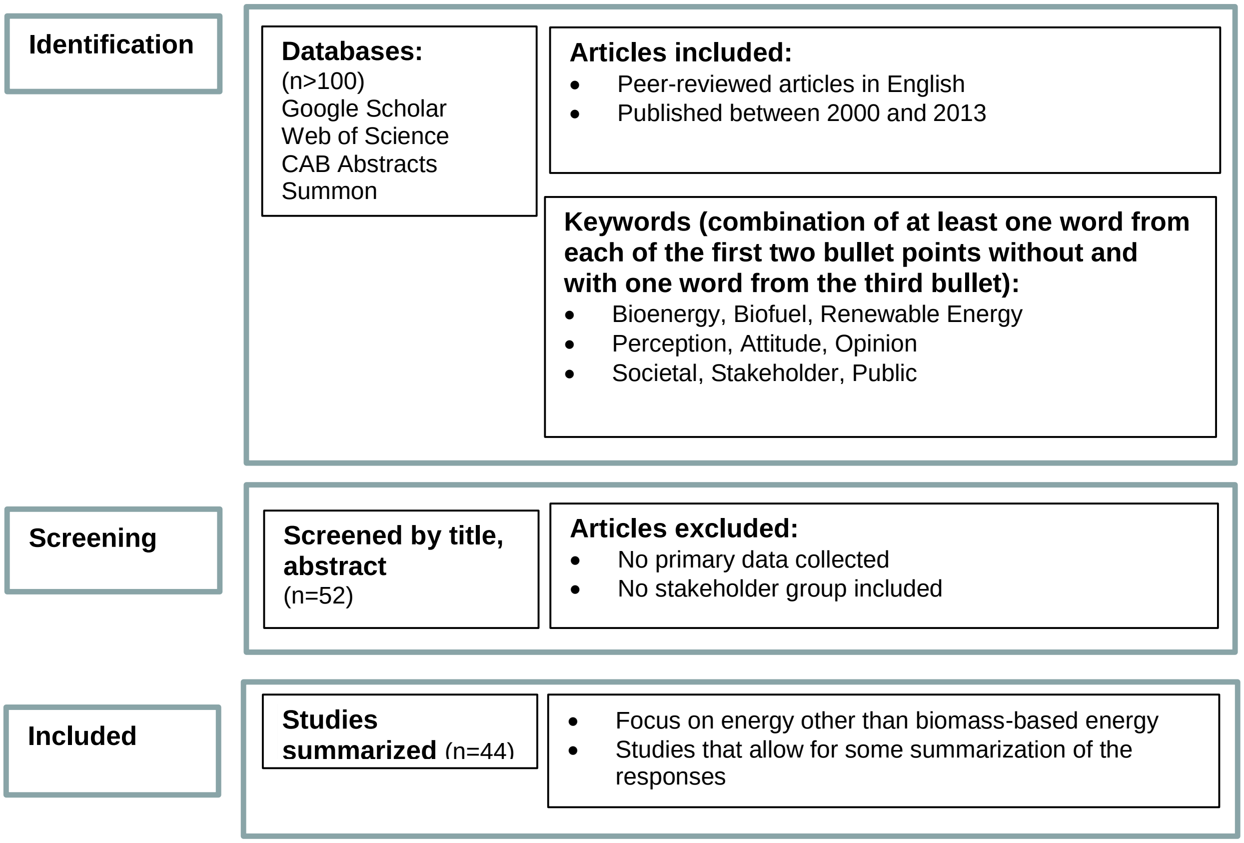

Figure 1 Methodology for Literature Search and Document Extraction

RESULTS

The 44 published articles based on the search criteria are presented in Table 1, with their authors, the year of publication, and the region represented.

Seven of the listed 44 articles focused on general renewable energy, instead of bioenergy or biofuels, specifically. However, they were included in our publication list of papers because they included bioenergy or biofuels, and respondents views on bioenergy or biofuels could be explicitly identified.

Table 1 shows an increasing number of publications focused on the stakeholder attitudes on bioenergy. The frequency of these articles increased rapidly in the late 2000s as researchers and industry recognized that public perceptions and acceptance were as important as technical and financial feasibility in the marketplace.

Table 1 Published Studies by Author, Year, Region, and Stakeholders

Index	**Author**	**Year Published**	**Country/Region (State if USA)**	**Stakeholders**
1	Aguilar and Cai	2010	USA (Across the Country)	General Public (n=217)
2	Aguilar *et al.*	2013	USA (Missouri)	Forest Landowners (n=607)
3	Bohlin and Roos	2002	Sweden – Europe	Forest Landowners (n=173)
4	Borchers *et al.*	2007	USA (Delaware)	General Public (n=128)
5	Cacciatore *et al.*	2012a	USA (Wisconsin)	General Public (n=556)
6	Cacciatore *et al.*	2012b	USA (Wisconsin)	General Public (n=593)
7	Delshad *et al.*	2010	USA (Indiana)	General Public (n=119 including 54 students, 65 citizens)
8	Dwivedi and Alavalapati	2009	USA (Southern States)	NGOs (n=7) Government (n=8) Industry (n=10) Academia (n=10)
9	Gautam *et al.*	2013	Nepal – Asia	Foresters (n=65)
10	Halder *et al.*	2013	Finland, Slovakia, Turkey – Europe; Taiwan – Asia	General Public (n=1,903, Students)
11	Halder *et al.*	2012b	Finland – Europe	Forest Landowners (n=79)
12	Halder *et al.*	2012a	Finland, Slovakia, Turkey - Europe; Taiwan – Asia	General Public (n=1,903, Students)
13	Halder *et al.*	2011	Finland – Europe; China – Asia	General Public (n=495, Students)
14	Halder *et al.*	2010	Finland – Europe	General Public (n=495, Students)
15	Hansla *et al.*	2008	Sweden – Europe	General Public (n=855)
16	Hartmann and Apaolaza-Ibanez	2012	Spain – Europe	General Public (n=726)
17	Hassan *et al.*	2013	Bangladesh – Asia	General Public (n=240)
18	Magar *et al.*	2011	Country Unspecified – Europe	Bioenergy Experts (n=92)

Table 1 continued

19	Mariasiu	2013	Romania – Europe	General Public (n=1,036)
20	Nyrud *et al.*	2008	Norway – Europe	General Public (n=808)
21	Panoutsou	2008	Greece – Europe	Farm Landowners (n=50) Industry End Users (n=15)
22	Paula *et al.*	2011	USA (Alabama)	Forest Landowners (n=363)
23	Paulrud and Laitila	2010	Sweden – Europe	Farm Landowners (n=988)
24	Petrolia *et al.*	2010	USA (Across the Country)	General Public (n=748)
25	Plate *et al.*	2010	USA (Florida)	General Public (n=298)
26	Popp *et al.*	2009	USA (Arkansas); Belgium - Europe	General Public (n=605, 242 in US, 363 in Belgium)
27	Qu *et al.*	2012	China – Asia	Forestry Professionals (n=74)
28	Qu *et al.*	2011	China – Asia	General Public (n=441, students)
29	Rogers *et al.*	2008	UK – Europe	General Public (n=29) End User Businesses (n=9)
30	Savvanidou *et al.*	2010	Greece – Europe	General Public (n=571)
31	Scarpa and Willis	2010	UK – Europe	General Public (n=1,279)
32	Selfa *et al.*	2011	USA (Iowa, Kansas)	General Public (n=661) Other Stakeholders (n=not reported)
33	Skipper *et al.*	2009	USA (Arkansas); Belgium – Europe	General Public (n=605, 242 in US, 363 in Belgium)
34	Ulmer *et al.*	2004	USA (Oklahoma)	General Public (n=685)
35	Upham *et al.*	2007	UK – Europe	Policy Makers (n=9) General Public (n=20)
36	Upham and Shackley	2007	UK – Europe	General Public (n=573)
37	Upham and Shackley	2006	UK – Europe	General Public (n=30, local community) Local government and industry (n=3)
38	Upreti and van der Horst	2004	UK – Europe	General Public (n=43) Other Stakeholders *** (n ~ >6, exact n not reported)
39	Van de Velde *et al.*	2009	Belgium – Europe	General Public (n=363)
40	Wegener and Kelley	2008	USA (across the country, States unspecified)	General Public* (n=1,049)
41	West *et al.*	2010	UK – Europe	General Public** (n~40-120, exact n not reported)
42	Zarnikau	2003	USA (Texas)	General Public** (n~ 1,400, exact n not reported)

Table 1 continued

43	Zhang *et al.*	2011	China – Asia	General Public (n=374)
44	Zografakis *et al.*	2010	Greece – Europe	General Public (n=1,440)

***** The authors collected data not specifically for their current article reported here but used their previously collected data instead to make observations about the topic under study
** The authors did not allude to the exact number of participants
*** Includes government personnel, some nongovernment and some industry personnel (exact n for each group not provided)

Approximately 9% of the articles were published between 2000 and 2004, and 30% between 2005 and 2009; 61% of the scientific peer reviewed articles included in this meta-study were published between 2010 and 2013, with a spike in 2010 (Fig. 2).

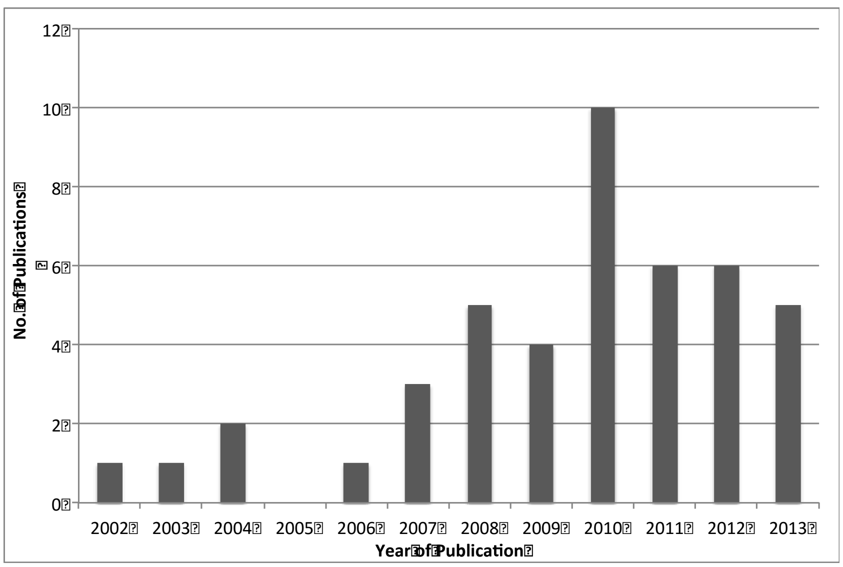

Figure 2 No. of Publications by Year

Approximately 57% of the published studies during the years 2000 to 2013 were based in Europe, about 36% in the US, and 16% in Asia. Of these, four articles compared attitudes of stakeholders in two or more regions (Europe and Asia in 2 articles and Europe and USA in 2 articles) as shown in Table 1.

A regional comparison of the articles showed 50% of the papers from US (n=16) with a focus on US South, 31% with a focus on US Midwestern states, and the rest with a focus on stakeholders across the US. Similar regional comparisons showed 96% of papers in Europe (n=25) with a focus on Western European stakeholders and 71% of papers in Asia (n=7) from Eastern Asian countries (*e.g.*, China, Taiwan).

The most analyzed stakeholder group in our list of articles was the general public or the consumer group (Table 1), which was reported in over 79% of the articles (n=34). Of these articles, six collected data from student groups with four articles focused on students with an average age of 15 years. The forest and farm landowners were the focus in 16% of the articles, followed by government or policy makers in 9.3% of the articles. Other stakeholder groups including non-government representatives, bioenergy plant/manufacturing representatives, employees in bioenergy plants, industry end-users, academics, *etc.*, made up the stakeholder focus in 19% of the studies. Seven articles included perceptions drawn from multiple stakeholder groups.

Data Collection Methods and Sampling

Table 2 shows the data collection methods used in the articles. About 73% of the reports used mail or electronic surveys, with interviews (face-to-face or telephone) being the second most common at 21%. A mixture of the two approaches was used in two studies. If an article included more than one stakeholder group, they usually used different data collection methods, and both the data collection methods were included in Table 2. For example, if a publication included both a general survey for input from the public at-large and the focus group with landowners it is treated as two observations.

There was substantial variation in the size of the respondents, with the mean number of respondents slightly above 600, and a median of 374.

The response rates were specified in 28 articles, with the mean of 38% and the median around 39%. Over 80% of the studies used a small geographical (local/ county/ village/ school) focus or sub-population *e.g*., students, drivers at gas stations.

Table 2 Data Collection Method

Data Collection Method	**% Publications* (No. of Publications)**
Survey (mail or computer-assisted)	73% (n=32)
Interview (face-to-face, telephone)	21% (n=9)
Focus Group	9% (n=4)
Mixed (survey, interview, face-to-face)**	4% (n=2)

* Numbers do not add to 100% because some articles (n=7) collected data from more than one stakeholder group with each group having a different data collection method reported here.
**Method is only considered mixed if more than one type of data collection method is used to generate output for the same stakeholder group in an article.

Demographics and Product Focus

Given the topic of the systematic review, most studies collected data on respondent attitudes, perceptions, and knowledge. Two publications were focused on respondent behavior (namely, what type of sources of information they used for biofuels/bioenergy information gathering, and what daily activities did they engage in that had green/low environmental footprint), and five articles focused on willingness to pay for biomass-based power or biofuels. One study also focused on willingness to supply biomass to the bioenergy industry. Table 3 shows the product/application focus in each article by region.

Table 3 Product/Application Focus of Perception Studies by Regions

(% of publications)

Product/Application on Focus in Publications	**USA (n=16)**	**Europe (n=25)**	**Asia (n=7)**	**% Total Publications* (n=44)**
Biofuels for transportation	36%	20%	14%	25%
Forest Bioenergy	18%	8%	43%	18%
Bio-power (electricity production)	13%	20%	0%	16%
Bioenergy for heat/power	0%	20%	0%	14%
Biofuels (unspecified and for heat/power)	25%	4%	14%	11%
Bioenergy (in general, unspecified)	0%	24%	29%	11%
Renewable energy in general (solar, wind, *etc*., including bio-mass-based energy)	6%	4%	0%	4.5%
Total	100%	100%	100%	100%

Note: Two studies were in Europe and the US, and two includes Europe and Asia.

About 4.5% of the articles were about renewable energy sources (including solar, wind, hydro, and included biomass-based energy). Bio-power was the focus of 16% of the articles (n=7). Biofuels were the focus in about 36% of publications (n=18), with 25% focused on biofuels for transportation and (n=12), and 11% focused on bio-power or heat (n=6). Bioenergy was the focus of 19 publications including 18% with a focus on forest bioenergy (n=8), 11% about bioenergy for heat or power (n=5), and 18% of the articles that did not specify the specific application of bioenergy (n=8).

Demographic information was reported by 31 studies, with gender, age, and education being the most commonly reported data (Table 4). For the studies that reported demographics, 62% of the respondents were male, the mean age was 45 years (22 articles excluding four articles specifically focused on students), and 56% of respondents had a college degree or higher in publications (n=12). Other demographics such as income, percentage of rural respondents, number of people in the household, area of land owned, and political affiliations were infrequently included.

Table 4 Most Common Demographic Data in articles (n=31)

Average demographics (or most frequently included demographic characteristics of the studies)	**Mean or most frequent**	**No. of articles reporting demographics**
Age	Mean age=44 years*	26
Gender (males)	Mean %=61.7%	26
Education	Mean % having at least a college degree = 56%	12

Note: *five studies reported median age or most frequent age group (the median was considered an approximation of the average and the center of the most frequent age group was taken to represent the mean age.

About 4.5% of the articles were about renewable energy sources (including solar, wind, hydro and included biomass-based energy). Bio-power was the focus on 16% of the articles (n=7). Biofuels were the focus in about 36% of publications (n=18), with 25% focused on biofuels for transportation and (n=12), and 11% focused on bio-power or heat (n=6). Bioenergy was the focus of 19 publications including 18% with a focus on forest bioenergy (n=8), 11% about bioenergy for heat or power (n=5), and 18% of the articles that did not specify the specific application of bioenergy (n=8).

Findings by stakeholder groups

General Public

The findings from the articles focused on the general public are provided in Table 5.

Bioenergy support and opposition

The general public is relatively unfamiliar with biomass energy, which explains their lack or lukewarm support to bioenergy (Upreti and van der Horst 2004; Upham and Shackley 2007; Dwivedi and Alavalapati 2009; Popp *et al.* 2009; Savvanidou *et al.* 2010; Halder *et al.* 2011; Mariasu 2012). The level of support of bioenergy/biofuels did not vary between geographical regions. Support or opposition to bioenergy was found to depend on many factors including respondent knowledge and opinion of various attributes, demography, and their experience with renewable energy in the past, and their exposure to the media. The findings from the articles show that the public support is moderate to low toward bioenergy and biofuel industry. However, greater enthusiasm is shown for second-generation biofuels (from cellulosic feedstocks) when the public is informed about them. The level of bioenergy support did not differ among articles across the years (we looked for differences between articles published before 2010 and those published in 2010 and beyond). Additonally, respondents across almost all articles indicated having low knowledge and awareness of bioenergy.

Attributes driving opinion about bioenergy (purchase/use)

Each article included information on how various *attributes of bioenergy* helped in shaping consumer's opinion about it either for purchase or use. Half of the studies measured these attributes/factors relative to gasoline or power, while other studies asked for the consumers' attributes on bioenergy in isolation. Nevertheless, there were no consistent differences in the findings about the important attributes among these studies. Studies show that the most important attribute that drives consumer opinion of bioenergy is economics, specifically the **purchase price** of bioenergy products (Zarnikau 2003; Panoutsou 2008; Popp *et al.* 2009; Savvanidou *et al.* 2010; Mariasu 2012). Respondents have the perception that bioenergy may cost them more than alternative products and indicate their unwillingness to pay a premium. Additionally, consumers indicated they are likely to use biofuels (bio-based transportation fuels) on the precondition that it does not have an adverse impact on their vehicle performance or damage their car. Consumer stakeholders were also skeptical that bioenergy industry can create any significant economic impact on development in rural areas. In addition to concern over **biofuel impact on vehicle functionality** (Delshad *et al.* 2010; Savvanidou *et al.* 2010; Mariasu 2012), people are concerned about bioenergy systems competing with food systems and that increasing bioenergy production will increase the price of food (Dwivedi and Alavalapati 2009; Popp *et al.* 2009; Halder *et al.* 2011). Thus, in a few articles, support to bioenergy was based on the precondition that bioenergy does not **compete with**

existing food supply and price. People were not in favor of increasing food prices to lower fuel prices. This finding was primarily limited to the US-based articles.

All articles reported consumer perceptions of **environmental impacts** of bioenergy. Concern for environmental benefit or impact of bioenergy in all studies was ranked lower than the concern for the price of biofuels and the effect of biofuels on vehicle functionality and efficiency. In over two-thirds of the articles, the general public considered bioenergy to be less detrimental to the environment. This lower environmental impact was reported largely in articles that compared perceptions of bioenergy environmental impacts to that of gasoline. The general public supported bioenergy if it leads to conservation of natural resources and low impact on green spaces across all geographies. Articles that considered public perceptions of communities that might host bioenergy plants are summarized later, and these articles highlighted some key, localized environmental issues such as odor, air pollution or truck traffic that would impact the local community (Delshad *et al.* 2010; Savvanidou *et al.* 2010).

Another factor included in articles is the public perception of bioenergy for improvement in **national security** (Dwivedi and Alavalapati 2009; Delshad *et al.* 2010). Consumers in some studies ranked this factor among other important factors such as environmental impacts of producing and using energy, while in others, it was not important at all in shaping the public's opinion about bioenergy. The importance of national security in consumer's bioenergy perception was only true for articles in the US and Asia but not in Europe.

In one-fifth of the public stakeholder-based articles, perceptions about the state of bioenergy technology were measured. Most articles reported that a large majority of stakeholders were not aware of and knowledgeable about the technologies used for production of bioenergy. When aware, respondents indicated that bioenergy *technology* was relatively weak and was not mature enough to warrant their support towards renewable energy projects.

Other factors such as creation and **increase in jobs and rural development** due to bioenergy and subjective norms were found to be important to consumers in a few studies. Subjective norms are people's perception of how the society views their actions, and this factor had a positive impact on their willingness to support bioenergy. Citizens favor small-scale local facilities to large bioenergy facilities, and their perception was guided by whether jobs will be created. Policy measures such as government regulations that mandate the use or production of biofuels was not ranked highly, and in fact, some studies in Europe show that government interference in this market is not well liked by the consumer groups (Upham and Shakeley 2007; Upham *et al.* 2007.) Additionally, government subsidies along the supply chain are not favored by the consumers.

Students (below 18 years of age) (n=6 articles) appear to have poor understanding of bioenergy and view bioenergy more negatively (especially for issues related to forest-based feedstocks) compared to other general consumer groups. Student opinions were mostly guided by their perceptions of the socio-environmental aspects of bioenergy (Halder *et al.* 2012a, 2013).

Of the 34 articles, seven measured perceptions of communities around planned bioenergy plants and current bioenergy pilot plant. These community perceptions have been separately examined in this work, as these communities are a specific subgroup of the general public, have prior experience, and are arguably, more informed compared to the general public. The following are the findings from these studies:

- The public sentiment toward ethanol or gasification plants in their communities ranges from neutral to negative (Zarnikau 2003; Delshad *et al.* 2010; Savvanidou *et al.* 2010; Zhang *et al.* 2011). Among the advantages cited by respondents were the modest economic benefits to community, the opportunity for jobs creation (although most respondents indicated the jobs would not be able to reduce poverty), positive disposition towards reduced emissions from bioenergy, and possible improvement in farmer's income. Respondents favored small-scale facilities over larger facilities, given that they will conserve natural resources and provide benefits such as solving local energy issues, growth in local employment, and allowing agricultural diversification. Large-scale plants should be sited outside of the rural habitation (preferably, existing industrial zones or commercial forest areas), according to citizens in four studies. Institutional support from local authorities is considered to be favorable for supporting bioenergy plants in the local area (Zarnikau 2003; Delshad *et al.* 2010).
- Siting decisions were the most common issues of concern to host communities (Upreti and van der Horst 2004). The respondents were unhappy that they were

not consulted before siting decisions for pilot plants were taken in their community. In addition, there was widespread concern about the future viability of the pilot plants and impacts of the future declines on the community once a pilot plant is on the ground. Almost all participating respondents indicated concern about pollution and odors from the plants, and traffic issues due to truck movement. Increased competition for water resources from other needs of the town/city as an impact of bioenergy plant needs was mentioned. People reported distrust for the developers and a lack of complete information about issues related to bioenergy plant locations (Upham and Shackley 2007).

Demographic effects

When looking at findings from the articles about the impact of demographics on shaping people's opinions about bioenergy, it was found that most studies measured and reported gender, age, education, and political affiliation (Table 5). Only a few studies also indicated income and number of people in the household, and these attributes were not included with enough frequency to allow for a quality analysis. Men were self-identified to be more knowledgeable about bioenergy issues than women across all regions. However, women were reported to be more likely to be supportive, to consider the benefits to be greater than the risks, and willing to pay a premium for bioenergy (Mariasiu 2013). Younger (less than 30 years of age) respondents were more likely to have a positive disposition towards bioenergy (power or fuel) than the older respondents (Zarnikau 2003). Articles published in the US showed that

Democrats were more likely to have a favorable outlook towards bioenergy technology and report concern about the environment than Republicans. The political content of media mostly affects this perception (Cacciatore *et al.* 2012a). The rural public is more likely to believe that bioenergy will produce jobs in rural areas and will benefit farmers. There were no consistent trends in the studies regarding the effects of respondent education in shaping consumer's opinion on bioenergy (Popp *et al.* 2009). Some studies showed that people with more educational credentials tended to be more supportive of biofuel while others found that higher education leads to more concerns about perceived risks of bioenergy. These differences were apparent among consumers within the US as well as in Europe.

Table 5 Perceptions of General Public (n=34 articles)

Focus Areas	**Key Findings**
Bioenergy general support/opposition	• Moderate to low support towards bioenergy (Zarnikau 2003; Delshad *et al.* 2010; Savvanidou *et al.* 2010; Zhang *et al.* 2011) • Public is relatively unfamiliar with the bioenergy industry and associated impacts (Upreti and van der Horst 2004; Savvanidou *et al.* 2010; Zhang *et al.* 2011) • Greater enthusiasm for second generation biofuels (Delshad *et al.* 2010; Zhang *et al.* 2011) • Support/Opposition depends on respondent awareness and knowledge, opinion on various attributes of product use, experience with renewable energy projects, and media exposure, among others (Upreti and van der Horst 2004; Halder *et al.* 2011, 2013) • Support is preconditioned on many factors/attributes around the application (Savvanidou *et al.* 2010)

Attributes driving opinion about bioenergy (purchase/use)	• Economic attributes: Price is the primary driving factor (Borchers *et al.* 2007; Savvanidou *et al.* 2010)
	  ○ Low willingness to pay (WTP) any premium for bioenergy use
	  ○ WTP depends on prevailing fuel/energy price
	• Market attributes: Low cost, consistent availability, performance of biofuels (on vehicles), effect on food availability and food price important (Popp *et al.* 2009; Savvanidou *et al.* 2010)
	• Technology and policy attributes: Biofuel and biopower technology is perceived as relatively immature; citizens do not favor subsidies along the supply chain and oppose regulations for green energy use (Delshad *et al.* 2010)
	• Environmental attributes: Environmental attributes are important only when compared to fossil fuels, odor or air pollution more important than other environmental factors (Delshad *et al.* 2010; Savvanidou *et al.* 2010)
	• Social attributes: Jobs and national security not as important as market factors; societal subjective norms important; local generation at small scale is perceived positively; institutional support (local authorities) is perceived positively (Delshad *et al.* 2010)

Demographic effects	• Females more likely to support bioenergy (Mariasiu 2013) • Younger generation more likely to support bioenergy (Zarnikau 2003) • Inconsistent relationship between education and support and perceptions of risk associated with bioenergy (Popp *et al.* 2009)
Feedstock preference	• Prefer feedstocks that have least impact on natural resources (Borchers *et al.* 2007; Delshad *et al.* 2010) • Prefer other renewable sources (solar, wind) over biomass (Borchers *et al.* 2007) • Disagreement over importance of grass and wood including wood residues for bioenergy
Information channels	• Mass media preferred by public (Delshad *et al.* 2010) • Utility companies ranked second (Borchers *et al.* 2007)
Other issues	• Siting issues are a challenge (Upreti and van der Horst 2004) • Not informed or no knowledge of bioenergy effects on environment (Upreti and van der Horst 2004).

Note: The findings noted in the above are only included if they are included in two or more papers or if adequate relevance is found regarding the focus areas.

Feedstock preference

Approximately 70% of the articles with respondents from the general public measured perceptions of different renewable energy sources including solar, wind, geothermal, hydro, and biomass. Studies across geographies overwhelmingly found that people support solar, wind, and hydro-based renewable sources more than any of the other sources of energy. In fact, biomass was ranked lowest of all sources in many studies (Borchers *et al.* 2007; Delshad *et al.* 2010; Halder *et al*. 2010, 2011). Respondents across the studies disagreed over the importance of biomass sources, such as grass and wood in generating renewable energy. Among biomass, corn stover and wood waste ranked higher than other sources (Delshad *et al.* 2010). Although studies show that grasses are viewed positively, the grass was ranked low relative to other feedstocks; the lack of agreement could be a characteristic of lack of knowledge about this source (Upreti and van der Horst 2004; Halder *et al.* 2011, 2013). Trees or wood as biomass sources were ranked low, and the respondents cited a lack of knowledge of how the harvest would impact the availability of green spaces, worry about loss of forest cover and other environmental impacts, and concern for sustenance of the forests as more and more wood was extracted. In summary, the preference for the biomass source closely coupled to how its use impacted the environment and the potential depletion of natural resources (Delshad *et al.* 2010; Savvanidou *et al.* 2010).

Other issues

One additional clear conclusion was the respondents' interest in becoming more informed about the effects of bioenergy and biofuels on the environment, and they were interested in receiving information. It is interesting to note that many respondents do not even have clear understanding of what defines a renewable resource, and whether wood and biomass resources are better or worse than coal, oil or natural gas.

Information sources

The studies that measured sources of information that the general public used for bioenergy and biofuels, found mass media (TV, newspapers) as the most important channels followed by utility companies. Note that the internet was not among the top-ranked media channels for information.

Landowners

The findings of the articles focused on the landowners are provided in Table 6. This table includes perceptions of both farm and forest landowners.

Landowners were moderately supportive of bioenergy primarily due to their perception of its positive impact on employment and rural economic development (Panoutsou 2008; Paulrud and Laitila 2010; Paula *et al.* 2011; Aguilar *et al.* 2013). Landowners indicated support for the bioenergy industry if it created rural employment and economic development. However, almost all landowner respondents indicated concerns about the long-term viability of the bioenergy industry (Paulrud and Laitila

2010). Both farm and forest landowners were concerned about the impacts such as loss of soil fertility if energy crops are grown or if thinned materials are removed from forest floors (Panoutsou 2008; Aguilar *et al.* 2013). National security and independence from foreign oil imports was not a major factor in decision-making to supply biomass for bioenergy. Lack of bioenergy market structure, lack of land availability, and no commercially successful examples of pilot plants were reported as the primary barriers to supplying to the energy industry.

Table 6 Perceptions of Landowners (n=7 articles)

Focus Areas	**Key Findings**
Bioenergy general support/opposition	• Moderate support for bioenergy (Panoutsou 2008; Paulrud and Laitila 2010) • Concern about long-term viability of the industry (Paulrud and Laitila 2010) • Positive opinion on employment, rural economic development (Panoutsou 2008; Paula *et al.* 2011; Aguilar *et al.* 2013) • Concern over environmental impacts of bioenergy (Panoutsou 2008; Aguilar *et al.* 2013)
Factors affecting barriers to supply	• Lack of market structure (Panoutsou 2008) • Available land to dedicate to energy crops (Panoutsou 2008) • No commercially successful examples (Paulrud and Laitila 2010) • Barriers to adoption of forest management plans (forest) (Aguilar *et al.* 2013) • Depressed prices for wood (forest) (Aguilar *et al.* 2013) • Loss of soil fertility (Panoutsou 2008; Aguilar *et al.* 2013)
Factors driving supply/harvest	• Higher price of energy crops vs. food or pulpwood prices (Paulrud and Laitila 2010; Aguilar *et al.* 2013) • Low investment cost (Paula *et al.* 2011) • Long term guaranteed contracts with fuel suppliers (farm) (Panoutsou 2008)
Demographic effects	• Those with large land area more likely to supply (Paulrud and Laitila 2010) • Older landowners are more skeptical of the viability (Paulrud and Laitila 2010)
Other	• Low awareness of benefits and bioenergy policies affecting landowners (forest) • Tax exemption not as important as price (forest) • US independence from imports of foreign oil not important

Landowners considered a higher price of biomass for energy compared to current uses as the most important factor driving their intentions to supply and produce biomass for bioenergy (Paulrud and Laitila 2010; Aguilar *et al.* 2013). They were also interested in supplying if it required low investment cost, used conventional equipment for establishment and harvesting (farmers), availability of forest-to-energy certification schemes (forest), and long-term guaranteed contracts with the biorefinery (Panoutsou 2008; Paula *et al.* 2011). The forest landowners indicated that certification of lands and tax exemptions from the government were not as important as the price of wood-derived energy. However, if forest-based bioenergy certification schemes were in place, they were perceived as helpful to increase market possibilities of forest biomass to energy as well as to improve management practices. In addition to concern over loss of land productivity associated with producing forest biomass, forest landowners were worried about changes that might be required for implementing forest management plans.

Farm landowners reported that long-term, guaranteed contracts with fuel suppliers, would increase their interests in producing and supplying energy crops, and they were even willing to consider a minimum loss in income in exchange for certainty (Panoutsou 2008). For farm landowners the local cooperatives should act as contract coordinators so farmers can receive support and guidance. They also indicated the need for some compensation or financing if conventional farm equipment cannot be used for bioenergy crops, and incentives to plant perennial energy crops with longer rotations. This incentive could come from the government or the industry.

Forest landowners reported limited awareness of the government programs that provided benefits for producing biomass and bioenergy, and were interested in learning more about bioenergy policies affecting them. A majority of farm landowners showed interest in planting energy crops, and as long as markets were available they were not concerned with whether the biorefinery was locally owned or not.

Demographics

The articles considered did not find any geographical difference in the perception of landowners about bioenergy. Landowners from the US, Europe and Asia stated lack of awareness, depressed price for bioenergy and land management needs as important barriers for bioenergy adoption. Landowners with larger land area responded positively to bioenergy because they can afford to take the risk (of part of land dedicated to energy crops). Older landowners were more skeptical of and less willing to produce biomass for energy relative to all landowners (Paulrud and Laitila 2010).

Female forest landowners, as well as those with lower levels of education, were more inclined to supply to the bioenergy industry (Halder *et al.* 2012b). They also favored government intervention in wood energy market more than others.

Government/Policy Makers (n=4 articles)

Government and policy makers (two articles included local government officials, and two did not define the type of government or policy makers) seemed to favor bioenergy in the four articles that included these stakeholders. According to these respondents, energy security and rural development with technology deployments are critical to success, followed by environmental factors such as reducing greenhouse gasses. This group perceived technological improvements leading to a successful demonstration at the ground as key to spur interest and growth in this industry. The government representatives also favored local biofuels plants as they have the potential to create stable jobs and communities. These stakeholder groups that it was essential that bioenergy did not compete with food production.

Forestry Professionals (n=2 articles)

Forestry professionals (in one article, forestry professionals were those employed in the forest service and in another, they were reported as foresters) were not completely informed about bioenergy and thus, were skeptical about its importance. They viewed wind and hydropower as better sources of renewable energy but believed that forest bioenergy has the potential to mitigate climate change. In order to be successful bioenergy has to be promoted as environmentally sound, and consistent with a sustainable forest management plan. They indicated interest in learning more about forest bioenergy. They favored partial reliance on support and subsidies from the government.

End-user Industries (cotton farmers and wood manufacturing units, n=4 articles)

This group was somewhat aware of biomass-based energy. They indicated interest in using bioenergy in their operations for heating. In some cases these groups considered bioenergy to be a competitor to the traditional forest products markets.

However, they recognized that in specific sites that bioenergy could have a positive impact on rural development and national security.

NGOs (n=2 articles)

NGOs (type of NGOs not defined in either article) consider rural development and environmental impacts as the most important opportunities and challenges for biomass-based energy. They also indicated that government support and commitment was important for the success of this industry. Risks and barriers perceived by them included uncertainty regarding markets and lack of commercial technology.

Academia (n=2 articles)

Competition from other renewable energy sources was reported as a threat to biomass power, and rural development and energy security were reported a opportunities. The academic community did not consider the environmental impact of bioenergy as a primary driver or barrier to the success of bioenergy. However, the absence of a competitive market, a lack of the certification system, and reliable technology were noted as significant barriers. Certification systems were viewed as necessary for sustainable production and use of biomass. This group also indicated the importance of bioenergy awareness programs to encourage bioenergy usage.

Table 7 Perceptions of Other Stakeholders (n=12 articles)

Focus Areas	Key Findings (where applicable)
Bioenergy general support/opposition	*Government /Policymakers*: Strong to moderate support towards bioenergy *Forestry professionals*: Skeptical about bioenergy, at best *Non-Government Organizations (NGOs)*: In favor of forest bioenergy (Dwivedi and Alavalapati 2009)
Strength of bioenergy	• Potential to create jobs, revitalize rural economy, lead to energy security (government, end user groups, NGOs, academia) (Dwivedi and Alavalapati 2009) • Mitigating climate change (forestry professionals)
Barriers to development	• Technology still under trial (government, NGOs) (Dwivedi and Alavalapati 2009) • Partial reliance on support and subsidies from government (forestry professionals) • Bioenergy threat to current forest products markets (end-users) • Uncertainty regarding markets (NGOs, academia) • Competition from other renewable sources (Academia) • Lack of certification systems governing bioenergy (academia)
Other	• Government support and commitment was important for the development of this industry (NGOs) (Dwivedi and Alavalapati 2009)

Factors Likely to Promote Success of Bioenergy industry

Based on the above discussion, there are several critical issues and factors that are likely to promote success that are outlined in Table 8.

Some of the key areas of focus for the general public to mitigate the risk perceptions and promote success are the following:

- Education and information dissemination: Limited public understanding of bioenergy and biomass technologies is evident from the included articles. This finding emphasizes the need for raising awareness for all citizens concerned with renewable energy sources and their link to general issues such as climate change and also to local issues, *e.g.*, rural income and community stability. One of the advantages of education is that people are willing to be engaged in the decision-making process. When designing campaigns, public authorities and bioenergy producers should consider issues such as the concerns of bioenergy use and conservation.

- A collaborative approach to decision-making: Stakeholders expect to be included in truly collaborative planning, interactive communication, public participation, and collective learning processes. Siting decisions for plants require situation analysis, *e.g*., what are the expected benefits and concerns, who are influential decision makers, how they see the proposed development, how can local interests be effectively represented, *etc.* for a local community. Institutional support from local authorities is also important for community-based renewable energy projects to be successful.

Table 8 Factors Likely to Promote Success by Stakeholder Groups

Key Stakeholders	Factors Likely to Promote Success
General Public	• Need for consistent and simple messages across channels from trusted sources (Upreti and van der Horst 2004; Halder *et al.* 2011; Halder *et al.* 2013) • Collaborative planning process that includes integration of local information into project design and consulting from local experts (enhancing security at local level- energy, health, safety) (Delshad *et al.* 2010)
Farm/Forest Landowners	• A model showing successful deployment at a small scale (with network of collaboration) essential (Paulrud and Laitila 2010) • Development of certification standards and labeling (Qu *et al.* 2012) • Institutional support (local government, local landowner associations) (Paulrud and Laitila 2010) • Education about production and economics (from extension agents) (Paulrud and Laitila 2010)
Others	• Education is key (Dwivedi and Alavalapati 2009) • Proper management of land

DISCUSSION

The present analysis of the literature highlights a lack of standard methodologies for both surveys and analyses. Wegener and Kelley (2008) indicate that when trying to understand people's attitude about the adoption of a particular bioenergy technology, an analysis of social norms (*e.g*., group norms endorsed by others) created by the actions of those in the local environment are extremely important. According to the authors, social norms are even more powerful in situations that are ambiguous (absence of factual information), as in the case of bioenergy. Thus, in the adoption of new technologies such as cellulosic ethanol purchase for vehicles, for example, people may look toward the norms of important reference groups, and those reference groups need to be identified in further studies.

Further, almost all papers included in this review measured attitudes; however, identifying attitudes is just the first step in predicting people's behavior in the future, according to the attitudinal behavioral theory (Fishbein and Ajzen 2010). Not all attitudes have a similar influence on behavior. For example, positive attitudes are more likely to guide future behavior (use of ethanol) if they are based on experience (actual driving of a car with ethanol) (Fazio and Zanna 1981; Wegener and Kelley 2008) or when people are constantly reminded of the issue (Fazio 1995). Thus, identification and classification of positive and negative attitudes will be key for guiding the behavior of each stakeholder group involved in the bioenergy industry.

The systematic literature review of previous studies points in one direction –toward stakeholder perception measured through surveys and focus groups – to reveal that bioenergy or biomass-based energy score low to moderate in stakeholder's cognition, and this difference is highlighted when compared to other renewable energy sources such as solar, wind, or hydropower energy. Penetration of these other sources of energy into the market for a long time, as well as media reports on biomass-based energy (notion of bioenergy placed within the context of climate change, carbon footprint, depleting fossil fuel, forest cover, global warming, *etc*.) is perhaps responsible for lack of knowledge and increasing consumer confusion. Nevertheless, based on the studies cited in this work, educating the public about these issues is an important precondition before achieving societal acceptance so that the renewable energy targets can be met. Although education is key, it is important to keep in mind that there are not enough real life examples to create a change in public attitude towards bioenergy, because there are relatively few opportunities to support bioenergy or to have a direct experience with bioenergy (either for heating homes or use in cars), and thus, there is not enough information to create a change in public thinking. Thus, creating a simple and consistent message without too many complex related issues is key to increasing public acceptance as the bioenergy industry moves towards growth and commercialization.

In this respect, the first challenge to overcome is to find a location for a project that can exploit the benefits from the project (Raven *et al.* 2007). The found location should be followed by a collaborative articulation of benefits and risks to stakeholders by bringing together the local community, industry, non-government organizations, local government officials, *etc.* in the same forum. These processes will help in facilitating early stakeholder involvement in projects and in creating a clear structure of expectations and communication of these benefits and risks. Raven *et al.* (2007) also discuss that different technologies and projects will have different key stakeholders with different needs and concerns that will guide social acceptance. This result is also true in the present findings. For example, this systematic review shows that each stakeholder group and categories within stakeholder groups (students *vs.* local communities) have varying awareness and understanding of factors that drive success of bioenergy with respect to siting of plants and managing needs vis-a-vis economic, environmental, and social issues. Thus, a one-size-fits-all model of communication will not work. Greater efforts must be placed on early stakeholder involvement and interactive communication with the target audience, particularly opinion formers. Creating socially acceptable projects that are locally embedded, provide local benefits, establish a continuity with existing physical, social and cognitive structures, and apply suitable participation procedures will be the key to success for the bioenergy industry.

The present systematic literature review found articles that show that as society looks toward continued investment in bioenergy, public acceptance will be essential and perception barriers should be accounted for in addition to the market infrastructures, financial, regulatory, and institutional barriers.

Limitations

Based on the results and discussions, we identify several gaps and limitations in perception research:

- Lack of surveys of all stakeholder groups in the same study;
- Lack of pre-biofuel implementation surveys and dynamic analysis based on measures and evaluation of the projects;
- Lack of focus on social impacts;
- Focus on bioenergy in general but less focus on specific product groups such as bioenergy for pellets or biofuels for transportation.

Future Research

The above limitations and gaps could be successfully utilized in future research for a more comprehensive understanding of the different stakeholder groups and the general public. For example, perception studies should target different stakeholder groups to get an overall understanding of all stakeholder groups. Venture capital firms and investment firms did not show up in the present findings; however, they are an important group of stakeholders who could help in the successful deployment of commercial pilot plants and should be included in the future research on bioenergy perceptions. There is a need to look at certification and labeling criteria for biomass–based energy and how that can help at each level of the supply chain. In addition, because bioenergy perceptions are formed based on media content and delivery, another important area of research could be on bioenergy based media content and informational content analysis (*e.g.*, what is the biofuels media exactly covering).

Additionally, while economic and ecological criteria are easy to measure, there is wide variation in the nature of the social indicators of success of technology. Quantification of social impacts of bioenergy such as ensuring equitable benefits and risks or improved or depleted the quality of life are difficult, as well as vary based on region, location or context of the study. Standardized indicators of social success criteria for bioenergy by a participatory process of involvement of key decision makers at the local level, could also be an important future research topic.

Based on the present methodology and the focus on peer-reviewed publications, the present synthesis suffers from several constraints that are important to note. The study did not include papers that targeted just renewable energy from any source except the relevant ones, and documents prepared for workshops, proceedings, or theses were not included in the group of included papers. Thus, the present analysis may have missed some primary data collected in these documents. For example, Segon *et al.* (2002) had some interesting findings of awareness of bioenergy and biomass benefits using a survey of the general public in Croatia. However, this paper was published by IEA Biomass Task 29 workshop and was not included in the present work. In addition, papers that used two secondary datasets such as in Binder *et al.* (2010) were not included due to the focus of the study on primary surveys.

CONCLUSIONS

A systematic analysis of the literature showed an increase in the number of publications/articles focused on societal aspects of bioenergy, including discussions about bioenergy perceptions of key stakeholders. This growth is an indication that the industry and the researchers recognize the importance of public acceptance and knowledge about bioenergy for the commercial success of the industry. As the technology and economics get better in the future, public perceptions will play a key role in the commercialization and development of this industry.

Most of the published studies were in the US and Europe, but other geographical regions such as Asia and Latin America are also focused on understanding public perception of bioenergy. It was found that as a group, “consumers” were the most frequently surveyed group. However, the number of respondents varied (24 to 1903) across studies. There is a need for standardized methods to improve interpretability and representation, which will improve the values of these studies.

In order for bioenergy to be successfully deployed, there is a strong need not only for educational programs with information on proper management and ecological effects of producing energy crops or harvesting (*e.g.*, proposals to buy wood fuels should be connected with information on ecological and silvicultural effects of wood fuel harvesting), but also policies should be developed by dialogue and collaboration between various government and institutional partners including local landowner association. It is essential that costs are distributed along the supply chain, so that producers do not have to bear the cost. In addition, if subsidies are provided, care should be taken to not attract only subsidy sensitive adopters as they are less devoted to products. Subsidies should be moderate, and extending the period of grants should be considered. If developed, certification schemes should be easy to follow, develop energy wood market, and promote environmental friendly management practices.

Of all the stakeholder groups, forest and farm landowners are most hesitant to participate in bioenergy programs; this is due to the lack of stable markets and successful conversion technologies. However, interest from landowners and other stakeholders is likely to be spurred by a successful small-scale demonstration. For other stakeholder groups, education and targeting their specific needs will be key to success.

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REFERENCES

Aguilar, F. X., and Cai Z. (2010). "Exploratory analysis of prospects for renewable energy private investment in the U.S.," Energy Economics 32(6), 1245-1252. DOI: 10.1016/j.eneco.2010.05.012

Aguilar, F. X., Daniel, M., and Narine, L. L. (2013). "Opportunities and challenges to the supply of woody biomass for energy from Missouri non-industrial privately owned forestlands," Journal of Forestry 111(4), 249-260. DOI: 10.5849/jof.13-009

Allport, F. H. (1955). Theories of Perception and the Concept of Structure. Wiley, New York, 709 pp.

Binder, A. R., Cacciatore, M. A., Scheufele, D. A., Shaw, B. R., and Corley, E. A. (2010). "Measuring risk/benefit perceptions of emerging technologies and their potential impact on communication of public opinion toward science," Public Understanding of Science 20(10), 1-18.

Bohlin, F., and Roos, A. (2002). "Wood fuel supply as a function of forest owner preferences and management styles," Biomass and Bioenergy 22(4), 237-249. DOI: 10.1016/S0961-9534(02)00002-8

Borchers, A. M., Duke, J. M., and Parsons, G. R. (2007). "Does willingness to pay for green energy differ by source?" Energy Policy 35(6), 3327-3334. DOI: 10.1016/j.enpol.2006.12.009

Cacciatore, M. A., Binder, A. R., Scheufele, D. A., and Shaw, B. R. (2012a). "Public attitudes toward biofuels," Politics and Life Sciences 31(1), 36-51. DOI: 10.2990/31_1-2_36

Cacciatore, M. A., Scheufele, D. A., and Shaw, B. R. (2012b). "Labeling renewable energies: How the language surrounding biofuels can influence its public acceptance," Energy Policy 51(12), 673-682. DOI: 10.1016/j.enpol.2012.09.005

Delshad, A. B., Raymond, L., Sawicki, V., and Wegener, D. T. (2010). "Public attitudes toward political and technological options for biofuels," Energy Policy 38(7), 3414-3425. DOI: 10.1016/j.enpol.2010.02.015

Deregowski, J. B., Muldrow, E. S., and Muldrow, W. F. (1972). "Pictorial recognition in a remote Ethiopian population," Perception 1(4), 417-425. DOI: 10.1068/p010417

Dwivedi, P., and Alavalapati, J. R. R. (2009). "Stakeholders' perceptions on forest biomass-based bioenergy development in the southern US," Energy Policy 37(5), 1999-2007. DOI: 10.1016/j.enpol.2009.02.004

Fazio, F. H. (1995). “Attitudes as object-evaluation associations: Determinants, consequences, and correlates of attitude accessibility,” in: Perry, R. E., and Krosnick, J. A. (eds.), Attitude Strength: Antecedents and Consequences, Erlbaum, Mahwah, NJ, pp. 79-124.

Fazio, R. H., and Zanna, M. P. (1981). “Direct experience and attitude behavior consistency,” in: Brkowitz, L. (ed), Advances in Experimental Social Psychology Vol. 14, Academic Press, New York, pp. 161-202. DOI: 10.1016/s0065-2601(08)60372-x

Fishbein, M., and Ajzen, I. (1975). Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research. Addison-Wesley, Reading, MA, 480 pp.

Fishbein, M., and Ajzen, I. (2010). Predicting and Changing Behavior: The Reasoned Action Approach, Psychology Press (Taylor & Francis), New York, 538 pp.

Fry, M., and Polonsky, M. J. (2004). “Examining the unintended consequences of marketing,” Journal of Business Research 57(11), 1303-1306. DOI: 10.1016/S0148-2963(03)00073-0

Gautam, Y. B., Pelkonen, P., and Halder, P. (2013). “Perceptions of bioenergy among Nepalese foresters – Survey results and policy implications,” Renewable Energy 57(9), 533-538. DOI: 10.1016/j.renene.2013.02.017

Gibson, E. J. (1969). Principles of Perceptual Learning and Development, Appleton-Century Crofts, New York. 538 pp.

Gough, D., Oliver, S., and Thomas, J. (2012). An Introduction to Systematic Reviews, Sage Publications Ltd., London, 304 pp.

Halder, P., Pietarinen, J., Havu-Nuutinen, S., and Pelkonen, P. (2010). “Young citizens’ knowledge and perceptions of bioenergy and future policy implications,” Energy Policy 38(6), 3058-3066. DOI: 10.1016/j.enpol.2010.01.046

Halder, P., Prokop, P., Chang, C., Usak, M., Pietarinen, J., Havu-Nuutinen, S., Pelkonen, P., and Cakir, M. (2012a). “International survey on bioenergy knowledge, perceptions, and attitudes among young citizens,” BioEnergy Research 5(1), 247-261. DOI: 10.1007/s12155-011-9121-y

Halder, P., Pietarinen, J., Havu-Nuutinen, S., Pelkonen, P., Chang, C., Prokop, P., and Usak, M. (2013). “Knowledge, perceptions, and attitudes as determinants of youths’ intentions to use bioenergy – A cross-national perspective,” International Journal of Green Energy 10(8), 797-813. DOI: 10.1080/15435075.2012.706244

Halder, P., Weckroth, T., Mei, Q., and Pelkonen, P. (2012b). "Nonindustrial private forest owners' opinions to and awareness of energy wood market and forest-based bioenergy certification – Results of a case study from Finnish Karelia. Energy," Sustainability and Society 2(19), 1-9. DOI: 10.1186/2192-0567-2-19

Halder, P., Havu-Nuutinen, S., Pietarinen, J., and Pelkonen, P. (2011). "Bio-energy and youth: Analyzing the role of school, home and media from the future policy perspectives," Applied Energy 88(4), 1233-1240. DOI: 10.1016/j.apenergy.2010.10.017

Hansla, A., Gamble, A., Juliusson, A., and Garling, T. (2008). "Psychological determinants of attitude towards and willingness to pay for green electricity," Energy Policy 36(2), 768-774. DOI: 10.1016/j.enpol.2007.10.027

Hartmann, P., and Apaolaza-Ibanez, V. (2012). "Consumer attitude and purchase intention toward green energy brands: The role of psychological benefits and environmental concern," Journal of Business Research 65(9), 1254-1263. DOI: 10.1016/j.jbusres.2011.11.001

Hassan, M. K., Halder, P., Pelkonen, P., and Pappinen, A. (2013). "Rural households' preferences and attitudes towards biomass fuels – Results form a comprehensive field survey in Bangladesh," Energy, Sustainability, and Society 3(24), 1-14.

Hemholtz, H. L., von. (1971). "the origin and correct interpretation of our sense impressions," in: Kahl, R. (ed.) Selected writings of Hermann Ludwig von Helmholtz (pp. 501-512), Wesleyan University Press, Middletown, CR (Original work published 1894).

Kunst-Wilson, W. R., and Zajonc, R. B. (1980). "Affective discrimination of stimuli that cannot be recognized," Science 207(4430), 557-558. DOI: 10.1126/science.7352271

Magar, S. B., Pelkonen, P., Tahvanainen, L., Toivonen, R., and Toppinen, A. (2011). "Growing trade of bioenergy in the EU: Public acceptability, policy harmonization, European standards and certification needs," Biomass and Bioenergy 35(8), 3318-3327. DOI: 10.1016/j.biombioe.2010.10.012

Mariasiu, F. (2013). "Consumers' attitudes related to biofuel use in transportation," International Review of Management and Marketing 3(1), 1-9.
McCormick, K. (2010). "Communicating bioenergy: A growing challenge," Biofuels, Bioproducts and Biorefining 4(5), 494-502. DOI: 10.1002/bbb.243

Miller, R. L., and Lewis, W. F. (1991). "A stakeholder approach to marketing management using the value exchange models," European Journal of Marketing 25(8), 55-68. DOI: 10.1108/03090569110003553

Moher, D., Liberati, A., Tetzlaff, J., and Altman, D.G. (2009). “Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement,” Annals of Internal Medicine 151(4), 264-269. DOI: 10.7326/0003-4819-151-4-200908180-00135

Nyrud, A. Q., Roos, A., and Sange, J. B. (2008). “Residential bioenergy heating: A study of consumer perceptions of improved woodstoves,” Energy Policy 36(8), 3169-3176. DOI: 10.1016/j.enpol.2008.04.019

Pacini, H., and Silveira, S. (2010). “Consumer choice between ethanol and gasoline: Lessons from Brazil and Sweden,” Energy Policy 39(11), 6936-6942. DOI: 10.1016/j.enpol.2010.09.024

Panoutsou, C. (2008). “Bioenergy in Greece: Policies, diffusion framework and stakeholder interactions,” Energy Policy 36(10), 3674-3685. DOI: 0.1016/j.enpol.2008.06.012

Paula, A., Bailey, C., Barlow, R. J., and Morse, W. (2011). “Landowner willingness to supply timber for biofuel: Results of an Alabama survey of family forest landowners,” Southern Journal of Applied Forestry 35(2), 93-97.

Paulrud, S., and Laitila, T. (2010). “Farmers’ attitudes about growing energy crops: A choice experiment approach,” Biomass and Bioenergy 34(12), 1770-1779. DOI: 10.1016/j.biombioe.2010.07.007

Petrolia, D. R., Bhattacharjee, S., Hudson, D., and Herndon, C. W. (2010). “Do Americans want ethanol? A comparative contingent-valuation study of willingness to pay for E-10 and E-85,” Energy Economics 32(1), 121-128. DOI: 10.1016/j.eneco.2009.08.004

Plate, R. R., Monroe, M. C., and Oxarart, A. (2010). “Public perceptions of using woody biomass as a renewable energy source,” Journal of Extension 48(3), 1-15.

Popp, M., Van de Velde, L., Vikery, G., Huylenbroeck, G. V., Verbeke, W., and Dixon, B. (2009). “Determinants of consumer interest in fuel economy: Lessons for strengthening the conservation argument,” Biomass and Bioenergy 33(5), 768-778. DOI: 10.1016/j.biombioe.2008.12.007

Qu, M., Ahponen, P., Tahvanainen, L., Gritten, D., Mola-Yudego, B., and Pelkonen, P. (2011). “Chinese university students’ knowledge and attitudes regarding forest bio-energy,” Renewable and Sustainable Energy Reviews 15(8), 3649-3657. DOI: 10.1016/j.rser.2011.07.002

Qu, M., Ahponen, P., Tahvanainen, L., Gritten, D., Mola-Yudego, B., and Pelkonen, P. (2012). “Practices and perceptions on the development of forest bioenergy in China from participants in national forestry training courses,” Biomass and Bioenergy 40(5), 53-62. DOI: 10.1016/j.biombioe.2012.01.050

Raven, R., Mourik, R., Feenstra, Y., and Heiskanen, E. (2007). “Modulating societal acceptance in new energy projects,” Proceedings of the 4th Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems, June 4-8, Dubrovnik, Croatia (pp. 1-12).

Rogers, J. C., Simmons, E. A., Convery, I., and Weatherall, A. (2008). “Public perceptions of opportunities for community-based renewable energy projects,” Energy Policy 36(11), 4217-4226. DOI: 10.1016/j.enpol.2008.07.028

Rohracher, H., Bogner, T., Späth, P., and Faber, F. (2004). “Improving the public perception of bioenergy in the EU,” Proceedings for the 18th International Association for People-Environment Studies, July 7-9.

Savvanidou, E., Zervas, E., and Tsagarakis, K. P. (2010). “Public acceptance of biofuels,” Energy Policy 38(8), 3482-3488. DOI: 10.1016/j.enpol.2010.02.021

Scarpa, R., and Willis, K. (2010). “Willingness to pay for renewable energy: Primary and discretionary choice of British households for micro-generation technologies,” Energy Economics 32(1), 129-136. DOI: 10.1016/j.eneco.2009.06.004

Šegon, V., Domac, J., and Kufrin, K. (2003). “National survey of knowledge, attitudes and perceptions about renewables and energy efficiency,” Proceedings of the IEA Bioenergy workshop on Socio-Economic drivers in implementing bioenergy projects: Education and promotion, June 18-20, Streatley, UK.

Selfa, T., Kulcsar, L., Bain, C., Goe, B., and Middendorf, G. (2011). “Biofuels bonanza?: Exploring community perceptions of the promises and perils of biofuels production,” Biomass and Bioenergy 35(4), 1379-1389. DOI: 10.1016/j.biombioe.2010.09.008

Skipper, D., Van de Velde, L., Popp, M., Vickery, G., Huylenborek, G. V., and Verbeke, W. (2009). “Consumers’ perceptions regarding tradeoffs between food and fuel expenditures: A case study of U.S. and Belgian fuel users,” Biomass and Bioenergy 33(6-7), 973-987. DOI: 10.1016/j.biombioe.2009.03.010

Ulmer, J. D., Huhnke, R. L., Bellmer, D. D., and Cartmell, D. D. (2004). “Acceptance of ethanol-blended gasoline in Oklahoma,” Biomass and Bioenergy 27(5), 437-444. DOI: 10.1016/j.biombioe.2004.04.005

Upham, P., and Shackley, S. (2006). “Stakeholder opinion of a proposed 21.5 MWe biomass gasifier in Winkleigh, Devon: Implications for bioenergy planning and policy,” Journal of Environmental Policy & Planning 8(1), 45-66. DOI: 10.1080/15239080600634144

Upham, P., and Shackley, S. (2007). “Local public opinion of a proposed 21.5 MW(e) biomass gasifier in Devon: Questionnaire survey results,” Biomass and Bioenergy 31(6), 433-441. DOI: 10.1016/j.biombioe.2007.01.017

Upham, P., Shackley, S., and Waterman, H. (2007). “Public and stakeholder perceptions of 2030 bioenergy scenarios for the Yorkshire and Humber region,” Energy Policy 35(9), 4403-4412. DOI: 10.1016/j.enpol.2007.03.002

Upreti, B. R., and van der Horst, D. (2004). “National renewable energy policy and local opposition in the UK: The failed development of a biomass electricity plant,” Biomass and Bioenergy 26(1), 61-69. DOI: 10.1016/S0961-9534(03)00099-0

U.S. Department of Energy. (2011). “U.S. billion-ton update: Biomass supply for a bioenergy and bioproducts industry,” R. D. Perlack and B. J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.

US Energy Information Administration. (2009). U.S. Energy Consumption by Energy Source. Retrieved from: http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/table1.html.

Van de Velde, L., Verbeke, W., Popp, M., Buysse, J., and Van Huylenbroeck, G. (2009). “Perceived importance of fuel characteristics and its match with consumer beliefs about biofuels in Belgium,” Energy Policy 37(8), 3183-3193. DOI: 10.1016/j.enpol.2009.04.022

Verbeke, W. (2007). “Consumer attitudes toward genetic modification and sustainability: Implications for the future of biorenewables,” Biofuels, Bioproducts & Biorefining 1(3),
Vernon, M.D. (1955). “The functions of schemata in perceiving,” Psychological Review 62(3), 180-192. DOI: 10.1037/h0042425

Wegener, D. T., and Kelly, J. R. (2008). “Social psychological dimensions of bioenergy development and public acceptance,” BioEnergy Research 1(2), 107-117. DOI: 10.1007/s12155-008-9012-z

West, J., Bailey, I., and Winter, M. (2010). “Renewable energy policy and public perceptions of renewable energy: A cultural theory approach,” Energy Policy 38(10), 5739-5748. DOI: 10.1016/j.enpol.2010.05.024

Zarnikau, J. (2003). “Consumer demand for ‘green power’ and energy efficiency,” Energy Policy 31(15), 1661-1672.

Zhang, Y., Yu, Y., Li, T., and Zou, B. (2011). “Analyzing Chinese consumers’ perception for biofuels implementation: The private vehicles owner's investigating in Nanjing,” Renewable and Sustainable Energy Reviews 15(5), 2299-2309. DOI: 10.1016/j.rser.2011.02.004

Zografakis, N., Sifaki, E., Pagalou, M., Nikitaki, G., Psarakis, V., and Tsagarakis, K. P. (2010). “Assessment of public acceptance and willingness to pay for renewable energy sources in Crete,” Renewable and Sustainable Energy Reviews 14, 1088-1095. DOI: 10.1016/j.rser.2009.11.009

CHAPTER 2

CONSUMERS' PERCEPTION OF BIOENERGY IN NORTH CAROLINA AND TENNESSEE

Robert Radics, Sudipta Dasmohapatra, and Stephen S. Kelley

A sample of consumers in North Carolina (NC) and Tennessee (TN) were surveyed in the fall of 2013 and spring 2014 to examine their perceptions and concerns about bioenergy. Approximately, 586 consumers completed the survey electronically (376 in NC, 210 in TN). The initial data was weighted to represent the adult population of NC and TN. The respondents recognized solar and wind energy sources mostly as renewable compared to all other energy sources including biomass-based energy. Respondents reported that the price of biofuels and compatibility of biomass-based fuels with their cars were the most important factors that influence their choice of biofuels versus gasoline at a pump. Results show that the acceptance of bioenergy, and specifically biofuels from the consumer's perspective, depend on the extent of knowledge and available information about the energy source. A principal component analysis (PCA) of bioenergy statements indicate seven distinct dimensions of consumer perceptions and attitudes towards bioenergy including bioenergy benefits to society, risks of bioenergy use, government support for bioenergy, increase in food cost, conditional use of trees as feedstocks, support for low-cost biofuel alternative to current energy, and market attribute-based purchases. The findings from this study highlight not only educational needs and outreach efforts but also reflects the need for trustworthy channels of communication, helpful policy, market, and institutional support for bioenergy success in NC and TN.

Keywords: Bioenergy, Biofuels, Consumers, Perception

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INTRODUCTION

The 2007 Energy Independence and Security Act (EISA) mandates the production and use of 36 billion gallons of bioethanol using renewable feedstocks by 2022. Of this, 21 billion gallons is required to be produced from non-corn feedstock. The U.S. Department of Energy has also highlighted the potential for production of other types of bioproducts (e.g., chemicals) for a greener, low-carbon society (U.S. Department of Energy 2011). The successful diffusion of technologies and acceptance of any new product such as bio-ethanol/diesel or other bio-products, is not solely dependent on its technical and economic advantages; societal acceptance and cultural dimensions play an important role, if not the key indicator for a bioenergy product's success in the marketplace (Miller and Lewis 1991, Rochracher et al. 2004, Dwivedi and Alavalapati 2009, Pacini and Silveria 2010, Halder et al. 2011).

A standard method for assessing societal acceptance is through stakeholders' perceptions of product performance, and their opinions of risks and opportunities in the product's use (Fry and Polonsky 2004, Rohracher et al. 2004, Johnston et al. 2013). In the last decade, many published studies have focused on stakeholder perceptions of bioenergy and biofuels by understanding the attitudes and sometimes behavior of the stakeholders (Zarnikau 2003, Upreti and van der Horst 2004, Upham and Shackley 2006, Upham et al. 2007, Wegener and Kelly 2008, Popp et al. 2009, Scarpa and Willis 2010, Savvanidou et al. 2010, West et al. 2010, Zografakis et al. 2010, Qu et al. 2011, Zhang et al. 2011, Cacciatore et al. 2012, Halder et al. 2012, Hassan et al. 2013.) Although a high percentage of these studies have an international focus, they still provide extremely useful information about bioenergy acceptance and stakeholder concerns, as this industry gains momentum across the globe. Nevertheless, we postulate that the production of the biomass and fuels were local activities, and hence, the most noticeable direct impacts will likely occur within a 100-mile radius of a bio-refinery. Selfa et al. (2011) point out that the local impacts of corn ethanol plants include issues like noticeable odors, and increases in air and water emissions. Additionally the authors found that citizens favored bioenergy because it lead to increased jobs for the community but were also concerned about the resulting increased local traffic and potential for higher food prices. The findings from past studies were discussed in the next section.

Key stakeholders within the bioenergy industry include the users or the general public, the provider of feedstocks or landowners, industry representatives, government and non-government organizations, investors, academics and researchers, and policy makers, among others.

This study aims to understand the perceptions of the general public (a key stakeholder for bioenergy growth) about bioenergy and specifically, biofuels, in the state of NC and TN. These two states among themselves represent the Southeast US belt, which is considered to have the potential for producing almost 50% of the next generation of biomass and biofuels according to the U.S. Department of Energy (U.S. Department of Energy 2011). More than 45% of cellulosic feedstocks and 70% of the forest biomass is produced in the Southeast U.S. (Dwivedi and Alavalapati 2009). The opportunities for biomass production in the Southeast US were driven by the relatively long growing season and abundance of rainfall, private land ownership patterns that allow shorter transportation distances, and a strong history of community and industrial support for farming and commercial forestry.

Most past studies on general public perceptions were either from outside of the US (EU or Asia) or when domestic (US), have either a different product focus (general green electricity or renewable electricity instead of biofuels or biomass-based energy, which is the focus of this study) or narrow geographic focus (one locality or community around a pilot plant or potential bioenergy plant) or conceptual focus (willingness to pay or economic focus) or segment of general public (students in high school or university). In essence, there were not many published studies that focus on the general public's perception of all four key themes of our study about biomass-based energy in Southeast U.S. Most survey studies either tend to group renewable energy sources together or tend to pose general queries specific to various renewable technologies (Rochracher et al. 2004), thus, providing highly dispersed results, indicating the need for a systematic studies that provide a better basis for strategies to clarify the public acceptance, primarily addressing the two states in the Southeast U.S.

Past studies on Consumer's Perception of Bioenergy and Biofuels

The desire to find sustainable and balanced solutions to energy production and use that trade off environmental, economic, and energy security with social impacts have amplified the interest in measuring stakeholder perceptions of bioenergy in the recent years (Resch et al. 2008, Abt et al. 2010). Studies focused on the consumer attitudes indicate a moderate to ambivalent support towards renewable energy including biomass-based energy (Dwivedi and Alavalapati 2009, Aguilar and Cai 2010, Delshad et al. 2010, Petrolia et al. 2010, Plate et al. 2010, Caccatiore et al. 2012, Mariasiu 2013). Most studies attribute the low acceptance and support for bio-based energy to the lack of awareness and knowledge about this industry (Upreti and van der Horst 2004, Delshad et al. 2010, Plate et al. 2010, Pires 2012, Halder et al. 2013, Mariasu 2013).

Most of the support or risk perception for biomass-based energy is guided by consumers' perception of its impact on the environment or the society. For example, citizens in some studies indicate that they would support bioenergy if it had a positive environmental impact compared to fossil fuels (Hansla et al. 2008, Nyrud et al. 2008, Qu et al. 2011, Hartmann and Apaolaza-Ibanez 2012). In fact, the perceived environmental attributes of biofuels were found to be a major factor in consumers' choice of biomass-based fuels at gas stations (Delshad et al. 2010, Pires 2012). Other studies found positive perception about renewable energy including biomass-based energy to depend on social benefits such as jobs for the community (Zografakis et al.

2010, Selfa et al. 2011, Caccatiore et al. 2012), national security (Petrolia et al. 2010, Qu et al. 2011), and risks such as increase in pollution, noise, traffic, air (Upham and Shackley 2007, Selfa et al. 2011), and threat to land availability for food production and increased food price (Bunntrup et al. 2009, Skipper et al. 2009, Savvanidou et al. 2010).

Some studies on consumer perceptions of renewable energy or bioenergy compared various biomass-based energy sources with that of other renewable sources. Nearly all studies found that citizens were more willing to support and accept solar, wind and hydro energy sources relative to biomass-based energy (Borcher et al. 2007, Dwivedi and Alavalapati 2009, Aguilar and Cai 2010, Delshad et. al. 2010, Pires 2012). This is in large part, due to the relatively recent introduction of bioenergy compared to the other energy sources in the marketplace and the associated lack of knowledge and understanding of biomass-based energy impacts on the society.

The type of feedstock used for producing biomass-based energy (particularly, fuels) is also shown to have an impact on public support. Studies have found higher levels of public support for energy produced from landfill wastes, wood waste, and grasses and corn stover, while trees, genetically modified organisms (GMOs) were moderately supported, and corn-based bioethanol has the lowest level of support (Delshad et. al. 2010, Pires 2012).

When asked about biomass-based fuels vs. gasoline choice at gas stations, the convenience and availability of biofuels at most filling stations, the price of biofuels vs. gasoline, and the compatibility of the car engine with biofuels were reported as important to consumers governing their choice of biofuels (Zarnikau, 2003, Upham et al. 2007, Borchers et al. 2007, Wegener and Kelley 2008, Van de Velde et al. 2009, Delshad et al. 2010, Halder et al. 2010, Savvanidou et al 2010, Qu et al. 2011, Halder et al. 2011, Pires 2011, Raza and Singh 2011, Mariasu 2013).

Studies have found that demographics also play an important role in differing public opinion on renewable energy. People with higher education and income tend to support renewable energy investments (including biofuels) more than those with low levels of education and income (Borchers et al. 2007, Aguilar and Cai 2010, Cacciatore et al. 2012). A few studies have also found that women were more likely to pay more for biomass-based energy than men (Aguilar and Cai 2010, Mariasiu 2013). Additionally, biofuel attitudes and support were reported to be affected by political partisanship. For example, self-identified Republicans were reported as less positive about biomass-based fuels and bioenergy than self-identified Democrats (Cacciatore et al. 2012, Tompson et al. 2012).

OBJECTIVES

The goal of the study was to examine the general public's understanding and perceptions of bioenergy and biofuels in NC and TN. Specifically, this study focused on the public concerns, support and risk evaluations of alternative bioenergy feedstocks and biofuels (used for transportation), and included the economic, environmental, social, and policy impacts of their production and use.

MATERIALS AND METHODS

An electronic survey instrument was used to collect data from the general public in NC and TN. The survey was designed using Qualtrics, an online survey software and insight platform. The survey questions were constructed based on past studies on consumer's perception of bioenergy (studies mentioned in introduction section) and vetted with project partners and experts (academia, extension, US Forest Service, industry). Prior to the data collection, a pilot study was conducted to test the effectiveness of the survey questions, check the questions' wording, and the survey length. A sample (n=34) of consumers responded to the pilot survey. Feedback from the pilot test was used to refine the survey instrument. The final version of the questionnaire (Appendix A) contained five categories of questions, including demographics, concerns regarding different environmental topics, energy sources, feedstock preference, and bioenergy-relevant self-constructed 38-item agreement question on four key aspects of bioenergy (economic, environment, social and policy). In case of concerns and relative agreement type questions five-element Likert scale was applied (1=strongly disagree and 5=strongly agree).

Approximately, two million email addresses for consumers in NC and TN were obtained from a third party marketing agency in NC for the data collection. An automatic email sender software was used for the survey distribution. Emails were randomly chosen to be sent in batches of 10,000 per batch to consumers in TN and NC in the fall of 2013 and early spring of 2014 (approximately 100,000 emails were sent). Almost half of the email addresses were not valid (bounce-backs), and no specific data could be obtained from the number of emails received by the consumers, thus making the exact response rate calculation difficult. The email contained a cover letter with a link to the survey. The cover letter included a valid letterhead and information about the importance of the study as well as incentive information for completing the survey (entry into the raffle of $25.00 Home Depot gift cards). Three weeks after the first email contact, consumers were sent a reminder to complete the survey, and three weeks after the first reminder they were sent a second reminder email to complete the survey following a modified version of Dillman et al.'s Tailored Design Method (2008).

Data collected from the responses was adjusted (weighted) to reflect the demographics of NC and TN based on the 2013 state census (Census Bureau 2014). This weighting (using a procedure called raking) is designed to improve the relationship between the sample and the population by fine-tuning the sampling weights of the cases when more than one weighting parameter or variable is used (Battaglia et al. 2004, Lavrakas 2008). The raking weighting method is similar to iterative proportional fitting that adjusts a set of data in a stepwise process so that its marginal totals match specified control totals on a specific set of variables (Battaglia et al. 2004). Variables included in the raking procedure for weighting in this study included age, gender, education and income of respondents.

Where applicable, for ordinal and interval level data, a significant difference between perceptions of the general public in NC and TN was conducted using Students' t-test (at 0.05 level). The proportional difference between the groups (NC and TN) was performed using chi-square test of difference (at 0.05 level).

RESULTS

Response and Demographics

We received 586 completed questionnaires with 377 completed questionnaires from NC and 209 responses from TN. Before the weighting adjustment described above, non-response bias was measured between early and late responses based on demographic and biofuel agreement statement variables using an independent samples t-test (continuous variables) and the chi-square test (nominal variables). A non-response bias analysis examines whether respondents of the study were different from non-respondents. Past research has shown that non-respondents behave similarly to the late respondents or respondents that respond after a reminder (Dillman et al. 2008). Early respondents in this study were defined as those who responded before any reminder was sent, and late respondents were defined as all those who answered after the reminder was mailed. These tests revealed no significant difference between the two respondent groups (early, n=405 vs. late, n=181) on any variable.

In general, respondents were more educated, more white/Caucasian and older compared to 2013 census data, especially in NC (Table 9). Thus, the responses were weighted so that the results were more representative of the state's population. The raking procedure has been effectively used in data with small samples (as in this study) providing very precise and unbiased estimates (Gelman 2007). The changes caused by raking to reflect the demographics of NC and TN were the largest where the sample and the population demographics differed the greatest, e.g., the NC population adjusted for education, and the TN age (65+). To reduce the larger weights, the variables such as age and education were binned to a smaller number of categories (instead of 7 age categories, we used only four age groups for age as shown in Table 9). The mode for the weight was found to be 1.12 and extremely large weights (~10) occurred only in 15% of the overall sample (minimum weight was 0.12.)

Table 9 Comparison of sample demographic and census data

Demographics	NC (%)	2013 Census (%)	TN (%)	2013 Census (%)
	n=377	9,848,000	n=209	6,496,000
Gender				
Male	54	49	46	49
Female	46	51	54	51
Education				
College 4 years and above	67	27	31	24
Ethnicity				
White/Caucasian	79	72	89	79
Black/African-American	10	22	7	17
Age (years)				
18-24	2	14	13	13.
25-44	27	36	55	35
45-64	53	35	31	35
65+	18	16	1	17

Level of Concern about Energy, Economy, and the Environment

Respondents were asked to indicate their level of concern about selected energy, economy, and environmental topics that impact bioenergy. The price of energy, unemployment, and US dependence on foreign oil were most important for the respondents (Figure 3). Among the selected topics, the respondents were least worried about greenhouse gas emissions and decreasing fossil reserves. The relatively high variation in response was found (standard deviation of 1.5 and above) on the topics of food price, global climate change, and greenhouse gas emission showing strong divergence in perceptions of these issues.

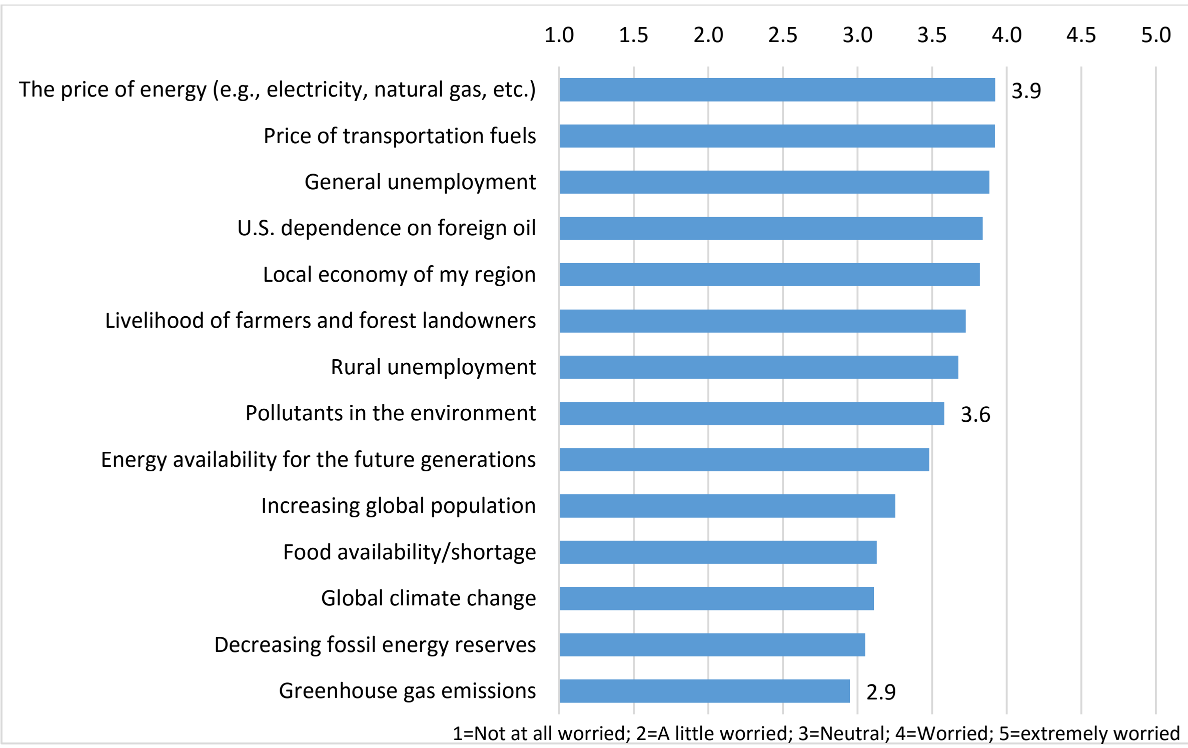

Figure 3 Level of Worry/Concern on Different Topics (mean) (n=586)

Between the two states, we found statistically significant differences in perceptions of the general public. NC citizens were significantly more worried about climate change (mean=3.2 for NC versus 2.9 for TN, p=0.03) and decreasing fossil energy reserves (mean=3.2 for NC versus 2.9 for TN, p=0.02). TN citizens were significantly more worried about U.S. dependence on foreign oil (p=0.003) and price of transportation fuels (p=0.012) (mean=4.1 for TN versus 3.7 for NC for both attributes), the price of energy (mean=4.1 for TN versus 3.8 for NC, p=0.018)), and general unemployment (mean=4.1 for TN versus 3.8 for NC, p=0.001).

Source of Energy Reported Renewable

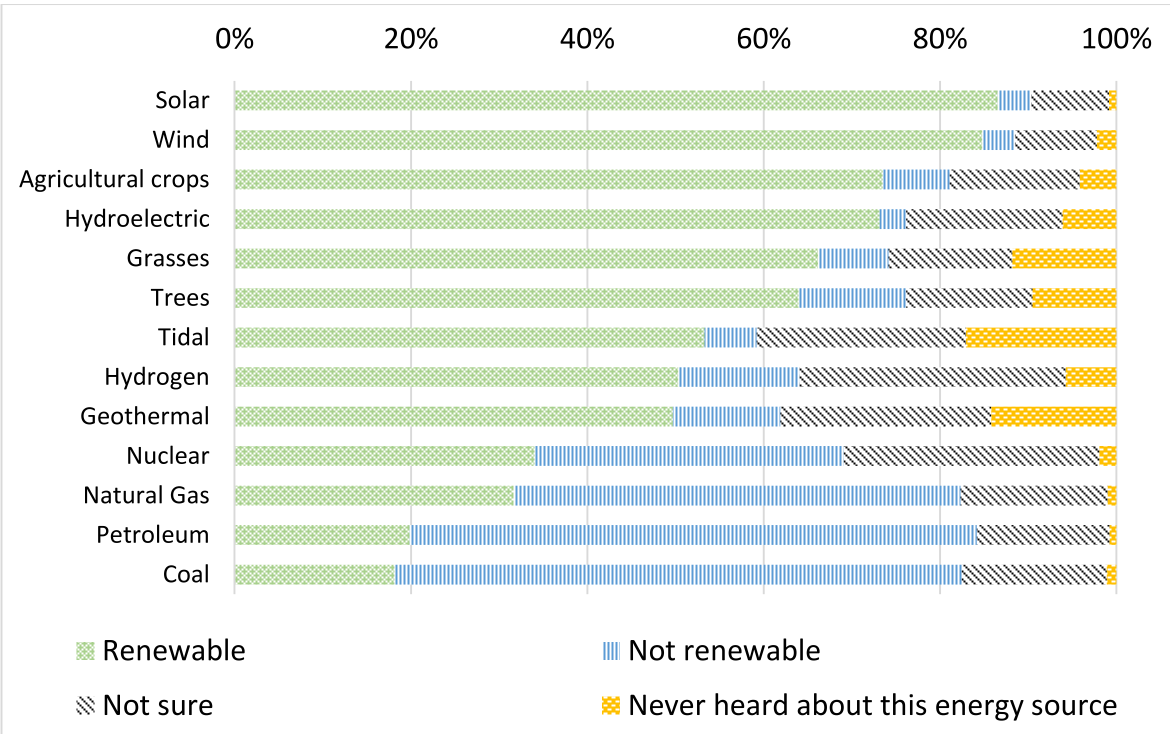

Figure 4 Source of Energy Reported Renewable (n=561)

Respondents were given a list of a variety of energy sources and asked to indicate if they were “renewable/non-renewable”. The respondents could indicate “not sure” or “never heard,” if those were appropriate alternatives. Somewhat surprisingly, approximately, 17% and 20% of respondents, respectively, indicated that coal and petroleum were “renewable”. Geothermal, tidal, trees and grasses, were ranked as the least recognized energy sources. Similar to past studies (Borcher et al. 2007, Dwivedi and Alavalapati 2009, Delshad et. al. 2010, Pires 2012), our results showed that more respondents recognized solar and wind energy as renewable than other energy sources, especially when compared with biomass-based energy sources (Figure 4).

Statistically significant difference was found between responses of consumers in NC and TN. In TN, 46% of the population reported nuclear energy as renewable compared to 27% in NC ($p=0.000$). Respondents from the two states also differed in their perceptions of tidal power as renewable source ($p=0.002$, 58% in NC and 46% in TN reporting this source as renewable) with as well as grasses as renewable energy source ($p=0.01$, 64% reporting renewable in NC and 70% in TN.)

It is interesting to note that among the above sources of energy, over 40% of respondents either hadn't heard about the tidal source for energy or were not sure about whether the source was renewable. Over 35% of people reported (and were equally split) that trees were not renewable or were not sure that trees were renewable, or they had never heard about trees as a source of energy.

Feedstock Awareness

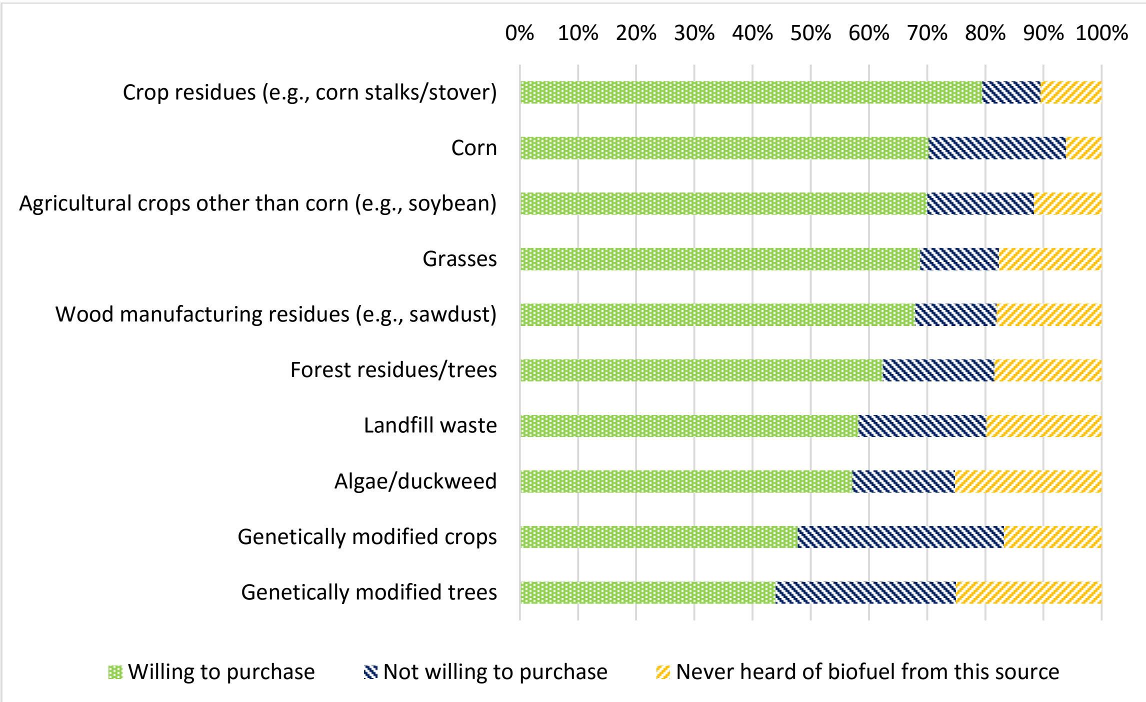

Figure 5 Willingness to Buy Biofuels (for transportation) Made from Different Biomass Feedstocks (n=558)

Respondents were asked a series of questions to indicate if their willingness to purchase transportation fuels based on various biomass sources. The willingness to buy was used to indicate respondent approval for the energy source similar to other studies (Borcher et al. 2007, Delshad et. al. 2010, Pires 2012). Figure 5 shows the most accepted biofuel sources were crop residues, corn, agricultural crops, and grasses followed by forest residues/trees. The least preferred sources for purchase were genetically modified trees and crops, which is consistent with earlier studies (Delshad et. al. 2010, Pires 2012). There appears a clear correlation between willingness to purchase and awareness of the biomass feedstock. Among feedstock sources for energy, genetically modified trees and algae/duckweed were reported most frequently as unheard of sources, followed by landfill wastes, forest and wood products residues or trees, grasses and genetically modified crops.

No significant difference between NC and TN citizens' feedstock preference (willingness to purchase) was found except for algae/duckweed (NC=73% willing to purchase and TN=83% willing to buy, p=0.017). We also found somewhat significant difference i (p=0.055) in willingness to purchase for grasses with 86% respondents in NC willing to purchase compared to 79% of respondents in TN. The lack of differences between NC and TN for the grasses is surprising since TN has invested an estimated $200 million, including $70 million of state funds, in deploying switchgrass as a biofuel feedstock (Nair 2015). This TN investment is reportedly successful in engaging farmers and has catalyzed the planting of more than 6,000 acres of switchgrass, but our study shows that 21% of citizens were not willing to purchase grass sourced bioenergy in TN (much higher than NC at 14% consumers not willing to purchase). The following figure 6 shows NC and TN consumer awareness of different sources of feedstocks. On average, NC consumers reported better awareness of most energy sources compared to TN consumers except somewhat for wood residues and more so for grasses perhaps due to the media above coverage and outreach on grass-based energy.

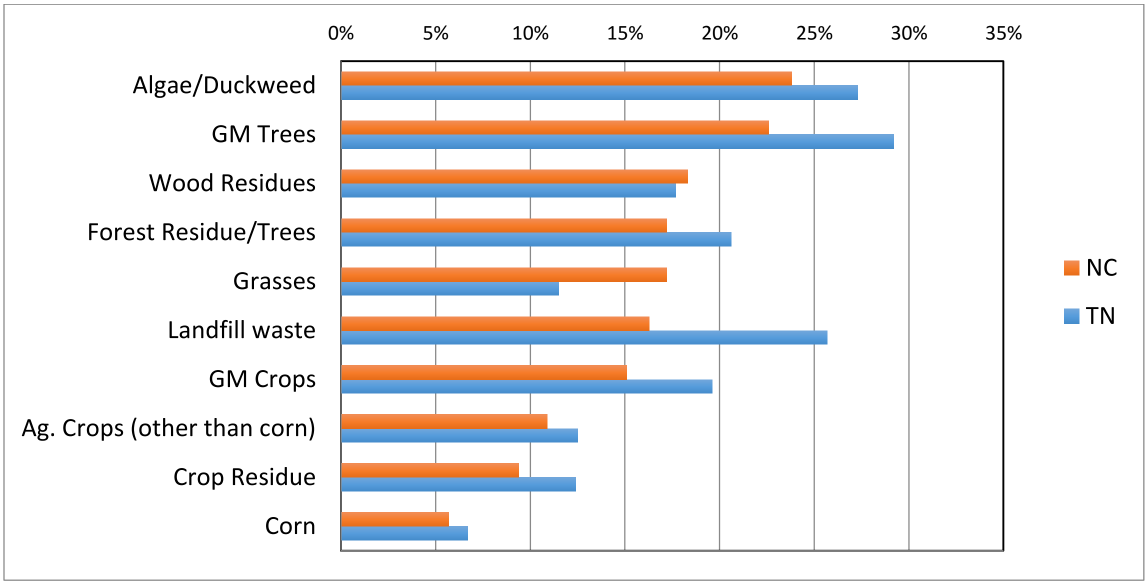

Figure 6 Percent of Consumers in NC and TN who were Unaware of Energy Sources (n=558)

Importance of Factors in the choice of Biofuels for Transportation

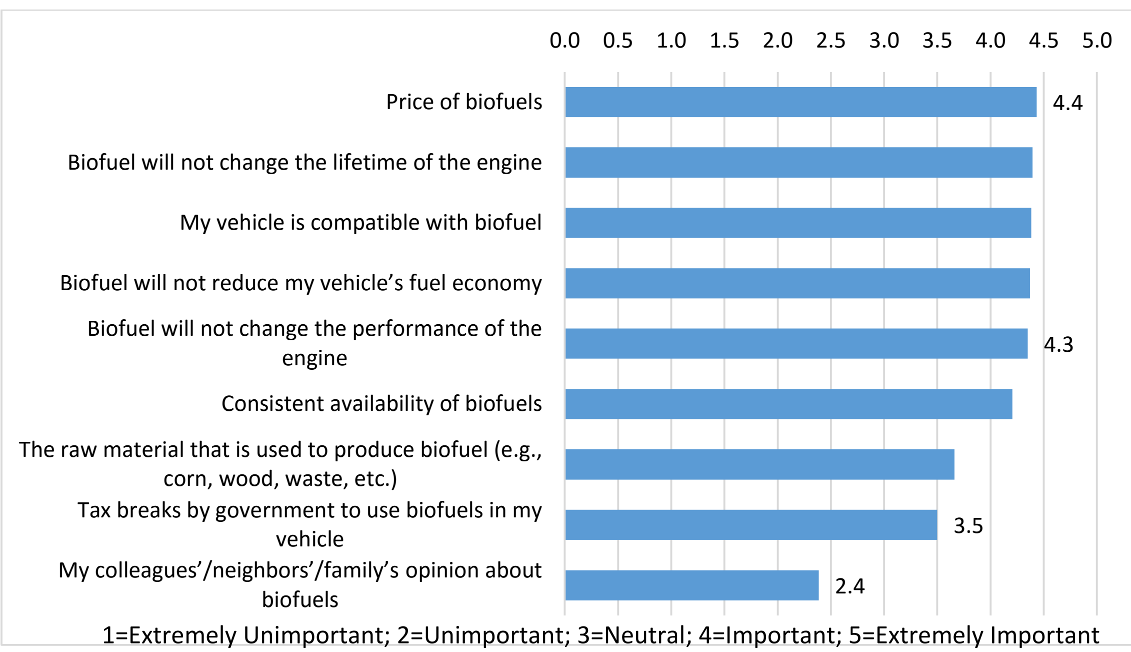

Figure 7 Importance of factors in the choice of biofuels for transportation (mean) (n=542)

When asked to report what factors would motivate their purchase of biomass-based fuels at gas pump, consumers indicated price, vehicle compatibility and performance as the most important factors (Figure 7). The opinion of friends and family was reported to have the least influence on the respondents' choice of biofuels at the pump.

Respondents in TN consistently rated the higher importance of all the above factors for the selection of biofuels at the pump compared to the NC respondents. The difference was significant ($p<0.05$) for all factors except, "biofuel will not change the lifetime of the engine", "neighbors/colleagues opinion about biofuels", and "raw material used to produce biofuel."

Relative Agreement Statements

Respondents were asked to indicate their relative agreement with 38 key bioenergy statements; some statements measured awareness or knowledge and some questions measured perceptions and opinions. The statements were developed with some on a positive and some on a negative scale and the order was randomized across respondents to avoid any bias. Some statements were based on general biomass-based energy products and others specifically focused on biofuels for transportation. The top ten statements by mean ratings of the respondents for all respondents, NC and TN respondents with the p-value for significant differences in mean ratings (alpha =0.05) between NC and TN is shown in Table 10 below.

Table 10 Mean ratings for bioenergy statements (Top ten rated statements)

Bioenergy Statements	Mean Ratings*			p-value** (difference NC and TN)
	Overall (n=533)	NC (n=327)	TN (n=206)	
Before I would purchase biofuels, I would like more information about how they would affect my vehicle	4.22	4.02	4.51	0.000
I would like my local power provider to use renewable fuel sources	3.95	3.92	4.01	0.254
I believe using landfill wastes could be a valuable source of bioenergy	3.87	3.81	3.96	0.050
I believe that the investment in the biofuel industry will create jobs	3.82	3.72	3.97	0.002
I believe that agricultural crops can be used for producing biofuel	3.82	3.74	3.94	0.014
I believe biofuel refineries in my region could provide better employment opportunities	3.80	3.71	3.93	0.007
Using biofuels will reduce US dependence on foreign oil	3.80	3.65	4.01	0.000
E-10 (10% ethanol) is currently blended with most gasoline at gas stations	3.74	3.76	3.73	0.737
I would purchase biofuel if it improves the power of my vehicle's engine	3.67	3.63	3.71	0.374
I would support the cutting of trees for biofuels if for each tree cut another was replanted	3.64	3.59	3.72	0.211

*Ratings were on a five-point agreement scale (1=strongly disagree to 5=strongly agree)
**Significant difference based on independent samples t-test (0.05 level of significance)

Overall, respondents gave highest rating to the statement "before I would purchase biofuels, I would like more information about how they would affect my vehicle" (mean =4.22) with a significant difference (p=0.000) between the respondents from the two states. TN respondents rated the factor much higher (mean=4.51) compared to NC respondents (mean=4.02). Respondents rated statements about local impacts more than other benefits/risks; for example, job/employment benefits of bioenergy or biofuels were estimated more than any of the other concepts such as environmental impacts and pollution, economic impacts, and other social impacts. In addition, respondents highly rated the use of renewable energy sources by the local provider (mean = 3.95). Other benefits of bioenergy that respondents rated high were increased national security and improvement in vehicle engine power.

Among sources of biomass for energy, landfill wastes, and agricultural crops were considered valuable sources for bioenergy more than trees, GM trees/crops, forest/crop residues, and corn. With regards to trees, respondents agreed that they would support cutting of trees only if another were replanted in its place (mean=3.64). Table 11 shows the five “least agreed” with statements. “Government should subsidize the production of biofuels,” “biofuels are not environmental friendly,” “Economics and credibility in information from government,” were among the five least motivational statements for respondents. More TN residents reported agreement (mean rating = 2.9) with a purchase of biofuels with a little premium over gasoline compared to residents of NC (mean rating=2.6).

Table 11 Mean ratings of bioenergy statements (Bottom five rated statements)

Bioenergy Statements	Mean Ratings			p-value** (difference NC and TN)
	Overall (n=533)	NC (N=327)	TN (n=206)	
I believe that the government will provide me more credible information about biofuels than the biofuel industry	2.53	2.47	2.62	0.197
I trust the government to give me credible information about biofuels	2.56	2.56	2.56	0.977
I would purchase biofuels even if it is a little more expensive than gasoline	2.69	2.59	2.85	0.022
Biofuels are not environmentally friendly (they take more energy to make than it is worth)	2.82	2.78	2.91	0.109
I think the government should subsidize the manufacturing of biofuels	2.96	2.94	3.00	0.570

*Ratings were on a five-point agreement scale (1=strongly disagree to 5=strongly agree)
**Significant difference based on independent samples t-test (0.05 level of significance)

5.7 Principal Component Analysis

In order to understand if there were any key dimensions of respondents' perceptions and attitudes toward bioenergy, we used principal component analysis (PCA) on the self-constructed agreement statements. A PCA is a multivariate statistical technique used to reduce the number of dimensions of a dataset by finding statistically correlated variables, while retaining as much as possible of the variation present in the dataset (Jolliffe 2002). This reduction is obtained by transforming to a new set of variables, called Principal Components, which were uncorrelated, and which were ordered so that the first few retain most of the variation present in all of the original variables. The Cronbach's alpha is calculated for each dimension showing the level of internal consistency of the variables. Alpha values of 0.50 and above were acceptable (Peterson 1994).

PCA of the relative agreement statements resulted in seven principal components (PC) or dimensions that explained 71.2% of the variation in the responses. These seven items show the consumer broader attitudes toward bioenergy. The items (variables) with low dimension loading (less than 0.50) were eliminated from the analysis resulting in only 24 agreement statements that fit well with the dimensions. These seven broad aspects of consumer attitudes toward bioenergy/biofuels were compiled in Table 12 with the corresponding variables and loadings (all loading greater than 0.50 were shown). The first dimension "Bioenergy Benefits to Society" (alpha =0.89) identifies variables/ statements that indicate bioenergy benefit for national security, improvement in jobs and rural economy, and higher benefits than risk of bioenergy use. The second dimension of bioenergy represented items that show the “Risks of Bioenergy Use” (alpha =0.78). The dimension consists of statements that reflect bioenergy use leading to negative environmental impact, reduction in vehicle performance and increase in costs. The third dimension “Government Support for Bioenergy” includes three items (alpha =0.80) that measure government support required for research and production of bioenergy as well as a source of information. The next dimension shows the competition of fuel vs. food in the society. This dimension measures “Increase in Food Cost” due to biofuel production (alpha = 0.87). The fifth dimension shows some imperative reasoning behind acceptance of trees as feedstock sources. This dimension is labeled “Conditional Use of Trees as Feedstocks” (alpha =0.69), including items such as support to cut trees only if it significantly reduced oil imports or if the cut tree were to be replaced by another. The next PC is supporting biofuels if it was lower in cost compared to gasoline or electricity. This dimension “Support Low-Cost Biofuel Alternative to Current Energy” has an alpha of 0.50. The last dimension (“Market Attribute-Based Purchase, alpha =0.58) includes consumer perception about biofuel purchase only if the common market attributes (price, availability and product performance) were satisfied.

Table 12 Key dimensions of consumers' bioenergy perception * (n=586)

Key Dimensions and Items	Loadings on Dimensions
Bioenergy Benefits to Society (PC1)	**Alpha=0.89**
I believe that investment in the biofuel industry will create jobs	**0.81**
Using biofuels will reduce US dependence on foreign oil	**0.77**
We should produce biofuels to meet our country's energy demand	**0.76**
I think the biofuel industry will improve the rural economy	**0.75**
I believe biofuel refineries in my region could provide better employment opportunities	**0.73**
I believe the biofuel industry will have more benefits than risks for the society	**0.66**
Risks of Bioenergy Use (PC2)	**Alpha=0.78**
I believe a biofuel facility in my local area will cause pollution issues	**0.73**
Biofuels are not environmentally friendly (they take more energy to make than it is worth)	**0.71**
I am concerned that using biofuels will lower my vehicle's gas mileage	**0.66**
I believe our taxes will rise if we produce and use biofuels at a large scale	**0.62**
I would not purchase biofuels because they might be bad for my car engine	**0.62**
Government Support for Bioenergy (PC3)	**Alpha=0.80**
I trust the government to give me credible information about biofuels	**0.81**
I think the government should subsidize the manufacturing of biofuels	**0.74**
I think the government should invest more in bioenergy research and production	**0.64**
Increase in Food Cost (PC4)	**Alpha=0.87**
I think biofuels will cause food to be more expensive	**0.84**
I think biofuels made from corn will cause food to be more expensive	**0.81**
Conditional Use of Trees as Feedstocks (PC5)	**Alpha=0.69**
I would support the cutting of trees for biofuels if it significantly reduces oil imports into the US	**0.84**
I would support the cutting of trees for biofuels if for each tree cut another was replanted	**0.77**

Table 12 continued

Support Low Cost Biofuel Alternative to Current Energy (PC6)	**Alpha=0.50**
I would only choose biofuels if they are lower in price than gasoline	**0.77**
I would purchase biofuels even if it is a little more expensive than gasoline	**-0.66**
I would not like my local power provider to use renewable fuels sources if it costs me more money	**0.58**
Market Attribute-Based Purchase (PC7)	**Alpha=0.58**
I would only purchase biofuels if they were the same price as gasoline	**0.80**
I would only purchase biofuels if they were available at most or all gas stations	**0.66**
I would purchase biofuel if it improves the power of my vehicle's engine	**0.63**

*Variation explained = 71.2%, Rotated components using Varimax, Rotation converged in 8 iterations, Kaiser-Myer-Olkin measure of sampling adequacy = 0.86, Bartlett's test of sphericity = 0.000.

5.8 Responses for an Open-ended Question

Respondents were asked to indicate any comments or concerns they may have about the bioenergy industry or biofuel industry. About 187 respondents completed this open-ended question. Responses to the open-ended question were varied, almost half of the respondents were not supportive of the bioenergy industry. People cited reasons such as higher costs of production, competition for land for food, reliance on tax subsidies, unintended environmental impacts such as air, water pollution, etc. Most people indicated support for other renewable energy sources such as wind, solar and hydropower as compared to biomass-based energy. Almost 30% of respondents who responded to the open-ended question were concerned about biofuel negatively affecting their vehicle performance (including support for bioenergy only if it is proven that there is no negative impact on the engines.) Approximately 20% of individuals indicated their support to bioenergy industry with half indicating support conditional upon no subsidies available and allowing a free market where biofuels compete with gasoline and other energy products. Surprisingly, only 5% of open-ended comments from were about bioenergy leading to reduced dependence on foreign oil and national security improvement with the use of bioenergy, which was found to be a major driver of public support in past studies (Dwivedi and Alavalapati 2009; Delshad et al. 2010). Approximately, a quarter of respondents acknowledged that they didn't have any information about bioenergy and would like to get more information about its economics, use and performance effects on vehicle, its environmental impacts, as well as its competition with food products. Some examples were indicated in table 13.

Table 13 some example of comments

"I think if it is cheaper than gas and your car runs the same, people will buy it."
"I have older cars. 10% Ethanol is all they can handle without damage. Using corn increases food prices."
"We have oil. A lot of oil. Drill it and use it! Sell it to the world."
"Need to reduce the dependence on oil and carbon emitting fuels or future generations will suffer."
"Keep the government out of the biofuels business. Let the market make its own case."
"Great ideas for wind, solar, biodiesel: will reduce need for Arab oil."
"Education is key for the understanding of what this process is about and why it is necessary for the US."
"I strongly oppose taking up land used for agricultural purposes to grow biofuel. I support using waste and non-food plants (but not trees we need them to pull CO_2 from the atmosphere)."

Sources of Bioenergy Information

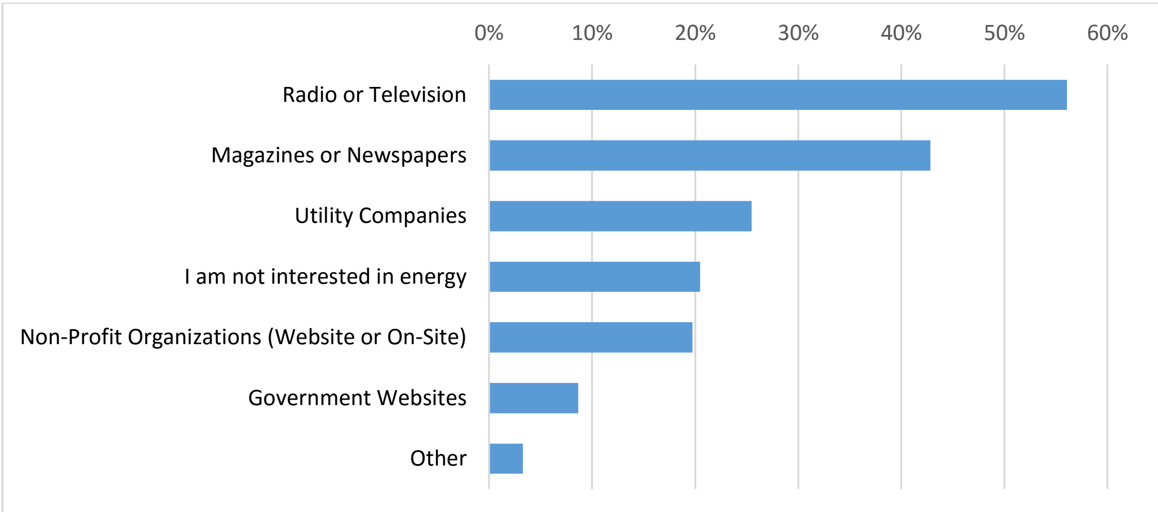

Figure 8 Information Sources used by the Respondents (n=586)

Most of the respondents reported using more than one information source when they indicated having heard or received any information on bioenergy (Figure 8). Radio and television was reported as the top ranked source for information on bioenergy (used 56.1% of the time to get information.) Magazines and newspapers were the second most important channels (42.8%) for bioenergy information followed by utility companies (25.5% of all sources). Governmental websites were the least commonly used sources of information for bioenergy information.

DISCUSSION AND CONCLUSIONS

The analysis of consumer data from NC and TN shows that the general public varies widely in their understanding and knowledge about biomass-based energy and biofuels (for transportation) among the general public. Results of our study shows consumers considering various aspects of bioenergy including impacts on society, environment, costs, land use and competitive products (mostly food), and vehicle compatibility with biofuels that will guide their support toward biofuels industry in the future.

Most consumers were worried about the price of energy over the price of fuels, unemployment, national security, and other critical environmental issues. This finding is consistent with another study that reported people citing energy issues as important more often that gas prices and environmental issues (Tompson et al. 2012). Other past studies have also identified these same concerns, although the ranking of these problems varies among these studies (Resch et al. 2008, Abt et al. 2010, Halder et al. 2010). For example, Plate et al. (2010) showed that environmental impacts were more important to consumers than local economy and jobs for bioenergy projects.

Among biomass sources, landfill wastes, agricultural crops, and trees were considered acceptable to consumers. However, consumers reported that they would support trees as feedstocks if they were replaced with another tree. This finding is consistent with the findings by Plate et al. (2010) that a loss of forest/wood was the most important factor among a number of concerns and beliefs in wood-to-energy projects.

Respondents recognized solar, and wind energy sources as the most “renewable” energy sources compared to all other energy sources including biomass-based energy consistent with past studies (Borcher et al. 2007, Delshad et. al. 2010, Savvanidou et al. 2010, Pires 2012). These results were not surprising given that the focus on bioenergy is recent whereas tidal, wind and solar technology research have been prevalent in large-scale commercial projects for the last couple of decades. Researchers also report that respondents tend to over-estimate the current potential of renewable energy sources such as solar power to meet rising demands for energy (Plate et al. 2010). Although bioenergy was less well recognized than solar or wind in our study, respondents indicated a strong preference for specific biomass feedstocks with crop residues, corn, agricultural crops, and grasses and more preferred. The least preferred biomass sources were the genetically modified crops and trees, and algae. In earlier studies, corn-based ethanol was found to be a less preferred feedstock (Delshad et. al. 2010, Pires 2012) whereas, respondents in our study ranked it second in their willingness to purchase bioenergy from corn. This may be because corn-based bioenergy is the prevalent source in the market today.

Our study shows that consumers were seeking more information and specifically information on biofuels' compatibility with their vehicle. Developing credible educational tools and an effective dissemination strategy could increase the acceptance of biofuels,

Interestingly, analysis of open-ended questions where the consumers indicated their concerns or comments about bioenergy showed opposition to bioenergy related to mostly risks and skepticism about bioenergy impacts on environmental and social well-being and reliance on subsidies. Most notably, the results of this study point out that a quarter of respondents were aware that they do not know much about the bioenergy industry and were interested in learning more. Past studies have shown that consumers were more curious and interested than skeptical or fearful about biomass-based energy (Plate et al. 2010). Consistent with prior work (Rochracher et al. 2004, Mccormick 2010) these results show that the acceptance of bioenergy, and specifically biofuels, will depend on the extent of knowledge and information available about production, economics, environment issues, social impacts, etc. There is no doubt that there is a significant lack of information about bioenergy as well as biofuels especially to the general public as showcased in earlier studies (Savvanidou et al. 2010). However, because of the multifaceted way in which the word “bioenergy” is used in the media as well as in research, the public is bound to have difficulty in understanding this concept. Bioenergy debate encompasses many areas including efficient resource use, climate change, carbon footprint, decrease in forest cover, sustainable development, food vs. fuel debate, etc. making it even more confusing for consumers to comprehend (Rochracher et al. 2004). In addition, it is well known that media content and channel on bioenergy has a significant impact on consumers’ opinion formation (Caccatiore 2012). National ad campaigns, the traditional press, local and national farm groups and NASCAR racecars all provide somewhat different views of biofuels. Thus, if the industry and government machinery wants the bioenergy technologies to be acceptable in the marketplace, they need to have a consistent and simpler message delivered through appropriate media channels to the end users/public. In addition, it is not only the channels and the message that is important, the interest about bioenergy from consumers may also be affected by how the informational materials were presented to this audience (Zarnikau 2003). It will also be useful if a deeper understanding is developed about any groups or segments of the population that have varying opinion in order to target these segments using appropriate messages and media content that would increase their knowledge and understanding of the bioenergy context (Plate et al. 2010, West et al. 2010, Zhang et al. 2011).

Channels for dissemination of information should be largely those that garner public trust. Some of the findings of this study show that people were concerned about the government being a credible source of information. This negative connotation with the word "government" is nothing new and is shown to be ranked lower than other sources of information (van der Horst 2002, Plate et al. 2010). Local sources (extension agents, foresters) as well as local utility companies, environmental groups were considered more trustworthy compared to what is title "government," newspapers, and online channels and should be used for information dissemination as much as possible (Plate et al. 2010, Tompson et al. 2012). In addition, collaboration with environmental organizations and academia for outreach is also key to successful information spread to the general public. As we look towards appropriate messaging of bioenergy information for the general public, it is important that information providers move away from rather formalized way of framing the concept (whether from government, local extension agents or non-government organizations) and move towards small successful case studies. For example, the technology can be showcased with a small-scale bioenergy project with the focus on local and regional benefits such as employment, agricultural diversification, and sense of contributing positively to tackling climate change. The respondents support bioenergy local impacts such as jobs/employment and use of renewable resources with local power provider along with other important factors such as national security, vehicle compatibility with biofuels, etc. Biomass energy production is an ideal candidate for decentralized production at the local and rural level (Gerber 2008) and can fit well if the production takes into consideration the local community opinion and participation.

Another area that will help clarify the confusion and information around bioenergy is on certification and labeling schemes of products and processes. Certification provides standardized information to buyers about product characteristics that will make it simpler to disseminate the messaging to the general public. Of course, who provides the certification and what kind of criteria is applicable to bioenergy products along with indicators and costs (who bears the cost) will be important in this development process.

Our findings on bioenergy statements also show that respondents agree with vehicle compatibility of with biofuels (for transportation) more than any other factors. Although we found that citizens in SE US were concerned about fuel compatibility with their vehicles, other studies in Europe show that about 80% of consumer were willing to use biofuels in their cars and 45% were also willing to pay a little premium for the current fuel cost for the use of biofuels (Savvanidou et al. 2010).

We find that environmental issues were not identified as most important to bioenergy choice or support. Respondents agreed that bioenergy is environmentally better than gasoline, but they rated these environmental impact statements lower than other statements. Selfa et al. (2011) also showed that the local community or general public cared about economic benefits, traffic, and resource competition but were not concerned about any environmental attributes when making decisions about support of local bioenergy projects.

This study showed that TN citizens consistently rated characteristics higher than the citizens of NC. NC consumers were found to be more concerned about climate change and biofuel concern on the environment whereas, TN residents were significantly more worried about U.S. dependence on foreign oil and price of transportation fuels and energy. On average, NC consumers reported better awareness of most energy sources compared to TN consumers except somewhat for wood residues and more so for grasses. We found a rather significant difference in willingness to purchase for grass-based feedstock with 86% respondents in NC willing to purchase compared to 79% of respondents in TN. As indicated earlier, the lack of differences between NC and TN perception of grass as an energy source is surprising because of significant investment by TN in deploying switchgrass as a biofuel feedstock (Nair 2015). In TN, 46% of the population in TN reported nuclear energy as renewable compared to 27% in NC. It could be that more exposure to nuclear power plants in the vicinity could lead to differing knowledge level between citizens of the two states (e.g., NC has four nuclear power plants, TN has two).

There were some inherent constraints of our data collection. The generalization of the results to southeastern U.S. is limited by the fact that only two states (NC and TN) were sampled, and there were significant differences between these states on some bioenergy aspects. So, while the results provide a useful look at how citizens in the two states that were of economic and political relevance to the SE region form opinions about bioenergy, it is important to note that these findings may not be applicable to all states in the Southeast or for citizens across other regions of the U.S. A second limitation concerns the use of weighting to weight the data to represent the two states. Although weights has been used successfully to make inferences to a larger population in various studies including for the Census data, it is to be noted that when one sample is considered to have a slight or a vast weight, it reduces the overall precision of the estimates which translates into increase in variance of the estimates (Lavrakas 2008). To correct for the precision, we used the raking method that has the advantage of working well with smaller samples and also with reducing the variance of the estimates (Battaglia et al. 2004, Lavrakas 2008). We also used smaller binned categories to constrain the inflation of the weighting estimates in our data.

While this study has identified some key attitudes and opinion dynamics around bioenergy and biofuels, future research will need to examine a number of additional issues to arrive at a more comprehensive understanding of attitude formation around bioenergy. As indicated earlier, given varying responses from consumers, we believe a segmentation of consumers or the general public (as shown by Van de Velde 2009) will be helpful in garnering a deeper understanding of how different the risk and opportunity perceptions were so that targeted strategies can be employed for messaging and reaching each unique segment.

It is important to explore the complex dynamics between particular stakeholders. Bioenergy has a significant impact on consumers, farmers, forest landowners, industry, NGOs, local communities and these stakeholders do not all benefit in the same way and at times these interests may be opposed. Thus, data on the other stakeholders will improve the overall understanding of different facets of the informed and uninformed public about bioenergy. Additionally, as indicated above, a content analysis of the media on the bioenergy based discussion and buzz will show what content is being delivered, in which channels and how people form attitudes based on that. Future research could include examining and identifying segments of consumers that may differ in their perceptions of bioenergy, examining a structured bioenergy certification criteria and standards for bioenergy products and processes which can ultimately lead to a competitive and sustainable bioenergy market.

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REFERENCES

Abt, R. C., Abt, K. L., Cubbage, F. W., and Henderson, J. D. (2010). Effect of policy-based bioenergy demand on southern timber markets: A case study of North Carolina. Biomass and Bioenergy, 34(12), 1679–1686.

Aguilar, F.X. and Cai Z. (2010). Exploratory analysis of prospects for renewable energy private investment in the U.S. Energy Economics, 32(6), 1245-1252.

Battaglia, M. P., Israel, D., Hoaglin, D. C., and Frankel, M. R. (2004). Tips and Tricks for Raking Survey Data. American Association for Public Opinion Research. Available at: https://www.amstat.org/sections/srms/proceedings/y2004/files/Jsm2004-000074.pdf.

Boboth, Z., Zimmer, A., Scott, M., Hilarides, E., Gromet, D. & Massey, C. (2007). Weighting for coverage bias in internet surveys. SDSU. Available at: http://www.sci.sdsu.edu/math-reu/2007-6.pdf.

Borchers, A. M., Duke, J. M., and Parsons, G. R. (2007). Does willingness to pay for green energy differ by source? Energy Policy, 35(6), 3327–3334.

Brinkman, N., Wang, M., Weber, T., and Darlington, T. (2005). Well-to-wheels analysis of advanced fuel / vehicle systems — A North American study of energy use, greenhouse gas emissions, and criteria pollutant emissions. Argonne National Laboratory, Argonne, IL. Available at:
http://www.transportation.anl.gov/pdfs/TA/339.pdf.

Brunntrup, M., Hermann, R., and Gaebler, M. (2009). Bio-energy in Namibia: Opportunities, threats and institutional challenges for rural development and food security. Proceeding paper from the XIII ICABR Conference on The Emerging Bio-Economy. Available at:
http://www.economia.uniroma2.it/icabr/Public/5/Paper/526.pdf

Cacciatore, M.A., Scheufele, D.A., and Shaw, B.R. (2012b). Labeling renewable energies: How the language surrounding biofuels can influence its public acceptance. Energy Policy, 51(12), 673-682.

Delshad, A. B., Raymond, L., Sawicki, V., and Wegener, D. T. (2010). Public attitudes toward political and technological options for biofuels. Energy Policy, 38(7), 3414–3425.

Dillman, D.A., Smyth, J.D. , and Christian, L.M. (2008). Internet, Mail and Mixed Mode Surveys: The Tailored Design Method, 3rd Edition. Wiley. 512p.

Dwivedi, P., and Alavalapati, J. R. R. (2009). Stakeholders' perceptions on forest biomass-based bioenergy development in the southern US. Energy Policy, 37(5), 1999–2007.

Fry, M. and Polonsky, M.J. (2004). Examining the unintended consequences of marketing. Journal of Business Research, 57(11), 1303-1306.

Halder, P., Pietarinen, J., Havu-Nuutinen, S., and Pelkonen, P. (2010). Young citizens' knowledge and perceptions of bioenergy and future policy implications. Energy Policy, 38(6), 3058–3066.

Halder, P., Prokop, P., Chang, C., Usak, M., Pietarinen, J., Havu-Nuutinen, S., Pelkonen, P., and Cakir, M. (2012a). International survey on bioenergy knowledge, perceptions, and attitudes among young citizens. BioEnergy Research, 5(1), 247–261.

Halder, P., Pietarinen, J., Havu-Nuutinen, S., Pelkonen, P., Chang, C., Prokop, P., and Usak, M. (2013). Knowledge, perceptions, and attitudes as determinants of youths' intentions to use bioenergy – a cross-national perspective. International Journal of Green Energy, 10(8), 797-813.

Halder, P., Weckroth, T., Mei, Q., and Pelkonen, P. (2012b). Nonindustrial private forest owners' opinions to and awareness of energy wood market and forest-based bioenergy certification – results of a case study from Finnish Karelia. Energy, Sustainability and Society, 2(19), 1-9.

Halder, P., Havu-Nuutinen, S., Pietarinen, J., and Pelkonen, P. (2011). Bio-energy and youth: Analyzing the role of school, home and media from the future policy perspectives. Applied Energy, 88(4), 1233-1240.

Hassan, M.K., Halder, P., Pelkonen, P., and Pappinen, A. (2013). Rural households' preferences and attitudes towards biomass fuels – results form a comprehensive field survey in Bangladesh. Energy, Sustainability, and Society. 3(24), 1-14.

Jolliffe, I.T. (2002). Principal Component Analysis, 2nd edition. Springer-Verlag, NY. 488p.

Junginger, M., Van Dam, J., Zarrilli, S., Ali Mohamed, F., Marchal, D., and Faaij, A. (2011). Opportunities and barriers for international bioenergy trade. Energy Policy, 39(4), 2028–2042.

Lavrakas, P. (2008). Encyclopedia of Survey Research Methods, Sage Publications, Thousand Oaks, CA. 1072p.

Miller, R.L. and Lewis, W.F. (1991). A stakeholder approach to marketing management using the value exchange models. European Journal of Marketing, 25(8), 55-68.

Nair, M. (2015). $70 million in Tennessee taxpayer dollars being invested in turning switchgrass into fuel. Available at: http://wate.com/2015/01/20/70-million-in-tennessee-taxpayer-dollars-being-invested-in-turning-switchgrass-into-fuel/.

Pacini, H., and Silveira, S. (2010). Consumer choice between ethanol and gasoline: Lessons from Brazil and Sweden. Energy Policy, 39(11), 6936-6942.

Peterson, A. R. (1994) A Meta-Analysis of Cronbach's Coefficient Alpha. Journal of Consumer Research Vol. 21, No. 2 (Sep., 1994), pp. 381-391

Petrolia, D. R., Bhattacharjee, S., Hudson, D., and Herndon, C. W. (2010). Do Americans want ethanol? A comparative contingent-valuation study of willingness to pay for E-10 and E-85. Energy Economics, 32(1), 121–128.

Plate, R.R., Monroe, M.C., and Oxarart, A. (2010). Public perceptions of using woody biomass as a renewable energy source. Journal of Extension. 48(3), 1-15.

Popp, M., Van de Velde, L., Vikery, G., Van Huylenbroeck, G.,Verbeke, W., and Dixon, B. (2009). Determinants of consumer interest in fuel economy: Lessons for strengthening the conservation argument. Biomass and Bioenergy, 33(5), 768-778.

Qu, M., Ahponen, P., Tahvanainen, L., Gritten, D., Mola-Yudego, B., and Pelkonen, P. (2011). Chinese university students' knowledge and attitudes regarding forest bio-energy. Renewable and Sustainable Energy Reviews, 15(8), 3649-3657.

Resch, G., Held, A., Faber, T., Panzer, C., Toro, F., and Haas, R. (2008). Potentials and prospects for renewable energies at global scale. Energy Policy, 36, 4048–4056.

Rohracher, H., Bogner, T., Späth, P., and Faber, F. (2004). "Improving the public perception of bioenergy in the EU." Final report. Available at: https://www.researchgate.net/profile/Philipp_Spaeth/publication/255626229_IMPROVING_THE_PUBLIC_PERCEPTION_OF_BIOENERGY_IN_THE_EU/links/54c226f60cf2911c7a46a8e0.pdf

Savvanidou, E., Zervas, E., and Tsagarakis, K. P. (2010). "Public acceptance of biofuels," Energy Policy 38(8), 3482-3488.

Scarpa, R., and Willis, K. (2010). Willingness-to-pay for renewable energy: Primary and discretionary choice of British households' for micro-generation technologies. Energy Economics, 32(1), 129–136.

Selfa, T., Kulcsar, L., Bain, C., Goe, B., and Middendorf, G. (2011). Biofuels bonanza?: Exploring community perceptions of the promises and perils of biofuels production. Biomass and Bioenergy, 35(4), 1379-1389.

Tompson, T., Benz, J., Broz, J. Kozey, M., Agiesta, J. and Junius, D. (2012). Energy Issues: How the public understands and acts. The Associate Press-NORC Center for Public Affairs Research. Available at: www.apnorc.org.

US Census Bureau (2014). Available at: http://quickfacts.census.gov/qfd/states/37000.html.

U.S. Department of Energy. (2011). U.S. billion-ton update: biomass supply for a bioenergy and bioproducts industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.

Upham, P., and Shackley, S. (2006). The case of a proposed 21.5 MWe biomass gasifier in Winkleigh, Devon: Implications for governance of renewable energy planning. Energy Policy, 34, 2161–2172.

Upham, P., Shackley, S., and Waterman, H. (2007). Public and stakeholder perceptions of 2030 bioenergy scenarios for the Yorkshire and Humber region. Energy Policy, 35(9), 4403–4412.

Upreti, B. R., and Van der Horst, D. (2004). National renewable energy policy and local opposition in the UK: The failed development of a biomass electricity plant. Biomass and Bioenergy, 26(1), 61–69.

Van de Velde, L., Verbeke, W., Popp, M., Buysse, J., and Van Huylenbroeck, G. (2009). Perceived importance of fuel characteristics and its match with consumer beliefs about biofuels in Belgium. Energy Policy, 37(8), 3183–3193.

Wegener, D. T., and Kelly, J. R. (2008). Social psychological dimensions of bioenergy development and public acceptance. BioEnergy Research, 1(2), 107–117.

West, J., Bailey, I., and Winter, M. (2010). Renewable energy policy and public perceptions of renewable energy: A cultural theory approach. Energy Policy, 38(10), 5739–5748.

Zarnikau, J. (2003). "Consumer demand for 'green power' and energy efficiency," Energy Policy 31(15), 1661-1672.

Zhang, Y., Yu, Y., Li, T., and Zou, B. (2011). “Analyzing Chinese consumers' perception for biofuels implementation: The private vehicles owner's investigating in Nanjing,” Renewable and Sustainable Energy Reviews 15(5), 2299-2309.

Zografakis, N., Sifaki, E., Pagalou, M., Nikitaki, G., Psarakis, V., and Tsagarakis, K. P. (2010). “Assessment of public acceptance and willingness to pay for renewable energy sources in Crete,” Renewable and Sustainable Energy Reviews 14, 1088-1095.

CHAPTER 3

USE OF MULTI-ATTRIBUTE DECISION SUPPORT SYSTEM TO COMPARE THE SOCIAL, ENVIRONMENTAL, AND ECONOMIC IMPACTS OF USING WOODY FEEDSTOCKS FOR PELLET PRODUCTION

Robert Radics, Sudipta Dasmohapatra, and Stephen S. Kelley

A Multi-Attribute Decision Support System (MADSS) was used to analyze woody feedstock alternatives – naturally regenerated hardwood, plantation pine, and plantation poplar - for pellet production using a combination of social, environmental, and economic sustainability criteria. The objective of this paper was to examine and apply a qualitative decision tool to evaluate the impacts of different sustainability indicators and the resulting trade-offs that need to be made to optimize these impacts. Our work builds on the use of key sustainability indicators defined by McBride et al. (2011) and Dale et al. (2013) for the evaluation of bioenergy alternative scenarios.

During the evaluation process of our example case, a team of experts used a nine-element scale (highest=9, lowest=1) for scoring 35 key sustainability indicators for the three production scenarios. The scores were used as inputs into the MADSS model and the resulting analysis showed plantation pine to be the most sustainable in pellet production (assuming similar technology, location, transportation, and logistics) closely followed by natural hardwood. On environmental and social indicators, natural hardwood performed better relative to plantation pine or plantation poplar. Economic sustainability was better in plantation pine and plantation poplar, due in large part to their higher growth rates compared to natural hardwood. Our results show the potential for using highly productive plantations for bioenergy production (pellets in

this case). In spite of some challenges, the use of a qualitative tool such as MADSS allows the inclusion of social indicators that are difficult to quantify for evaluating overall sustainability (Dale et al. 2013). We discuss challenges as well as opportunities for using this tool within this paper.

Keywords: Multi-Attribute Decision Supporting System, Bioenergy, Sustainability, Woody Biomass, Pellets

INTRODUCTION

Increase in the use of biomass for energy production to achieve a low-carbon sustainable economy requires a better understanding of the economic, environmental and social impacts across the forest products supply chain (Cambero and Sowlati 2014). Comparing the complex array of these sustainability impacts require good data, a set of well-defined criteria/indicators and a carefully designed analytical framework (Scott et al. 2012, Zanakis et al. 1998).

A wide variety of optimization methods, predictive models, and qualitative methods have been developed and used in the past to address technical and economic, environmental, political and legal, and social issues. The most popular among those are the multi-objective methods of optimization which involves the simultaneous optimization of several competing objectives while finding an optimum solution over a feasible set of decisions (Deb 2009, Chase 2009, Marler and Arora 2004, Zitzler et al. 2004). There are two types of multi-objective methods- generating methods and preference methods. In generating methods, objectives are not commonly prioritized; if they are, they combined into one scalar objective or one objective is minimized or maximized while keeping other objectives constrained without taking into account the preferences of decision makers (Marler and Arora 2004). While in preference methods, decision makers specify goals and preferences and the optimum solutions are generated as a weighted average of the objective functions around the goals or through interactivity and continuous interface with the decision makers (Rangaiah 2008, Hakanen et al. 2006). The proponents of the preference methods indicate that it is important to include stakeholders' preferences when optimizing each of the sustainability objective functions because of the conflicting concerns of economics, environment and social issues that may dominate stakeholders' goals. Jin (2005) looked at first implementing multi-criteria decision analysis tools (MCDA) to explore sustainability concepts to identify environmental metrics. Sengupta et al. (2008) used a Monte-Carlo analysis optimization framework to determine the optimal configuration in a chemical complex system using economic, energy, and environmental costs as constraints.

Most of the tools in the forestry-based optimization literature consist of multi-criteria decision tools. These multi-criteria decision tools have been applied to bioenergy systems, to better understand the trade-off with alternative scenarios. Cambero and Sowlati (2014) performed a comprehensive literature review of the environmental, social, and economic optimization studies of the forest biomass supply chain. They analyzed 54 assessment studies focused on forest supply chain. Of these 22 focused on the economic impacts, and 28 on the environmental impacts. There were four combined studies, and the social sustainability area was not assessed. Prior work has also focused on optimization of the forest supply chain (35 papers), with 28 studies having a focus on economics. Only four of these optimization studies include a combination of environmental and economic criteria, and only 3 included social, environmental and economic criteria.

The past studies show that multi-criteria decision making process are useful when there is a need for considering a large number of stakeholders with different perspectives which is important when making social impact-based decisions as in the case of bioenergy problems (Scott et al. 2012). Stakeholders' participation has been emphasized as key to the large-scale development of sustainable bioenergy systems (Bucholcz et al. 2007) and their involvement is essential when considering the success of bioenergy. These bioenergy systems are complex, require a large set of indicators for different attributes, and include a large number of stakeholders with different values and interests. Thus, multi-criteria decision-making processes are one way to collect this very diverse array of attributes and stakeholders' interests, and to improve the understanding of the impacts and trade-offs for specific cases (Den Herder et al. 2012).

Scott et al. (2012) reviewed the multi criteria decision-making methods for bioenergy systems (57 studies). The most frequently applied method was using one of a variety of analytical algorithms for optimization (71.9%; 41 papers). Qualitative and/or stakeholder interviews were used in seven studies (12.3%). At least one sustainability attribute was addressed in twelve studies (14.1%). Alternative Multi-Criteria Analysis (MCA) tools (Super Decisions, DecideIT, Decision Lab, and NAIADE) were reviewed and compared for their applicability for collecting and multi-stakeholder input into an analysis of bioenergy systems (Buchholz et al. 2009). As expected these MCA tools had strengths and weaknesses depending on the specific application. This analysis concluded that the most important features for MCA were ‘criteria weighting and ranking’, sensitivity analysis, and identifying features with large uncertainties. These MCA tools have limited visualization options, which limits communication and feedback.

Specific examples of the use of MCA tools includes an analysis of carbon dioxide capture and storage based on stakeholder interviews (Shackley and McLahlan, 2006). They identified subgroups that were business focused and environmental/society focused and evaluated the impacts of weighting the stakeholders’ preferences. A MCA study, based on expert and stakeholder interest groups, evaluated bioenergy sustainability (Eghali et al. 2007). This sustainability framework highlights the need for best practices with modeling, quality data and an assessment of uncertainty.

While there are a variety of alternatives for quantitative analysis of specific alternatives when there is well developed data on the alternatives, there is also a need for qualitative tools that can be used to provide an initial evaluation of complex alternatives. In both cases the alternatives will have many attributes and input from a wide variety of different stakeholders (Botanic 2008). But in the case of initial evaluations there is likely to be missing or inaccurate data, qualitative attributes, attributes with different units, and more highly varied input from stakeholders. In all these decision making processes there are questions about the relative accuracy of the ‘data’, much of which is based on models, projections or extrapolations; subjective or value-based judgements; data with inherently large natural variations; and external interactions that can impact the ranking of the alternative cases being evaluated.

Recently, McBride et al. (2011) and Dale et al. (2013) developed a series of environmental and socio-economic indicators that can be used for multi-attribute decision-making processes for several alternative agriculture-based biomass production systems. They subsequently developed Multi-Attribute Decision Supporting System (MADSS) approach to analyze qualitative information regarding different bioenergy feedstocks and makes them comparable to the supply chain (Parish et al. 2015).

We will be using this qualitative tool in this paper to optimize the three sustainability objectives in the case of bioenergy production. The case we focus on is that of the production of wood pellet, primarily for the export market. The export market for wood pellets have jumped from 8.5 to 120 PJ (from ~380,000 metric ton to 5,345,000 metric ton) between 2000 and to 2010 (Lamers et al. 2012), and additional increases have been projected in the coming decade. Wood pellet energy could contribute to a sustainable, low-carbon economy if its environmental performance is better than the alternative fossil energy, and if it is economically viable and socially accepted (Elghali et al. 2007).

OBJECTIVES

The goal of this paper was to demonstrate the use of the Multi Attribute Decision Support System (MADSS) for an evaluation of the economic, environmental, and social impacts of using three different feedstocks (plantation pine, plantation poplar, and natural hardwood) for production of bioenergy pellets. The Plantation poplar to pellet production is considered as a potential scenario because this production system is still under development and there are very small pilot demonstrations but no large scale commercial deployments. Thus, economic risks for this feedstock system is taken into consideration when evaluating outputs. In addition to developing the use of the indicators and tool, the tradeoffs between the different criteria for different feedstock production cases are examined.

MATERIALS AND METHODS

Thirty five sustainability indicators were defined by McBride et al. (2011) and Dale et al. (2013) in the MADSS qualitative model. The MADSS model runs in DEXi 4.0, a commercial software package. The DEXi model represents a decomposition of a decision problem to sub-problems what are easier to resolve as subgroups. The software can address many complex decision problems with multiple attributes, qualitative reasoning, missing or inaccurate data. The software also has good visualization capabilities that can be used for communication of intermediate and final results of the model (Bohanec 2008).

We adapted the MADSS model for optimizing the bioenergy pellets from the three feedstocks. Similar to McBride et al. (2011), we used the Delphi method (Iqbal and Pipon-Young 2009) to solicit inputs from experts (in forestry silviculture, production, processing, operations, supply chain, environmental management, water and soil management, energy management, process control, economics, product quality, and markets) from within the Integrated Southeastern Partnership for Integrated Biomass Supply Systems (IBSS) team (http://www.se-ibss.org/). The experts examined whether to use all 35 indicators and define each of the indicators used to determine sustainability ad well as rated the indicators based on a nine-point rating scale where 1= low/decreased to 9=high or increased for the three bioenergy feedstock to pellet production scenarios.

The experts agreed on using 35 indicators but defined and categorized some of the indicators differently based on the bioenergy use case (pellets). Once the structure and the indicators were agreed upon, the group of experts individually scored the indicators, using a 9-point scale, for the three different biomass production systems and then finalized the scores (reached a concensus score for each indicator) in group discussions. In contrast to the McBride et al. (2011) and Dale et al. (2013) study where a 3-point scale was used, this study used a 9-point scale to better differentiate the three alternative biomass production cases. In the evaluation, the expert panel considered the entire pellet production process from feedstock production to power generation and export, as shown in Figure 9. The expected rotation length for plantation pine was assumed as 30 years, for plantation poplar was assumed as five years, and for natural hardwood was assumed as 80 years. We assume that the feedstocks are grown in the same location and the amount of pellets produced is the same for each scenario. The technology and transportation were also assumed to be constant across the three feedstock-to-pellet systems. Plantation pine, which is practiced on more than 30 million acres in the US, was defined as the base case when the evaluation needed a comparison between feedstocks.

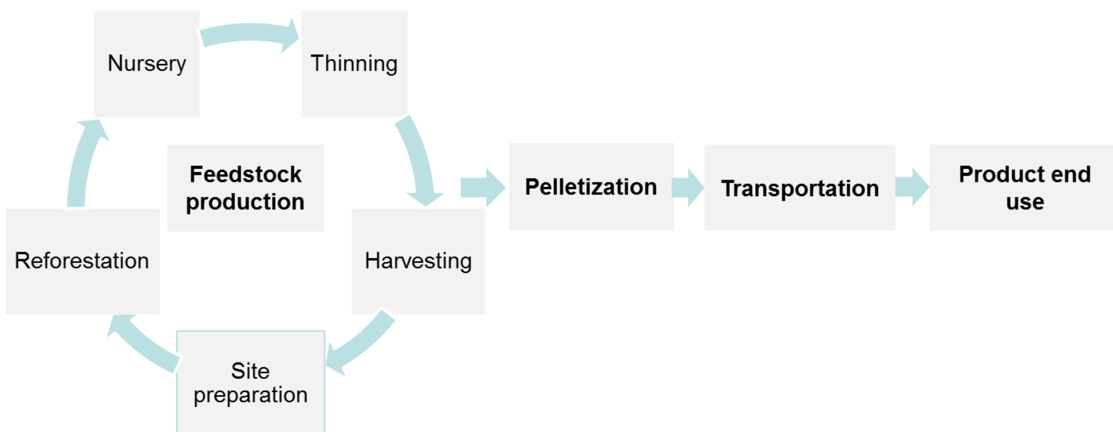


Figure 9 Forest biomass supply chain process

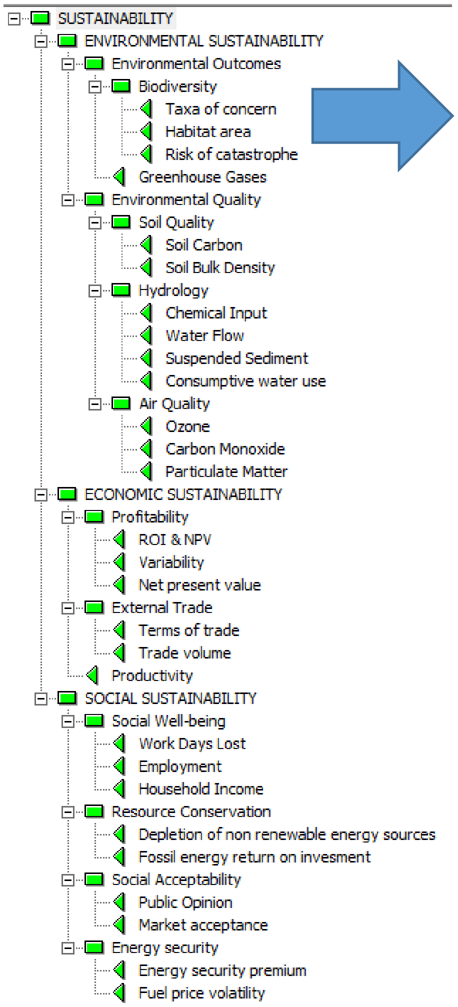
Table 14 shows the system structure of indicators that the expert panel agreed on, combined into corresponding subcategories, that are rolled up into the economic, environmental and social attributes of sustainability as shown in Table 14.

Table 14 Attributes, subcategories and indicators used

Attributes	Sub-category	Indicator
Social sustainability	Social well-being	Employment; number of local people hired
		Household income; change in dollars/year
		Work days lost due to injury
	Energy security	Energy security premium; decrease in risk of energy price changes, macroeconomic losses
		Fuel price volatility; standard deviation of monthly fuel price changes over the year
	Resource conservation	Depletion of non-renewable energy resources; change
		Fossil energy return on investment (fossil EROI); ratio of fossil energy input of useful energy output
	Social acceptability	Public opinion on harvest; percent of favorable opinion
		Public acceptance of using source of woody biomass; opinion of harvesting for bioenergy
Economic sustainability	External trade	Terms of trade; price of export/price of import
		Trade volume; change
	Profitability	Return on investment (ROI)
		Net present value (NPV)
		Variability in annual profit
	Productivity	Productivity, yield; amount of biomass produced
Environmental sustainability	Soil quality	Total organic carbon (TOC); change
		Bulk density; change, measure of soil compaction
	Water quality and quantity	Chemical inputs; overall change due to chemical use
		Suspended sediment concentration in streams; change
		Consumptive water use
		Water flow; water availability for other purposes
	Greenhouse gases	CO2 equivalent emissions
	Biodiversity	Presence of taxa of special concern
		Habitat area of taxa of special concern; change
		Risk of catastrophe; change in probability of catastrophe
	Air quality	Tropospheric ozone emission
		Carbon monoxide emission
		Total particulate matter less than 2.5 µm diameter (PM2.5)

Source: Adapted from McBride et al. (2011) and Dale et al. (2013)

Table 14 defines each of the indicators and shows the subcategory to which the indicators were included in the model. The indicators were then input into a decision tree within the DEXi software for the three feedstock pellet production scenario based on the MADSS model. The structure of the decision tree is shown in Figure 10. For each of the three scenarios, each indicator was given a value on the 9-point scale based on the consensus of the expert panel – this was done to examine variability in the ratings and is different from the McBride et al. (2011) and Dale et al. (2013) method. The 9-point scale was rolled up into three categories; 1-3 points were qualitatively given a low/decreased category, 4-6 points were qualitatively rolled up into a medium category and 7-9 points were given a value of high/increased category). The three category rating score for sustainability is used to compare to the method used by McBride et al. (2011) who use three categories to score their indicators and categories of sustainability. Thus, each indicator received one of the three values (high/medium/low) which was combined to indicate the value of the sub-categories and sustainability attributes. Each indicator group on the same level (e.g., Taxa of concern, Habitat area, and Risk of catastrophe) were aggregated to the next level of subcategory (e.g. indicators that inform Biodiversity) to form the relevant utility table. The rules of decisions were defined under the assumption that the same level of indicators or subcategories had similar weights, and for achieving a higher level of sustainability more indicators (>50%) should have higher sustainability values than lower sustainability values. An example showing this rule for biodiversity sub category (defined by the three indicators mentioned above) is shown in Figure 10. The first row indicates that if the taxa of concern is decreasing, habitat area is decreasing and risk of catastrophe is increasing then the overall biodiversity sub-category is low. Here we assume that each of the three indicators have an equal weight on the overall biodiversity impact. If any of the three indicators was weighted more or less, that could change the value of the biodiversity impact category. A utility table with all possible end results based on the individual indicator values was calculated and is shown in Appendix B. The tree structure was created by making the assumption that indicators or subcategories on the same branch had the same weight of impact on the sustainability attribute (e.g., Biodiversity and Greenhouse Gases had the same weight of impact on Environmental Sustainability, or Ozone and Taxa of Concern had the same weight of impact on Environmental Sustainability). Thus, the more were the number of indicators on a subcategory or subcategories within an attribute, the lower was the impact of the individual indicator on the subcategory or the subcategory on the attribute. At any time, the indicators or attributes could be weighted more or less than each other, but this additional level of complexity was not added in this paper.



	Taxa of concern	Habitat area	Risk of catastrophe	Biodiversity
1	Decreasing population	Decreasing	Increasing	**less biodiversity**
2	Decreasing population	Decreasing	No change	**less biodiversity**
3	Decreasing population	Decreasing	Decreasing	**less biodiversity**
4	Decreasing population	No change	Increasing	**less biodiversity**
5	Decreasing population	No change	No change	**less biodiversity**
6	Decreasing population	No change	Decreasing	**some biodiversity**
7	Decreasing population	Increasing	Increasing	**less biodiversity**
8	Decreasing population	Increasing	No change	**some biodiversity**
9	Decreasing population	Increasing	Decreasing	**some biodiversity**
10	No change	Decreasing	Increasing	**less biodiversity**
11	No change	Decreasing	No change	**less biodiversity**
12	No change	Decreasing	Decreasing	**some biodiversity**
13	No change	No change	Increasing	**less biodiversity**
14	No change	No change	No change	**some biodiversity**
15	No change	No change	Decreasing	**more biodiversity**
16	No change	Increasing	Increasing	**some biodiversity**
17	No change	Increasing	No change	**more biodiversity**
18	No change	Increasing	Decreasing	more biodiversity
19	Increasing population	Decreasing	Increasing	**less biodiversity**
20	Increasing population	Decreasing	No change	**some biodiversity**
21	Increasing population	Decreasing	Decreasing	**some biodiversity**
22	Increasing population	No change	Increasing	**some biodiversity**
23	Increasing population	No change	No change	**some biodiversity**
24	Increasing population	No change	Decreasing	more biodiversity
25	Increasing population	Increasing	Increasing	**some biodiversity**
26	Increasing population	Increasing	No change	more biodiversity
27	Increasing population	Increasing	Decreasing	more biodiversity

Figure 10 Decision tree and utility table in DEXi

As indicated earlier, each indicator first received a score on the nine-point sustainability scale. The model was also analyzed at the 9-element scale level without rolling the ratings into three categories to show the variability in the rating scores across the three sustainability attributes. Figure 11 shows the structure and application of the sustainability scores. The given weights for all the indicators are the same (value of 5 here but it could be 1), plantation pine feedstock for pellet production is highest in fossil energy return on investment for social attributes. Similarly, plantation popular is higher value in employment and household income as well as in public opinion and market acceptance for social attributes. The natural hardwood feedstock is rated highest for resource conservation indicators as compared to plantation pine and plantation poplar for social attribute category.

The second table shows the values for each of the subcategories as combined from the corresponding indicators. Similarly the last table shows the overall sustainability scores (based on the 9-element scale) for each of the feedstocks for each sustainability metric (Figure 12). On environmental indicators, natural hardwood received the highest score on sustainability compared to the other two feedstocks for pellet production whereas, on economic indicators, plantation pine received the highest score for sustainability. On social sustainability, plantation pine was scored slightly more than plantation poplar, which was scored higher than natural hardwood. Note that this difference may not be statistically significantly different (not enough data points to calculate the difference).

			Sustainability score			
	Sub-Category	**Indicator**	**Plantation Pine**	**Plantation Poplar**	**Natural Hardwood**	**Weight**
Social	Social well- being	**Employment**	6	8	2	5
		Household income	6	8	2	5
		Work days lost due to injury	6	4	7	5
	Energy security	Energy security premium	7	3	7	5
		Fuel price volatility	7	2	5	5
	Resource conservation	**Depletion of non-renewable energy resources**	5	2	8	5
		Fossil energy return on investment (fossil EROI)	8	5	8	5
	Social acceptability	**Public opinion**	5	8	3	5
		Market acceptance	5	8	7	5
Economic	External trade	Terms of trade	5	4	5	5
		Trade volume	6	3	3	5
	Profitability	Return on investment (ROI)	7	3	8	5
		Net present value (NPV)c,d	7	3	8	5
		Variability	8	6	3	5
	Productivity	Aboveground net primary productivity (ANPP)/yield	5	8	2	5
Environmental	Soil quality	Total organic carbon (TOC)	5	5	7	5
		Bulk density	5	5	5	5
	Water quality and quantity	Chemical inputs	2	1	9	5
		Suspended sediment concentration in streams (and export)	5	2	8	5
		Water flow	5	2	8	5
		Consumptive water use (incorporates base flow)	7	2	8	5
	Greenhouse gases	CO_2 equivalent emissions (CO_2 and	2	5	8	5
	Biodiversity	Presence of taxa of special concern	5	2	9	5
		Habitat area of taxa of special concern	5	2	9	5
		Risk of catastrophe	8	5	5	5
	Air quality	Tropospheric ozone	5	2	8	5
		Carbon monoxide	5	2	8	5
		Total particulate matter less than 2.5 μm diameter (PM2.5)	5	2	8	5

	Sustainability score			
Category	**Plantation Pine**	**Plantation Poplar**	**Natural Hardwood**	**Weight**
Social well-being	6.0	6.7	3.7	5
Energy security	7.0	2.5	6.0	5
Resource conservation	6.5	3.5	8.0	5
Social acceptability	5.0	8.0	5.0	5
External trade	5.5	3.5	4.0	5
Profitability	7.3	4.0	6.3	5
Productivity	5	8	2	5
Soil quality	5.0	5.0	6.0	5
Water quality and quantity	4.8	1.8	8.3	5
Greenhouse gases	5	5	8	5
Biodiversity	6.0	3.0	7.7	5
Air quality	5.0	2.0	8.0	5

Figure 11 Sustainability scores by feedstocks by categories and indicators on the nine-element scale

	Sustainability score			
Attributes	**Plantation Pine**	**Plantation Poplar**	**Natural Hardwood**	**Weight**
Social	6.13	5.17	5.67	5
Economic	5.94	5.17	4.11	5
Environmental	5.15	3.35	7.58	5
Total sustainability score	5.74	4.56	5.79	

Figure 12 Sustainability attributes

RESULTS

Sustainability attributes

The final output showing the results for the three sustainability attributes, e.g., economic, environmental and social, for the three individual bioenergy cases are presented in Figures 13 and 14. In these graphical illustrations, the higher the numeric score or closer to exterior boundary the attribute or indicator, the more “sustainable” the attribute or indicator.

Figure 13 highlights the differences between the three feedstock cases for the three sustainability attributes (economic, environmental and social). Plantation pine was scored highest among all sustainability attributes. Natural hardwood was scored high on environmental sustainability, and intermediate on social and economic sustainability due to relatively low growth rates and long rotation length compared to the plantation pine. Plantation Poplar was scored as low in environmental sustainability due to more frequent chemical usage, and negative environmental impacts of frequent harvesting. Plantation Poplar received intermediate scores on economic and social sustainability. The fossil energy usage and the return on investment for the current plantation poplar systems were rated higher than that for natural hardwoods or plantation pine.

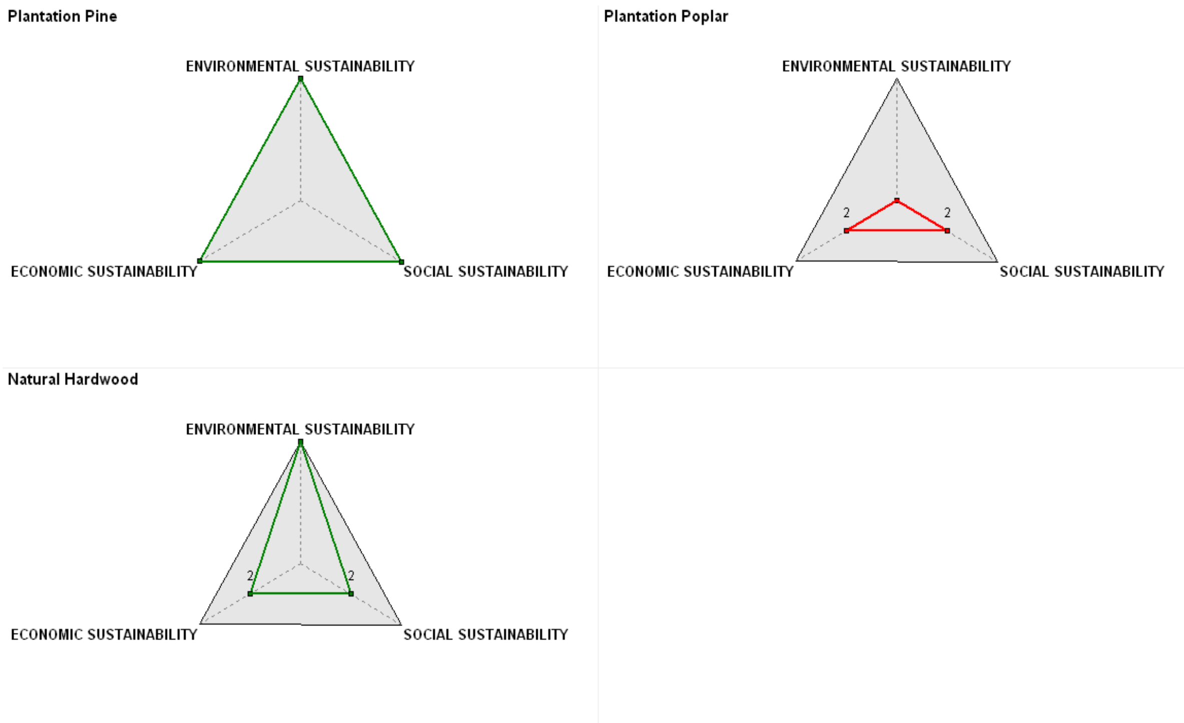


Figure 13 Sustainability attributes for the three feedstock systems based on the three qualitative categories (high/medium/low sustainability scores

In case of the sustainability scores based on the nine-point sustainability rating scale (shown in Figure 14), natural hardwood was scored the highest in overall sustainability. In the nine-point scale the environmental sustainability scores for natural hardwood performed significantly higher (7.58), than the plantation pine (5.15), and plantation Poplar (3.35) and consequently had a higher contribution on overall sustainability. The high environmental attribute value of hardwood was obtained because of the high scores on water quality, greenhouse gases, biodiversity, and air quality subcategories (8.3, 8.0, 8.7, and 8.0, respectively on the 9-point rating scale). The low environmental sustainability attribute of plantation poplar was due to the low values of water quality, biodiversity, and air quality subcategories (1.8, 2.0, and 2.0, respectively). The assumptions of low rotation length (and corresponding human disturbance) and the forest management process including the frequency and volume of chemical use and equipment use – led to the low rating of environmental quality indicators. Social and economic attributes scores did not show large differences among feedstock systems as the environmental attribute did.

The trade-offs between environmental and economic attributes are highlighted for plantation poplar. The environmental attribute scores for are negatively impacted by the frequency of human disturbances to the land, specifically chemical use during establishment and equipment use during harvesting. The proposed poplar plantation systems have much higher productivity (growth rates) scores but this is compensated by factors such as much higher planting/investment costs, limited alternative markets if the potential for bioenergy market is eliminated, and the associated risk with a new technology.

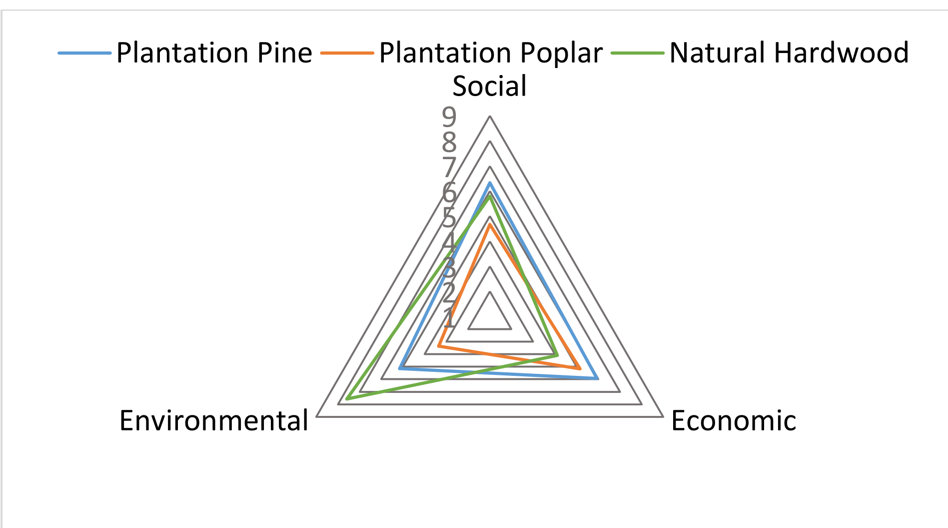


Figure 14 Sustainability attributes for the three feedstock systems based on the nine-point sustainability rating scale

Impacts on the Environmental Attribute

Figures 15 and 16 detail the differences between the feedstocks for the subcategories that combine into the environmental attribute. These subcategories include, biodiversity, air quality, hydrology, soil quality, and greenhouse gases. Based on these five subcategories the environmental attributes for each feedstock create a pentagon, where the area inside the pentagon reflected by the bold lines correspond to the relative merits of the attribute; the larger the area inside the lines, the better the scores.

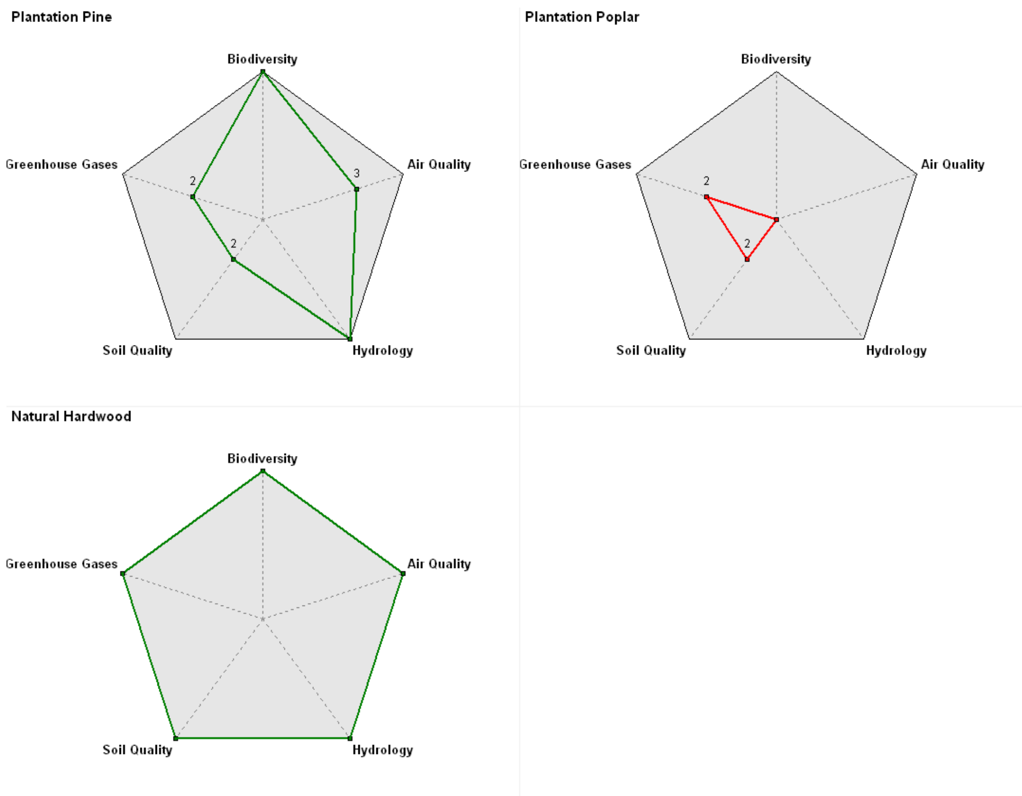


Figure 15 Environmental sustainability indicators for the three feedstock systems (based on the three qualitative categories (high/medium/low)

The environmental sustainability scores according to the three categories as well as based on the nine-point scale shows that natural hardwood feedstock system to pellets was rated as the most sustainable, followed by plantation pine, and plantation poplar. The high score for the environmental attributes of natural hardwood were a result of the long rotation period (80 years) and limited chemical inputs and infrequent harvesting which minimize the impacts on water and soil. The hardwood forests are also expected to have the highest level of biodiversity compared to the other two forest systems (poplar and pine plantations). The environmental attributes of plantation pine received intermediate or medium sustainability rating, resulting from more frequent chemical and equipment use generating intermediate values for the air quality, soil quality, and greenhouse gas subcategories as explained previously. The relative ranking of environmental sustainability of the three feedstocks is consistent with earlier findings from a multi-attribute analysis that suggest more intensive forest management practices lower the environmental sustainability of woody feedstocks (Werhahn-Mees et al. 2011).

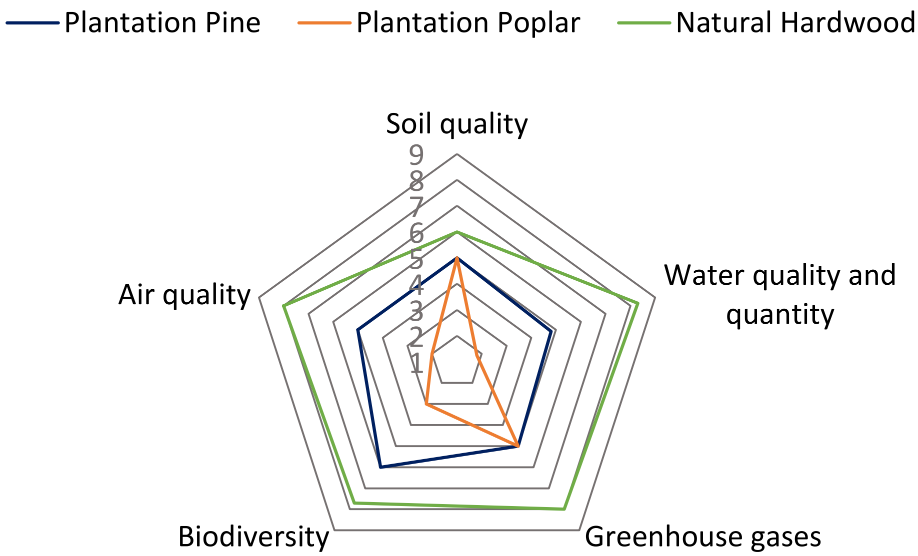


Figure 16 Environmental sustainability scores for the three feedstock systems based on the nine-point rating scale

Impacts on Social Attributes

Figures 17 and 18 show the social attributes for the three feedstock in more detail. Subcategories that combine into the social attribute include, energy security, resource conservation, social acceptability, and social well-being. Based on these four subcategories the social attributes for each feedstock is shown in the figures, where the area inside the diamond corresponds to the relative merits of the attribute. Similar to the figures shown before, the larger the area the, better the social sustainability score.

Figure 17 presents social sustainability performance of feedstock using the three categories (high/medium/low) and figure 18 shows the same performance using the nine-point rating scale. Plantation pine was scored to have the most positive social attributes, with high (resource conservation, energy security) and intermediate (social well-being, social acceptability) subcategory values. Natural hardwood was rated high on resource conservation and energy security values, intermediate on social acceptability, and rated low on social well-being due to the fewer jobs (not requiring intensive management) and lower household income. Plantation poplar received a high score on social well-being, and social acceptance indicators, intermediate score on energy, and low score on resource conservation indicators. Specifically, the resource conservation indicator received a very low score due to the relative high and frequent fuel and chemical use. The rapid growth of poplar forest plantations impact the social sustainability attributes in two ways: first, it increases employment and with new harvesting methods is potentially safer for employees compared to existing methods. The rapid growth of the plantation trees also provides some hedging against some fluctuations in the economic cycle. The social acceptance with respect to harvesting and use of the biomass for bioenergy is also scored high.

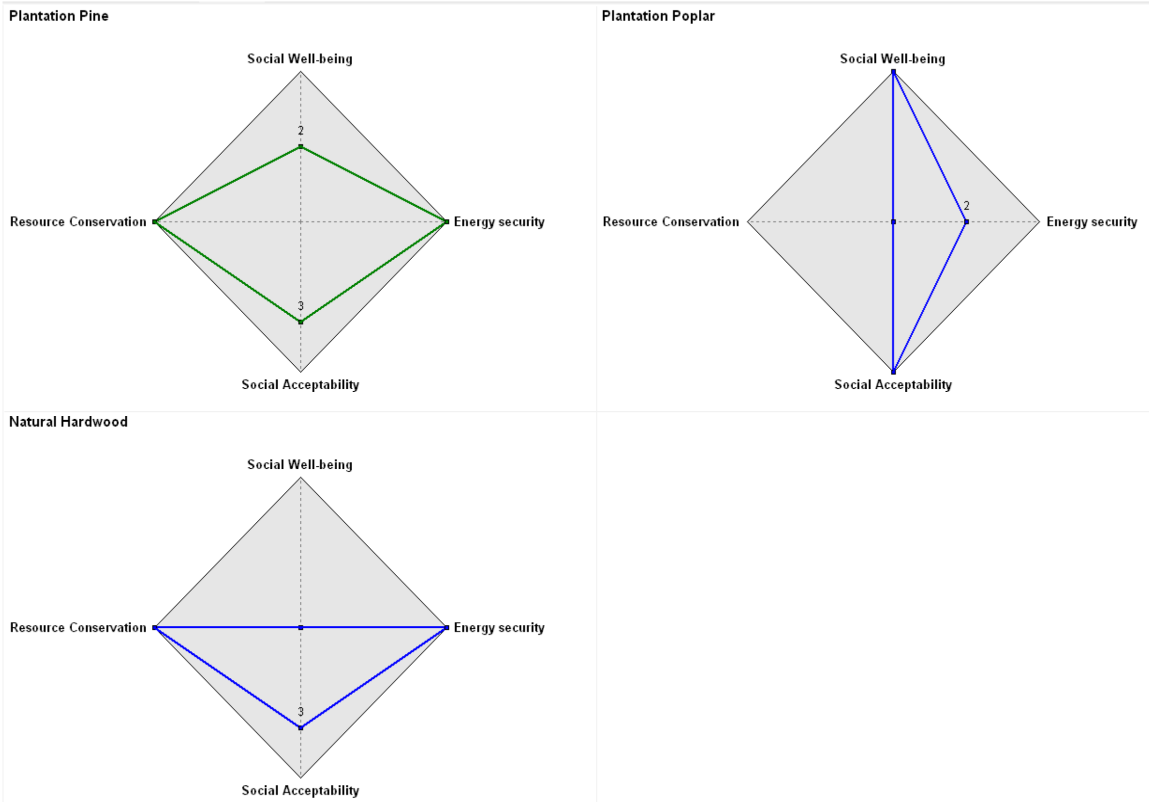


Figure 17 Social sustainability indicators for the three feedstock systems (based on the three qualitative categories (high/medium/low)

In figure 18, the sustainability scores based on the 9-point scale showed similar sustainability scores for social attributes for the three feedstocks as in the three category scores. Plantation pine was scored as the best and plantation poplar and natural hardwood were scored as poor performers on sustainability from a social perspective. Instead of the four indicators, if employment and social acceptability were the only two social indicators considered such as in some earlier multi attribute assessment studies (Werhahn-Mees et al. 2011, Den Herder et al. 2012, Päivinen et al. 2012), plantation poplar would be scored as the most socially sustainable feedstock.

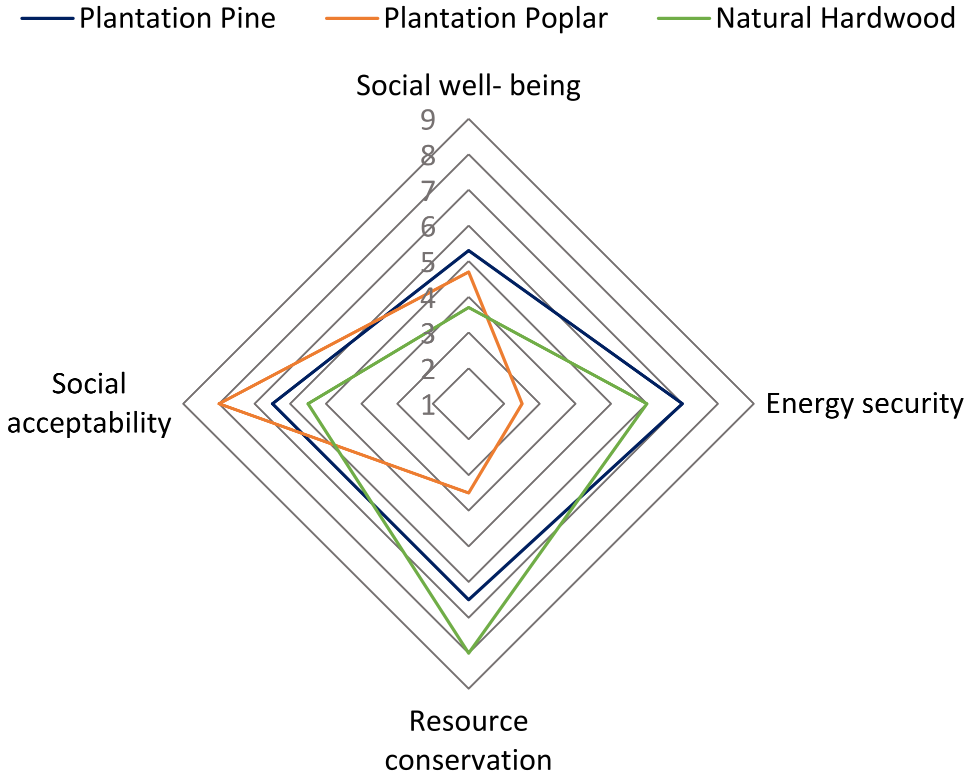


Figure 18 Social sustainability scores for the three feedstock systems based on the nine-point rating scale

Economic sustainability attribute

Figures 19 and 20 show the differences between the feedstocks from an economic point of view. Figure 20 presents economic performance evaluated using the three categorical ratings. Plantation pine was the only feedstock that was not scored low on any sustainability subcategories (profitability was high, productivity was intermediate, and external trade was intermediate) and thus, it received the highest overall economic sustainability score. Plantation poplar was rated low on economic sustainability scores as the experts viewed the profit value to be lower than the other two feedstocks due to uncertain market for pellets for this feedstock. Natural hardwood was rated the lowest on economic sustainability because of its low score on productivity and intermediate score on external trade subcategory values. Figure 21 showed the same result on the nine point scale for sustainability.

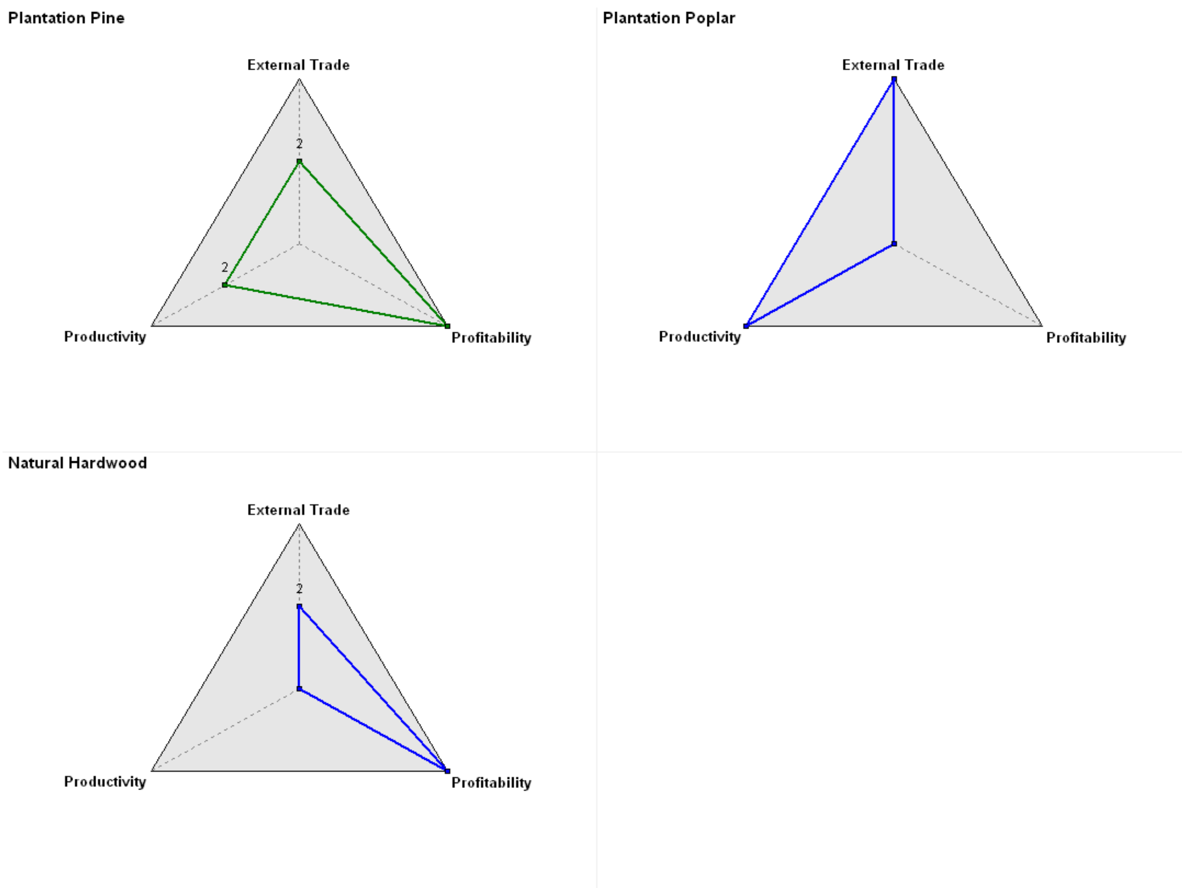


Figure 19 Economic sustainability indicators for the three feedstock systems (based on the three qualitative categories (high/medium/low)

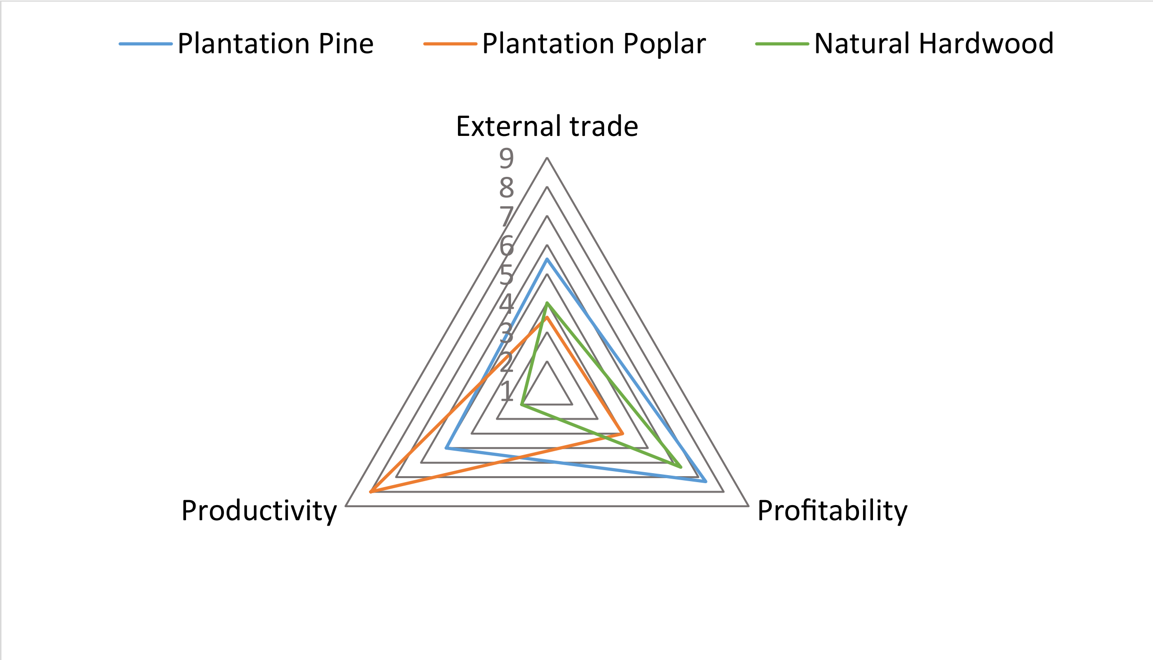


Figure 20 Economic sustainability scores for the three feedstock systems based on the nine-point rating scale

DISCUSSION

The sustainability of plantation pine, plantation poplar, and natural hardwood feedstocks for pellet production were compared within this case study. The impact of sustainability varied for the three feedstock systems based on whether we examine the economic, environmental, or social sustainability attributes. Pine plantations-based pellets were scored high among all three feedstocks for their social sustainability and their economic sustainability, however, natural hardwoods fared the best on environmental sustainability attributes. The indicators were weighted similar across the three sustainability attributes, however, if we consider the preference-based methods of optimization where stakeholders set their goals of sustainability, given that each stakeholder group has a different focus on sustainability, tradeoffs will have to be made among the indicators and weights of indicators have to be varied resulting in entirely different results.

We found no difference between the results from the three-item scale (high, medium low) and the nine-item sustainability rating scale, thus, indicating support for the parsimonious (small item) scale. However, readers should be cautioned on putting too much faith into this interpretation because the three-item categories were created by combining the items from the nine-point scale. Additionally, the nine-item scales produce visualizations that reveal more variability and clear interpretation than the three-item scale.

The MADSS tool with the three-category rating as well as the nine-category rating scale is a qualitative tool used to optimize the three sustainability attributes of economics, environment and society. This type of qualitative tool has its greatest advantage for categories and indicators when it is difficult to translate the indicator impacts to quantitative figures to input into a mathematical optimization tool. This is particularly true in the case of social indicators of sustainability which are difficult to quantify (e.g., public opinion or acceptance). The graphical interface of the tool supports the interpretation, comparison between scenarios and communication of the findings. However, the tool has some implicit disadvantages such as less variability in ratings and thus, qualitative measures, dependence on experts or a subset of stakeholders that may bias results, and provide subjective results. Table 15 summarizes the attributes of using a qualitative tool such as DEXi with MADSS and a Quantitative decision support tool such as Linear Programming.

Table 15 A Comparison of the qualitative and quantitative Decision Supporting tools

Qualitative tool	Quantitative tool
Solve complex decision problems	Solve complex decision problems
Handle many attributes, many problems	Handle many attributes, many problems
Flexible, qualitative reasoning	Equations define the values
Can be used in case of missing or inaccurate data	Quality of input data define the quality of the results
Attributes with different measurement units are comparable	Usually same measurement units are required
Support group decision, discussions, and communication	Inputs are collected, the results are provided by mathematical algorithm
Based on experts or stakeholders opinion (e.g. Delphi method)	Based on the established algorithm
Use ranking/rating scales	Multi-attribute optimization based on actual data
Good graphical interface	Limited graphical interface in most tools
Large variation in evaluations (subjective)	Objective, repeatable results
Can analyze tradeoffs	Can analyze tradeoffs
Can be used as a screening for quantitative methods	

CONCLUSIONS AND FUTURE WORK

We adapted the originally developed MADSS model by McBride et al. (2011) and Dale et al. (2013) for the feedstock to pellet cases. The indicators, the structure, and the utility tables were defined according to the specifics of the forest biomass supply system and experts panel's knowledge. Although expert panel consisted of representatives from various fields of the bioenergy supply chain, it should be noted that qualitative data collection techniques such as what we used in this paper with a limited expert panel may lead to variability in results in similar future studies. Assumptions about bioenergy pellet markets have been made for plantation poplar although there are currently no commercial plants that produce this bioenergy product. Although the assumptions have been made within reasonable limits, future studies should use data from real on-the-ground cases when plantation poplar-based pellets are a reality. Future studies could also look at developing sensitivity analysis for each of the indicators and subcategories based on stakeholder preferences and their impact on overall economic, environment and social sustainability determined. In other words, the weights for the indicators as well as the subcategories could be modified and the results of the higher or lower weights could be visualized on the impact attributes. We used the 35 sustainability indicators used by McBride et al. (2011) and Dale et al. (2013) for qualitative optimization. In future studies, a subset of these indicators or new indicators could be developed and used that are relevant to the case study.

ACKNOWLEDGEMENT

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REFERENCES

Bohanec, M.(2008). DEXi: Program for Multi-Attribute Decision Making User's Manual. Retrieved 08/09/2015 from:
http://kt.ijs.si/MarkoBohanec/pub/DEXiManual30r.pdf

Brown, Mark J., New, Barry D. (2013).North Carolina, 2011 forest inventory and analysis factsheet. E-Science Update SRS-080. Asheville, NC: US Department of Agriculture Forest Service, Southern Research Station. 5p.

Buchholz, T. S., Volk, T. a., & Luzadis, V. a. (2007). A participatory systems approach to modeling social, economic, and ecological components of bioenergy. Energy Policy, 35(12), 6084–6094. doi:10.1016/j.enpol.2007.08.020

Buchholz, T., Rametsteiner, E., Volk, T. a., & Luzadis, V. a. (2009). Multi Criteria Analysis for bioenergy systems assessments. Energy Policy, 37(2), 484–495.

Cambero, C., & Sowlati, T. (2014). Assessment and optimization of forest biomass supply chains from economic, social and environmental perspectives - A review of literature. Renewable and Sustainable Energy Reviews, 36, 62–73.

Crisp, J., Pelletier, D., Duffield, C., Adams, a, & Nagy, S. (2009). The Delphi method? Nursing Research, 46(2), 116–118.

Dale, V. H., Efroymson, R. a., Kline, K. L., Langholtz, M. H., Leiby, P. N., Oladosu, G. Hilliard, M. R. (2013). Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators, 26, 87–102.

Den Herder, M., Kolström, M., Lindner, M., Suominen, T., Tuomasjukka, D., & Pekkanen, M. (2012). Sustainability impact assessment on the production and use of different wood and fossil fuels employed for energy production in North Karelia, Finland. Energies, 5(11), 4870–4891. doi:10.3390/en5114870

Elghali, L., Clift, R., Sinclair, P., Panoutsou, C., & Bauen, A. (2007). Developing a sustainability framework for the assessment of bioenergy systems. Energy Policy, 35(12), 6075–6083. doi:10.1016/j.enpol.2007.08.036

Iqbal L., S.& Pipon-Young (2009). The Delphi method. The Psychologist, 22, 598–601.

Junginger, M., Bolkesjø, T., Bradley, D., Dolzan, P., Faaij, A., Heinimö, J., Wit, M. De. (2008). Developments in international bioenergy trade. Biomass and Bioenergy, 32(2008), 717–729.

Lamers, P., Junginger, M., Hamelinck, C., & Faaij, A. (2012). Developments in international solid biofuel trade - An analysis of volumes, policies, and market factors. Renewable and Sustainable Energy Reviews, 16(5), 3176–3199. doi:10.1016/j.rser.2012.02.027

McBride, A. C., Dale, V. H., Baskaran, L. M., Downing, M. E., Eaton, L. M., Efroymson, R. Storey, J. M. (2011). Indicators to support environmental sustainability of bioenergy systems. Ecological Indicators, 11(5), 1277–1289.

Päivinen, R., Lindner, M., Rosén, K., & Lexer, M. J. (2012). A concept for assessing sustainability impacts of forestry-wood chains. European Journal of Forest Research, 131(1), 7–19.

Parish ES, VH Dale, BC English, SW Jackson, DD Tyler. In press. Assessing multimetric aspects of sustainability: Application to a bioenergy crop production system in East Tennessee. Ecosphere

Shackley, S., & McLachlan, C. (2006). Trade-offs in assessing different energy futures: a regional multi-criteria assessment of the role of carbon dioxide capture and storage. Environmental Science and Policy, 9(4), 376–391. doi:10.1016/j.envsci.2006.01.006

Scott, J. A., Ho, W., & Dey, P. K. (2012). A review of multi-criteria decision-making methods for bioenergy systems. Energy, 42(1), 146–156. http://doi.org/10.1016/j.energy.2012.03.074

Zanakis, S. H., Solomon, A., Wishart, N., & Dublish, S. (1998). Multi-attribute decision making: A simulation comparison of select methods. European Journal of Operational Research, 107(3), 507–529.

Werhahn-Mees, W., Palosuo, T., Garcia-Gonzalo, J., Röser, D., & Lindner, M. (2011). Sustainability impact assessment of increasing resource use intensity in forest bioenergy production chains. GCB Bioenergy, 3(2), 91–106.

Marler, R.T. and J.S. Arora. 2004. Survey of multi-objective optimization methods for engineering. Structural Multidisc Optimization. 26: 369-395.

Zitzler, E., M. Laumanns, and S. Bleuler. 2004. A tutorial on Evolutionary Multiobjective Optimization. Swedish Federal Institute of Technology, Zurich, Available at: http://www.cs.cinvestav.mx/~emooworkgroup/zitzler04.pdf

Chase, M. M. Rademacher, E. Goodman, R. Averill, and R. Sidhu. 2009. A benchmark study of multi-objective optimization methods. Red Cedar Technology. Available at: www.redcedartech.com/pdfs/MO-SHERPA_paper.pdf.

Deb, K. 2009. Multi-objective optimization using evolutionary algorithms. Wiley. pp. 544.

Rangaiah, G.P. 2008. Multi-objective optimization: Techniques and applications in chemical engineering. World Scientific Publishing Company, 400pp.

Jin, X. 2005. Approaching sustainability in engineering design with multiple criteria decision analysis (dissertation). Chemical engineering, Still water, Oklahoma State University, pp. 236. Available at: https://shareok.org/bitstream/handle/11244/7157/School%20of%20Chemical%20Engineering_07.pdf?sequence=1

Sengupta, D., R. Pike, T. Hertwig, and H. Lou. (2008). Developing and integrating sustainable chemical processes into existing petro-chemical plant complexes. AIChE Annual National Meeting, Philadelphia, PA.

Hakanen, J., J. Hakala, and J. Manninen. 2006. An integrated multiobjective design tool for process design. Applied Thermal Engineering. 26(13): 1393-1399.

CHAPTER 4

USE OF LINEAR PROGRAMMING TO OPTIMIZE THE SOCIAL, ENVIRONMENTAL, AND ECONOMIC IMPACTS OF USING WOODY FEEDSTOCKS FOR PELLET PRODUCTION AND TORREFIED PELLET PRODUCTION

Robert Radics, Sudipta Dasmohapatra, Stephen S. Kelley*

Linear programming was used to optimize the forest biomass supply chain for bioenergy production. Sixteen different scenarios (combinations of feedstocks, products, markets, and end use) were optimized for wood pellets and torrefied pellets (also called black pellets) production in NC. Two different feedstocks (roundwood and wood residues), two different products (white pellet, torrefied pellet), two markets (domestic, international), and two end uses (power generation, heating) were evaluated with the linear programming tool. The monetized social, environmental, and economic impacts of these different alternatives were measured, and the trade-offs analyzed. Using economic criteria alone, the optimization model showed that the best solution was to use a combination of 70% roundwood and 30% forest residue feedstock to produce black pellet sold for heating in the EU. The predicted $5.4 million annual profit was generated by the high prices for power in the EU. Selected economic and social benefits (profit, employment, and landowner payment) were monetized and then included in the linear programming analysis. As anticipated, the inclusion of all three benefits lead to a different optimized solution. For example, roundwood costs more than forest residue, but provides more jobs and landowner income, which offsets the higher feedstock cost, resulting in higher overall benefits. In a second example, black pellets produced from roundwood and sold to the EU market for heating was found to be optimum. Black pellet was advantageous because of their higher energy density, which reduced shipping (container ships for transportation) costs and corresponding emissions across the transportation system. In addition, they required more starting biomass per unit of final product, thus, providing local jobs and landowner income. When the cost of carbon emissions were included at 12.8 $/ton of carbon, the environmental benefits from black pellets compared to coal were found to be significant, and the overall profit increased from $16.9 million to $25.4 million.

Keywords: Bioenergy, Linear Programming, Optimization, Sustainability, Woody Biomass, Pellets, Torrefied Pellet

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INTRODUCTION

In the past decade, the advantages, opportunities, and potential costs of the growing bioenergy industry has commanded considerable research and commercial development. The technical feasibility, economic rationality, social and environmental impacts of bioenergy processes have all been researched in some detail. Biomass for bioenergy is often available in large amounts, can be produced locally, and is convenient for use in decentralized energy systems (Gerber 2008). In some geographical regions, forest residues are available in large quantities and can be used as a feedstock for valuable products (U.S. Department of Energy 2011).

Biomass for bioenergy has benefits as well as costs for the environment and society (Scott et al. 2012).

The role of CO_2 in climate change and the increasing demand for national energy security including energy independence have put more emphasis on bioenergy (Abt et al. 2010). Bioenergy is also reported to have the potential to shift global energy systems towards sustainability (Resch et al. 2008). It is generally accepted as a carbon neutral substitute for fossil energy, although the details of the biomass production system and the specific location have to be critically examined to justify the claim of carbon neutrality (Johnson 2009, Mathews 2008). Moreover, it is clear that carbon emission and other environmental attributes such as water use or a loss of biodiversity may be in conflict with one another.

When considering biomass for bioenergy, the concerns regarding socio-environmental costs are even more prominent. In the case of forest biomass there is increasing competition between feedstocks going into bioenergy production versus the current forest products industry. There are also pressures from increased harvesting, or the use of forest residues, due to their potential impacts on wildlife and biodiversity. With agricultural biomass, the concerns center on direct competition for the feedstock, e.g., corn, or indirect competition for high quality agricultural land. This competition can lead to increased food prices and social instability, particularly in developing countries (Brunntrup et al. 2009).

The increasing pressure on the biomass sources - especially in the forests – has motivated a series of studies designed to better understand the tradeoffs between economic, environmental, and social goals (Cambero and Sowlati 2014). Bioenergy could lead to a low-carbon economy if it is shown to be economically viable, environmentally better than fossil energy, and socially acceptable (Elghali et al. 2007). To this end, Cambero and Sowlati (2014) conducted a literature review of the environmental, social, and economic optimization studies of the forest biomass supply chain by analyzing 54 individual studies. Figure 1 shows the classification of studies of forest biomass supply chain.

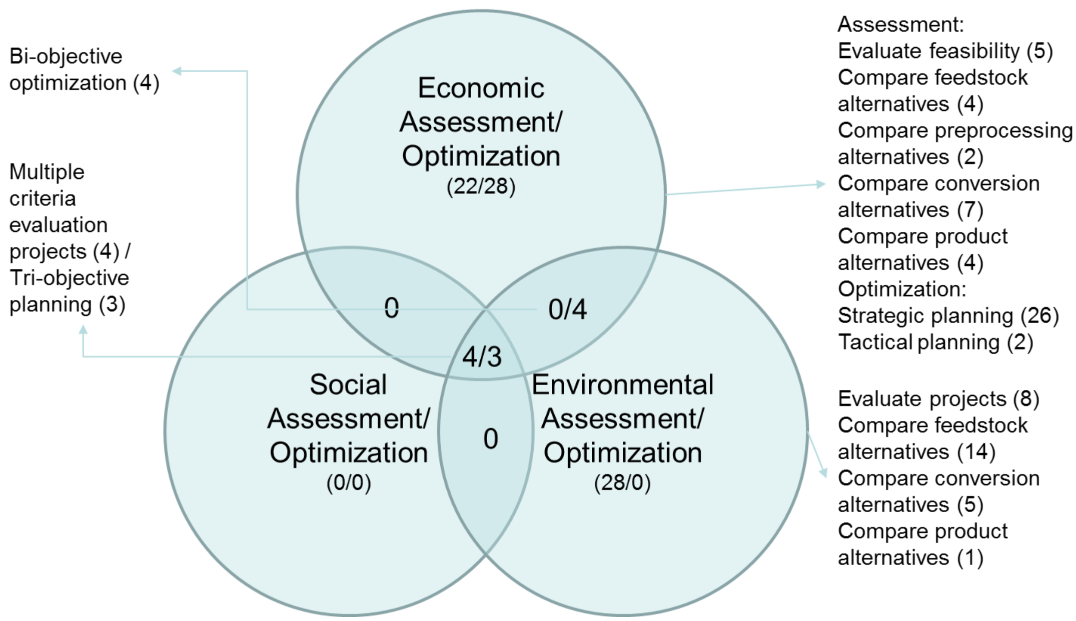

Figure 21 Classification of studies of forest biomass supply chain Source: Cambero and Sowlati, 2014. Note: The number of studies in parenthesis (assessment / optimization).

Figure 21 indicates that very little available research and literature on optimizing the social impacts of forest supply chain. Additionally, the impacts from the interaction between the social and environmental attributes, or interaction between social and the economic attributes have not been optimized. These authors suggest a need to develop tools for the optimization of the social, environmental, and economic benefit of the forest biomass supply chain. Based on their evaluation of the literature, Cambero and Sowlati (2014) note that there is also a particular need for more detailed analysis of the social impacts of forest bioenergy systems.

The tri-objective optimization studies generally use multi-objective mixed-integer linear programming model, or multi-criteria approaches to linear programming (Cucek et al. 2012, You et al. 2012, Saccheli et al. 2014). Socio-economic indicators, LCA results (carbon footprint or greenhouse gasses), and costs are used in these optimization models with carbon footprint used as the environmental indicator, and number of jobs created as the social indicator.

Wood Pellets as Bioenergy

One of the popular commercial bioenergy product is wood pellets. The US pellet production increased from 8.5 to 120 PJ (from ~380,000 metric ton to 5,345,000 metric ton) between 2000 and to 2010 (Lamers et al. 2012), and the trend is expected to continue in the next decade. The goals of wood pelletization (white pellets, hence referred to as WP) include increasing biomass density and decreasing freight costs, and is some cases to make the co-firing with coal, more reliable. Torrefied pellet (also called black pellet, hence referred as BP) production are being developed with the goal of further increasing the energy density, reducing grinding energy, and to eliminate the pellet's sensitivity moisture (Bergmann 2005). While WP have an energy density of 7.8-10.5 GJ/m^3, the energy density of BP ranges between 14-18.5 GJ/m^3. Production of BP results in significant reduction in transcontinental freight costs, and depending on the design and operation of the BP manufacturing plant, can compensate the higher costs and increased demand for biomass feedstock.

OBJECTIVES

The goal of this work was to develop and apply a multi-criteria optimization framework and tool to optimize social, environmental, and economic features of the forest biomass supply chain that helps in bioenergy generation. A linear programming tool was used to optimize key attributes of the bioenergy supply chain for pellet production. In this case study the bioenergy feedstocks, products, markets, and end use were all considered, along with their social, environmental, and economic attributes. Trade-offs among the competing goals were studied.

MATERIALS AND METHODS

The optimization process followed for the multi-criteria impacts is shown in Figure 22.

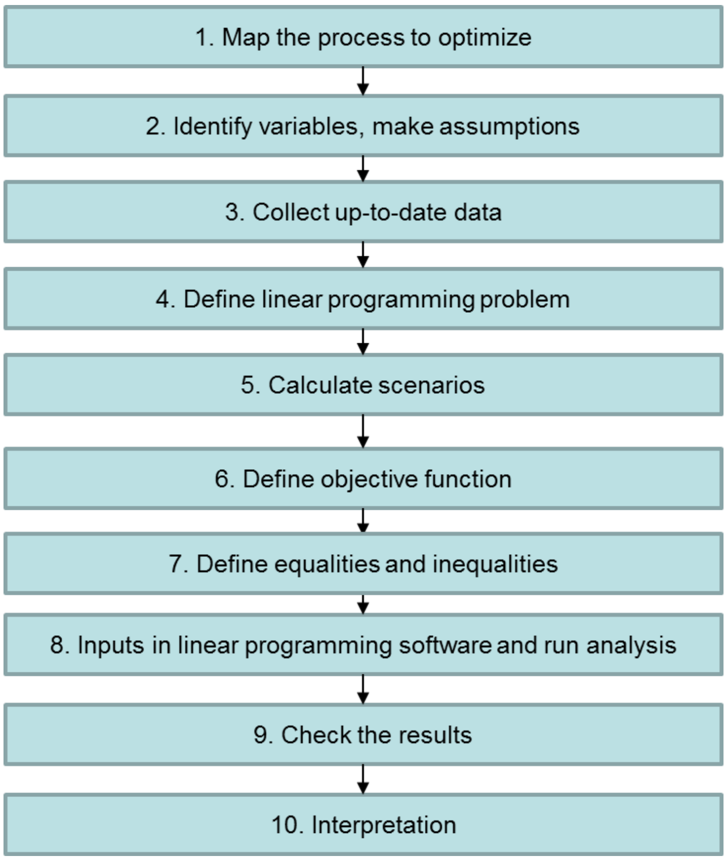

Figure 22 Optimization process

A pellet manufacturing plant that can produce either WP or BP was included as the case for optimization in this paper. We assume that the pelletizing machine capacity limits the overall pellet production. Figure 23 shows the overall supply chain and the two pellet production processes.

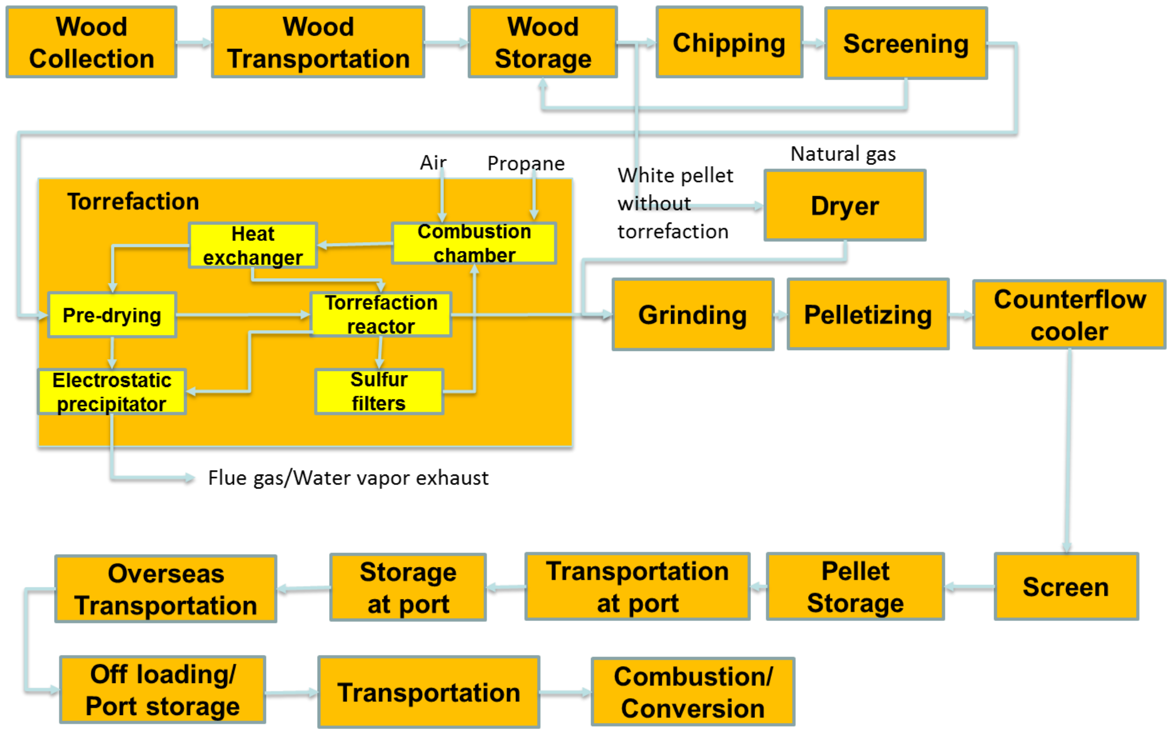

Figure 23 Forest biomass supply chain for White Pellets (WP) and Black Pellets (BP) adapted from Pirraglia et al. 2010 and Pirraglia et al. 2012

The feasible size of a WP or BP biomass processing plant was defined with a production capability of 75,000 tons/year. Data were collected about available forest biomass including costs of the biomass, freight costs, sales prices, and social and environmental impacts. Data sources such as previously published articles, interviews with biomass industry players, and market databases were used (Qian and McDow 2013). The environmental and social impacts were monetized in the optimization model using data from previous publications and existing market data (Fraas and Lutter 2012, Hill et al 2009, Matthews and Lave 2000, Trasande et al. 2005).

The unfeasible alternatives were eliminated during data collection. Preliminary limitations were based on legal compliance and profitability without focusing on negative externalities, but considering positive externalities. For the linear programming optimization technique, the Matlab software was used.

Several assumptions were made before running the optimization model. We assumed 16 combinations of feedstock, process, market location and end use (Wood pellet or torrefied wood pellet products were considered to be produced from forest residue or roundwood, for heating or co-firing in coal power plants to the US or the EU). The available forest residue feedstock was rationalized to be 30% of the total feedstock used (474 Giga Btu's/year). Torrefaction process was considered to decrease the biomass by 30%, and was estimated to use 10% of the energy of the feedstock (Bergmann 2005). The plant was assumed to be located in Eastern North Carolina, with the port in Morehead City, and the EU port was assumed to be in Amsterdam. Table 16 shows all the study assumptions in detail.

Table 16 Summary of assumptions

Assumption	Basis of Assumption (Source)
Process	
Energy density: WP 11 GJ/m3 BP 16 GJ/m3 WP 14.89 MBtu/t; BP 18.96 MBtu/t	Bergmann 2005
Maximum capacity: WP 1117 GBtu, or BP 1422 GBtu in any combination up to 75,000 t/year defined by the pelletizing machinery capacity	Pirraglia et al. 2010
Economic	
Feedstock Roundwood $36 /green ton delivered 45% moisture Forest residue $24 /green ton delivered 45% moisture	Market information (RISI North American Wood Fiber & Biomass market January 2015), investor interviews
Operation and depreciation	Bergman 2005, McDow 2013, investor interviews
Freight 16.38 $/t	Wuehlisch 2011
Sales price US power 3.7 $/GJ; EU power 9.8 $/GJ; EU heating 11.1 $/GJ	IRENA 2012 market prices
Environmental	
Emissions	
Pellet production and transportation	Magelli et al. 2009
Biomass combustion	US EPA emission includes wood residue
Costs	
CO2 12.78 $/t	California Air Resources Board Data 10.15.2015
SOx 7004 $/t	Matthews and Lave 2000
Mercury 25,700,000 $/t	Trasande et al. 2005
PM 3918 $/t	Fraas and Lutter 2012
Social	
Landowner payment: 80% of feedstock costs	McDow 2013
Benefit from employment	Pirraglia et al. 2012
Multiplier of benefits (to credit additional benefits in the region): employment =2.025, landowner payment =1.5.	Jeuck et al. 2015.

The economic calculations showing profit per MBtu for all sixteen combinations of feedstocks, product, market and end-use is shown in Table 17. For the same sixteen supply chain scenarios, Table 18 shows the results from monetization of economic, environmental and social attributes. Figure 24 shows the objective functions (three equations) and inequalities defined in the linear programming problem for optimization. Matlab code for economic optimization is in Appendix C.

Table 17. Economic calculation

	$/MBtu	Feedstock cost of end product MBtu (7% moisture)	Total feedstock costs	Technology costs (OPEX and Depreciation)	Freight	Total cost	Sales price /MBTU	Profit /MBTU
1	WP F. Residue US Power	3.02	3.02	3.02	0.54	6.58	7.60	1.02
2	WP Roundwood US Power	4.53	4.53	3.02	0.54	8.08	7.60	-0.48
3	BP F. Residue US Power	3.02	3.36	3.32	0.42	7.10	7.60	0.50
4	BP Roundwood US Power	4.53	5.03	3.32	0.42	8.77	7.60	-1.17
5	WP F. Residue EU Power	3.02	3.02	3.02	1.64	7.68	11.45	3.77
6	WP Roundwood EU Power	4.53	4.53	3.02	1.64	9.18	11.45	2.27
7	BP F. Residue EU Power	3.02	3.36	3.32	1.28	7.96	11.45	3.49
8	BP Roundwood EU Power	4.53	5.03	3.32	1.28	9.63	11.45	1.82
9	WP F. Residue US Heating	3.02	3.02	3.02	0.54	6.58	11.50	4.92
10	WP Roundwood US Heating	4.53	4.53	3.02	0.54	8.08	11.50	3.42
11	BP F. Residue US Heating	3.02	3.36	3.32	0.42	7.10	11.50	4.40
12	BP Roundwood US Heating	4.53	5.03	3.32	0.42	8.77	11.50	2.73
13	WP F. Residue EU Heating	3.02	3.02	3.02	1.64	7.68	12.92	5.24
14	WP Roundwood EU Heating	4.53	4.53	3.02	1.64	9.18	12.92	3.74
15	BP F. Residue EU Heating	3.02	3.36	3.32	1.28	7.96	12.92	4.96
16	BP Roundwood EU Heating	4.53	5.03	3.32	1.28	9.63	12.92	3.29

Table 18 Monetized economic, environmental, and social attributes

$/MBtu	Feedstock MBtu	Product Energy MBtu	A Economic benefits (profit)	B Social benefits	C Total environ-mental	D Assumed biomass carbon neutrality	E Economic + social benefits	F Economic + social - Environmental
	F_i	E_i	P_i	S_i	Ent	En_i	E_i+S_i	$E_i+S_i-En_i$
WP Forest Residue US Power	F_1	E_1	1.02	8.42	1.51	0.37	9.44	7.93
WP Roundwood US Power	F_2	E_2	-0.48	10.29	1.51	0.37	9.81	8.29
BP Forest Residue US Power	F_1	E_3	0.50	8.59	1.52	0.30	9.09	7.57
BP Roundwood US Power	F_2	E_4	-1.17	10.66	1.52	0.30	9.49	7.97
WP Forest Residue EU Power	F_1	E_5	3.77	8.42	2.22	1.08	12.19	9.98
WP Roundwood EU Power	F_2	E_6	2.27	10.29	2.22	1.08	12.56	10.34
BP Forest Residue EU Power	F_1	E_7	3.49	8.59	1.90	0.68	12.08	10.18
BP Roundwood EU Power	F_2	E_8	1.82	10.66	1.90	0.68	12.48	10.58
WP Forest Residue US Heating	F_1	E_9	4.92	8.42	1.51	0.37	13.34	11.83
WP Roundwood US Heating	F_2	E_{10}	3.42	10.29	1.51	0.37	13.71	12.19
BP Forest Residue US Heating	F_1	E_{11}	4.40	8.59	1.52	0.30	12.99	11.47
BP Roundwood US Heating	F_2	E_{12}	2.73	10.66	1.52	0.30	13.39	11.87
WP Forest Residue EU Heating	F_1	E_{13}	5.24	8.42	2.22	1.08	13.66	11.45
WP Roundwood EU Heating	F_2	E_{14}	3.74	10.29	2.22	1.08	14.03	11.81
BP Forest Residue EU Heating	F_1	E_{15}	4.96	8.59	1.90	0.68	13.55	11.65
BP Roundwood EU Heating	F_2	E_{16}	3.29	10.66	1.90	0.68	13.95	12.05

Note: F1 Forest residue, F2 Roundwood
E1-E16 represents energy of pellet produced in different scenarios.

Objective function: Maximize -->

Equation 1 - Economic

$$Profit = \sum_{i=1}^{16} Pi * Ei$$

Equation 2 – Economic + Social

$$Profit + Social\ benefit = \sum_{i=1}^{16} (Pi + Si) * Ei$$

Equation 3 – Economic + Social - Environmental

$$Profit + Social\ benefits - Environmental\ costs = \sum_{i=1}^{16} (Pi + Si - Eni) * Ei$$

Constraints:

$F_1=E_1+E_3/.9+E_5+E_7/.9+E_9+E_{11}/.9+E_{13}+E_{15}/.9$

$F_2=E_2+E_4/.9+E_6+E_8/.9+E_{10}+E_{12}/.9+E_{14}+E_{16}/.9$

GBTU of WP= 1117GBTU /year --> $E_1+ E_2 + E_5 + E_6 + E_9 + E_{10} + E_{13} + E_{14} <=1117$ GBTU

GBTU of BP + WP = 1422 GBTU/year --> $\sum_{i=1}^{16} Ei \leq 1422$

Max 30% forest residue (GBTU) <= (30% of roundwood) --> $F_1<=0.3*(F_2 + F_1)<=474$

Figure 24 Linear programming problem definition and optimization equations

RESULTS AND DISCUSSION

The columns A, B and C in Table 18 provides a summary of all the input data for the optimization. Table 18 is arranged to highlight the differences due to the 1) proposed product (power vs heat), 2) geographic location of the “buyer” (US vs EU), 3) the fuel type (WP vs BP), and 4) the biomass source (round wood vs forest residue).

Based on these different scenarios several general conclusions could be drawn. The profit (sales price- (feedstock cost + operation and depreciation + freight cost)) range from - 1.17 $/MBtu to 5.24 $/MBtu. The major drivers for the cost vary based on the specific case. In general, biomass power had a lower financial return than biomass heating, and this difference ranged between 1.47 and 3.90 $/MBtu. This is due to the price premium offered for the heating market (IRENA 2012), although the volume for power is many orders of magnitude larger. The EU power market consistently provides a higher return than the US market due to the EU market subsidies. Looking only at the EU markets, the white pellet had slightly (10%, 0.28-0.45 $/MBtu) better return above black pellet, because the higher costs of black pellet production are mostly offset by the higher energy density and lower shipping cost per MBtu of BP. In the US markets, the white wood pellets provided a higher return due to their lower manufacturing costs, and the limited cost advantage for transportation of the final product. Finally, the lower cost forest residues provided a better return than roundwood, although the volume of available forest residues may be limited. Note that the potential differences in the ash content was not included in this initial analysis.

As highlighted in Table 16, the **social benefits** were dictated by landowner payments and the jobs created during the harvesting of the biomass. Thus the volume of biomass consumed during the processing was the major driver for the social benefits in this case study. The actual impacts differed by 1.95-2.06 $/MBtu for residues vs roundwood, and the BP provided 0.17-0.35 $/MBtu more benefit than WP (Table 18, column B). The market and the end use of the product had no influence on social benefits in the considered region around the pellet mill. The model showed four different social benefit values per MBtu of pellet produced. The WP production from forest residue provided the lowest social benefit at 8.42 $/MBtu and the BP production resulted in a slightly higher social benefit of 8.59 $/MBtu because of the 30% higher feedstock demand in the pellet plant. WP production from roundwood accounted for 10.29 $/MBtu of social benefit, because of the higher landowner payment for roundwood above forest residue. The highest social benefit of 10.66 $/MBtu was achieved by BP from roundwood due to the higher landowner payment and higher feedstock demand. The market and the end use of the product had no influence on social benefits of the considered region around the pellet mill.

The results of integrating **social and economic benefits together are** presented in Table 18, column E. Because feedstock costs accounted for a significant portion of the end product value (50%), and hence, higher landowner payments, social benefits were higher than economic benefits in all scenarios. The somewhat similar ranges of social and economic benefits (-1.17 to 5.24 $/MBtu and 8.42-10.66 $/MBtu) made the aggregation and optimization useful. The need for higher feedstock amounts for BP production resulting in higher landowner payments showed BP as more socio-economically beneficial compared to when considering just economic benefits. Additionally, roundwood feedstock became more advantageous than forest residue socially, because of the higher landowner payment when roundwood feedstock was used.

The **environmental costs** are determined by carbon accounting for 75-80 % of the total environmental costs in all cases. The end use part of the supply chain accounted for 75% of the total environmental costs from all emissions studied (CO_2, SO_x, PM, Hg). The torrefaction process accounted for 7% of the total environmental costs. Emissions from ocean transportation to EU accounted for 26% of the total environmental burden for BP and 32% for WP.

The model reported four values for environmental costs, influenced by the market (domestic or EU) from transportation emissions, and from the production process for BP or WP (Table 18, column C). In the domestic market, BP and WP had similar emission costs (1.52 $/MBtu and 1.51 $/MBtu, respectively) although from different sources. While torrefaction caused significant environmental costs, the BP process was credited by the lower emissions from drying and grinding. Compared to WP, the BP transported to EU had a significant advantage in environmental costs (1.90 $/MBtu for BP versus 2.22 $/MBtu for WP), due to the higher energy density of BP and thus lower ocean transportation cost of energy.

The feedstock and the end use variables had no effect on the environmental costs. In Table 18 column D, biomass combustion was assumed to be carbon neutral, and due to that assumption, environmental cost values were reduced ranging from 0.30 $/Mbtu to 1.08 $/MBtu. Corresponding to that, the environmental cost advantage of BP above WP increased (increased values ranged from 0.32 $/MBtu to 0.40 $/MBtu) due to the eliminated environmental burden from the torrefaction carbon emission.

When economic benefits, social benefits and environmental costs were considered together, the rank of the 16 combinations remained the same as that of the economic and social benefits together. The only difference due to adding the environmental attribute was that BP was found to be even more advantageous compared to WP (Table 18 column F).

The results of the optimization of the process economics by itself are shown in Table 19, Column A. The highest annual profit was generated by BP production for EU heating market using a combination of forest residue (427 GBtu) and roundwood (995 GBtu). As noted in Table 16, for this relatively large pellet facility, we assumed that only 30% biomass could be derived from forest residues. BP production was predicted to be more profitable, because of the higher energy density in the 75,000 t/year capacity. The optimized model used the maximum available forest residue feedstock (474 GBtu) and filled the rest of the feedstock demand by using the higher cost roundwood (1104 GBtu). The total annual profit achieved was $5.4 million.

The combined social and economic optimization also identified BP production for the EU heating market as the preferred outcome (Table 19, column B). However, there was a change in the preferred source of the biomass feedstock from a combination of forest residues and roundwood to roundwood alone. This result was counter-intuitive as roundwood cost more compared to forest residues which should drive up the cost of the pellets. However, there were also greater social benefits derived from roundwood use, including higher payments to landowners, and associated economic multiplier for the community. Based on the assumptions used for this work, the range of social and economic benefits (-1.17-5.24 $/MBtu and 8.42-10.66 $/MBtu) were similar, highlighting the value of the optimization in evaluating and comparing multiple goals. The social and economic benefits together resulted in a profit of $19.6 million a year, which is 4 times higher than the economic benefit alone.

The three-component optimization (economic, social, and environmental) resulted in the same combination of biomass feedstock, and bioenergy product use and location as shown earlier (Table 19, column C). Again roundwood alone was the preferred feedstock, and the EU heating market was the preferred use and location. The social benefits were the most significant component in this optimization, accounting for 80% of the aggregated benefits. The total economic, social and environmental benefits were estimated to be $17.1 million, which was lower than the benefits observed when economic and social attributes were combined (due to additional environmental costs.)

Taking this analysis one step further, we evaluated the benefits when biomass combustion was considered "carbon neutral" and the CO_2 emitted from biomass was not treated as a cost. This specific analysis removed CO_2 emission costs from the torrefaction process and the final combustion of BP, whereas only from the final combustion when WP was considered. The CO_2 emissions from the natural gas fired dryer used in the manufacturing of WP remained an environmental cost for WP. This analysis showed an increase in the value of the BP in the EU heating market to $18.9 million.

Finally, the environmental impacts of using BP for the EU heating market were compared to that from the use of coal for the same market (Table 20). As noted in Table 16, this work used four environmental elements- SO_x, CO_2, mercury emissions and PM 2.5 to define the overall "costs" of the different technology options. Using these four attributes, this analysis shows that SO_x and CO_2 dominate the differences between BP and coal. The avoided environmental costs from using BP instead of coal, for heating, resulted in $8.2million of total benefits per year.

Table 19 Optimized scenarios

	A Economic optimization		B Economic+Social optimization		C Economic+Social+ Environmental optimization	
	GBtu/year	mm$/year	GBtu/year	mm$/year	GBtu/year	mm$/year
Biomass Feedstock Source						
Forest Residue	474	NA	0	NA	0	NA
Roundwood	1,104	NA	1,578	NA	1,578	NA
Scenario						
BP Forest Residue EU Heating	427	2.1	0	0	0	0
BP Roundwood EU Heating	995	3.2	1,422	19.8	1,422	17.1
TOTAL BENEFIT/year	**NA**	**5.4**	**NA**	**19.8**	**NA**	**17.1**

Note: Maximum BP production is 1422 GBtu a year, maximum WP production is 1117 GBtu/year.

The mill can produce 27% more BP than WP in GBtu.

Table 20 Environmental costs of carbon neutral biomass and coal energy

	SO_X $/MBTU	CO_2 $/MBTU	HG $/MBTU	PM $/MBTU	ENERGY GBTU	TOTAL MM$/YEAR
BP	0.07	0.15	0.05	0.07	1422	0.5
COAL	4.60	1.30	0.10	0.05	1422	8.6

DISCUSSION

The goal of the study was to define the process model and data for the variables of interest, and then define equations and inequalities that allow for optimization of the economic, social, and environmental benefits, and costs of the forest biomass supply system for bioenergy production. Linear programming was used for optimizing the multi-objective system in our study. The process requires careful definition of the process and the linear programming equations as shown in Figures 4 and 5. Once the model is developed it can be used to evaluate a number of alternative scenarios. The biggest challenge for any model development and analysis is quality of the data, and this research showcases the unavailabilty of consistent and standardized data. Defining the process constriants and assumptions that describe the process outline are also a challenge in optimization. For example, in this paper we used pellet plant capacity as the constraint, but we could also standardize the analysis by placing restrictions on the land available for biomass production or the total BTU delivered to the combustion system(s).

There are several detailed studies that have publised economic data for production of both WP or BP but these data are erratic and varied and have many different assumptions. Additionally, the sources of the available literature, market data, and investor interviews differed. Further, many important factors were not considered that could simplify the analysis and allow testing of the optimization tool (e.g., competing feedstock demand or the end use had no influence on the cost of operation).

The social benefits should be analyzed in further detail, especially landowner payments. In this paper, employment and feedstock payments to the landowner were considered to be social benefits for the local community. A multiplier was applied for estimating the benefits of these activities across the community. Purely measuring social benefits based on employees' and landowners' income increase may be misleading, because they do not consider the consequence of the overall impact on the society. To improve accuracy of the social assessment, stumpage prices, farmers' cost of biomass production, and employment from forest management should also be analyzed in more detail. The transfer of the profit from the pellet mill to the landowners or the local community did not lead to an increase in the social and economic benefits taken together. The study indicated that a higher socio-economic benefit was available only to higher value end product or the lower production cost of the feedstocks. The higher production costs of feedstock meant that we could not achieve the most efficient sustainable use of our natural resources. The lower value product sold (e.g.,wood chips instead of pellet) reflects that the social benefit of the generated value was transferred to the community.

The detailed environmental emissions from a real process and their costs were very difficult to define. Some environmental costs are relatively easy to track, e.g., SO_x and CO_2, but these costs vary with change in government regulations and may even change dramatically, over a short period of time.

The estimations of the social costs of CO_2 have a high uncertainity. Under Executive Order 12866 - the Social Cost of Carbon for Regulatory Impact cost were higher

(\$36/t) than the applied California Air Resources Board Data (\$12.87/t). Although, the best scenario would not change by the three times higher costs, the environmental costs would increase by 100%. In the case of the carbon neutral biomass combustion assumption, the increase is approximately 25% compared to the \$12.87/t CO2 cost environmental burden calculation. The higher estimated cost of carbon significantly increases the advantage of pellet above coal. Further analysis could look at developing a sensitivity analysis for pollutant costs, comparing the applied market and social costs of pollution for a better understanding of the environmental and social tradeoffs. Finally, the spatial distribution of the environmental impacts were not considered in this case study, although trade-offs between social benefits and environmental costs may exist locally. A significant limitation of the monetized comparison, aggregation, and optimization is the application of the same weights to all benefits, although the level of benefits will realistically vary based on different stakeholders' perspective.

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REFERENCES

Abt, R. C., Abt, K. L., Cubbage, F. W., & Henderson, J. D. (2010). Effect of policy based bioenergy demand on southern timber markets: A case study of North Carolina. Biomass and Bioenergy, 34(12), 1679–1686.

Balaman, Y. Ş., & Selim, H. (2014). A fuzzy multiobjective linear programming model for design and management of anaerobic digestion based bioenergy supply chains. Energy, 74, 928–940.

Bergman, P. C. A. (2005). Combined torrefaction and pelletisation The TOP process, (July).

Brunntrup, M., Hermann, R., & Gaebler, M. (2009). Bio-energy in Namibia: opportunities, threats and institutional challenges for rural development and food security. Challenges (pp. 18–20).

Cambero, C., & Sowlati, T. (2014). Assessment and optimization of forest biomass supply chains from economic, social and environmental perspectives - A review of literature. Renewable and Sustainable Energy Reviews, 36, 62–73.

Čuček, L., Varbanov, P. S., Klemeš, J. J., & Kravanja, Z. (2012). Total footprints-based multi-criteria optimisation of regional biomass energy supply chains. Energy, 44(1), 135–145.

Dale, V. H., Efroymson, R. a., Kline, K. L., Langholtz, M. H., Leiby, P. N., Oladosu, G. A., Davis, M. R., Downing, M. E., Hilliard, M.R. (2013). Indicators for assessing socioeconomic sustainability of bioenergy systems: A short list of practical measures. Ecological Indicators, 26, 87–102.

Dantzig, G. B. (2002) Linear Programming. Operations Research 50(1):42-47.

Fraas, A., & Lutter, R. (2012). Efficient pollution regulation: Getting the prices right: Comment. American Economic Review, 102(5), 602–607. doi:10.1257/aer.102.1.602

Gerber, N. (2008). Bioenergy and Rural Development in Developing Countries: a review of existing studies. Discussion Papers, (June). Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1162142

Hill, J., Polasky, S., Nelson, E., Tilman, D., Huo, H., Ludwig, L. Bonta, D. (2009). Climate change and health costs of air emissions from biofuels and gasoline.

Proceedings of the National Academy of Sciences of the United States of America, 106(6), 2077–82. doi:10.1073/pnas.0812835106

Jeuck, J., T.E. McConnell, R. Bardon, and D. Hazel. 2015. North Carolina's forests and forest industry by the numbers. North Carolina Cooperative Extension Service College of Natural Resources Extension Forestry departmental factsheet. 1 p.

Johnson, E. (2009). Goodbye to carbon neutral: Getting biomass footprints right. Environmental Impact Assessment Review, 29(3), 165–168. doi:10.1016/j.eiar.2008.11.002

Mathews, J. A. (2008). Carbon-negative biofuels. *Energy Policy*, *36*(3), 940–945. doi:10.1016/j.enpol.2007.11.029

Matthews, H. S., & Lave, L. B. (2000). Applications of environmental valuation for determining externality costs. Environmental Science and Technology, 34(8), 1390–1395. doi:10.1021/es9907313

Pirraglia, A., Gonzalez, R., & Saloni, D. (2010). Techno-economical analysis of wood pellets production for U.S. manufacturers. *BioResources*, *5*(2006), 2374–2390.

Pirraglia, A., Gonzalez, R., Denig, J., & Saloni, D. (2012). Technical and Economic Modeling for the Production of Torrefied Lignocellulosic Biomass for the U.S. Densified Fuel Industry. BioEnergy Research, 6(1), 263–275.

Resch, G., Held, A., Faber, T., Panzer, C., Toro, F., & Haas, R. (2008). Potentials and prospects for renewable energies at global scale. Energy Policy, 36, 4048–4056.

Sacchelli, S., Bernetti, I., De Meo, I., Fiori, L., Paletto, a., Zambelli, P., & Ciolli, M. (2014). Matching socio-economic and environmental efficiency of wood-residues energy chain: A partial equilibrium model for a case study in Alpine area. Journal of Cleaner Production, 66, 431–442.

Spath, P., Mann, M., & Kerr, D. (1999). Life cycle assessment of coal-fired power production. National Renewable Energy Laboratory. doi:10.2172/12100

Trasande, L., Landrigan, P. J., & Schechter, C. (2005). Public Health and Economic Consequences of Methyl Mercury Toxicity to the Developing Brain. Environmental Health Perspectives, 113(5), 590–596. doi:10.1289/ehp.7743

Magelli, F., Boucher, K., Bi, H. T., Melin, S., & Bonoli, A. (2009). An environmental impact assessment of exported wood pellets from Canada to Europe. *Biomass and Bioenergy*, *33*(3), 434–441. http://doi.org/10.1016/j.biombioe.2008.08.016

McDow, "The Wood Pellet Value Chain," U.S. Endowment for Forestry and Communities, 2013.

Wuehlisch 2011. Financial analysis of the transport of wood chips as an option among other solid fiber based combustibles from the USA to Germany. Master Thesis. University of North Carolina Wilmington. Retrieved at 10.20.2015 from http://csb.uncw.edu/imba/annals/VonWuehlischC.pdf

California Air Resources Board Data. Retrieved at 10.15.2015 from http://www.arb.ca.gov/cc/capandtrade/auction/auction.htm

IRENA 2012. Renewable energy technologies: Cost analyses series. Volume 1: Power Sector. Issue 5/5. Retrieved at 10.12.2015 from:
https://www.google.com/search?q=irena+2012+pellet+market&ie=utf-8&oe=utf-8

RISI North American Woodfiber & Biomass Markets. Retrieved at 10.20.2015 from http://www.risiinfo.com/Marketing/Indices/NAWBM_sample.pdf

US Government Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. 2015.

US EPA emission factors wood residue combustion in boilers. Retrieved at 10.20.2015. from http://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s06.pdf

CONCLUSIONS

This study examined societal acceptance and adoption of bioenergy and applied two models – one quantitative and one qualitative - to understand the integration of social impacts with economic and environmental impacts for evaluation of optimization and trade-offs for sustainable bioenergy.

A systematic analysis of the literature showed an increase in the number of publications/articles focused on societal aspects of bioenergy, including discussions about bioenergy perceptions of key stakeholders, although the total number of studies on the societal impacts still lag behind those focused on the financial aspects. This growth is an indication that the industry and the researchers recognize the importance of public acceptance and knowledge about bioenergy for the commercial success of the industry.

Most of the published studies were in the U.S. and Europe, but other geographical regions such as Asia and Latin America also showed increase interest in the public perception and adoption of bioenergy. This systematic review showed that as a group, “consumers” were the most frequently surveyed group. However, the number of respondents, and their corresponding robustness, varied (24 to 1903) across studies. There is a need for standardized methods to collect and analyze perception results to improve interpretability and representation. In order for bioenergy to be successfully deployed, there is a strong need not only for educational programs with information on proper management and ecological effects of producing or harvesting energy crops, but also policies that should be developed to meet sometimes conflicting economic, environmental and societal goals. The policies should be developed through dialogue and collaboration between various government and institutional partners including the extension personnel and local landowners association. Our assessment showed that among all the stakeholder groups, forest and farm landowners were the most hesitant to participate in bioenergy programs. However, interest from landowners and other stakeholders was likely to be spurred by successful small-scale demonstrations in their local communities. For other stakeholder groups, education and targeting their specific needs were key to successful adoption of bioenergy.

The analysis of consumer perceptions about bioenergy (in NC and TN) showed that the general public varied widely in their understanding and knowledge about biomass-based energy and biofuels (for transportation). Results of our study showed consumers considered various aspects of biofuels including impacts on society, environment, costs, land use, competitive products (mostly food), and vehicle compatibility with biofuels that will guide their support for a future biofuels industry. The general public seek more general knowledge, and specifically more information on biofuels' compatibility with their vehicle. Developing credible educational tools, consistent information, and an effective dissemination strategy through efficient channels is likely to increase the acceptance of biofuels for transportation. Respondents valued the local impacts of bioenergy such as jobs/employment and use of renewable resources with local power provider. One key for consumer acceptance of bioenergy will be small-scale demonstration projects focused on local and regional benefits such as employment and agricultural diversification. Another area of focus by the industry should be to provide clear, consistent information about bioenergy and help develop a common, easy to use certification and labeling scheme for resulting products and processes. Bioenergy certification should be able to provide standardized information to buyers about the product characteristics that would make it simpler to disseminate the message to the general public.

Channels for effective dissemination of information are those that are trusted by the target audience. Local sources (extension agents, foresters) as well as local utility companies and environmental groups were considered more trustworthy by the consumers in our study compared to what is labeled “government”. In addition, collaboration with environmental organizations and academia may also be help to successfully reach the public.

Extension of the perception results from the two states studies (NC and TN) to the southeastern U.S. is limited by the fact that there were significant differences between these states on some key bioenergy aspects. This study showed that TN citizens consistently rated characteristics higher than the citizens of NC. NC consumers were found to be more concerned about climate change and the effects of biofuel on the environment, whereas, TN residents were significantly more concerned about U.S. dependence on foreign oil, and price of transportation fuels and energy. So, while the results provided useful information about how citizens in the two states view bioenergy, it is important to note that these findings may not be applicable to all states in the Southeast or for citizens across other regions of the U.S.

While this study has identified some key attitudes and opinion dynamics around bioenergy and biofuels, future research will need to examine a number of additional issues to arrive at a more comprehensive understanding of regional attitudes on bioenergy. Given varying responses from consumers, we believe a segmentation of consumers or the general public will be helpful in garnering a deeper understanding of how different the risk and opportunity perceptions could be so that targeted strategies can be employed for messaging and reaching each unique segment. It is also important to explore the complex dynamics between particular stakeholders. Bioenergy may have a significant impact on consumers, farmers, forest landowners, industry, NGOs, and local communities, however, since each of these stakeholders will not all benefit in the same way, or at time, some of these interests will be in conflict. Thus, data on specific stakeholder segments could improve the overall understanding of the informed and uninformed public views' of bioenergy.

We used two different tools, one qualitative and one quantitative, to measure and optimize economic, environmental and social sustainability attributes of bioenergy systems. The qualitative model used was a Multi Attribute Decision Support System (MADSS) based on the established indicator system by McBride et al. (2011) and Dale et al. (2013) within the DEXi software. Thirty-five key sustainability indicators for three production scenarios were ranked and used as inputs into the MADSS model. The resulting analysis showed plantation pine to be the most sustainable for production of bioenergy pellets (assuming similar technology, location, transportation, and logistics) closely followed by natural hardwood. On environmental and social indicators of sustainability, natural hardwood performed better relative to plantation pine or plantation poplar. Economic sustainability scored better for plantation pine and plantation poplar, due in large part to their higher growth rates compared to natural hardwood. Our results show the potential for using highly productive plantations for bioenergy production. This type of qualitative tool has its greatest advantage as a screening tool when it is difficult to translate the indicator into the quantitative terms needed for more rigorous mathematical optimization tools. This is particularly true in the case of social indicators of sustainability which are difficult to quantify (e.g., public opinion or acceptance). The ease of use and the graphical interface of the MADSS tool supports the interpretation, comparison between scenarios, and communication of the findings of optimum sustainability.

Linear programming was the quantitative tool used for optimizing bioenergy sustainability for pellet production. Four variables were considered including, the market (power vs district heating), the market location (EU vs US), the form of the biomass (standard wood pellets (WP) vs. torrefied black pellets (BP), and the source of the biomass (forest residues vs. roundwood). The financial, environmental and social impacts of these production alternatives were then evaluated using a system of equalities, inequalities and constraints. The financial, environmental and social impacts included the total production costs, e.g., capital, operating, transportation and storage; the environmental costs associated with the emission of CO_2, SO_X, mercury and PM 2.5, and social costs (benefits), e.g., landowner payments, employment and community benefits. All of these indicators were monetized to create a set of variables with common units. Using economic criteria alone, the optimization showed that the best solution was to use a combination of 70% roundwood and 30% forest residue feedstock to produce BP sold for power generation in the EU. An optimization of all three sustainability criteria showed that BP produced from roundwood sold for district heating in the EU was preferred. The results from the optimization also show that using biomass for power production is significantly better than power derived for coal. Treatment of the CO_2 from biomass as an emission cost or as carbon neutral did not change the preference of biomass over coal.

These results are based on the specific indicators used for this study, and different stakeholders', e.g., industry, landowners, consumers, policy makers or environmentalists, may desire different indicators or different weights on the selected indicators. For example, for communities around bioenergy plants the community benefits of jobs and landowner payments (indicators of social sustainability) may become more important than environmental or economic impacts producing a different outcome. Doing this type of sensitivity analysis will require an accurate model developed with defined constraints and assumptions, which in turn depends on availability of quality data. There are significant challenges associated with data availability and quality for modeling sustainability. The available financial data for operating plants is proprietary, and publically available data differs between sources. Social data on jobs/employment at the production facility and landowner payments, stumpage prices, does not include wider measures of community benefits. Although there has been much work in defining environmental costs and benefits, these costs are driven by regulations which vary over time. This study highlights the need for more standardized data on all the three aspects of sustainability with common definitions that could become globally relevant but locally adaptable to different bioenergy scenarios. It also highlights the need for tools that can include data uncertainty in the analysis.

In total this work shows that bioenergy has the potential to make significant contributions to a sustainable economy and social well-being as the technology becomes more efficient and the stakeholders are better informed of the economic, environmental and social impacts in a clear and consistent manner. This study also provides some important results on how societal analysis and tools for communication can be used engage and inform stakeholders for a bioenergy future.

FUTURE RESEARCH

Improve knowledge, credibility, and transparency

To make progress in this complex arena there is a need to develop creditable stakeholder specific, education tools, and an effective dissemination strategy using communication channels that are effective for specific stakeholders'. Segmentation of a larger stakeholder group (like general public or landowners), the spatial distribution of the segments, the segments' preferences, knowledge, and interests are all needed for an efficient education and communication strategy. It is also important to explore the dynamics between particular stakeholders. Bioenergy has a significant impact on consumers, farmers, forest landowners, industry, NGOs, local communities and these stakeholders do not all benefit in the same way and at times these interests may be opposed.

There is a need to look at certification and labeling criteria for biomass–based energy for improving credibility and support conscious stakeholder decisions. These certifications could be similar to the Environmental Product Declarations that have been developed for wood products (AM Wood Council website - http://www.awc.org/greenbuilding/epd)

Making multi-attribute decision support tools more credible requires both better data and communication tools. These should be applied specific case studies that highlight the strengths and limitations of these tools for analysis of complex natural resource systems. The use of multi-attribute evaluation for analysis of trade-offs is an invaluable life skill so could be made a part of K12 curriculum.

Developing decision-making tools, support to find the best decisions

Customized models of multi-attribute decision supporting tools and optimizations models need to apply for other areas of bioenergy that need more case studies and real world applications for improving the tools and make the results understandable.

In the specific case of the linear programming optimization model for pellet production that was developed as part of this work there is a need for more detailed data across the board. Including the optimization of the pellet plant capacity, considering the increasing feedstock transportation cost from higher feedstock needs, and the ocean vessel capacity, as well as the costs of storage at the port, would improve the model. The environmental costs of emissions and the costs of other environmental impacts need more accurate and accepted values. The non-emission related environmental costs and the spatial distribution of the environmental impacts have to be analyzed and included in the optimization model, also the trade-offs between social benefits and environmental costs.

APPENDICES

APPENDIX A

Southeastern Partnership for Integrated Biomass Supply Systems

Consumer Questionnaire

I. DEMOGRAPHICS

1. What is the ZIP/postal code of your current residence?

____

2. What is your gender?

Male ☐
Female ☐

3. What is your year of birth? ______________________________

4. Please indicate your educational background?
Years of HS completed _________________________
Years of College completed _________________________

5. What was your total household income in 2012 (include all income earners in your household)?

Under $25,000 ☐
$25,000 to less than $50,000 ☐
$50,000 to less than $100,000 ☐
$100,000 to less than $150,000 ☐
$150,000 and over ☐
Prefer not to answer ☐

6. Which of the following best describes your ethnicity (please select all that apply)?

White/Caucasian ☐
Black/African-American ☐
American Indian/Native American ☐
Asian/Oriental ☐
Native Hawaiian or Other Pacific Islander ☐
Hispanic/Latino ☐

Some Other Race (please specify) ____________________
Prefer not to answer ☐

II. ENVIRONMENTAL SPECIFIC QUESTIONS

7. Evaluate your level of concern about the following topics ((1) Not at all Concerned; (2) A Little Concerned; (3) Neutral; (4) Concerned; (5) Extremely Concerned)
I am concerned about:

	1 Not at all concerned	2 Moderately concerned	3 Neutral	4 Concerned	5 Extremely concerned
Pollutants in the environment	☐	☐	☐	☐	☐
Increasing global population	☐	☐	☐	☐	☐
Food availability/shortage	☐	☐	☐	☐	☐
Energy availability for the future generations	☐	☐	☐	☐	☐
Global climate change	☐	☐	☐	☐	☐
Greenhouse gas emissions	☐	☐	☐	☐	☐
Decreasing fossil energy reserves	☐	☐	☐	☐	☐
U.S. dependence on foreign oil	☐	☐	☐	☐	☐
Price of transportation fuels	☐	☐	☐	☐	☐
The price of energy (e.g., electricity, natural gas)	☐	☐	☐	☐	☐
General unemployment	☐	☐	☐	☐	☐
Rural unemployment	☐	☐	☐	☐	☐
Livelihood of farmers and forest landowners	☐	☐	☐	☐	☐
Local economy of my region	☐	☐	☐	☐	☐

8. How much gasoline do you personally buy in a week (your best estimate)?

I do not buy transportation fuel ☐
Under 5 gallon ☐
5 gallon to less than 10 gallon ☐
10 gallon to less than 20 gallon ☐
20 gallon to less than 40 gallon ☐
40 gallon or over ☐

9. Where do you get your information about energy?
Magazines or Newspapers ☐
Government websites ☐
Utility company (website or mail) ☐

Non-profit organizations (website or on-site)	☐
Word-of-mouth or Social Networks (e.g. Facebook, Twitter, MySpace)	☐
Radio or Television	☐
School/University or Scholarly journal articles	☐
Other (please specify)	______________
I am not interested in energy	☐

10. I have heard that biofuel can be made from trees, agricultural crops or grasses?

Agricultural crops

Yes ☐ No ☐

Grasses

Yes ☐ No ☐

Woody Crops/Forest Residues

Yes ☐ No ☐

Trees

Yes ☐ No ☐

Please read the following information before answering the next section:

<u>Renewable sources are resources that can be naturally replenished over time.</u>

11. Which of the following sources of energy would you consider to be renewable? (Select one) (1) Renewable; (2) Not renewable; (3) Not sure; (4) Never heard of this energy source

	1 Renewable	2 Not renewable	3 Not sure	4 Never heard about this energy source
Electricity from:				
Coal	☐	☐	☐	☐
Petroleum	☐	☐	☐	☐
Natural gas	☐	☐	☐	☐
Nuclear	☐	☐	☐	☐

Hydrogen	☐	☐	☐	☐
Geothermal	☐	☐	☐	☐
Wind	☐	☐	☐	☐
Trees	☐	☐	☐	☐
Agricultural crops	☐	☐	☐	☐
Grasses	☐	☐	☐	☐
Hydroelectric	☐	☐	☐	☐
Solar	☐	☐	☐	☐
Tidal	☐	☐	☐	☐
Transportation fuel from:				
Petroleum	☐	☐	☐	☐
Natural gas	☐	☐	☐	☐
Hydrogen	☐	☐	☐	☐
Trees	☐	☐	☐	☐
Agricultural crops	☐	☐	☐	☐
Grasses	☐	☐	☐	☐

Please read the following information before answering questions (12-16):

<u>Biomass feedstocks are materials such as trees, corn, grass, etc., that may be used to produce renewable transportation fuels. E.g., Biofuel is a renewable transportation fuel produced from renewable/natural feedstocks.</u>

12. If biofuels (as a transportation fuel) were available from the following sources, which of the following would you be willing to purchase? ((1)Willing to purchase ; (2) Not willing to purchase; (3) Never heard of biofuel from this source). Please take into consideration that the different residues and wastes are used for low value products currently.

	1 Willing to purchase	2 Not willing to purchase	3 Never heard of biofuel from this source
Corn	☐	☐	☐
Other agricultural crops (e.g. soybean)	☐	☐	☐
Crop residues (e.g., corn stalks/stover)	☐	☐	☐
Grasses	☐	☐	☐
Wood manufacturing residues (e.g. sawdust	☐	☐	☐
Forest Residues/Trees	☐	☐	☐
Landfill waste	☐	☐	☐
Algae/duckweed	☐	☐	☐
Genetically modified crops	☐	☐	☐
Genetically modified trees	☐	☐	☐

13. If biofuel for transportation was available at gas stations, what are the most important factors that will influence you to choose biofuel over gasoline? ((1) Extremely unimportant; (2) Unimportant; (3) Neither unimportant nor important; (4) Important; (5) Extremely important or inevitable)

	1 Extremely Unimportant	2 Unimportant	3 Neither unimportant nor important	4 Important	5 Extremely important or inevitable
My vehicle is compatible with biofuel	☐	☐	☐	☐	☐
Biofuel will not change the performance of the engine	☐	☐	☐	☐	☐
Biofuel will not change the lifetime of the engine	☐	☐	☐	☐	☐
Biofuel will not reduce my vehicle's fuel economy	☐	☐	☐	☐	☐
Price of biofuels	☐	☐	☐	☐	☐
Availability of biofuels	☐	☐	☐	☐	☐
My colleagues'/neighbors'/family's opinion about biofuels	☐	☐	☐	☐	☐
The raw material that is used to produce biofuel (e.g., corn, wood, waste, etc.)	☐	☐	☐	☐	☐
Tax breaks by government to use biofuels in my vehicle	☐	☐	☐	☐	☐

14. Please rate your relative agreement of the following statements considering biofuels for transportation ((1) Strongly disagree; (2) Disagree; (3) Neither disagree nor agree; (4) Agree; (5) Strongly agree)

	1 Strongly disagree	2 Disagree	3 Neither disagree nor agree	4 Agree	5 Strongly agree
Before I would purchase biofuels, I would like more information about how they would affect my vehicle	☐	☐	☐	☐	☐
I would not purchase biofuels because they might be bad for my car engine	☐	☐	☐	☐	☐
I would only purchase biofuels if they were available at most or all gas stations	☐	☐	☐	☐	☐
I would purchase biofuel if it increases the power of my vehicle's engine	☐	☐	☐	☐	☐
I believe that biofuel will not be available at all gas stations	☐	☐	☐	☐	☐

I am concerned that using biofuel will lower my vehicle's gas mileage	☐	☐	☐	☐	☐
E-10 (10% ethanol) is currently blended with most gasoline at gas stations	☐	☐	☐	☐	☐
I will not be concerned if higher blends (more than 10% ethanol) was used with gasoline at gas stations	☐	☐	☐	☐	☐
I would like the government to provide me with more information about biofuels	☐	☐	☐	☐	☐
I think biofuel production will help improve national security	☐	☐	☐	☐	☐
Government should fund research on biofuels	☐	☐	☐	☐	☐
Using biofuels will reduce US dependence on foreign oil	☐	☐	☐	☐	☐
We should produce biofuels to meet our country's energy demand	☐	☐	☐	☐	☐
I think the government should subsidize the manufacturing of biofuels	☐	☐	☐	☐	☐
Government should provide tax breaks if we use biofuels in our vehicles	☐	☐	☐	☐	☐
I believe our taxes will rise if we produce biofuel from trees/ crops	☐	☐	☐	☐	☐
I believe that investment in biofuel industry will create jobs	☐	☐	☐	☐	☐
I believe biofuel industry will have more benefits than risks for the society	☐	☐	☐	☐	☐
I trust the government to give me credible information about biofuels	☐	☐	☐	☐	☐

I trust that non-profits will give me more credible information about biofuels than the industry	☐	☐	☐	☐	☐
I believe biofuel refineries in my region could provide employment opportunities	☐	☐	☐	☐	☐
I think the biofuel industry will improve the rural economy	☐	☐	☐	☐	☐
Biofuels are not environmentally friendly (they take more energy to make than it is worth)	☐	☐	☐	☐	☐
Biofuels have a lower environmental impact than gasoline	☐	☐	☐	☐	☐
I believe a biorefinery plant in my local area will cause pollution	☐	☐	☐	☐	☐
I would purchase biofuels even if it is a little more expensive than gasoline	☐	☐	☐	☐	☐
I would only purchase biofuels if they were the same price as gasoline	☐	☐	☐	☐	☐
I would only choose the biofuel if it is lower in price than gasoline	☐	☐	☐	☐	☐
Biofuels can be produced economically	☐	☐	☐	☐	☐
I believe that genetically modified crops can be used for producing biofuel	☐	☐	☐	☐	☐
I believe that agricultural crops can be used for producing biofuel	☐	☐	☐	☐	☐
I believe that grasses can be used for producing Biofuel	☐	☐	☐	☐	☐
I believe that trees can be used for producing biofuel	☐	☐	☐	☐	☐

I believe using landfill wastes could be a valuable source of bioenergy	☐	☐	☐	☐	☐
I would like my local power provider to use renewable fuels sources	☐	☐	☐	☐	☐
I think biofuels will cause groceries to be more expensive	☐	☐	☐	☐	☐
I think biofuels made from grasses will cause groceries to be more expensive.	☐	☐	☐	☐	☐
I think biofuels made from corn will cause groceries to be more expensive.	☐	☐	☐	☐	☐
I think biofuels made from trees will cause groceries to be more expensive.	☐	☐	☐	☐	☐
I would not like my local power provider to use renewable fuels sources if it costs me more money	☐	☐	☐	☐	☐
I would support the cutting of trees for biofuels if trees were replanted in the same place	☐	☐	☐	☐	☐
I would support the cutting of trees for biofuels if it significantly reduces oil importation	☐	☐	☐	☐	☐

15. If you have any other comments or concerns about the biofuel or energy industry please indicate in the space provided below.

16. Your input is extremely valuable to us; if you would like to stay informed about our survey and receive a copy of the survey summary please provide your email address below:

APPENDIX B

A sample utility table, all possible cases and decisions by cases

Decision rules SUSTAINABILITY

LOW SUSTAINABILITY

Use scale orders

Use weights

	ENVIRONMENTAL SUSTAINABILITY	ECONOMIC SUSTAINABILITY	SOCIAL SUSTAINABILITY	SUSTAINABILITY
1	LOW ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	LOW SUSTAINABILITY
2	LOW ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	LOW SUSTAINABILITY
3	LOW ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
4	LOW ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	LOW SUSTAINABILITY
5	LOW ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	LOW SUSTAINABILITY
6	LOW ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
7	LOW ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
8	LOW ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
9	LOW ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
10	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	LOW SUSTAINABILITY
11	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	LOW SUSTAINABILITY
12	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
13	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	LOW SUSTAINABILITY
14	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
15	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	HIGH SUSTAINABILITY
16	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
17	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
18	INTERMEDIATE ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	HIGH SUSTAINABILITY
19	HIGH ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
20	HIGH ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
21	HIGH ENVIRONMENTAL SUSTAINABILITY	LOW ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
22	HIGH ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
23	HIGH ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	HIGH SUSTAINABILITY
24	HIGH ENVIRONMENTAL SUSTAINABILITY	INTERMEDIATE ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	HIGH SUSTAINABILITY
25	HIGH ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	LOW SOCIAL SUSTAINABILITY	INTERMEDIATE SUSTAINABILITY
26	HIGH ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	INTERMEDIATE SOCIAL SUSTAINABILITY	HIGH SUSTAINABILITY
27	HIGH ENVIRONMENTAL SUSTAINABILITY	HIGH ECONOMIC SUSTAINABILITY	HIGH SOCIAL SUSTAINABILITY	HIGH SUSTAINABILITY

APPENDIX C

Matlab code, optimizing economic

```
%% Lower bounds
lb=zeros(18,1);
%% Upper bounds
ub=inf(18,1);
ub(1:2,1)=1580;
ub(3:18,1)=1422;
%% Linear inequality
A=zeros(5,18); b=zeros(1,5);
A(1,1)=1; b(1)=474;
A(2,2)=1; b(2)=1580;
A(3,3:18)=1; b(3)=1422;
A(4,3)=1; A(4,4)=1; A(4,7)=1; A(4,8)=1; A(4,11)=1; A(4,12)=1; A(4,15)=1; A(4,16)=1; b(4)=1117;
A(5,3)=1.27; A(5,4)=1.27; A(5,5)=1; A(5,6)=1; A(5,7)=1.27; A(5,8)=1.27; A(5,9)=1; A(5,10)=1;
A(5,11)=1.27; A(5,12)=1.27; A(5,13)=1; A(5,14)=1; A(5,15)=1.27; A(5,16)=1.27; A(5,17)=1;
A(5,18)=1; b(5)=1422;
%% Linear equality
Aeq=zeros(2,18); beq=zeros(2,1);
Aeq(1,[1,3,5,7,9,11,13,15,17])=[1,-1,-1.11,-1,-1.11,-1,-1.11,-1,-1.11];
Aeq(2,[2,4,6,8,10,12,14,16,18])=[1,-1,-1.11,-1,-1.11,-1,-1.11,-1,-1.11];
%% Objective function
f=zeros(1,18);
f(1)=0;
f(2)=0;
f(3)=-1.02;
f(4)=-0.00;
f(5)=-0.50;
f(6)=-0.00;
f(7)=-3.77;
f(8)=-2.27;
f(9)=-3.49;
f(10)=-1.82;
f(11)=-4.92;
f(12)=-3.42;
f(13)=-4.40;
f(14)=-2.73;
f(15)=-5.24;
f(16)=-3.74;
f(17)=-4.96;
f(18)=-3.29;
%% Solve problem
[x fval]=linprog(f,A,b,Aeq,beq,lb,ub);
```