Social Life Cycle Assessment:
Socioeconomic Evaluation of Biogas Plants and Short Rotation Coppices

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Abstract

Up to now, various methodological problems have hampered the application of the Social Life Cycle Assessment (SLCA) approach. The objective of this article is to introduce a modified, empirically based method of running a regionally differentiated SLCA. The modified SLCA method is illustrated by reference to two different bio-energy value chains (biogas and short rotation coppices) and a reference chain (wheat production). The socioeconomic comparison of different value chains shows that biogas production offers better results overall than reference value chains and can thus be considered sustainable from a social point of view. The results provide multifaceted socioeconomic data, offering the necessary informational input for political and managerial decision-making.

1 Introduction

Due to strong societal demands in Germany to decrease the use of fossil and nuclear energies, many regional political bodies have increased their efforts to generate energy from renewable sources and to advance regional energy autonomy. An example of this is the establishment of two bioenergy regions in South-East Lower Saxony as well as Western Thuringia. Both regions especially emphasize the production of biogas and woodchips from short rotation coppices (SRC). However, as evidenced by the recent sharp rise in media criticism of biogas production (e.g., regarding its influence on the price of electricity; Zschache et al., 2010), the planning process so far has failed to comprehensively consider the effects of increasing the production of renewable energies on relevant stakeholders.

Social Life Cycle Assessment (SLCA) is an instrument for the systematic assessment of the socioeconomic aspects of supply chains (Benoit and Mazijn, 2010). Although designed as an integral part of a Life Cycle Sustainability Assessment (LCSA), its application has been hampered by methodological flaws. Against this background, it is the aim of this paper to propose a modified SLCA approach that overcomes the methodological shortcomings of SLCA and to apply it to the biogas and woodchip supply chains in the above-mentioned bioenergy regions. This will improve the applicability of SLCA and result in additional information on the socioeconomic effects of bioenergy production for political decision-makers and managers in the bioenergy sector. Below, existing research on the socioeconomic effects of bioenergy production (section 2) and the regions of study and methodological aspects (section 3) will be presented. After presenting the results of a SLCA (section 4), the article closes with a short discussion of our conclusions (section 5).

2 Socioeconomic Aspects of Bioenergy Production

Socioeconomics considers the social and economic effects that economic activities have on society (Mikl-Horke, 2011) or on specific stakeholders. Previous studies of bioenergy production have concerned themselves for the most part with ecological and economic aspects. Studies on biogas production, for instance, which has experienced the highest growth rate in the bioenergy branch in the recent past in Germany, have revealed several observations: Biogas production was initially warmly welcomed by the mass media as a means of making an essential contribution to the intended shift towards renewable energy production (Zschache et al., 2010). Its ecological advantages were strongly emphasized. Furthermore, it was pointed out that bioenergy would not only decrease the rising costs of energy associated with the use of limited fossil energy resources by providing an additional supply option, but also reduce the risk of potentially wide-spread destruction (e.g., atomic reactor accidents) while simultaneously improving the security of the national supply (Billharz, 2005). However, more recently there has been increasing criticism of biogas production. Here, economic and ecological factors are of less concern than socioeconomic ones, including changes is the familiar landscape, increased land lease prices and the crowding-out of established forms of agricultural production (Zschache et al., 2010; Emmann and Theuvsen, 2012). Despite the increased relevance of socioeconomic concerns, up to now it has been the ecological and economic aspects of renewable energy, especially in biogas production, that have predominated in the literature (Luo et al., 2009).

Disregarding the lack of a comprehensive valuation approach, studies have been carried out on various partial aspects of the socioeconomics of bioenergy production. The effects on the regional economy and on the job market are two of the most heavily researched aspects of biogas production. With regard to the regional economy, studies emphasize the contributions of, for instance, biogas production to farm incomes and value added in rural areas (Emmann and Theuvsen, 2012). Fritsche et al. (2007) identified the creation of jobs not only in biogas production but also in the area of facility construction and maintenance as positive regional economic effects. In 2011 the renewable energy sector employed 124,400 workers. However, it has been pointed out that the net employment effect is certainly much less due to losses of jobs in fossil and nuclear energy sectors and the costs incurred by rising energy costs (Lehr et al., 2011). A positive net employment effect of 1,600 was found in a study conducted by Nusser et al. (2007). In addition, other positive economic effects, such as increased government revenues, were highlighted. In contrast, Pfaffenberger et al. (2003) describe a negative total employment effect for the renewable energy sector. Heißenhuber et al. (2008) also note a loss of jobs as a result of the crowding-out of labor-intensive livestock farming by labor-extensive biogas production (De Witte, 2012). In addition, jobs are lost upstream and downstream in the supply chain, for example, in the dairy industry.

Besides employees, the biogas chain includes other relevant stakeholders: purchasers, suppliers, the local populace (neighbors), competitors for production factors, the wider society, and consumers. Since there is no holistic set of criteria for the assessment of biogas production from the perspective of various stakeholders, previous studies have limited themselves, for the most part, to certain aspects of socioeconomic concerns. For example, there has been research on increased noise and air pollution affecting the local populace due to increased traffic (Braun et al., 2007), the rise in land lease prices (Kilian et al., 2008; Habermann and Breustedt, 2011; Emmann and Theuvsen, 2012), and the effects on extensive milk production (Bronner, 2010). In addition, although further potential areas of socioeconomic concern recognized in these studies were also deemed important (e.g., the impoverishment of the agricultural structure, effects on food production and on food prices), because of the lack of valid means of measurement, no closer examination of these aspects has been undertaken (Geldermann et al., 2012; Pastowski, 2007). Thus, the problem remains that existing studies have been unable to investigate socioeconomic concerns in a thorough or comprehensive fashion.

Socioeconomic evaluations that consider the supply chain in its entirety and, therefore, hope to meet the informational demands of diverse stakeholders need the most comprehensive compilation of socioeconomic evaluation criteria possible. In this case, of particular note is initial research done to compile catalogues of evaluation criteria for industrial production (Grießhammer et al., 2007; Spillemaeckers et al., 2004) as well as for agriculture and forestry (Breitschuh et al., 2008; FSC, 2012). Renn und Carrera (2008) used Delphi surveys to compare various Swiss supply chains in the energy sector, among them biogas production, with the help of a model that evaluated multiple criteria. They examined internal security, political stability, effects on human health, the social components of risks, the performance of the industry, effects on customers, contribution to government responsibilities, and effects on the operator. Despite these initial efforts, the methodological limitations in the area of socioeconomic evaluation, especially the lack of objective methods for measuring qualitative aspects (Prakash, 2012), are clear. Previous observations, therefore, have confined themselves primarily to quantitatively measureable effects, such as revenues and changes in the job market.

3 Social Life Cycle Assessment

The Life Cycle Sustainability Assessment (LCSA) has been suggested as a solution to this problem because its orientation to a life cycle considers holistic, ecological, economic, and social aspects (Klöppfer and Renner, 2007). However, the implementation of SLCA has also been suggested (Benoit and Mazijn, 2010; Dreyer et al., 2006; Hunkeler, 2006) in order to achieve holistic social or socioeconomic evaluation sustainability in the LCSA (Norris, 2006).

The SLCA is an instrument for conducting comparative socioeconomic evaluations of products, processes and entire supply chains. It offers holistic indicators that satisfy the informational needs of all relevant stakeholders while also considering qualitative indicators in its evaluation (Benoit and Mazijn, 2010; Ciroth and Franze, 2012). Analogous to the LCA approach (ISO 14040), the SLCA used in this research is carried out in three phases: the definition of the goal and scope of the research, the Life Cycle Impact Assessment, and the evaluation and documentation of results:

- Definition of Goal and Determination of Scope of Study:
  - *Determination of purpose and research objects*
  - *Definition of systematic limitations*
  - *Choice of functional unit*
  - *Determination of reference system for the comparison of socioeconomic effects*
- Life Cycle Impact Assessment:
  - *Identification of relevant socioeconomic indicators*
  - *Measurement of the parameter values of socioeconomic indicators*
- Evaluation and Documentation Phase:
  - *Evaluation, preparation, and illustration of the determined effects on the socioeconomic environment, taking into account referential supply chains and all relevant stakeholders*

However, the establishment of the SLCA has remained in an early developmental stage so far due to methodological difficulties and a thorough evaluation of this method is still on-going. Methodological problems, such as the lack of suitable procedures for objective measurement of qualitative socioeconomic aspects (e.g., the negative perception of changes in the landscape), have strongly hindered the establishment of the SLCA (Prakash, 2012). The following will, therefore, provide only an initial approach for applying an SLCA to the supply chain of renewable energy.

4 Study Design and Regions

4.1 Study Design

The main goal of the present study is the socioeconomic evaluation of the biogas and SRC supply chains for the supply of electricity in two regions in Germany. The study examines the agricultural production of the biomass, its transportation to and fermentation in a biogas production facility, and the subsequent conversion of the biogas to electricity. Similarly, the SRC is analyzed from the cultivation of substrate through the entry of electricity into the power network. Wheat flour production is used as the reference supply chain. Agricultural land use in hectares will be the functional unit for modeling the production chain, defining the system limitations, and assuring comparability.

In order to overcome the methodological shortcomings of SLCA, this study proposes a modified three-step SLCA approach. It includes a qualitative study to select potential socioeconomic indicators, a quantitative study to select relevant criteria for evaluation and attribute weights to the criteria, and a socioeconomic evaluation. The latter two steps are based on large-scale surveys of stakeholders and experts. This survey-based approach helps to fix methodological flaws, such as problems with the measurement of qualitative indicators.

Table 1.
Detailed description of the life cycle impact assessment.

Qualitative preliminary study	Quantitative preliminary study	Socioeconomic evaluation
Purpose: Potential socioeconomic criteria for evaluation for the observed supply chains determined by qualitative preliminary studies, description of the socioeconomic reality	Purpose: Evaluation of the relevance of potential indicators by use of a quantitative analysis	Purpose: Comparative measurement of the specificity of the criteria for evaluation derived by preliminary studies
Related Method: Quality feedback from experts, meta-analysis of scientific publications and relevant specialist literature, desktop research	Related Method: Differentiated survey of 307 participants by region, based on the observation of two regions	Related Method: Online survey of 88 experts in order to compare and evaluate derived criteria for evaluation and oral evaluation regarding supply chain quality
Provisional Result: Socioeconomic description of reality, selection of potential socioeconomic indicators	Provisional Result: Testing of potential socioeconomic indicators and identification of relevant criteria for evaluation	Result: Evaluation of various supply chains considering the informational needs of all relevant stakeholders

A qualitative preliminary study was not undertaken because an earlier study had already revealed 19 criteria for SLCA evaluation of bioenergy (Henke and Theuvsen, 2013a, Henke und Theuvsen, 2013b). These were applied to the quantitative preliminary research in 2013 with 307 participants in two regions. The socioeconomic evaluation is based on expert feedback. To this end, a partially standardized online survey was conducted in order to apply the 19 evaluation criteria to the comparison of various supply chains. This approach improves “the chances of retrieving a greater amount of data" (Seipel and Rieker, 2003, p. 149) through the use of the empirical survey elements and ensures the overall comparability of the test persons. The additional use of open questions provided further insights.

In this study an individual is considered to be an expert when it can be legitimately assumed that he or she has specialized knowledge in the target area, bioenergy production (Nagel and Meuser, 2009; Gläser and Laudel, 2010). Experts were found via online research of trade associations, industry experts and enterprises, and regulatory bodies and scientific communities. Of the invited experts, 88 responded to the survey, which was carried out between November 2012 and January 2013.

The expert survey consisted of two parts: The first focused on localization and self-appraisal of the respondents’ expertise regarding the supply chains under study. The second was the actual evaluation. The latter part was divided into thematic sections (e.g., employees, society, regional population) and requested a comparative judgment of socioeconomic criteria using 7-point Likert scales. It also offered the opportunity for a qualitative verbal socioeconomic evaluation of the supply chains. Quantitative data was analyzed using descriptive statistical methods (means comparison, significance test [Tamhane-t2]) (Lamnek, 2005). The qualitative data was subjected to a qualitative content analysis (Henke and Theuvsen, 2011; Gläser and Laudel, 2010; Mayring, 2002).

4.2 Regions of study

One region studied was the Thuringia Agricultural Plains (2,716 km^2 area with a population of 317,800). It comprises the regions of Unstrut-Hainich, Sömmerda, and Gotha. The average area devoted to agriculture (AA) is over 215 ha per farm (e.g., in the Unstrut-Hainich region: 272.4 ha) and thus greatly exceeds the national average of 55.8 ha AA per farm. In addition, the percentage of leased area (83%) is significantly higher than the national average (60%). In this region the lease payment of €100/ha to €200/ha also is lower than the national average (€203/ha) (Statistische Ämter des Bundes und der Länder, 2011). In the region under consideration, arable farming predominates, and there are currently 29 biogas facilities in operation. The percentage of maize is roughly 7% in Gotha, 8% in Sömmerda, and 5% in Unstrut-Hainich (TLS, 2010). The analysis of the extent of the SRC cultivated area was more difficult; however, 2.72 ha SRC cultivated area were identified in Sömmerda and 1.15 ha in Unstrut-Hainich.

The second region studied was Göttingen in South-East Lower Saxony, with a population of 258,166 and an area of 1,117 km^2. In this region 56,710 ha are farmed; the average agricultural area per farm is 72.7 ha, thus slightly below the national average. The agricultural area comprises 49,062 ha of cultivated land and 7,488 ha of permanent grassland. With a lease rate of 51.5% for the farmed area, Lower Saxony lies slightly below the national average (around 60%). In addition, the lease price in the Göttingen region (€200/ha–€300/ha) is roughly equal to the national average of €203/ha (Statistische Ämter des Bundes und der Länder, 2011). Despite the region’s edaphic excellence for wheat, 15 biogas facilities were in operation in 2012. The percentage of maize in the crop rotation is less than 10% of the agricultural area (Schütte, 2012). The SRC cultivated area in the region, which comprised ten units and five owners, was 10.5 ha.

5 Results of the Social Life Cycle Assessment

5.1 Relevant Criteria for Socioeconomic Evaluation

The regionally differentiated quantitative study regarding the perceived importance of relevant assessment criteria was based on a survey of stakeholders in both regions. It confirmed the set of criteria used for both regions (see Table 2). Only the criteria effects on tourism, effects on consumers, effects on employees, job security, and effect on the regional economy revealed significant differences between the regions under analysis. In the Göttingen region those criteria—with the exception of effects on tourism—proved to be less relevant. However, a statistically significant difference between the regions was not determined for any criteria, thereby obviating any need to continue separate presentations of the regions in course of the study.

Table 2.
Importance of various SLCA criteria (authors' data).

	Assessment Criteria	*Related Indicators Chosen*	*MW*
Perspective of the Regional Population	Effects on the environment	effects on the environment, local biodiversity and fauna	1.02
	Relationships with the regional population	adequate response to complaints from the population, keeping promises made to society, potential for conflict	0.85
	Changes to landscape	alteration of landscape, protection of unique landscapes, damage to landscape	1.00
	Effects on lifestyle of neighbors	health risks for regional population, pollution from emissions, traffic control, effects on leisure time activities	0.96
	Regional economic effect	influence on regional economy, influence on local population, crowding out of existing businesses	0.88
	Potential for conflict	potential for conflict within the village community	0.70
	Effects on tourism	effects on regional tourism	0.26
Perspective of the Employees	Work-life balance	adherence to work hours typical of branch, adequate vacation, individual arrangement of work schedule	0.77
	Remuneration	remuneration, regulated social benefits, level of compensation	1.08
	Disabled employees	handicapped accessible workplace, preference in hiring	0.77
	Effects on employees	adherence to labor legislation, union organization, percentage of hired-out workers	0.94
	Job benefits	company pension, motivation for employees, possibilities for continuing education	0.87
	Job safety	health risks, potential for accidents	1.17
Perspective of Society/ Consumers	Effects on food supply	crowding-out of food production, primary use of waste products for energy production	1.06
	Effects on consumers	consumer benefits, health risks, price development for industries as well as consumers	0.90
	Effects on poorer regions of the world	effect on people in poorer regions of the world, secondary effects on land use in poorer regions of the world	0.95
	Business ethics	influence on political decision-makers, corruption, fair trade	1.09
	National interests	renewable energy supply, availability of apprenticeship placements, contribution to increasing national competitiveness	0.93
	Effect on national budget	number of subsidies received, use of tax loopholes, contribution to the national economy	0.50
Comparison of mean of perceived importance of various SLCA assessment criteria on a scale of -2 (very unimportant) to +2 (very important).			

5.2 Quantitative Results of the SLCA

In general, the regional influence of all evaluation criteria (EC) was found to be positive, with one exception: biogas. Biogas production was determined to exert a negative influence on the landscape and on local tourism. In contrast, SRC is attributed with a positive influence on local tourism as well as the landscape. Biogas production also received negative evaluations (on average) with regard to its effects on the regional population, food supply, and the poorer regions of the world (Table 3). With a few exceptions, such as employment opportunities for disabled people, most other criteria were rated positively. There were some slight differences between the value chains under analysis; for instance, with regard to the contribution to national interests, wheat production received a significantly lower rating than biogas and wood chips from SRC. Regarding work safety, biogas production is rated somewhat lower than the production of wheat or wood chips, for example, concerning the risk of accidents.

Table 3.
Comparison of mean values of relevant evaluation criteria.

Assessment criteria: Regional Population (n=75-88)[1]	Biogas	SRC	Wheat
Effects on the environment ***a c	-0.34	1.05	-0.10
Relationships with regional population ***a **b	-0.13	0.43	0.35
Changes to landscape ***a b	-0.79	0.49	0.21
Effects on lifestyle of neighbors ***a b **c	-0.88	0.51	0.09
Regional economic effects	0.55	0.51	0.39
Potential for conflict ***a b	-1.00	0.14	0.38
Effects on tourism ***a ** c	-0.48	0.39	-0.05
Assessment criteria: Society/ Consumers (n=75-76)[1]			
Effects on food supply ***a b	-0.55	0.22	0.23
Effects on consumers	0.09	0.37	0.35
Effects on poorer regions of the world***a	-0.37	0.22	-0.04
Business ethics **c	-0.01	0.34	-0.03
National interests ***b c	1.57	1.39	0.80
Effect on national budget	0.07	0.28	0.17
Assessment criteria: Employees (n=75-80)[1]			
Work-life balance ***a c	-0.22	0.86	0.09
Remuneration ***a	0.73	0.22	0.46
Disabled employees	-0.68	-0.78	-0.74
Employee position	0.18	0.06	0.24
Job benefits **a	0.35	0.00	0.12
Job safety	-0.09	0.16	0.09
*Test of significance between groups: a= biogas – SRC, b= biogas – wheat, c= wheat SRC, *p ≤ 0.1; ** p ≤ 0.05; *** p ≤ 0.01. -3= negative influence to +3= positive influence.* *[1]= Fluctuations due to missing data*			

5.3 Differences between regions

The analysis showed no significant differences between the regions regarding the evaluation of the wheat and SRC supply chains. A few criteria concerning biogas production revealed significant differences, reflecting a more critical perception of biogas in the Göttingen region (Table 4).

Table 4.
Evaluation of biogas production.

Evaluation criteria (n=56)	Göttingen region	Thuringia	*Significance*
Effects on tourism	-1.30	-0.17	0.010
Effects on the environment	-0.81	0.21	0.040
Changes to landscape	-1.06	-0.56	0.192
Effects on lifestyle of neighbors	-1.11	-0.67	0.204

6 Conclusions

In this study a modified SLCA approach was suggested to evaluate socioeconomic concerns by applying it to various forms of renewable energy production. Up to now, methodological problems have prevented the application of this method on a wider scale. Thus, it was of particular concern to address these issues in the modification. This paper has discussed the value of using a modified SLCA approach to evaluating socioeconomic concerns by applying it to various forms of renewable energy production. The essence of the approach introduced here comprises the identification of socioeconomic criteria for evaluation by using a quantitative survey which avoids individual subjective evaluations through the introduction of an online survey of experts as well as the application of reference supply chains. In this way, our approach provides an improved basis for comparison and interpretation, yielding an overview of evaluation criteria as well as an instrument for the evaluation of qualitative socioeconomic criteria (e.g., influence on the landscape). The comparative approach based on the evaluation of reference chains also considerably increases the explanatory power of the evaluation results and provides a way to ascertain qualitative criteria for evaluation within a temporally and geographically variable socioeconomic environment.

The application of this approach to selected value chains has revealed the practicability of the suggested method. The online survey of experts was proven suitable and increased the applicability of the SLCA when transferred to other supply chains. Therefore, this paper helps to overcome the frequently mentioned methodological shortcomings of the SLCA (Finkbeiner et al., 2010; Prakash, 2010; Ciroth and Franze, 2012).

With regard to our findings, the comparison of various forms of renewable energy production showed that, in general, biogas production is clearly rated lower than other supply chains. Key points of criticism are its impact on food supply and the related negative influence on poorer regions of the world due to potential price effects resulting from food shortages (Pastowski, 2007). Further negative criticism addresses its effects on the landscape, possible conflicts with the regional populace, increased traffic, a reduction in the recreational value of the landscape, and negative effects on tourism. In this respect, the current investigation confirms earlier studies, such as media analyses (Zschache et al., 2010) and farmer surveys (Emmann, 2013).

The results of the regionally differentiated SLCA confirm the earlier findings of Henke and Theuvsen (2013). Both evaluations reveal a clearly lower ranking for biogas production. In contrast to the previous study, this research took into account different regions. Nonetheless, it revealed only marginal differences with regard to the identification of relevant socioeconomic indicators and their actual evaluation. Due to the geographical proximity and structural similarity of the regions under study, this result does not come as a surprise but underpins the validity and reliability of the SLCA approach.

The results have important implications for policymakers. They should take greater note of the diverse interests at stake when considering future legislation on renewable energies. A more holistic view could help to minimize negative socioeconomic effects and thus maintain the social acceptance of bioenergy production. Future legislation on renewable energies must also pay greater attention to the effects of bioenergy production on poorer regions of the world in order to avoid any exacerbation of ecological or social problems (e.g., clearance of primeval forests, rising food prices).

The results also underpin the relevance of the way renewable energy projects are implemented. Increased participation on the part of stakeholders is recommended in order to gain the acceptance of all interested parties. Operators of biogas plants, therefore, should seek to cooperate with regional stakeholders (e.g., neighbors) and later, during production, should maintain comprehensive interaction with the public, by such means as implementing effective complaint management techniques or a code of conduct for drivers of biomass transports (e.g., voluntary reduction of speed, immediate cleaning of streets). In general, this underscores the high importance of systematic stakeholder management (Schaper et al., 2013).

Finally, it must be pointed out that concerns beyond the realm of this study—which is limited to energy production until electricity is fed into the power network—need to be addressed in future research. Some difficulties, such as the effect of renewable energy production on the stability of electricity networks or the much-debated construction of new long-distance high-voltage transmission lines, just begin where this study concludes.

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