Renewable and Sustainable Energy Reviews 115 (2019) 109352

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Projecting socio-economic impacts of bioenergy: Current status and limitations of *ex-ante* quantification methods

Marnix L.J. Brinkman[a,*], Birka Wicke[a], André P.C. Faaij[b], Floor van der Hilst[a]

[a] Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, 3584 BD Utrecht, the Netherlands
[b] Energy and Sustainability Research Institute, University of Groningen, Blauwborgje 6, 9747 AC Groningen, the Netherlands

ARTICLE INFO

Keywords:
Sustainability
Certification
Bioenergy
Social impacts
Methods
Projections

ABSTRACT

The socio-economic effects of bio-energy are not unequivocally positive, although it is one of the main arguments for supporting its expansion. An *ex-ante* quantification of the impacts is necessary for transparently presenting the benefits and burdens of bioenergy before they occur, and for minimising unwanted outcomes. In this article, the status, limitations, and possibilities for improvements in *ex-ante* quantitative research methods for investigating socio-economic impacts of bioenergy are mapped. For this, a literature review to identify relevant indicators, analyse the latest quantitative *ex-ante* research methods, and to assess their ability and suitability to measure these indicators was performed. The spatial aggregation of existing analyses was specifically considered because quantitative information on different spatial scales shows the geographic distribution of the effects. From the 236 indicators of socio-economic impacts spread over twelve impact categories that were found in this review, it becomes evident that there are clear differences in the *ex-ante* quantification of these indicators. The review shows that some impact categories receive more attention in *ex-ante* quantification studies, such as project-level economic feasibility and national-level macroeconomic impacts, while other relevant indicators have not been *ex-ante* quantified, such as community impacts and public acceptance. Moreover, a key blind spot regarding food security impacts was identified in the aggregation level at which food security impacts are quantified, which does not match the level at which the impacts occur. The review also shows that much more can be done in terms of *ex-ante* quantification of these impacts. Specifically, spatial disaggregation of models and model collaboration can extend the scope of socio-economic analyses. This is demonstrated for food security impacts, which shows the potential for future household-level analysis of food security impacts on all four pillars of food security.

1. Introduction

Modern bioenergy is seen as a solution to mitigate climate change, increase energy independence, and stimulate the economy [1–3]. The scientific and political debate on bioenergy has primarily focused on climate change and other environmental impacts of bioenergy (e.g. Refs. [4,5]); however, socio-economic development is an integral aspect of sustainable development and should be considered in this context as well [6–8]. Although countries with a bioenergy mandate expect bioenergy to contribute to a number of socio-economic goals, such as domestic energy security, job creation, and rural development [1,9], the socio-economic impacts of bioenergy are not unequivocally positive [10–13]. Previous studies have identified negative socio-economic impacts, such as competition with food production and disregard for local land rights [9,14–16].

Hence, principles and certification schemes for sustainable bioenergy feedstock production and conversion have been introduced to avoid negative impacts of bioenergy [17–19]. Certification schemes, like the Roundtable on Sustainable Biomaterials (RSB) [20–22], Roundtable on Responsible Soy [23], and Bonsucro [24] have set sustainability standards that need to be met by producers. Although these certification schemes include socio-economic impacts of bioenergy, they focus more on the environmental impacts [17,25–28]. Further, the principles on socio-economic impacts are often formulated as general principles that are vague and cannot always be quantified [11,25–27,29]. For example, multiple certification schemes (e.g. Refs. [24,30]) have set employees' freedom from discrimination as one of their criteria. The availability of a company policy document against discrimination is enough to meet the criteria, without a requirement for measuring whether discrimination actually takes place. However,

* Corresponding author.
E-mail addresses: m.l.j.brinkman@uu.nl (M.L.J. Brinkman), b.wicke@uu.nl (B. Wicke), a.p.c.faaij@rug.nl (A.P.C. Faaij), f.vanderhilst@uu.nl (F. van der Hilst).

https://doi.org/10.1016/j.rser.2019.109352
Received 24 March 2019; Received in revised form 5 August 2019; Accepted 22 August 2019
Available online 18 September 2019
1364-0321/ © 2019 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Abbreviations

CGE	Computable General Equilibrium
IO	Input output
PE	Partial Equilibrium
SAM	Social Accounting Matrix
(s)LCA	(social) Life Cycle Assessment

quantitative information on the size of the impacts helps understand the scale of an effect and to transparently weigh the positive and negative aspects of bioenergy implementation [11,31,32]. The quantitative information on the socio-economic effects of bioenergy using objective measurements of the socio-economic impacts can then help facilitate and inform the decision-making processes [29,33,34].

Studying the present and past bioenergy projects to determine success factors and barriers can help stimulate the sustainable production of bioenergy. Despite that, to avoid negative impacts or overly optimistic expectations [1,35], the direction and magnitude of the socio-economic impacts of the future development of bioenergy needs to be assessed before actual production. *Ex-ante* knowledge of the potential positive and negative impacts of bioenergy and the balance between the two enables policymakers to minimise undesirable impacts.

Although there is consensus on the key socio-economic areas of concern regarding bioenergy [11,17,18,36], there is less agreement on the indicators that could and should be used to measure the socio-economic performance of bioenergy supply chains [10,17,29,37,38]. The impacts of bioenergy are diverse and cannot be characterised with a single comprehensive value. Therefore, each potential socio-economic impact is described by multiple indicators that account for the various dimensions of each socio-economic impact [11,39–41]. Securing a consensus on the clear indicators of potential socio-economic impacts can help formulate sustainability criteria and measure compliance [38]. This helps promote the overall sustainability of bioenergy [29,38,42].

The socio-economic impacts of bioenergy are not evenly distributed geographically. The impacts at the spatial aggregation level must be considered when including the geographic distribution of the socio-economic impacts in an analysis [11,43–46]. Assessing socio-economic effects at a high aggregation level can obscure regional variation, because the average would smoothen the regional differences, making it impossible to consider the distribution of the effect [47,48]. In contrast focussing only on the effects of a specific bioenergy project in the production region itself would neglect the effects that occur outside that area [49]. Furthermore, a focus on only the region with bioenergy ignores the effects that are indirectly caused by bioenergy (e.g. reduced demand in sectors supplying to the fossil fuel industry) and the cumulative effects of multiple bioenergy projects in a country, such as effects on food prices. The potential effects need to be analysed at various spatial scales to be able to comprehensively capture the socio-economic impacts of bioenergy. Information on the spatial distribution of the socio-economic effects can help avoid a disproportionate accumulation of negative impacts in a specific area.

Ex-ante assessment of the socio-economic impacts of bioenergy requires using methods and models that translate scenarios and assumptions of bioenergy implementation to effects on the various indicators. The selection of a method or combination of methods is important for the quantification of the impacts, as all methods have specific strengths and weaknesses, which affect their ability and suitability to quantify the socio-economic indicators. Such methods vary on some aspects, such as the indicators to be quantified, data inputs required, inclusion of indirect effects, and spatial scales to be included. This means the selection of a method also affects the final outcome of the assessment [50]. Currently, there is no overview of the available methods for quantitative *ex-ante* assessment of socio-economic impacts at different spatial scales and an assessment of their suitability and ability that would help identify the blind spots and associated knowledge gaps.

The shortcomings discussed above hinder agreement on the appropriate indicators of the socio-economic impacts of bioenergy at the relevant scales and the methodology for their quantification. Therefore, this paper aims to map the current status of quantitative *ex-ante* research on the socio-economic impacts of bioenergy, its limitations, and options for improvement. For this, a literature review is performed, to identify relevant indicators, analyse the latest *ex-ante* quantification methods and tools, and assess their ability and suitability to assess these indicators at different spatial scales.

2. Material and method

The approach for this literature review consists of two parts. In the first part, relevant indicators of the socio-economic impacts of bioenergy were selected. In the second part, available methods and their ability and suitability to quantify the relevant socio-economic impacts at different spatial levels were identified.

The first step was to make an overview of the socio-economic impacts of bioenergy based on previous reviews of sustainability criteria for bioenergy (e. g. Refs. [1,11,51,52]). This overview made it possible to later cluster the indicators per impact and to identify potential blind spots where no relevant indicators are available for an identified impact. The impacts that were mentioned in at least two different studies were included as the list was meant to be exhaustive, but not too disaggregated.

Those indicators of socio-economic impacts of bioenergy were considered *relevant* for *ex-ante* quantification if they a) reflect the effects[1] of bioenergy b) are included in certification schemes or agreed upon in stakeholder consultation processes, and c) can be assigned a numerical value. Certification schemes and stakeholder consultations represent the indicators that the public, policymakers, companies, and other stakeholders consider most important [53]. To obtain the list of relevant indicators, an overview was made of all indicators of the socio-economic impacts of bioenergy that were identified in the previous step based on the previous studies, as well as the certification schemes and standards for good practices (e.g. Refs. [21,30,54,55]).

Similar indicators were merged into one indicator to avoid duplication. To cull a long-list of indicators to a list of relevant indicators, those indicators that did not meet the following criteria for relevance were removed (as illustrated in Fig. 1):

1) the indicators that reflect an attribute of the bioenergy project, rather than an impact, conform Meyer et al. [19].
2) the indicators that require a qualitative assessment, and
3) the indicators that have not been included in a certification scheme or named by stakeholders in a stakeholder consultation process.

In the second part, the studies were reviewed that quantified *ex-ante* the socio-economic impacts of bioenergy to get an overview of *available* methods and the spatial level at which these are used. Studies quantifying one or more socio-economic impacts of bioenergy were selected using the Scopus search engine in April 2018. Only studies published after 2014 were selected, to include only the most recent literature. The used search terms included the name of each impact and terms related to the list of relevant indicators (for a complete overview, see Table

[1] This is analogous to the categorisation of Meyer et al. [19] who assessed the environmental indicators of bioenergy certification schemes. Since some studies and certification schemes are designed to assess the sustainability of an ongoing project, they contain indicators that reflect properties of management or production (e.g. the availability of a management plan), rather than the impacts of bioenergy.

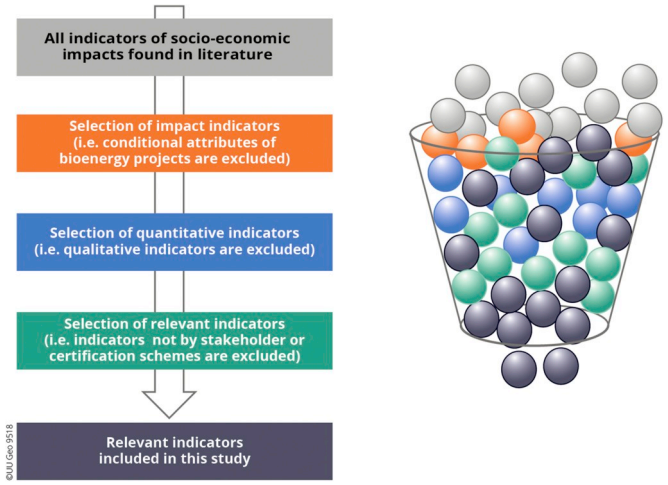


Fig. 1. Selection process of relevant indicators of socio-economic impacts of bioenergy.

A.1). These were combined with the terms 'bioenergy', 'biomass', 'biofuel', 'biodiesel', 'ethanol', and 'charcoal'. This yielded around 400–2700 papers per impact category (see Table A.1). Papers whose title and abstract were unrelated to this research were discarded. The selection of sources was then narrowed down by excluding studies that did not focus on *ex-ante* assessment. From the remaining papers, the assessed indicators, the method used, and the spatial scale of the study were recorded, i.e. the level at which the analysis was done, and the results presented (e.g. continental, local, or national level). From the method and discussion sections of these selected papers and review studies, the potential, limitations, strengths, and weaknesses of the methods, i.e. their *suitability* to *ex-ante* quantify the socio-economic impacts of bioenergy, were then discussed. This discussion also included opportunities to improve the *ex-ante* quantification methods.

3. Results

3.1. Relevant indicators

13 socio-economic impacts categories for bioenergy were identified: employment and income, food security, macroeconomic development, rural economic development, energy access, energy independence, economic feasibility, health and safety, land rights, working conditions, social acceptability, equal opportunities, and community impacts. For these impacts 236 indicators were mentioned in reviews, certification schemes, and guides of good practice. Table A.2 in the appendix gives an overview of all indicators. Of these 236 indicators, 46 are considered relevant, which means they reflect the effects of bioenergy, are included in certification schemes or agreed upon in stakeholder consultation processes, and a numerical value can be assigned to them. This list was obtained (see Table 1) by removing those indicators that: a) do not reflect impacts (78), or b) are not quantifiable (32), or c) are not included in certification schemes or mentioned by stakeholders (80), as illustrated in Fig. 2. Table 1 gives an overview of the 46 indicators that are considered relevant.

The highest number of relevant indicators was found for employment and income, with nine relevant quantitative indicators that provide insight into the effects on this category. These relevant indicators contain the whole spectrum of impacts: from the number of jobs created and lost in other sectors to information on who benefits from these jobs (e.g. locals or migrants) and the income generated for the employees. The indicators for employment and income are also the indicators mentioned the most in the literature, and are often mentioned as important by the stakeholders (e.g. for food security effects, the indicators reflect the four pillars of food security —availability, access, utilisation and stability—identified by the United Nations Food and Agriculture Organisation (FAO) which means all aspects of the issue are included [56]. For land rights, working conditions, economic feasibility, community impacts, energy access, and equal opportunities, only two to four relevant indicators were identified, but there is a high consensus on each of these indicators, illustrated by the large number of sources that include them. For health and safety, four relevant indicators were identified, but none of them had been named more than three times. Although macroeconomic impacts, rural economic development, and energy independence are often the rationale used for implementing bioenergy, few relevant indicators are available, and they are seldom mentioned.

Social acceptability is the only impact category for which no relevant indicator was found, since the indicators that have been found (e.g. commitment to ethical conduct [30], effective stakeholder participation [6,10], transparency [6,57]) are either qualitative or not included in a certification scheme or mentioned in a stakeholder consultation process.

3.2. Ability to quantify

In total, 218 studies that contained an *ex-ante* quantification of relevant socio-economic indicators were reviewed. As some studies have quantified multiple indicators, a total of 474 *ex-ante* quantifications was analysed. The indicator that is quantified the most is profitability, which is included in over 50 of the selected studies.

From the actual quantification of the indicators in the various studies (see Table A.3 in the appendix and Fig. 3), it is shown that macroeconomic impacts, employment and income, and rural development are quantified the most often and at almost all spatial levels. For macroeconomic impacts, there are many methods available to quantify the four indicators (see Table 1 and Table A.3); although most studies use input-output modelling in combination with other methods.

No study was found that *ex-ante* quantified the community impacts of bioenergy. Although management has a strong influence on the outcome of this indicator, it is difficult to quantify it, which increases the uncertainty. This also renders the projections of this indicator less valuable.

Other indicators that were not found to be quantified *ex-ante* are:

- ratio of local and migrant workers, and ratio between permanent and temporary jobs (in employment & income);
- seasonality of hunger (in food security);
- capacity of infrastructure (in economic feasibility);
- crime, indoor wood cooking, risk of HIV and other diseases (in health and safety);
- education provided to employees (in working conditions).

For rural development, equal opportunities, and health and safety categories, this means only two indicators are quantified *ex-ante,* and for working conditions, just one. For employment and income, the absence of these two indicators means that two of the three indicators for the social distribution of employment are not quantified, with only the ratio of skilled/unskilled employees being quantified. This indicates that *ex-ante* quantification of employment and income impacts of bioenergy are not comprehensive.

Most indicators are quantified using a regional- or national-level method. There are exceptions to this. For example, profitability and total investment are almost always quantified at the project level, as that is where these impacts occur and the methodology applied—cash flow analysis can quantify the profitability at the project level. Food prices and trade, however, are usually quantified at the national or higher level, although the impacts could be from local to global level [61]. This means lower aggregation level impacts are not included in the current methods, and the geographic distribution of these effects have not been quantified *ex-ante* in the reviewed studies.

Table 1
Overview of the relevant indicators of socio-economic impacts of bioenergy and their units of measurement. The certification schemes, and stakeholder consultations, and previous studies that include these indicators are presented.

Impact category	Indicator	Unit	Stakeholder	Certification	Source
Employment & Income	Household income	€ dy^{-1}	[58][,a]	[21]	[6,21,59–61]
	Job loss of other activities	#[b]		[21]	[21,61]
	Ratio between local/migrant workers	%		[62]	[11,51,52,62–64]
	Contribution of feedstock sales to household income	%/€ dy^{-1}	[41][,c]		[10,11,41,57]
	Job creation (in the bioenergy sector or company)	#/# MJ^{-1}/fte/# ha^{-1}	[41,65,66][,d,e]	[23,62]	[6,11,41,67,68] [1,23,57,59,62,64]
	Ratio permanent/temporary (casual/daily) jobs	%	[41]		[11,41,51,63]
	Ratio skilled/unskilled jobs and availability thereof	%	[41]		[11,41,51,67,68]
	Total wages in the sector	€	[65]		[11,68]
	Wage levels at bioenergy company, compared to minimum or median wage	%/€ dy^{-1}	[41,66]	[23,30,55,62]	[11,23,24,29,30,41,51,52,55,62,64,69]
Food security	Change in area of food crops	ha/%		[22]	[11,22]
	Change in calorie/nutrient deficit score	gr cap^{-1} day^{-1}/kcal cap^{-1} day^{-1}		[22]	[22,67,70]
	Change in yields of main staple crops	t ha^{-1}		[22]	[11,22]
	Lowest monthly calorie deficit/seasonality of hunger	kcal cap^{-1} dy^{-1}		[22]	[22]
	Price of national food basket	Δ%/Index/€/€ cap^{-1} dy^{-1}	[37,41]		[10,11,22,41,67,68,70]
	Supply of national food basket	t/%/kcal	[37,41]		[11,41,67,70]
Macroeconomic development	Change in GDP	€	[65]		[10,11,68]
	Sector contribution to GDP or GRDP	€/%	[37]		[11,64,70]
	Trade volume	€ yr^{-1}	[65]		[6,60]
Rural economic development	Gross value added	€ MJ^{-1}/%	[41]	[24]	[11,24,41,63]
	Change in share of people below the poverty line/number of poor people	Δ%	[37,65]		[10,11,59,61,70]
Energy access	Bioenergy to expand access to modern energy services	l yr^{-1}/MJ yr^{-1}/%	[41]	[62]	[10,11,41,62]
	Share of population that has increased access to energy	Δ %	[41]		[1,11,41]
Energy independence	Change in fossil fuel imports	MJ yr^{-1}/€ yr^{-1}/t yr^{-1}	[37]		[1,61]
	Energy diversity/diversification of the energy mix	(Herfindahl) index/MJ bioenergy in TPES	[41]		[1,11,41,60]
	Change in consumption of fossil fuel and traditional biomass	MJ yr^{-1}/€ yr^{-1}	[41]		[41,59]
Economic feasibility	Productivity/resource efficiency	t ha^{-1}/MJ ha^{-1}/€ MJ^{-1}	[41,58]	[24]	[6,11,24,41,52,60]
	Capacity of infrastructure and logistics for distribution of bioenergy	#/MJ yr^{-1}	[41]		[21,41,59,61]
	Total investment	€	[58]		[11]
	Profitability (yearly, net present value, return on investment, payback period, internal rate of return)	€ yr^{-1}/€/%/year	[58,65]		[6,11,70]
Health & Safety	Crime rate	%		[21]	[10,21]
	Indoor wood cooking	Δ %		[22]	[22,59,61]
	Change in mortality and burden of disease attributable to indoor smoke	%	[41,57][,g]		[11,41]
	Risk of HIV/aids and other diseases	%		[21]	[10,21]
	Traffic safety	# accidents		[21]	[21]
Land rights	Expansion of biofuel feedstock over other crops	ha/%	[41]	[21]	[11,21,41,64]
	Loss of natural resources and grazing land	ha		[21]	[10,21]
	Number of land conflicts	#		[30]	[10,11,30,63,64,71]
	Share of land acquisitions that comply with formal or socially accepted procedure regarding absolute numbers and area	%	[66]	[30]	[10,11,23,30,67]
Working conditions	Number of work related accidents and health issues	# yr^{-1} per 1000 employees/time lost to accidents		[24]	[11,24,51,63,69]
	Incidence of occupational injury, illness and fatalities	#/%/# ha^{-1}/# MJ^{-1}	[41]		[11,41,64]
	Training and/or education provided to employees	%/# yr^{-1}	[41,58,65]	[54]	[10,11,41,51,54,62,63]
Equal opportunities	Change in unpaid time spent by woman and children in collecting biomass	hrs household $^{-1}$ week $^{-1}$	[41]	[22]	[11,22,41]
	Female participation (in a type of work, sector, company, management)	%		[23]	[11,23,51]
	Share of women wages comparted to men's	%	[65]	[23,62]	[11,23,29,62,64]

(*continued on next page*)

Table 1 (*continued*)

Impact category	Indicator	Unit	Stakeholder	Certification	Source
Community Impacts	Access to water supply	%		[21,22,30]	[10,21,22,30,52,64,69,70]
	Community investment	€		[62]	[11,62]

[a]The indicators that were used in the final indicator list of Vaidya & Mayer [58] were those supported by the stakeholders.
[b]The symbol # signifies a unit that is counted (i.e number of).
[c]GBEP [41] is a tool designed for stakeholders, therefore all indicators are included.
[d]Gaitán-Cremaschi et al. [65] determined the importance of issues based on a stakeholder consultation. Issues were considered important when at least 65% of the respondents rated it at least 4 out of 5 on a Likert scale.
[e]Manik et al. [66] the indicators with the highest weight were selected as relevant.
[f] The indicators considered as "most relevant" or "very relevant" in Van Dam et al. [37].
[g]From the study of Baudry et al. [57] those indicators were included that were named by at least half of the stakeholder groups.

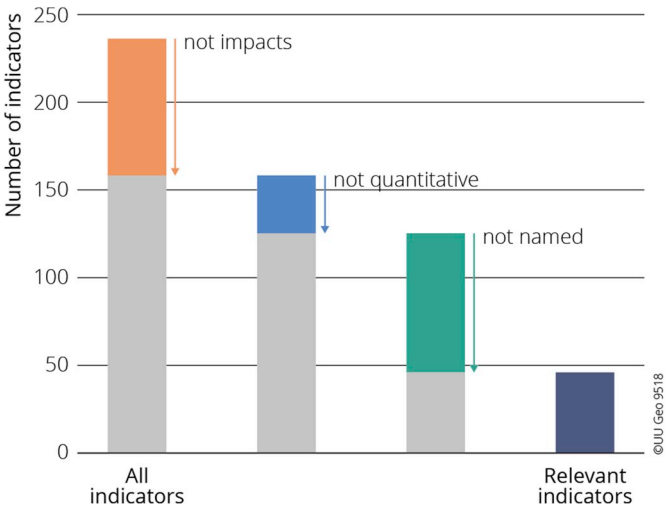


Fig. 2. Process to cull the long-list of 236 total indicators to the list of 46 relevant indicators.

3.3. Suitability

This section focusses on the macroeconomic models [input-output (IO), computable general equilibrium (CGE) models and partial equilibrium (PE) models], because studies employing a macroeconomic model either alone or in combination with other methods, cover almost the entire spectrum of socio-economic impacts (see Fig. 3 and Table A.3 in the appendix). The suitability of the methods are evaluated based on its operation and limitations, the indicators it addresses, the spatial levels it can be applied at, and how the suitability of the method for *ex-ante* quantification of socio-economic impacts of bioenergy can be further extended and improved by combining with other methods.

3.3.1. Input output models

An IO model consists of a static overview of all deliveries to and from each economic sector in a single geographic area; it links the additional demand proportionally to extra production in all supplying sectors [72,73]. IO models are used to calculate the socio-economic impacts of bioenergy because they can differentiate between direct, indirect, and induced effects[2] and, are relatively easier to use than CGE and PE models and can include multiple impacts [47,73,74].

On a national level, an IO model is generally used to determine the effect on GDP [47,73–83] or regional value added [47,77,79,83–87]. The IO approach can be extended to other socio-economic impacts by relating the economic activity in a sector to the socio-economic impact (e.g. employment per million dollar) [73]. For example, job creation (e.g. Refs. [47,79,83,86,87]), job loss in other sectors [88], educational level [89], occupational accidents [90], and traffic safety [91]. To apply this method, sectoral data on these impacts are required. Such data can be provided by the social hotspots database [69], which contains sectoral data on socio-economic impacts that can be coupled to the outcomes of an IO model [28,69,89].

An IO model is based on the economic interactions between specified sectors in the social accounting matrix (SAM) for a specific area, meaning socio-economic impacts can be calculated only for that area and spatial level without interaction with the rest of the world. Multi-region IO models broaden the IO approach by including the interaction between the sectors in various countries (e.g. Ref. [74]) or regions

[2] *Direct* effects are from the expansion of the bioenergy sector, *indirect* effects are those that occur as a result of additional economic activities in the supplying sectors, including the suppliers of the suppliers, and *induced* effects are from spending the additional income that households earned from the direct and indirect activities [47,73].



Fig. 3. Relative frequency of use of a spatial aggregation level (left) or quantification method (right). The size of a bubble reflects the number of studies with a specific combination of impacts, methods, and spatial scale.

within a country (e.g. Refs. [47,77]). This helps identify areas where the effects of bioenergy materialise (e.g. where employment will increase) and activities that generate economic activity elsewhere (i.e. cause the largest spill-over effect) [47,74,77,80,83,92]. The downside of the additional information on the distribution of the socio-economic effects over different regions or countries, is the reliance on generally poor-quality trade data and exchange rate effects [93].

One limitation of IO models is the time lag in the availability of data. Owing to the data intensity for producing SAMs and the infrequent updates the data are not current. This means new developments, such as new or rapidly-expanding sectors (e.g. bioenergy) and their interactions with other sectors, are not covered well. Furthermore, due to their static nature, IO models cannot endogenously incorporate technical progress (e.g. more efficient production methods) or structural changes to the economy [87,94]. Changing the technical coefficients of the model can help include technical change and thereby make the IO model more accurate and suitable for projecting socio-economic impacts [95]. Updating the technological coefficients can show the effects of mechanisation in feedstock production on employment [47].

Although in practice, the additional demand for bioenergy leads to effects in other sectors through price dynamics, competition, and substitution, this effect is not included in IO models [96,97]. This can result in overstating the size of the socio-economic impacts of bioenergy [97]. By linking the IO model to other models (e.g. CGE or land use) or using the outcomes of these models, the IO model can take price dynamics, competition, and substitution effects into account. The other models can help determine the size [98,99] or regional distribution [47,84] of future bioenergy demand as input to the IO model [100]. This improves the quality and the spatial detail of the calculated socio-economic impacts, when combined with a multi-regional IO model.

3.3.2. Computable general equilibrium models

CGE models are a type of macroeconomic models that include a global coverage[3] of all sectors of the economy and the economic interactions of supply, demand, and competition between the sectors that lead to a state of equilibrium [101]. CGE models are used for studying the socio-economic impacts of bioenergy because of their ability to include indirect effects, and the global scope matches the chain of effect of bioenergy [102–107]. CGE models are most suitable for mid-term analysis, typically 10–20 years in the future.

For socio-economic impacts of bioenergy, CGE models are usually used to calculate change in GDP [105–116], price and supply of food [101,105–107,109,114,115,117,118], trade volume [101,106,107,112], and wages [105,107,109,112,114] because of bioenergy expansion (see Fig. 3 and Table A.3). The effects that are calculated directly by the model are changes in price and production volume of economic sectors and the interactions between the sectors. CGE models are limited to monetary interactions that do not correspond well with physical volumes [104]. This means, for example, food is only included based on its monetary value, although the nutritional intensity (nutrients per $) can vary significantly. This leads to uncertain results as it is difficult to assess indicators based solely on the monetary value of a sector, especially in aggregated sectors. One key example is land use, for which the competition between bioenergy and other sectors is very important. To include other effects (such as job creation) it is possible to use the same method as in an IO model—relating the impact to the economic intensity of a sector [109,119,120].

Most CGE models use national-or-higher-level aggregate data for the interaction between the various sectors. Hence, the effects do not account for variations at lower spatial levels. The same holds true the sectoral aggregation; variation within sectors cannot be detected with a CGE model, even though there will be winners and losers within a sector. It becomes necessary to modify the CGE model to provide more detailed results, including the social or geographical distribution of effects. While most CGE models contain only one household per region, it is possible to derive household-level results by splitting that single household into multiple households in a specific area [107,121]. By differentiating the households according to region, income [122,123], or location (urban/rural [122]), additional information on the social and geographical distribution of the effects of bioenergy can be derived. Another option is to extend the analysis with microsimulations, which

[3] Disaggregated in multiple countries or continents.

does not rely on the disaggregation of top-down SAM to various households, but uses bottom-up data from a household survey to simulate the effects of price and income changes on thousands of different households [107,108,111,124]. This approach can show the distribution of the socio-economic effects for multiple households [125]. Using microsimulations, impacts can be determined at household or local level and can include, for example, household income and poverty rate [105,107,108,111].

CGE models are dynamic, meaning the relations between the sectors can change over time in response to changes in the economy, based on the models' elasticities [113]. Therefore, projections can include the effects of developing technology. However, as these effects are based on historical data, the modifications to the model's elasticities are also confined to those based on historical data. The time lag between the base year and publication year for SAMs is even longer in CGE modelling than in IO, as its production is a more data-intensive process. Bottom-up technology assessment [126] or adaptations from the structure of the sector in other areas [123] can be used to include bioenergy expansion to new areas in a CGE model. Nevertheless, this does not account for all structural changes to the economy in general and agriculture in particular. More sustainable production methods and potential for faster progress in the agricultural sector are not included in the CGE models, although these are important for sustainable bioenergy production, for example, by limiting competition for land (e.g. Refs. [127,128]). Incorporating the potential to reduce negative impacts, either via technology or policy interventions, in the CGE models would enable higher quality assessment of the sustainability impacts. For example, for the effects on food security, competition for land plays a major role.

One basic assumption of CGE models is that an economy tends towards equilibrium. However, this does not exist in practice [119]. Further, disregarding the adjustment path towards equilibrium might mean overlooking periods of extreme food price volatility, food shortages or other potential negative effects of bioenergy in the short run [129]. The equilibrium assumption has implications specifically for the projections on employment because labour is not a normal commodity [116,119] as employees cannot be as easily transferred from one sector or region to another as capital can. Thus, additional employment in a specific sector does not necessarily compensate for job losses in another sector or region [119]. This means unemployment from displacement of production (e.g. in the fossil fuel sector) is likely to be underestimated in a CGE model, especially in the short term, because labour markets require time to adjust. These limitations have a smaller impact, -the longer time-frame used in the CGE model [104].One option to address this issue is to distinguish different skill levels in employment and thereby, make labour a less homogeneous good in the model [108].

Linking a CGE model to other models can help overcome the lack of detail in the relations between the sectors in the global model. For example, by linking a CGE to an energy sector model, such as MARKAL [116], a biophysical model [105,130], a land use model [47,131] or detailed technical modelling of biofuel production chains [130], the modelling outcomes of the CGE can be more spatially explicit or better account for variation within economic sectors, which is not included in the economic model itself.

3.3.3. Partial equilibrium

PE models are similar to CGE models -they also use the laws of supply and demand to establish a new equilibrium after an economic shock has been introduced. Regardless, instead of the highly aggregated sectoral that is used in a CGE model, only a limited number of sectors is included in a PE model, and these are represented in greater detail. Modelling of the sector(s) included in the PE model is more extensive, and includes many products and interrelations between sectors; hence, PE models are typically used for longer-term analyses (up to 40 years).

PE models are most commonly used to calculate the impacts on trade [132–140], food prices, and food supply [98,134,135,140–146]. Most studies present the results on national [98,116,132–139,144,145,147–150] or higher [99,140–143,146] spatial aggregation levels. The increased detail in the energy sector, compared with CGE or IO models, helps provide projections on, for example, the role of bioenergy in the energy mix [137,151,152], change in fossil fuel imports [99,135,149,151] and changes in the use of traditional bioenergy [145,152]. Further, a PE model can be adapted to include spatially explicit land-use modelling, to reflect the competition between various land uses (e.g. Ref. [153]). As competition takes into account local suitability, the projections of land use are more detailed than in a CGE model. PE models are, for example, used to project reduction in land for food production [143,150], or to determine where current agricultural land is replaced by bioenergy feedstock [148,149,154].

PE models include only a partial representation of the economy and assume fixed prices and income in other sectors (i.e. *ceteris paribus*). This means socio-economic effects for the other sectors are not included. However, in reality, the effects of bioenergy are not limited to the few sectors that are included in the PE model. This problem can be partly mitigated by combining the global modelling of a CGE model with the detailed analysis of a PE model [116], or combining several PE models [140].

3.3.4. Bottom-up and process modelling

Bottom-up models are a heterogeneous group of various analytical and process models. One commonality of the methods is that they start with a detailed representation of the interactions between inputs and outputs and do not contain explicit modelling of interactions outside the production chain, such as market-based effects [104,155,156].

The social-economic impacts are analysed starting from the technical performance of the bioenergy supply chain and its energy and mass balance. The technical model can then be used to project the total investment (e.g. Refs. [157–160]) and profitability (e.g. Refs. [161–163]) of a project. Some studies use special process modelling software, such as ASPEN (e.g. Refs. [161,164]), or a spreadsheet model [161,165,166] for modelling and cost estimation using the share of labour in the total cost, or extrapolating the labour requirement to estimate job creation at the project level (e.g. Refs. [167–169]), the ratio between skilled and unskilled employees [168], or wages [170,171].

These bottom-up models are almost exclusively used for project-level estimations for the near future. Although the methods are rigorous and includes all aspects of the production process, they cannot account for indirect effects of investment on the rest of a region or country, neglecting the effects of competition and additional production in the rest of the economy [50,172].

Bottom-up modelling can be combined with macroeconomic modelling, such as IO or CGE analysis to account for indirect effects [172,173]. In the latter case, the dynamic changes to the economy can also be included. In such combined approaches, the detail of the process modelling can be integrated with the potential of the macroeconomic models to calculate indirect effects.

3.3.5. Cash flow analysis

Cash flow analysis makes an overview of all expected monetary incomes and expenditures and calculates profitability, taking opportunity costs and interest rates of capital into account. It is typically combined with bottom-up and process modelling (e.g. Refs. [174–178]), it is relatively easy, and transparent. The data requirement can be low, depending on the depth of the process modelling, although for new processes, the availability can be low and the data uncertain. Cash-flow analysis is usually done at the project level. Combining cash flow analysis with Monte Carlo simulation can provide information on the uncertainties of outcomes [179].

3.3.6. Social life cycle assessment

Another distinctive set of methods are life cycle assessment (LCA)

and social LCA (sLCA) [180,181]. LCA is a standardised method that inventories all physical and energy input and output flows of specific production process and calculates their environmental impacts. In the context of socio-economic impacts of bioenergy, only the impacts of fossil fuel use and its reduction [182–184] and human health effects for employees [65] or the general public are relevant. For example, respiratory diseases caused by sulphur dioxide and NO_x emissions from using biofuels in the transport sector [80,183,185,186]. These health effects (expressed as disability-adjusted life years) could be converted to economic damages (in monetary terms), and included in economic modelling (e.g. Ref. [187]).

sLCA is an extension of the LCA framework that relates the input and output of a production process to social impacts instead of environmental impacts [180,188]. Not all studies quantify the impacts, but rather use a narrative to indicate the risk of negative impacts [69,180,188,189]. In bioenergy, job creation [89,90,190], wages [89,90,190], and occupational accidents [89,90,190] have been *ex-ante* quantified using sLCA. These impacts are connected to the production chain, but since no region-specific data are available, the results are presented without specifying the location [51]. (s)LCA focuses on a specific production system, with clearly defined boundaries. This means the cumulative effects or indirect effects on other systems, for example, arising from competition for land, are not included.

Some studies use a hybrid input-output-(s)LCA approach [73,77,89–91,191,192], where the detailed modelling of the production system is replaced with the more general approach of IO modelling [181,193]. This sacrifices detail in the exact inputs and location of production and spatial detail. However, it makes it possible to include indirect effects in a (s)LCA [193]. Further, the process information gathered for the LCA can also be used as an input for the technical coefficients in the IO model.

3.3.7. Other methods

A few additional methods have been used to *ex-ante* quantify socio-economic impacts of bioenergy. For impacts at a low spatial level, system dynamics models [75,194–196] and agent based modelling [197,198] have been used. These models represent a bioenergy systems based on the actors and their interactions [199]. Despite that, these are typically applied to explain the present state of a system, *ex-post*, rather than project future responses. Spatially-explicit methods (e.g. Refs. [47,200–202]) have typically been used in combination with macro-economic models. The macroeconomic effects calculated using CGE or IO were converted to spatial effects using land-use allocation methods (e.g. Ref. [47]). Integrated assessment models [203–206] and biophysical [207] models have been used to determine impacts ar a global level, to calculate mostly land-use change effects especially relevant for food security. Game theory is relatively new and only one study was found that used this approach in the context of socio-economic impacts of bioenergy - to determine trade impacts [208]. Game theory is generally used to analyse competition and cooperation and, in this sense, could be relevant to analyse the interactions between bioenergy and other agricultural sectors [209,210]. Many studies have used different types of optimisation models [206,211–223], mostly as an extension to bottom-up/process modelling to determine the best achievable outcome. These models can be used to explore the socio-economic effects in an optimal situation [221].

4. Discussion

Socio-economic impacts are an integral aspect of sustainability of bioenergy and should preferably be quantified *ex-ante* to enable informed decision making and to stimulate the development of sustainable bioenergy. This study reviewed the state-of-the-art *ex-ante* assessments of socio-economic impacts of bioenergy. Using previous studies, guidelines of good practice, and certification schemes, the relevant indicators and the ability and suitability of methods to quantify these indicators at various spatial levels, were identified and analysed. The review shows the multiple methods (see Fig. 3) available for *ex-ante* quantification of the impacts of bioenergy (see Table 1). These methods can be applied at different aggregation levels (see Fig. 3), which makes it possible to analyse the geographic distribution of the impacts. The review also identifies the gaps and limitations at specific spatial levels in their ability to quantify *ex-ante* the relevant indicators of socio-economic impacts of bioenergy.

There are some limitations to these findings. When making the overview the applied indicators of socio-economic impacts, not all existing certification schemes and guides for good practice were analysed on the presence of socio-economic indicators. For example the European Commission has already recognised 15 certification schemes to be used for biofuels under the Renewable Energy Directive [224]. Some of these are for specific production chains (e.g. U.S. Soybean Sustainability Assurance Protocol or Roundtable on Sustainable Palm Oil), and can therefore be tailored to these production chains and contain socio-economic impacts that are not relevant in other production chains. However, as some of the most relevant certification schemes are analysed in this study it is unlikely major impact categories were overlooked. In addition, some of these certification schemes recognise biomass that is certified using other schemes as compliant in their scheme (e.g. Ref. [225]). This means there cannot be a large discrepancy between them. Another potential limitation to this study's findings, is that potentially useful methods for projecting socio-economic impacts of bioenergy can have been overlooked. The study focussed on the methods that have been applied in the context of bioenergy. This means, that methods from other fields of research may have been ignored.

The gaps in literature identified in this study are discussed in greater detail in section 4.1. These gaps should be the focus of future studies that aim to quantify the socio-economic impacts of bio-energy. Section 4.2 gives final remarks on *ex-ante* quantification of socio-economic impacts of bioenergy.

4.1. Gaps and limitations

***Ex-ante* quantification of social acceptability and community impacts has not been found, but other socio-economic impacts of bioenergy are quantified *ex-ante*.** The absence of quantitative projections is likely a result of the importance of the local context and the specific management choices for the actual performance of (local) projects [3,11]. As these factors may play a large role, the uncertainty of a projection would be greater. Although social acceptability and community impacts are not *ex-ante* quantifiable, it does not mean these should not play a role in decision making. However, neither of these impacts has attracted much support during stakeholder consultations, even when the subject has been explicitly addressed [65,66,226]. Only in the case described by Dale et al. [227], there is some support amongst stakeholders to include public opinion in the sustainability criteria of bioenergy.

One important aspect in the quantification of socio-economic impacts is the inability to include the social context in *ex-ante* quantitative models. The social context contains aspects, such as cultural norms, strength of government, and local institutions [27,228–231]. Together with other aspects that can be included in the models, such as the biophysical, economic situation, technological and feedstock choice, the social context also influences the magnitude and importance of the socio-economic impacts of bioenergy [11,232,233]. The social context influences the sustainability criteria used for bioenergy production and their enforcement [27,232]. Many certification schemes demand compliance with local laws, for example, for land acquisition or labour rights. However, for countries with weak legal frameworks or that set a low bar for the sustainability of bioenergy, this demand for compliance with local laws may not guarantee positive effects for the population [27,230,234]. Integrating this social context

in *ex-ante* modelling is a challenge. For models that are calibrated to historical data, such as CGE, PE, and land-use models, the effects of the social context are implicitly included. During the model calibration phase, the model is benchmarked and adapted to reflect past outcomes [153,235]. The real-life data (as opposed to model outcomes), which are used to calibrate the models, indirectly reflect the choices that people made within their respective social context. As a consequence of adapting the models to fit these actual outcomes, the elasticities, which represent the market responses to changes, reflect these choices. Nevertheless, the effectiveness of a calibration procedure depends on the availability of high quality datasets for the model calibration [97,236]. Therefore, future work in the form of monitoring of, say, agricultural, performance is needed to improve data availability and model outcomes. These data can also help better include technological progress in the models.

In the context of the environmental performance of bioenergy, Davis et al. [237] used the term 'management swing potential' to indicate how much impact management can have on the environmental effects of bioenergy. It can be hypothesised that the management swing potential for socio-economic impacts differs among various impacts, depending on the importance of the management compared to biophysical and social context factors for the specific socio-economic impacts [11,59]. For the socio-economic impacts where the management swing potential is relatively large (e.g. labour rights or freedom from discrimination), making projections becomes more difficult. This can be partly overcome by varying potential management strategies using scenario analysis to reflect the range in outcomes. This could also be applied to make projections on community impacts, for which no other quantification methods were found.

Indirect effects are often not properly captured by the models. It is important to determine indirect effects of bioenergy deployment, such as on food security, because these are an important part of the total effects. However, only a few methods are able to include these indirect effects. As these effects are often the result of competition or substitution between the economic sectors in the model, macro-economic models can include effects outside the bioenergy sector. Nevertheless, as the spatial detail of these macroeconomic models is relatively low, the indirect impacts are determined at a higher aggregation level. This means that the impacts are not specifically calculated at the lower spatial level where these impacts occur. Inclusion of multiple households in these models or lower-aggregation-level analysis is be required to increase the level of detail (see also Fig. 4 or e.g. Ref. [238]).

Additionally, not all socio-economic impacts that can be quantified by the methods are actually presented as results in the studies. For example, IO studies that present the net employment effects of

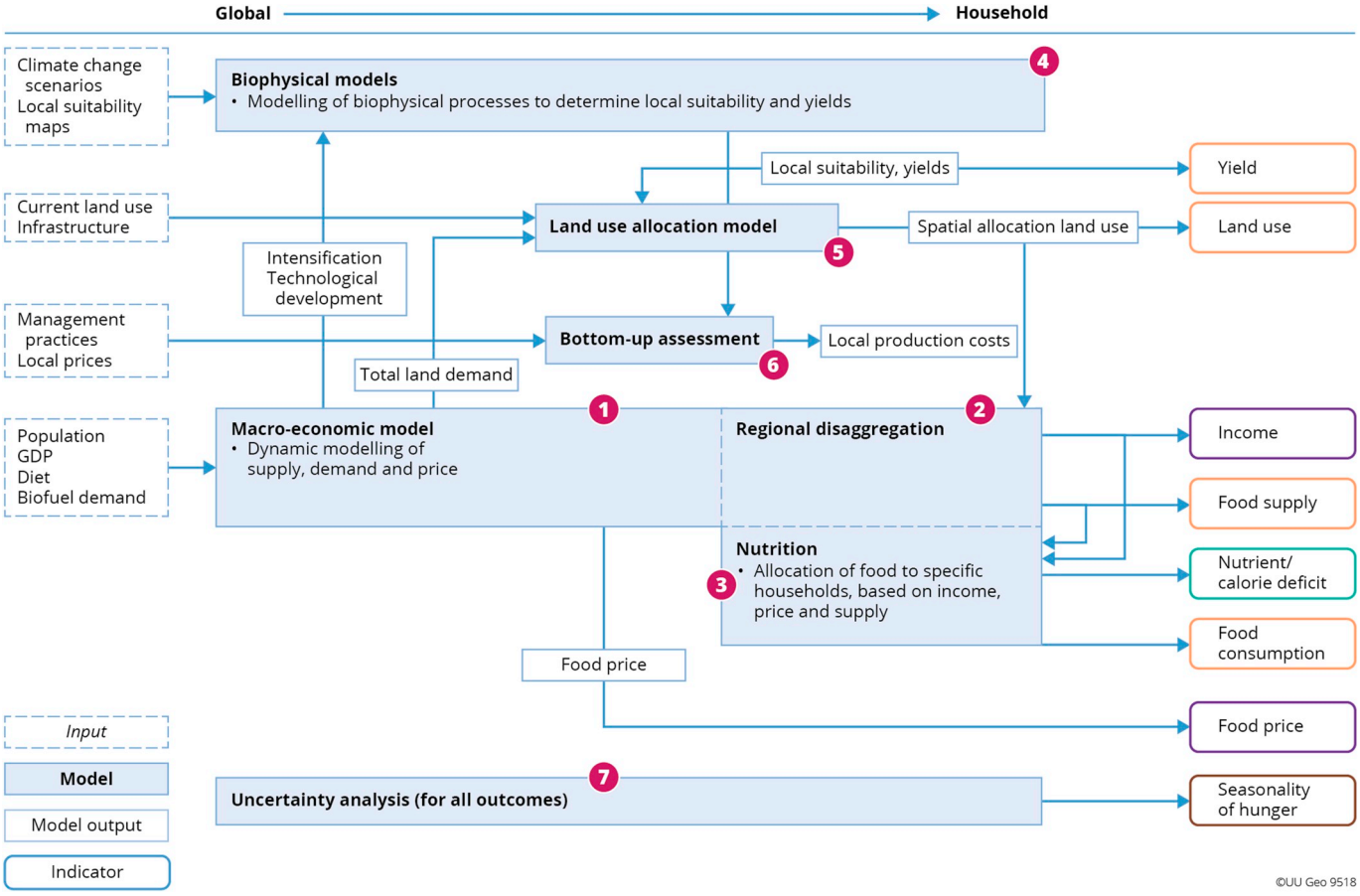


Fig. 4. Model collaboration to overcome the identified blind spots of food security impacts at low aggregation level. A macroeconomic model (e.g. CGE) gives the global context, dynamics, and (indirect) interactions (1). This information can be disaggregated to a lower level (2) for example by distinguishing multiple households within the country, and used to determine the effects on food consumption and nutrition (3), based on the changes in income, prices, and production. The local context is included through a link with a land use model (4) that provides spatial explicit allocation of the land use. A bottom-up model can be used to determine local agricultural and bioenergy processing costs, which can be converted to cost structures to be used in the macroeconomic model, for example, by including local input prices and management practices. Land use allocation is dependent on the local conditions such as the current biophysical conditions (4). To account for the seasonal variation, uncertainty analysis (7) can be applied to provide information on the variations in food supply throughout the year. The colour of the indicators on the right hand-side of the figure relate to the pillars of food security: availability (orange), access (purple), utilisation (green), and stability (black). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

bioenergy can also calculate the job loss in other sectors [47,88]. However, this is often not included, omitting an important indirect effect. Another example of indirect effects that are not presented by the studies are the health and safety aspects of indoor smoke resulting from use of traditional bioenergy. Increasing household income leads to a switch to other fuel sources [239,240] and, thereby, to better indoor air quality and lower health impacts [241,242]. Other aspects that are linked to income are the time spent by women gathering fuelwood [243,244]. These aspects are not directly included in studies on bioenergy use. Despite that, this would become possible by explicitly linking these impacts to the income effects of bioenergy.

One key blind spot is the lack of methods to assess the local effects of bioenergy on food supply and price. Smith and Bustamante [61] have shown that the food security impacts of bioenergy range from local to global. However, to our knowledge, no local- or household-level assessment of the effect of bioenergy on the availability or price of food has been published so far. The only sub-national food security impacts that were found to be structurally quantified *ex-ante* are the effects on agricultural land use [194,201,245,246]. Although this is a useful proxy to show the impact of bioenergy on food availability, it does not include the effects of additional income or a potential switch to a higher yielding crop. As no low-aggregation-level *ex-ante* quantification has been found, it is hard to assess the distribution of food security effects of bioenergy at the aggregation level at which it is most relevant (i.e. households).

Current methods for *ex-ante* assessment of socio-economic impacts of bioenergy can provide more information than what is obtained, but more work is needed to include the effects on all relevant spatial levels. It appears that not all socio-economic effects of bioenergy are so far quantified *ex-ante* at the spatial levels where those impacts occur. Regardless, the analysis can be extended beyond what has already been done. Here, it is demonstrated how a combination of different methods can be used to extend the analysis of the socio-economic impacts of bioenergy beyond the current state-of-the-art. This also addresses the blind spots in the assessment of the geographic distribution and illustrates how the distribution of food security impacts of bioenergy can be determined for a specific case.

Six relevant indicators of food security were identified in section 3.1: i) area of food crops, ii) food prices, iii) food supply, iv) calorie/nutrient deficit score, v) yields of main staple crops, and vi) lowest monthly calorie deficit/seasonality of hunger (see Table 1). To quantify these impacts *ex-ante* on a low spatial-aggregation level, potential connections between existing models and are discussed and illustrated in Fig. 4. Fig. 5 shows the spatial level at which each pillar of food security can be quantified.

The scenarios for socio-economic development at the macro level (population, global economic growth, etc. [203]) and the bioenergy demand for which the food security effects are to be assessed are the starting point for the analysis of food security impacts of bioenergy at the household-level. A macroeconomic model (1, in Fig. 4), such as a CGE or PE model (e.g. Ref. [247]) can account for the dynamics in demand and supply of all sectors in response to the bioenergy demand in such scenarios. This includes the indirect effects in the rest of the economy as a result of this increased bioenergy demand. The economic dynamics of the macroeconomic model lead to national-or-higher-level projections on developments in food demand, supply, and prices as well as the aggregate information on average household income. A disaggregated macroeconomic model (2, in Fig. 4) that spatially disaggregates -regions or income groups (e.g. Ref. [121]) to gain insight in the geographical or social distribution of these effects. The use of a macroeconomic model with sub-national sectors enables the inclusion of selected household types in the economic dynamics of the model (see e.g. Ref. [248]). Disaggregation to household types for specific regions or income groups can provide information on the distribution of the food security effects within a country.

The land use of each crop determined in the macroeconomic model can be spatially disaggregated using a land-use allocation model (5, in Fig. 4) that can operate at the desired spatial level (e.g. Refs. [249,250]). The inputs for the land allocation model are maps of current land use and infrastructure, information on local suitability and yields, for example, from the biophysical model (4, in Fig. 4), and the total land demand in future scenarios. The biophysical models use information on climate, local soil conditions, technological development, and intensification to determine the suitability and potential yields in each location (see e.g. Ref. [251]). The outcomes of the land allocation model can be used to determine land use in the regions of the disaggregated macroeconomic model. Integrating the macroeconomic and land allocation models enable the inclusion of feedback mechanisms between the demand and supply of land. Further, this can help better project yield development and competition for land between among agricultural demands by including both biophysical and economic dynamics that determine yield development. Specific local conditions can be factored into the cost structures for agriculture or bioenergy conversion in the macroeconomic model using bottom-up technology projections (6, fin Fig. 4) that are dependent on local prices, management practices and yields (e.g. Ref. [126]).

A nutrition module (3, in Fig. 4) added to a CGE model, for example, through post analysis [120] or microsimulations [252], can project the consumption changes resulting from changes in income, prices, and production. Combining these model outputs with information on the energy and nutrient content of food products can then give the household calorie and nutrient consumption. Comparing this to the

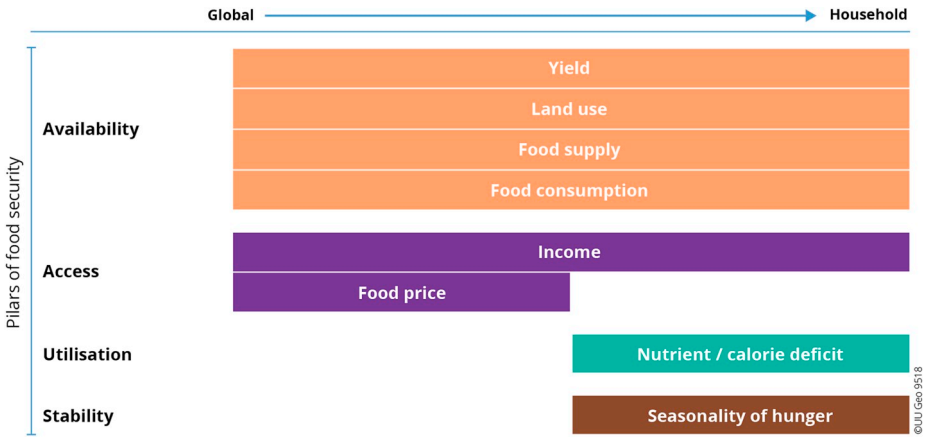


Fig. 5. *Aggregation level for ex-ante quantification of food security indicators. The indicators are classified based on the four pillars of food security (availability, access, utilisation and stability) as defined by the FAO* [56].

recommended nutrient and energy intake then indicates whether there is a surplus or deficit in food consumption. The seasonal variation in calorie intake can be determined in an uncertainty analysis (7, in Fig. 4), where the information on total food supply, with household survey data and for example Monte Carlo simulations are used to determine the likelihood of the food supply dropping below the required level. Fig. 5 presents the levels at which the pillars of food security can be quantified ex-ante.

4.2. Conclusions

Ex-ante quantification of the socio-economic impacts of bioenergy is an important aspect in the assessment of its sustainability because quantitative information can help present the effects in a transparent and objective manner, providing insight into the trade-offs between the positive and negative impacts. Based on the lessons learnt from this review three recommendations for improved assessment of socio-economic impacts are made: i) extending the analysis to more indicators and aggregation levels; ii) improving the macroeconomic models and their data requirements; and iii) reassessing the role of socio-economic impacts in certification schemes.

To enable a comprehensive *ex-ante* assessment of the socio-economic impacts of bioenergy, more efforts need to be made to improve the quantification of those indicators for which no quantification methods have been found. This could require developing new methods, or as illustrated for food security in Fig. 4, collaboration of existing methods to provide more insights into the distribution on lower aggregation levels. Another option is to explore new indicators that can be quantified *ex-ante* and can be used as a proxy for the missing indicator [253]. For example, use the change in the share of households above a certain income threshold as a proxy for the reduction in health effects of indoor smoke (e.g. Refs. [239–242]).

Extending the analysis to a lower spatial aggregation level and/or other sectors helps show the distribution of the socio-economic impacts, but it is not yet feasible for most cases because data unavailability. Since a CGE, PE or IO model, or a combination of these is the most likely option to *ex-ante* assess the socio-economic impacts of bioenergy at a lower spatial aggregation level, timely availability of social accounting matrices is required. Disaggregated models are only available for specific situations. The data intensity makes it unfeasible to disaggregate a macroeconomic model for each specific study. For low spatial aggregation levels, high-quality data are difficult to obtain and depend on the quality of data collection. In countries with a large informal economy and few resources for gathering data, data collection is more difficult and data quality is often poor. At the same time, these countries are also the most likely to experience negative impacts of bioenergy, which is why it is even more important to have high-quality data and *ex-ante* assessment of socio-economic impacts. This need for better-quality data also applies to technological development in agriculture and conversion processes. Although technological progress can significantly influence the occurrence and level of socio-economic impacts of bioenergy, it is only included with a delay. This makes it more difficult to include the effects of more sustainable practices in *ex-ante* analyses.

Further, the availability of spatial land use information is crucial. Land use dynamics are important to determine the competition for land and other resources. Land use allocation could increase the spatial detail of the socio-economic impacts (e.g. Ref. [47]), but it depends on the availability and the quality of spatial data for current land use and local suitability to properly model the land-use dynamics [131]. This underlines the importance of developing land use and land quality maps of areas where bioenergy can have a direct or indirect impact.

The review of the socio-economic indicators in certification schemes shows that these play a relatively minor role as compared to environmental indicators. Moreover, the socio-economic criteria used are mostly based on past performance, rather than *ex-ante* projections. However, an *ex-ante* assessment of the socio-economic impacts of bioenergy can help promote the positive impacts and avoid production where negative impacts could occur. Such *ex-ante* assessments can go together with certification as it is equally important to verify the actual production practices. This can help stimulate sustainable production of bioenergy.

Acknowledgements

This work was carried out within the Be-Basic R&D Program, which was granted a FES subsidy from the Dutch Ministry of Economic Affairs, Agriculture and Innovation (ELI). The authors want to thank Margot Stoete for her work on the illustrations.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2019.109352.

References

[1] Hunsberger C, German LA, Goetz A. “Unbundling” the biofuel promise: querying the ability of liquid biofuels to deliver on socio-economic policy expectations. Energy Policy 2017;108:791–805. https://doi.org/10.1016/j.enpol.2017.04.017.
[2] Slade R, Di Lucia L, Adams P. How policy makers learned to start worrying and fell out of love with bioenergy. Greenhouse gas balances of bioenergy systems. Elsevier Inc.; 2017. p. 11–28. https://doi.org/10.1016/B978-0-08-101036-5.00002-1.
[3] Chum H, Faaij APC, Moreira J, Berndes G, Dhamija P, Dong H, et al. Bioenergy. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, editors. IPCC special report on renewable energy sources and climate change mitigation. Cambridge, United Kingdom and New York, NY: Cambridge University Press; 2011. p. 209–332.
[4] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Science 2008;319:1235–8. https://doi.org/10.1126/science.1152747.
[5] Searchinger TD, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, et al. Use of U.S. Croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 2008;319:1238–40. https://doi.org/10.1126/science.1151861.
[6] Dale VH, Efroymson RA, Kline KL, Langholtz MH, Leiby PN, Oladosu GA, et al. Indicators for assessing socioeconomic sustainability of bioenergy systems: a short list of practical measures. Ecol Indicat 2013;26:87–102. https://doi.org/10.1016/j.ecolind.2012.10.014.
[7] United Nations. Resolution adopted by the general assembly on 16 September 2005. World Summit Outcome; 2005. p. 1–38. A/RES/60/1.
[8] Fritsche UR, Eppler U, Fehrenbach H, Giegrich J. Linkages between the sustainable development goals (SDGs) and the GBEP sustainability indictors for bioenergy (GSI). Darmstadt, Berlin, Heidelberg: IINAS & ifeu; 2018.
[9] Ahmed A, Campion BB, Gasparatos A. Biofuel development in Ghana: policies of expansion and drivers of failure in the jatropha sector. Renew Sustain Energy Rev 2017;70:133–49. https://doi.org/10.1016/j.rser.2016.11.216.
[10] van Dam J, Faaij APC, Rutz D, Janssen R. Socio-economic impacts of biomass feedstock production. Utrecht, Netherlands: Global Bio-Pact; 2010.
[11] van Eijck J, Diaz-Chavez RA, Wright A, Rom Colthoff J, Gerber Machado P, Hilbert JA, et al. Identification and analysis of socio-economic indicators; illustrated by bioenergy systems in eight case study countries. In: van Eijck J, editor. Socio-economic impacts of biofuels in developing countries, ’s hertogenbosch. Netherlands: Uitgeverij BOXpress; 2014. p. 295–367.
[12] Goldemberg J, Coelho ST, Guardabassi P. The sustainability of ethanol production from sugarcane. Energy Policy 2008;36:2086–97. https://doi.org/10.1016/j.enpol.2008.02.028.
[13] Martinelli LA, Garrett R, Ferraz S, Naylor R. Sugar and ethanol production as a rural development strategy in Brazil: evidence from the state of São Paulo. Agric Syst 2011;104:419–28. https://doi.org/10.1016/j.agsy.2011.01.006.
[14] Ji X, Long X. A review of the ecological and socioeconomic effects of biofuel and energy policy recommendations. Renew Sustain Energy Rev 2016;61:41–52. https://doi.org/10.1016/j.rser.2016.03.026.
[15] Thondhlana G. Land acquisition for and local livelihood implications of biofuel development in Zimbabwe. Land Use Policy 2015;49:11–9. https://doi.org/10.1016/j.landusepol.2015.06.025.
[16] Hunsberger C, Work C, Herre R. Linking climate change strategies and land conflicts in Cambodia: evidence from the Greater Aural region. World Development; 2018. https://doi.org/10.1016/j.worlddev.2018.02.008.
[17] Scarlat N, Dallemand J-F. Recent developments of biofuels/bioenergy sustainability certification: a global overview. Energy Policy 2011;39:1630–46. https://doi.org/10.1016/j.enpol.2010.12.039.
[18] van Dam J, Junginger M, Faaij APC. From the global efforts on certification of bioenergy towards an integrated approach based on sustainable land use planning. Renew Sustain Energy Rev 2010;14:2445–72. https://doi.org/10.1016/j.rser.

2010.07.010.
[19] Meyer MA, Priess JA. Indicators of bioenergy-related certification schemes - an analysis of the quality and comprehensiveness for assessing local/regional environmental impacts. Biomass Bioenergy 2014;65:151–69. https://doi.org/10.1016/j.biombioe.2014.03.041.
[20] RSB. Roundtable on sustainable biomaterials: principles and criteria 3.0. Geneva, Switzerland: Roundtable on Sustainable Biomaterials; 2016.
[21] RSB. RSB social impact assessment (SIA) guidelines vol. 01. Geneva, Switzerland: Roundtable on Sustainable Biomaterials; 2016.
[22] RSB. RSB food security guidelines vol. 01. Geneva, Switzerland: Roundtable on Sustainable Biomaterials; 2011.
[23] Roundtable on Responsible Soy Association. RTRS standard for responsible Soy production. Zürich, Switserland: RTRS; 2010.
[24] Bonsucro. Production standard EU RED production standard V4.2. London, UK: Bonsucro; 2014. https://doi.org/10.16576/j.cnki.1007-4414.2015.01.043.
[25] German LA, Schoneveld GC. A review of social sustainability considerations among EU-approved voluntary schemes for biofuels, with implications for rural livelihoods. Energy Policy 2012;51:765–78. https://doi.org/10.1016/j.enpol.2012.09.022.
[26] Mai-Moulin T, Armstrong S, van Dam J, Junginger M. Toward a harmonization of national sustainability requirements and criteria for solid biomass. Biofuels, Bioproducts and Biorefining 2017;6:246–56. https://doi.org/10.1002/bbb.1822.
[27] de Man R, German LA. Certifying the sustainability of biofuels: promise and reality. Energy Policy 2017;109:871–83. https://doi.org/10.1016/j.enpol.2017.05.047.
[28] Ekener-Petersen E, Höglund J, Finnveden G. Screening potential social impacts of fossil fuels and biofuels for vehicles. Energy Policy 2014;73:416–26. https://doi.org/10.1016/j.enpol.2014.05.034.
[29] Lewandowski I, Faaij APC. Steps towards the development of a certification system for sustainable bio-energy trade. Biomass Bioenergy 2006;30:83–104. https://doi.org/10.1016/j.biombioe.2005.11.003.
[30] RSPO. Rspo P&C 2013: audit Checklist for assessing compliance. Kuala Lumpur, Malasia: Roundtable on Sustainable Palm Oil; 2015.
[31] Myllyviita T, Leskinen P, Lähtinen K, Pasanen K, Sironen S, Kähkönen T, et al. Sustainability assessment of wood-based bioenergy - a methodological framework and a case-study. Biomass Bioenergy 2013;59:293–9. https://doi.org/10.1016/j.biombioe.2013.07.010.
[32] Kline KL, Oladosu Ga, Dale VH, McBride AC. Scientific analysis is essential to assess biofuel policy effects: in response to the paper by Kim and Dale on "Indirect land-use change for biofuels: testing predictions and improving analytical methodologies. Biomass Bioenergy 2011;35:4488–91. https://doi.org/10.1016/j.biombioe.2011.08.011.
[33] Gallego Carrera D, Mack A. Sustainability assessment of energy technologies via social indicators: results of a survey among European energy experts. Energy Policy 2010;38:1030–9. https://doi.org/10.1016/j.enpol.2009.10.055.
[34] Böhringer C, Löschel A. Computable general equilibrium models for sustainability impact assessment: status quo and prospects. Ecol Econ 2006;60:49–64. https://doi.org/10.1016/j.ecolecon.2006.03.006.
[35] Banerjee A, Halvorsen KE, Eastmond-Spencer A, Sweitz SR. Sustainable development for whom and how? Exploring the gaps between popular discourses and ground reality using the Mexican jatropha biodiesel case. Environ Manag 2017;59:912–23. https://doi.org/10.1007/s00267-017-0848-x.
[36] van Dam J, Junginger M, Faaij APC, Jürgens I, Best G, Fritsche U. Overview of recent developments in sustainable biomass certification. Biomass Bioenergy 2008;32:749–80. https://doi.org/10.1016/j.biombioe.2008.01.018.
[37] van Dam J, Junginger M. Striving to further harmonization of sustainability criteria for bioenergy in Europe: recommendations from a stakeholder questionnaire. Energy Policy 2011;39:4051–66. https://doi.org/10.1016/j.enpol.2011.03.022.
[38] Markevičius A, Katinas V, Perednis E, Tamaauskien M. Trends and sustainability criteria of the production and use of liquid biofuels. Renew Sustain Energy Rev 2010;14:3226–31. https://doi.org/10.1016/j.rser.2010.07.015.
[39] Bell S, Morse S. Sustainability indicators: measuring the immeasurable? second ed. London, UK: Earthscan; 2008. https://doi.org/10.1016/S0743-0167(99)00036-4.
[40] Diaz-Chavez RA. Assessing biofuels: aiming for sustainable development or complying with the market? Energy Policy 2011;39:5763–9. https://doi.org/10.1016/j.enpol.2011.03.054.
[41] GBEP. The global bioenergy partnership sustainability indicators for bioenergy. Rome, Italy: Food and Agriculture Organisation; 2011.
[42] Buchholz TS, Volk TA, Luzadis VA. A participatory systems approach to modeling social, economic, and ecological components of bioenergy. Energy Policy 2007;35:6084–94. https://doi.org/10.1016/j.enpol.2007.08.020.
[43] Creutzig F, Corbera E, Bolwig S, Hunsberger C. Integrating place-specific livelihood and equity outcomes into global assessments of bioenergy deployment. Environ Res Lett 2013;8:035047https://doi.org/10.1088/1748-9326/8/3/035047.
[44] Hodbod J, Tomei J, Blaber-Wegg T. A comparative analysis of the equity outcomes in three sugarcane-ethanol systems. J Environ Dev 2015;24:211–36. https://doi.org/10.1177/1070496515583556.
[45] Mattila TJ, Judl J, Macombe C, Leskinen P. Evaluating social sustainability of bioeconomy value chains through integrated use of local and global methods. Biomass Bioenergy 2018;109:276–83. https://doi.org/10.1016/j.biombioe.2017.12.019.
[46] Dale VH, Lowrance R, Mulholland P, Robertson GP. Bioenergy sustainability at the regional scale. Ecol Soc 2010;15.
[47] Brinkman MLJ, da Cunha MP, Heijnen S, Wicke B, Guilhoto JJM, Walter A, et al. Interregional assessment of socio-economic effects of sugarcane ethanol production in Brazil. Renew Sustain Energy Rev 2018;88:347–62. https://doi.org/10.1016/j.rser.2018.02.014.
[48] Vos R, de Jong N. Trade liberalization and poverty in Ecuador: a CGE macro-microsimulation analysis. Econ Syst Res 2003;15:211–32. https://doi.org/10.1080/0953531032000091180.
[49] Burnquist HL, da Costa CC, Guilhoto JJM. Impacts of changes in regional sugar and ethanol exports upon Brazilian overall economy. 2004.
[50] Schlosser JA, Leatherman JC, Peterson JM. Are biofuels revitalizing rural Economies ? Projected versus actual labor market impacts in the great plains. American agricultural economics association annual meeting. 2008.
[51] Siebert A, Bezama A, O'Keeffe S, Thrän D. Social life cycle assessment indices and indicators to monitor the social implications of wood-based products. J Clean Prod 2018;172:4074–84. https://doi.org/10.1016/j.jclepro.2017.02.146.
[52] Lim CI, Biswas W. An evaluation of holistic sustainability assessment framework for palm oil production in Malaysia. Sustainability 2015;7:16561–87. https://doi.org/10.3390/su71215833.
[53] Halder P, Arevalo J, Mola-yudego B, Gritten D. Energy Security and Development 2015:377–91. https://doi.org/10.1007/978-81-322-2065-7.
[54] International Organisation for Standardisation. ISO 13065: sustainability criteria for bioenergy. 2015. Geneva, Switzerland.
[55] Department for Transport. Renewable transport fuel obligation guidance Part Two carbon and sustainability. London, UK: Department for Transport; 2018.
[56] Food and Agriculture Organisation. Rome declaration on world food security. 1996http://www.fao.org/docrep/003/w3613e/w3613e00.HTM, Accessed date: 15 June 2016.
[57] Baudry G, Delrue F, Legrand J, Pruvost J, Vallée T. The challenge of measuring biofuel sustainability: a stakeholder-driven approach applied to the French case. Renew Sustain Energy Rev 2017;69:933–47. https://doi.org/10.1016/j.rser.2016.11.022.
[58] Vaidya A, Mayer AL. Use of a participatory approach to develop a regional assessment tool for bioenergy production. Biomass Bioenergy 2016;94:1–11. https://doi.org/10.1016/j.biombioe.2016.08.001.
[59] Creutzig F, Ravindranath NH, Berndes G, Bolwig S, Bright R, Cherubini F, et al. Bioenergy and climate change mitigation: an assessment. GCB Bioenergy 2015;7:916–44. https://doi.org/10.1111/gcbb.12205.
[60] Domac J, Richards K, Risovic S. Socio-economic drivers in implementing bioenergy projects. Biomass Bioenergy 2005;28:97–106. https://doi.org/10.1016/j.biombioe.2004.08.002.
[61] Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA, et al. Chapter 11: agriculture, forestry and other land use (AFOLU). In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, editors. Climate change 2014: mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change Cambridge, United Kingdom and New York, NY: Cambridge University Press; 2014. p. 812–922. https://doi.org/10.1017/CBO9781107415416.
[62] RSB. RSB guidance on principles & criteria for sustainable biofuel production. Geneva, Switzerland: Roundtable on Sustainable Biomaterials; 2010.
[63] Diaz-Chavez RA, Rettenmaier N, Rutz D, Janssen R. Global-Bio-Pact set of selected socio-economic sustainability criteria and indicators. 2012.
[64] Blom M, Solmar C. How to socially assess biofuels - a case study of the UNEP/SETAC code of practice for social- economical LCA. Luleå tekniska universitet; 2009.
[65] Gaitán-Cremaschi D, Kamali FP, van Evert FK, Meuwissen MPM, Oude Lansink AGJM. Benchmarking the sustainability performance of the Brazilian non-GM and GM soybean meal chains: an indicator-based approach. Food Policy 2015;55:22–32. https://doi.org/10.1016/j.foodpol.2015.05.006.
[66] Manik Y, Leahy J, Halog A. Social life cycle assessment of palm oil biodiesel: a case study in Jambi Province of Indonesia. Int J Life Cycle Assess 2013;18:1386–92. https://doi.org/10.1007/s11367-013-0581-5.
[67] Hasenheit M, Gerdes H, Kiresiewa Z, Beekman V. Summary report on the social, economic and environmental impacts of the bioeconomy. 2016.
[68] O'Brien M, Bringezu S. Tools for evaluating and monitoring the EU bioeconomy: Indicators vol. 14. 2013.
[69] Benoît-Norris C, Norris GA, Aulisio Cavan D. Social hotspots database: suporting documentation. York, MN: new earth; 2013.
[70] Arodudu O, Helming K, Wiggering H, Voinov A. Towards a more holistic sustainability assessment framework for agro-bioenergy systems — a review. Environ Impact Assess Rev 2017;62:61–75. https://doi.org/10.1016/j.eiar.2016.07.008.
[71] Kessler JJ, Rood T, Tekelenburg T, Bakkenes M. Biodiversity and socioeconomic impacts of selected agro-commodity production systems. J Environ Dev 2007;16:131–60. https://doi.org/10.1177/1070496507302516.
[72] Miller RE, Blair PD. Input-output analysis: foundations and extensions. second ed. Cambridge, UK: Cambridge University Press; 2009.
[73] de Carvalho AL, Antunes CH, Freire F. Economic-energy-environment analysis of prospective sugarcane bioethanol production in Brazil. Appl Energy 2016;181:514–26. https://doi.org/10.1016/j.apenergy.2016.07.122.
[74] de la Rúa C, Lechón Y. An integrated Multi-Regional Input-Output (MRIO) Analysis of miscanthus biomass production in France: socio-economic and climate change consequences. Biomass Bioenergy 2016;94:21–30. https://doi.org/10.1016/j.biombioe.2016.08.003.
[75] Jin E, Sutherland JW. A proposed integrated sustainability model for a bioenergy system. Procedia CIRP 2016;48:358–63. https://doi.org/10.1016/j.procir.2016.03.159.
[76] Malik A, Lenzen M, Ralph PJ, Tamburic B. Hybrid life-cycle assessment of algal biofuel production. Bioresour Technol 2015;184:436–43. https://doi.org/10.1016/j.biortech.2014.10.132.

[77] Malik A, Lenzen M, Geschke A. Triple bottom line study of a lignocellulosic biofuel industry. GCB Bioenergy 2016;8:96–110. https://doi.org/10.1111/gcbb.12240.

[78] Moon D, Kitagawa N, Sagisaka M, Genchi Y. Economic impact of utilizing woody biomass to manufacture high value-added material products: a study of cellulose nanofiber and high standard chip-dust production in Maniwa. Japan. Nihon Enerugi Gakkaishi/Journal of the Japan Institute of Energy 2015;94:582–7. https://doi.org/10.3775/jie.94.582.

[79] Okkonen L, Lehtonen O. Local, regional and national level of the socioeconomic impacts of a bio-oil production system – a case in Lieksa. Finland. Renewable and Sustainable Energy Reviews 2017;71:103–11. https://doi.org/10.1016/j.rser.2017.01.003.

[80] Perrin A, Wohlfahrt J, Morandi F, Østergård H, Flatberg T, De La Rua C, et al. Integrated design and sustainable assessment of innovative biomass supply chains: a case-study on miscanthus in France. Appl Energy 2017;204:66–77. https://doi.org/10.1016/j.apenergy.2017.06.093.

[81] Santamaría M, Azqueta D. Promoting biofuels use in Spain: a cost-benefit analysis. Renew Sustain Energy Rev 2015;50:1415–24. https://doi.org/10.1016/j.rser.2015.04.192.

[82] Sievers L, Schaffer A. The impacts of the German biofuel quota on sectoral domestic production and imports of the German economy. Renew Sustain Energy Rev 2016;63:497–505. https://doi.org/10.1016/j.rser.2016.05.058.

[83] Veiga JPS, Malik A, Lenzen M, Ferreira Filho JB de S, Romanelli TL. Triple-bottom-line assessment of São Paulo state's sugarcane production based on a Brazilian multi-regional input-output matrix. Renew Sustain Energy Rev 2018;82:666–80. https://doi.org/10.1016/j.rser.2017.09.075.

[84] He L, English BC, Menard RJ, Lambert DM. Regional woody biomass supply and economic impacts from harvesting in the southern. U.S. Energy Economics 2016;60:151–61. https://doi.org/10.1016/j.eneco.2016.09.007.

[85] Lehtonen O, Okkonen L. Socio-economic impacts of a local bioenergy-based development strategy - the case of Pielinen Karelia. Finland. Renewable Energy 2016;85:610–9. https://doi.org/10.1016/j.renene.2015.07.006.

[86] Xu Z, Smyth CE, Lemprière TC, Rampley GJ, Kurz WA. Climate change mitigation strategies in the forest sector: biophysical impacts and economic implications in British Columbia, Canada. Mitig Adapt Strategies Glob Change 2018;23:257–90. https://doi.org/10.1007/s11027-016-9735-7.

[87] Zhang Y, Goldberg M, Tan E, Meyer PA. Estimation of economic impacts of cellulosic biofuel production: a comparative analysis of three biofuel pathways. Biofuels, Bioproducts and Biorefining 2016;10:281–98. https://doi.org/10.1002/bbb.1637.

[88] Dampier JEE, Shahi C, Lemelin RH, Luckai N. Assessment of potential local and regional induced economic impact of an energy policy change in rural Northwestern Ontario. Energy, Sustainability and Society 2016;6:14. https://doi.org/10.1186/s13705-016-0079-7.

[89] Souza A, Watanabe MDB, Cavalett OO, Ugaya CML, Bonomi A. Social life cycle assessment of first and second-generation ethanol production technologies in Brazil. Int J Life Cycle Assess 2018;23:617–28. https://doi.org/10.1007/s11367-016-1112-y.

[90] Papong S, Rewlay-ngoen C, Itsubo N, Malakul P. Environmental life cycle assessment and social impacts of bioethanol production in Thailand. J Clean Prod 2017;157:254–66. https://doi.org/10.1016/j.jclepro.2017.04.122.

[91] Strogen B, Bell K, Breunig H, Zilberman D. Environmental, public health, and safety assessment of fuel pipelines and other freight transportation modes. Appl Energy 2016;171:266–76. https://doi.org/10.1016/j.apenergy.2016.02.059.

[92] Henderson JE, Joshi O, Parajuli R, Hubbard WG. A regional assessment of wood resource sustainability and potential economic impact of the wood pellet market in the. U.S. South. Biomass and Bioenergy 2017;105:421–7. https://doi.org/10.1016/j.biombioe.2017.08.003.

[93] Wiedmann T. A review of recent multi-region input-output models used for consumption-based emission and resource accounting. Ecol Econ 2009;69:211–22. https://doi.org/10.1016/j.ecolecon.2009.08.026.

[94] da Cunha MP, Scaramucci JA. Bioethanol as basis for regional development in Brazil: an input-output model with mixed technologies. 46th congress of the european regional science association. ERSA); 2006.

[95] Scaramucci JA, da Cunha MP. Socioeconomic impacts of producing ethanol in Brazil: an inter-regional input-output model. 2006.

[96] Wicke B, Smeets EMW, Tabeau A, Hilbert JA, Faaij APC. Macroeconomic impacts of bioenergy production on surplus agricultural land—a case study of Argentina. Renew Sustain Energy Rev 2009;13:2463–73. https://doi.org/10.1016/j.rser.2009.05.010.

[97] Allan G. The regional economic impacts of biofuels: a review of multisectoral modelling techniques and evaluation of applications. Glasgow, UK: University of Strathclyde; 2012.

[98] Çağatay S, Taşdoğan C, Özeş R. Analysing the impact of targeted bio-ethanol blending ratio in Turkey. Bio base Appl Econ 2017;6:209–27. https://doi.org/10.13128/BAE-16395.

[99] Koelbl BS, Wood R, van den Broek MA, Sanders MWJL, Faaij APC, van Vuuren DP. Socio-economic impacts of future electricity generation scenarios in Europe: potential costs and benefits of using CO2 Capture and Storage (CCS). International Journal of Greenhouse Gas Control 2015;42:471–84. https://doi.org/10.1016/j.ijggc.2015.08.010.

[100] Bonfiglio A, Esposti R. Analysing the economy-wide impact of the supply chains activated by a new biomass power plant. The case of cardoon in Sardinia. Bio Base Appl Econ 2016;5(1):5–26. https://doi.org/10.13128/BAE-15247.

[101] Beckman J, Gooch E, Gopinath M, Landes M. Market impacts of China and India meeting biofuel targets using traditional feedstocks. Biomass Bioenergy 2018;108:258–64. https://doi.org/10.1016/j.biombioe.2017.11.018.

[102] Choumert Nkolo J, Combes Motel P, Guegang Djimeli C. Income-generating effects of biofuel policies: a meta-analysis of the CGE literature. Ecol Econ 2018;147:230–42. https://doi.org/10.1016/j.ecolecon.2018.01.025.

[103] van Tongeren F, van Meijl H, Surry Y. Global models applied to agricultural and trade policies: a review and assessment. Agric Econ 2001;26:149–72.

[104] Wicke B, van der Hilst F, Daioglou V, Banse M, Beringer T, Gerssen-Gondelach SJ, et al. Model collaboration for the improved assessment of biomass supply, demand, and impacts. GCB Bioenergy 2015;7:422–37. https://doi.org/10.1111/gcbb.12176.

[105] Schuenemann F, Thurlow J, Zeller M. Leveling the field for biofuels: comparing the economic and environmental impacts of biofuel and other export crops in Malawi. Agric Econ 2017;48:301–15. https://doi.org/10.1111/agec.12335.

[106] Ge J, Lei Y. Policy options for non-grain bioethanol in China: insights from an economy-energy-environment CGE model. Energy Policy 2017;105:502–11. https://doi.org/10.1016/j.enpol.2017.03.012.

[107] Cabral FJ, Cissé F, Diagne A, Siwa M. Global biofuel production and poverty in Senegal. Econ Bull 2017;37:1435–49. https://doi.org/10.1016/j.apenergy.2012.03.031.

[108] Argüello R, Valderrama-Gonzalez D. Sectoral and poverty impacts of agricultural policy adjustments in Colombia. Agric Econ 2015;46:259–80. https://doi.org/10.1111/agec.12155.

[109] Choi D. “Land grab” or development opportunity? The effect of transnational farmland investments on the Ghanaian economy. Develop Econ 2018;56:3–34. https://doi.org/10.1111/deve.12157.

[110] Chunark P, Limmeechokchai B, Fujimori S, Masui T. Renewable energy achievements in CO2mitigation in Thailand's NDCs. Renew Energy 2017;114:1294–305. https://doi.org/10.1016/j.renene.2017.08.017.

[111] Debela GM, Tamiru S. Biofuels, poverty, food security and growth in Ethiopia: a computable general equilibrium microsimulation analysis. In: Heshmati A, editor. Poverty and well-being in east africa: a multi-faceted economic approach Cham: Springer International Publishing; 2016. p. 241–66. https://doi.org/10.1007/978-3-319-30981-1_11.

[112] Lefèvre J, Wills W, Hourcade JC. Combining low-carbon economic development and oil exploration in Brazil? An energy–economy assessment. Clim Policy 2018;3062:1–10. https://doi.org/10.1080/14693062.2018.1431198.

[113] Oladosu G. An economic evaluation of alternative biofuel deployment scenarios in the USA. AIMS Energy 2017;5:374–96. https://doi.org/10.3934/energy.2017.3.374.

[114] Reimer JJ, Zheng X. Economic analysis of an aviation bioenergy supply chain. Renew Sustain Energy Rev 2017;77:945–54. https://doi.org/10.1016/j.rser.2016.12.036.

[115] Thurlow J, Branca G, Felix E, Maltsoglou I, Rincón LE. Producing biofuels in low-income countries: an integrated environmental and economic assessment for Tanzania. Environ Resour Econ 2016;64:153–71. https://doi.org/10.1007/s10640-014-9863-z.

[116] van Meijl H, Tsiropoulos I, Bartelings H, Hoefnagels R, Smeets EMW, Tabeau A, et al. On the macro-economic impact of bioenergy and biochemicals – introducing advanced bioeconomy sectors into an economic modelling framework with a case study for The Netherlands. Biomass Bioenergy 2018;108:381–97. https://doi.org/10.1016/j.biombioe.2017.10.040.

[117] Wu JJ, Langpap C. The price and welfare effects of biofuel mandates and subsidies. Environ Resour Econ 2015;62:35–57. https://doi.org/10.1007/s10640-014-9814-8.

[118] Hasegawa T, Fujimori S, Shin Y, Tanaka A, Takahashi K, Masui T. Consequence of climate mitigation on the risk of hunger. Environ Sci Technol 2015;49:7245–53. https://doi.org/10.1021/es5051748.

[119] Mu Y, Cai W, Evans SG, Wang C, Roland-Holst D. Employment impacts of renewable energy policies in China: a decomposition analysis based on a CGE modeling framework. Appl Energy 2018;210:256–67. https://doi.org/10.1016/j.apenergy.2017.10.086.

[120] Rutten M, Tabeau A, Godeschalk F. A new methodology for incorporating nutrition indicators in economy-wide scenario analyses. The Hague, Netherlands: LEI Wageningen UR; 2013.

[121] Kuiper MH, Shutes LJ. Expanding the household coverage of global simulation models: an application to Ghana. The Hague, Netherlands: LEI Wageningen UR; 2014.

[122] Hartley F, van Seventer DE, Tostão E, Arndt C. WIDER Working Paper 2016/177 Economic impacts of developing a biofuel industry in Mozambique. Helsinki: Finland; 2016.

[123] Elizondo A, Boyd R. Economic impact of ethanol promotion in Mexico: a general equilibrium analysis. Energy Policy 2017;101:293–301. https://doi.org/10.1016/j.enpol.2016.11.017.

[124] Schuenemann F, Msangi S, Zeller M. Policies for a sustainable biomass energy sector in Malawi: enhancing energy and food security simultaneously. World Dev 2018;103:14–26. https://doi.org/10.1016/j.worlddev.2017.10.011.

[125] Davies JB. Combining microsimulation with CGE and macro modelling for distributional analysis in developing and transition countries. International Journal of Microsimulation 2009;2:49–65.

[126] Gerber Machado P. Sustainable development potentials and pathways for biobased economy options: an integrated approach on land use, energy systems, economy and greenhouse gases emissions. UNICAMP; 2017.

[127] Brinkman MLJ, Wicke B, Faaij APC. Low-ILUC-risk ethanol from Hungarian maize. Biomass Bioenergy 2017;99:57–68. https://doi.org/10.1016/j.biombioe.2017.02.006.

[128] Brinkman MLJ, van der Hilst F, Faaij APC, Wicke B. Low-ILUC-risk rapeseed biodiesel: potential and indirect GHG emission effects in Eastern Romania.

Biofuels 2018:1–16. https://doi.org/10.1080/17597269.2018.1464873.
[129] Achterbosch T, Woltjer G, van Meijl H, Tabeau A, Bartelings H, van Berkum S. An economy-wide assessment of the food security impacts of changes in biofuel policies and use Government policies largely drive bioenergy markets. Netherlands: Den Haag; 2013.
[130] Hoefnagels R, Banse M, Dornburg V, Faaij APC. Macro-economic impact of large-scale deployment of biomass resources for energy and materials on a national level-A combined approach for The Netherlands. Energy Policy 2013;59:727–44. https://doi.org/10.1016/j.enpol.2013.04.026.
[131] Rutten M, Van Dijk M, Van Rooij W, Hilderink H. Land use dynamics, climate change, and food security in Vietnam: a global-to-local modeling approach. World Dev 2014;59:29–46. https://doi.org/10.1016/j.worlddev.2014.01.020.
[132] Johnston CMT, van Kooten GC. Global trade impacts of increasing Europe's bioenergy demand. J For Econ 2016;23:27–44. https://doi.org/10.1016/j.jfe.2015.11.001.
[133] Jonsson R, Rinaldi F. The impact on global wood-product markets of increasing consumption of wood pellets within the European Union. Energy 2017;133:864–78. https://doi.org/10.1016/j.energy.2017.05.178.
[134] Kochaphum C, Gheewala SH, Vinitnantharat S. Does palm biodiesel driven land use change worsen greenhouse gas emissions? An environmental and socio-economic assessment. Energy for Sustainable Development 2015;29:100–11. https://doi.org/10.1016/j.esd.2015.10.005.
[135] Moschini G, Lapan H, Kim H. The renewable fuel standard in competitive equilibrium: market and welfare effects. Am J Agric Econ 2017;99:1117–42. https://doi.org/10.1093/ajae/aax041.
[136] Nuñez HM, Önal H. An economic analysis of transportation fuel policies in Brazil: fuel choice, land use, and environmental impacts. Energy Econ 2016;55:319–31. https://doi.org/10.1016/j.eneco.2016.02.013.
[137] Börjesson Hagberg M, Pettersson K, Ahlgren EO. Bioenergy futures in Sweden - modeling integration scenarios for biofuel production. Energy 2016;109:1026–39. https://doi.org/10.1016/j.energy.2016.04.044.
[138] Dafnomilis I, Hoefnagels R, Pratama YW, Schott DL, Lodewijks G, Junginger M. Review of solid and liquid biofuel demand and supply in Northwest Europe towards 2030 – a comparison of national and regional projections. Renew Sustain Energy Rev 2017;78:31–45. https://doi.org/10.1016/j.rser.2017.04.108.
[139] Debnath D, Whistance J, Thompson W. The causes of two-way U.S.–Brazil ethanol trade and the consequences for greenhouse gas emission. Energy 2017;141:2045–53. https://doi.org/10.1016/j.energy.2017.11.048.
[140] Deppermann A, Blesl M, Boysen O, Grethe H, Bruchof D. Linkages between the energy and agricultural sectors: insights from European Union greenhouse gas mitigation scenarios. Mitig Adapt Strategies Glob Change 2016;21:743–59. https://doi.org/10.1007/s11027-014-9621-0.
[141] Baldos ULC, Hertel TW. Debunking the “new normal”: why world food prices are expected to resume their long run downward trend. Global Food Security 2016;8:27–38. https://doi.org/10.1016/j.gfs.2016.03.002.
[142] Beghin JC, Bureau JC, Gohin A. The impact of an EU–US transatlantic trade and investment partnership agreement on biofuel and feedstock markets. J Agric Econ 2017;68:321–44. https://doi.org/10.1111/1477-9552.12200.
[143] Chakravorty U, Hubert MH, Moreaux M, Nøstbakken L. Long-run impact of biofuels on food prices. Scand J Econ 2017;119:733–67. https://doi.org/10.1111/sjoe.12177.
[144] Deppermann A, Offermann F, Puttkammer J, Grethe H. EU biofuel policies: income effects and lobbying decisions in the German agricultural sector. Renew Energy 2016;87:259–65. https://doi.org/10.1016/j.renene.2015.10.005.
[145] Dodder RS, Kaplan PO, Elobeid A, Tokgoz S, Secchi S, Kurkalova LA. Impact of energy prices and cellulosic biomass supply on agriculture, energy, and the environment: an integrated modeling approach. Energy Econ 2015;51:77–87. https://doi.org/10.1016/j.eneco.2015.06.008.
[146] Frank S, Böttcher H, Gusti M, Havlík P, Klaassen G, Kindermann G, et al. Dynamics of the land use, land use change, and forestry sink in the European Union: the impacts of energy and climate targets for 2030. Clim Change 2016;138:253–66. https://doi.org/10.1007/s10584-016-1729-7.
[147] Stern T, Ledl C, Braun M, Hesser F, Schwarzbauer P. Biorefineries' impacts on the Austrian forest sector: a system dynamics approach. Technol Forecast Soc Chang 2015;91:311–26. https://doi.org/10.1016/j.techfore.2014.04.001.
[148] Bryan BA, Nolan M, McKellar L, Connor JD, Newth D, Harwood T, et al. Land-use and sustainability under intersecting global change and domestic policy scenarios: trajectories for Australia to 2050. Glob Environ Chang 2016;38:130–52. https://doi.org/10.1016/j.gloenvcha.2016.03.002.
[149] Chiodi A, Deane P, Gargiulo M, Ó Gallachóir B. The role of bioenergy in Ireland's low carbon future – is it sustainable? Journal of Sustainable Development of Energy, Water and Environment Systems 2015;3:196–216. https://doi.org/10.13044/j.sdewes.2015.03.0016.
[150] Chen X, Önal H. Renewable energy policies and competition for biomass: implications for land use, food prices, and processing industry. Energy Policy 2016;92:270–8. https://doi.org/10.1016/j.enpol.2016.02.022.
[151] Vaillancourt K, Bahn O, Roy PO, Patreau V. Is there a future for new hydrocarbon projects in a decarbonizing energy system? A case study for Quebec (Canada). Appl Energy 2018;218:114–30. https://doi.org/10.1016/j.apenergy.2018.02.171.
[152] Drouineau M, Assoumou E, Mazauric V, Maïzi N. Increasing shares of intermittent sources in Reunion Island: impacts on the future reliability of power supply. Renew Sustain Energy Rev 2015;46:120–8. https://doi.org/10.1016/j.rser.2015.02.024.
[153] Havlík P, Schneider U, Schmid E, Böttcher H. Global land-use implications of first and second generation biofuel targets. Energy Policy 2011;39:5690–702. https://doi.org/10.1016/j.enpol.2010.03.030.
[154] Costanza JK, Abt RC, McKerrow AJ, Collazo JA. Bioenergy production and forest landscape change in the southeastern United States. GCB Bioenergy 2017;9:924–39. https://doi.org/10.1111/gcbb.12386.
[155] Roos A, Rakos C. The limits of modelling. Experiences with bioenergy in practice - could models have predicted this outcome? Biomass Bioenergy 2000;18:331–40. https://doi.org/10.1016/S0961-9534(99)00097-5.
[156] Hondo H, Moriizumi Y. Employment creation potential of renewable power generation technologies: a life cycle approach. Renew Sustain Energy Rev 2017;79:128–36. https://doi.org/10.1016/j.rser.2017.05.039.
[157] Onarheim K, Solantausta Y, Lehto J. Process simulation development of fast pyrolysis of wood using aspen plus. Energy Fuels 2015;29:205–17. https://doi.org/10.1021/ef502023y.
[158] Pellegrini LA, Guido G De, Consonni S, Bortoluzzi G. From biogas to biomethane: how the biogas source influences the purification costs. Chemical Engineering Transactions 2015;43:409–14. https://doi.org/10.3303/CET1543069.
[159] Bechara R, Gomez A, Saint-Antonin V, Schweitzer JM, Maréchal F. Methodology for the design and comparison of optimal production configurations of first and first and second generation ethanol with power. Appl Energy 2016;184:247–65. https://doi.org/10.1016/j.apenergy.2016.09.100.
[160] Food and Nutrition Board Institute of Medicine. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. National Academies; 2005.
[161] Chagas MF, Bordonal RO, Cavalett O, Carvalho JLN, Bonomi A, La Scala N. Environmental and economic impacts of different sugarcane production systems in the ethanol biorefinery. Biofuels, Bioproducts and Biorefining 2016;10:89–106. https://doi.org/10.1002/bbb.1623.
[162] Wan YK, Sadhukhan J, Ng DKS. Techno-economic evaluations for feasibility of sago-based biorefinery, Part 2: integrated bioethanol production and energy systems. Chem Eng Res Des 2016;107:102–16. https://doi.org/10.1016/j.cherd.2015.09.017.
[163] Petersen AM, Van der Westhuizen WA, Mandegari MA, Görgens JF. Economic analysis of bioethanol and electricity production from sugarcane in South Africa. Biofuels, Bioproducts and Biorefining 2018;12:224–38. https://doi.org/10.1002/bbb.1833.
[164] Archambault-Léger V, Losordo Z, Lynd LR. Energy, sugar dilution, and economic analysis of hot water flow-through pre-treatment for producing biofuel from sugarcane residues. Biofuels, Bioproducts and Biorefining 2015;9:95–108. https://doi.org/10.1002/bbb.1524.
[165] Manganaro JL, Lawal A, Goodall B. Techno-economics of microalgae production and conversion to refinery-ready oil with co-product credits. Biofuels, Bioproducts and Biorefining 2015;9:760–77. https://doi.org/10.1002/bbb.1610.
[166] Liu W, Wang J, Richard TL, Hartley DS, Spatari S, Volk TA. Economic and life cycle assessments of biomass utilization for bioenergy products. Biofuels, Bioproducts and Biorefining 2017;11:633–47. https://doi.org/10.1002/bbb.1770.
[167] Kattumuri R, Kruse T. Renewable technologies in Karnataka, India: jobs potential and co-benefits. Clim Dev 2017;0:1–14. https://doi.org/10.1080/17565529.2017.1410085.
[168] Kemausuor F, Bolwig S, Miller S. Modelling the socio-economic impacts of modern bioenergy in rural communities in Ghana. Sustainable Energy Technologies and Assessments 2016;14:9–20. https://doi.org/10.1016/j.seta.2016.01.007.
[169] Santos VEN, Magrini A. Biorefining and industrial symbiosis: a proposal for regional development in Brazil. J Clean Prod 2018;177:19–33. https://doi.org/10.1016/j.jclepro.2017.12.107.
[170] Kristianto Y, Zhu L. Techno-economic optimization of ethanol synthesis from rice-straw supply chains. Energy 2017;141:2164–76. https://doi.org/10.1016/j.energy.2017.09.077.
[171] Huang H, Long S, Singh V. Techno-economic analysis of biodiesel and ethanol co-production from lipid-producing sugarcane. Biofuels, Bioproducts and Biorefining 2016;10:299–315. https://doi.org/10.1002/bbb.1640.
[172] Silalertruksa T, Gheewala SH, Hünecke K, Fritsche UR. Biofuels and employment effects: implications for socio-economic development in Thailand. Biomass Bioenergy 2012;46:409–18. https://doi.org/10.1016/j.biombioe.2012.07.019.
[173] Neuwahl F, Löschel A, Mongelli I, Delgado L. Employment impacts of EU biofuels policy: combining bottom-up technology information and sectoral market simulations in an input–output framework. Ecol Econ 2008;68:447–60. https://doi.org/10.1016/j.ecolecon.2008.04.018.
[174] Dang Q, Hu W, Rover M, Brown RC, Wright MM. Economics of biofuels and bioproducts from an integrated pyrolysis biorefinery. Biofuels, Bioproducts and Biorefining 2016;10:790–803. https://doi.org/10.1002/bbb.1681.
[175] Mandegari MA, Farzad S, van Rensburg E, Görgens JF. Multi-criteria analysis of a biorefinery for co-production of lactic acid and ethanol from sugarcane lignocellulose. Biofuels, Bioproducts and Biorefining 2017;11:971–90. https://doi.org/10.1002/bbb.1801.
[176] Walsh MJ, Gerber Van Doren L, Shete N, Prakash A, Salim U. Financial tradeoffs of energy and food uses of algal biomass under stochastic conditions. Appl Energy 2018;210:591–603. https://doi.org/10.1016/j.apenergy.2017.08.060.
[177] Shane A, Gheewala SH, Phiri S. Rural domestic biogas supply model for Zambia. Renew Sustain Energy Rev 2017;78:683–97. https://doi.org/10.1016/j.rser.2017.05.008.
[178] Jonker JGG, van der Hilst F, Junginger HM, Cavalett O, Chagas MF, Faaij APC. Outlook for ethanol production costs in Brazil up to 2030, for different biomass crops and industrial technologies. Appl Energy 2015;147:593–610. https://doi.org/10.1016/j.apenergy.2015.01.090.
[179] Rezende ML, Richardson JW. Economic feasibility of sugar and ethanol production in Brazil under alternative future prices outlook. Agric Syst 2015;138:77–87. https://doi.org/10.1016/j.agsy.2015.05.004.

[180] Ekener E, Hansson J, Gustavsson M. Addressing positive impacts in social LCA—discussing current and new approaches exemplified by the case of vehicle fuels. Int J Life Cycle Assess 2018;23:556–68. https://doi.org/10.1007/s11367-016-1058-0.
[181] Guinée JB, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonamici R, et al. Life cycle assessment: past, present, and future. Environ Sci Technol 2011;45:90–6. https://doi.org/10.1021/es101316v.
[182] Monteleone M, Cammerino ARB, Garofalo P, Delivand MK. Straw-to-soil or straw-to-energy? An optimal trade off in a long term sustainability perspective. Appl Energy 2015;154:891–9. https://doi.org/10.1016/j.apenergy.2015.04.108.
[183] Neri E, Cespi D, Setti L, Gombi E, Bernardi E, Vassura I, et al. Biomass residues to renewable energy: a life cycle perspective applied at a local scale. Energies 2016;9. https://doi.org/10.3390/en9110922.
[184] Broeren MLM, Dellaert SNC, Cok B, Patel MK, Worrell E, Shen L. Life cycle assessment of sisal fibre – exploring how local practices can influence environmental performance. J Clean Prod 2017;149:818–27. https://doi.org/10.1016/j.jclepro.2017.02.073.
[185] Chiesa M, Monteleone B, Venuta ML, Maffeis G, Greco S, Cherubini A, et al. Integrated study through LCA, ELCC analysis and air quality modelling related to the adoption of high efficiency small scale pellet boilers. Biomass Bioenergy 2016;90:262–72. https://doi.org/10.1016/j.biombioe.2016.04.019.
[186] Gibon T, Hertwich EG, Arvesen A, Singh B, Verones F. Health benefits, ecological threats of low-carbon electricity. Environ Res Lett 2017;12. https://doi.org/10.1088/1748-9326/aa6047.
[187] Dalal K, Svanström L. Economic burden of disability adjusted life years (DALYs) of injuries. Health 2015;07:487–94. https://doi.org/10.4236/health.2015.74058.
[188] Benoît-Norris C, Vickery-Niederman G, Valdivia S, Franze J, Traverso M, Ciroth A, et al. Introducing the UNEP/SETAC methodological sheets for subcategories of social LCA. Int J Life Cycle Assess 2011;16:682–90. https://doi.org/10.1007/s11367-011-0301-y.
[189] Kühnen M, Hahn R. Indicators in social life cycle assessment: a review of frameworks, theories, and empirical experience. J Ind Ecol 2017;21:1547–65. https://doi.org/10.1111/jiec.12663.
[190] Cardoso TF, Watanabe MDB, Souza A, Chagas MF, Cavalett O, Morais ER, et al. Economic, environmental, and social impacts of different sugarcane production systems. Biofuels, Bioproducts and Biorefining 2018;12:68–82. https://doi.org/10.1002/bbb.1829.
[191] Lazarus W, Headlee WL, Zalesny RS. Impacts of supplyshed-level differences in productivity and land costs on the economics of hybrid poplar production in Minnesota, USA. Bioenergy Research 2015;8:231–48. https://doi.org/10.1007/s12155-014-9520-y.
[192] Palma-Rojas S, Caldeira-Pires A, Nogueira JM. Environmental and economic hybrid life cycle assessment of bagasse-derived ethanol produced in Brazil. Int J Life Cycle Assess 2017;22:317–27. https://doi.org/10.1007/s11367-015-0892-9.
[193] Mattila TJ, Pakarinen S, Sokka L. Quantifying the total environmental impacts of an industrial symbiosis – a comparison of process-hybrid and input–output life cycle assessment. Environ Sci Technol 2010;44:4309–14.
[194] Szarka N, Wolfbauer J, Bezama A. A systems dynamics approach for supporting regional decisions on the energetic use of regional biomass residues. Waste Manag Res 2018;36:332–41. https://doi.org/10.1177/0734242X18757626.
[195] Barisa A, Romagnoli F, Blumberga A, Blumberga D. Future biodiesel policy designs and consumption patterns in Latvia: a system dynamics model. J Clean Prod 2015;88:71–82. https://doi.org/10.1016/j.jclepro.2014.05.067.
[196] Applanaidu SD, Abidin NZ, Sapiri H, Zabid MFM. Impact of various palm-based biodiesel blend mandates on Malaysian crude palm oil stock and price: a system dynamics approach. Asian Soc Sci 2015;11:190–203. https://doi.org/10.5539/ass.v11n25p190.
[197] Huang S, Hu G. Biomass supply contract pricing and environmental policy analysis: a simulation approach. Energy 2018;145:557–66. https://doi.org/10.1016/J.ENERGY.2018.01.015.
[198] Shu K, Schneider UA, Scheffran J. Optimizing the bioenergy industry infrastructure: transportation networks and bioenergy plant locations. Appl Energy 2017;192:247–61. https://doi.org/10.1016/j.apenergy.2017.01.092.
[199] Moncada JA, Junginger M, Lukszo Z, Faaij APC, Weijnen M. Exploring path dependence, policy interactions, and actor behavior in the German biodiesel supply chain. Appl Energy 2017;195:370–81. https://doi.org/10.1016/j.apenergy.2017.03.047.
[200] Lamers P, Hoefnagels R, Junginger M, Hamelinck C, Faaij APC. Global solid biomass trade for energy by 2020: an assessment of potential import streams and supply costs to North-West Europe under different sustainability constraints. GCB Bioenergy 2015;7:618–34. https://doi.org/10.1111/gcbb.12162.
[201] Schorling M, Enders C, Voigt CA. Assessing the cultivation potential of the energy crop Miscanthus × giganteus for Germany. GCB Bioenergy 2015;7:763–73. https://doi.org/10.1111/gcbb.12170.
[202] Sosa A, McDonnell K, Devlin G. Analysing performance characteristics of biomass haulage in Ireland for bioenergy markets with GPS, GIS and fuel diagnostic tools. Energies 2015;8:12004–19. https://doi.org/10.3390/en81012004.
[203] Doelman JC, Stehfest E, Tabeau A, van Meijl H, Lassaletta L, Gernaat DEHJ, et al. Exploring SSP land-use dynamics using the IMAGE model: regional and gridded scenarios of land-use change and land-based climate change mitigation. Glob Environ Chang 2018;48:119–35. https://doi.org/10.1016/j.gloenvcha.2017.11.014.
[204] Schwanitz VJ, Longden T, Knopf B, Capros P. The implications of initiating immediate climate change mitigation - a potential for co-benefits? Technol Forecast Soc Chang 2015;90:166–77. https://doi.org/10.1016/j.techfore.2014.01.003.
[205] Popp A, Calvin K, Fujimori S, Havlik P, Humpenöder F, Stehfest E, et al. Land-use futures in the shared socio-economic pathways. Glob Environ Chang 2017;42:331–45. https://doi.org/10.1016/j.gloenvcha.2016.10.002.
[206] Muratori M, Calvin K, Wise M, Kyle P, Edmonds J. Global economic consequences of deploying bioenergy with carbon capture and storage (BECCS). Environ Res Lett 2016;11. https://doi.org/10.1088/1748-9326/11/9/095004.
[207] Boysen LR, Lucht W, Gerten D. Trade-offs for food production, nature conservation and climate limit the terrestrial carbon dioxide removal potential. Glob Chang Biol 2017;23:4303–17. https://doi.org/10.1111/gcb.13745.
[208] Roni MS, Lamers P, Hoefnagels R. Investigating the future supply distribution of industrial grade wood pellets in the global bioenergy market. Biofuels 2018;7269:1–14. https://doi.org/10.1080/17597269.2018.1432268.
[209] Yue D, You F, Snyder SW. Biomass-to-bioenergy and biofuel supply chain optimization: overview, key issues and challenges. Comput Chem Eng 2014;66:36–56. https://doi.org/10.1016/j.compchemeng.2013.11.016.
[210] Bai Y, Ouyang Y, Pang JS. Biofuel supply chain design under competitive agricultural land use and feedstock market equilibrium. Energy Econ 2012;34:1623–33. https://doi.org/10.1016/j.eneco.2012.01.003.
[211] Cambero C, Sowlati T. Incorporating social benefits in multi-objective optimization of forest-based bioenergy and biofuel supply chains. Appl Energy 2016;178:721–35. https://doi.org/10.1016/j.apenergy.2016.06.079.
[212] Djanibekov U, Gaur V. Nexus of energy use, agricultural production, employment and incomes among rural households in Uttar Pradesh, India. Energy Policy 2018;113:439–53. https://doi.org/10.1016/j.enpol.2017.11.023.
[213] Miret C, Chazara P, Montastruc L, Negny S, Domenech S. Design of bioethanol green supply chain: comparison between first and second generation biomass concerning economic, environmental and social criteria. Comput Chem Eng 2016;85:16–35. https://doi.org/10.1016/j.compchemeng.2015.10.008.
[214] Radics RI, Dasmohapatra S, Kelley SS. Use of linear programming to -optimize the social, −environmental, and economic impacts of using woody feedstocks for pellet and -torrefied pellet production. Biofuels, Bioproducts and Biorefining 2016;10:446–61. https://doi.org/10.1002/bbb.1658.
[215] Shukery MFM, Haslenda-Hashim, Lim JS. Superstructure-based synthesis and optimisation of an oil palm eco-industrial town: a case study in Iskandar Malaysia. Clean Technol Environ Policy 2016;18:2131. https://doi.org/10.1007/s10098-016-1281-1.
[216] Tziolas E, Manos B, Bournaris T. Planning of agro-energy districts for optimum farm income and biomass energy from crops residues. Operational Research 2017;17:535–46. https://doi.org/10.1007/s12351-016-0236-y.
[217] Winter E, Faße A, Frohberg K. Food security, energy equity, and the global commons: a computable village model applied to sub-Saharan Africa. Reg Environ Chang 2015;15:1215–27. https://doi.org/10.1007/s10113-014-0674-0.
[218] Vass MM, Elofsson K. Is forest carbon sequestration at the expense of bioenergy and forest products cost-efficient in EU climate policy to 2050? J For Econ 2016;24:82–105. https://doi.org/10.1016/j.jfe.2016.04.002.
[219] Hombach LE, Büsing C, Walther G. Robust and sustainable supply chains under market uncertainties and different risk attitudes – a case study of the German biodiesel market. Eur J Oper Res 2018;269:302–12. https://doi.org/10.1016/j.ejor.2017.07.015.
[220] Ben Fradj N, Jayet PA, Aghajanzadeh-Darzi P. Competition between food, feed, and (bio)fuel: a supply-side model based assessment at the European scale. Land Use Policy 2016;52:195–205. https://doi.org/10.1016/j.landusepol.2015.12.027.
[221] Kesharwani R, Sun Z, Dagli C. Biofuel supply chain optimal design considering economic, environmental, and societal aspects towards sustainability. Int J Energy Res 2018:1–30. https://doi.org/10.1002/er.4006.
[222] Orjuela-Castro JA, Aranda-Pinilla JA, Moreno-Mantilla CE. Identifying trade-offs between sustainability dimensions in the supply chain of biodiesel in Colombia. Comput Electron Agric 2018. https://doi.org/10.1016/j.compag.2018.03.009.
[223] Raftery JP, Karim MN. Economic viability of consolidated bioprocessing utilizing multiple biomass substrates for commercial-scale cellulosic bioethanol production. Biomass Bioenergy 2017;103:35–46. https://doi.org/10.1016/j.biombioe.2017.05.012.
[224] European Commission. List of approved voluntary schemes 2018. https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/voluntary-schemes.
[225] ISCC. Acceptance of other schemes: overview of voluntary and national schemes accepted by ISCC 2018. https://www.iscc-system.org/about/acceptance-of-other-schemes/.
[226] Buchholz T, Luzadis VA, Volk TA. Sustainability criteria for bioenergy systems: results from an expert survey. J Clean Prod 2009;17:S86–98. https://doi.org/10.1016/j.jclepro.2009.04.015.
[227] Dale VH, Kline KL, Richard TL, Karlen DL, Belden WW. Bridging biofuel sustainability indicators and ecosystem services through stakeholder engagement. Biomass Bioenergy 2017. https://doi.org/10.1016/j.biombioe.2017.09.016.
[228] Zezza A. Sustainability certification in the biofuel sector:A case study of Brazilian ethanol. Cambridge, MA: Belfer Center for Science and International Affairs, Harvard University; 2013.
[229] Florin MJ, van de Ven GWJ, van Ittersum MK. What drives sustainable biofuels? A review of indicator assessments of biofuel production systems involving smallholder farmers. Environ Sci Policy 2014;37:142–57. https://doi.org/10.1016/j.envsci.2013.09.012.
[230] Renzaho AMN, Kamara JK, Toole M. Biofuel production and its impact on food security in low and middle income countries: implications for the post-2015 sustainable development goals. Renew Sustain Energy Rev 2017;78:503–16. https://doi.org/10.1016/j.rser.2017.04.072.
[231] Boamah F, Overå R. Rethinking livelihood impacts of biofuel land deals in Ghana. Dev Change 2016;47:98–129. https://doi.org/10.1111/dech.12213.
[232] Bracco S. Effectiveness of EU biofuels sustainability criteria in the context of land

acquisitions in Africa. Renew Sustain Energy Rev 2015;50:130–43. https://doi.org/10.1016/j.rser.2015.05.006.
[233] Clancy JS. Are biofuels pro-poor? Assessing the evidence. Eur J Dev Res 2008;20:416–31. https://doi.org/10.1080/09578810802245618.
[234] Tomei J. The sustainability of sugarcane-ethanol systems in Guatemala: land, labour and law. Biomass Bioenergy 2015;82:94–100. https://doi.org/10.1016/j.biombioe.2015.05.018.
[235] McKitrick RR. The econometric critique of computable general equilibrium modeling: the role of functional forms. Econ Modell 1998;15:543–73. https://doi.org/10.1016/S0264-9993(98)00028-5.
[236] Efroymson RA, Dale VH, Kline KL, McBride AC, Bielicki JM, Smith RL, et al. Environmental indicators of biofuel sustainability: what about context? Environ Manag 2013;51:291–306. https://doi.org/10.1007/s00267-012-9907-5.
[237] Davis SC, Boddey RM, Alves BJR, Cowie AL, George BH, Ogle SM, et al. Management swing potential for bioenergy crops. GCB Bioenergy 2013;5:623–38. https://doi.org/10.1111/gcbb.12042.
[238] van der Hilst F, Verstegen JA, Woltjer G, Smeets EMW, Faaij APC. Mapping land use changes resulting from biofuel production and the effect of mitigation measures. GCB Bioenergy 2018:804–24. https://doi.org/10.1111/gcbb.12534.
[239] Danlami AH, Applanaidu S-D, Islam R. From biomass cooking fuel source to modern alternative for Bauchi State households: a preliminary analysis. Biofuels 2017;8:323–31. https://doi.org/10.1080/17597269.2016.1226724.
[240] Chen Q, Yang H, Liu T, Zhang L. Household biomass energy choice and its policy implications on improving rural livelihoods in Sichuan, China. Energy Policy 2016;93:291–302. https://doi.org/10.1016/j.enpol.2016.03.016.
[241] Nayek S, Padhy PK. Daily personal exposure of women cooks to respirable particulate matters during cooking with solid bio-fuels in a rural community of West Bengal, India. Aerosol and Air Quality Research 2017;17:245–52. https://doi.org/10.4209/aaqr.2016.01.0028.
[242] Verma M, Pervez S, Deb MK, Majumdar D. Domestic use of cooking fuel in India: a review on emission characteristics and associated health concerns. Asian J Chem 2018;30:2018. https://doi.org/10.14233/ajchem.2018.21006.
[243] Behera B, Rahut DB, Jeetendra A, Ali A. Household collection and use of biomass energy sources in South Asia. Energy 2015;85:468–80. https://doi.org/10.1016/j.energy.2015.03.059.
[244] Burke PJ, Dundas G. Female labor force participation and household dependence on biomass energy: evidence from national longitudinal data. World Dev 2015;67:424–37. https://doi.org/10.1016/j.worlddev.2014.10.034.
[245] Branca G, Cacchiarelli L, Maltsoglou I, Rincón LE, Sorrentino A, Valle S. Profits versus jobs: evaluating alternative biofuel value-chains in Tanzania. Land Use Policy 2016;57:229–40. https://doi.org/10.1016/j.landusepol.2016.05.014.
[246] Yengoh GT, Armah FA. Land access constraints for communities affected by large-scale land acquisition in Southern Sierra Leone. Geojournal 2016;81:103–22. https://doi.org/10.1007/s10708-014-9606-2.
[247] Woltjer G, Kuiper M, Kavallari A, van Meijl H, Powell J, Rutten M, et al. The magnet model - module description. Wageningen, The Netherlands: LEI Wageningen UR; 2014.
[248] Brinkman M, Levin-Koopman J, Wicke B, Faaij APC, van der Hilst F. Distribution of food security impacts of biofuels, a case study of Ghana. Quantifying impacts of bioenergy; 2018. p. 123–44.
[249] Verstegen JA, van der Hilst F, Woltjer G, Karssenberg D, de Jong SM, Faaij APC. What can and can't we say about indirect land-use change in Brazil using an integrated economic - land-use change model? GCB Bioenergy 2016;8:561–78. https://doi.org/10.1111/gcbb.12270.
[250] van der Hilst F, Verstegen JA, Zheliezna T, Drozdova O, Faaij APC. Integrated spatiotemporal modelling of bioenergy production potentials, agricultural land use, and related GHG balances; demonstrated for Ukraine. Biofuels, Bioproducts and Biorefining 2014;8:391–411. https://doi.org/10.1002/bbb.1471.
[251] Fischer G, Nachtergaele FO, Prieler S, Teixeira E, Toth G, van Velthuizen H, et al. Global agro-ecological zones (GAEZ): model documentation. Laxenburg, Austria and Rome, Italy: IIASA and FAO; 2012.
[252] Pauw K, Thurlow J. Agricultural growth, poverty, and nutrition in Tanzania. Food Policy 2011;36:795–804. https://doi.org/10.1016/j.foodpol.2011.09.002.
[253] McBride AC, Dale VH, Baskaran LM, Downing ME, Eaton LM, Efroymson RA, et al. Indicators to support environmental sustainability of bioenergy systems. Ecol Indicat 2011;11:1277–89. https://doi.org/10.1016/j.ecolind.2011.01.010.