



A Sustainability Framework for Assessing Studies about Marginal Lands for Planting Perennial Energy Crops

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6 2 **A Sustainability Framework for Assessing Studies about**
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10 3 **Marginal Lands for Planting Perennial Energy Crops**

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11
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14
15 26 He has worked on the valuation of non-market externalities and on biomass resource assessment in the
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18 27 U.S.

21 28 **Abstract**

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23
24 29 One of the issues with large-scale perennial energy crop production is increasing land use competition
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26 30 between “food and feed” and “fuel.” A commonly suggested solution is to limit energy crop plantation
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28 31 to marginal lands. However, the concept and the methods used to assess marginal lands remain vague
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31 32 and inconsistent across bioenergy-related studies. We propose a sustainability-based framework to
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33 33 review and classify studies for marginal lands used for bioenergy crops. This framework innovatively
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35 34 puts the marginal land in a sustainability-based framework showing the interaction of biophysical,
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38 35 socioeconomic, qualitative, and quantitative assessments. We found that current studies lack integration
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40 36 of biophysical and socioeconomic considerations in the marginal land analysis. In addition, current
41
42 37 studies lack qualitative approaches to assess marginal land. We suggest that future work should
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45 38 emphasize integrating biophysical, socioeconomic, quantitative, and qualitative analysis for sustainable
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47 39 marginal land identification and use.

50 40 **Keywords**

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52
53 41 **Marginal Lands; Bioenergy Crops; Sustainability; Switchgrass; Miscanthus; Shrub Willow**

42 **1. Introduction**

43 Increasing demand for bioenergy has fueled research on sustainable energy feedstocks. Various crops
44 have been proposed as raw materials. First-generation energy feedstock, e.g., corn, has contributed the
45 overwhelming majority of biofuels to date in the U.S.^{1,2} However, dependency on one feedstock makes
46 biofuel production particularly vulnerable to yield shocks for that commodity. Also, corn-based ethanol
47 may draw doubts on achieving the goals of lessening energy dependence and reducing GHG emission.³
48 Recent attention has been paid towards the second-generation perennial energy crops. Led by perennial
49 grasses, such as switchgrass (*Panicum virgatum*) and miscanthus (*Miscanthus x giganteus*), and by fast-
50 growing woody crops, such as shrub willow (*Salix* spp.) and hybrid poplar (*Populus* spp.), energy crops
51 are currently under consideration because of their environmental and social benefits in many regions of
52 the U.S.^{4,5} However, planting these crops at a large enough scale can cause land competition between
53 food and fuel.^{6,7} A commonly suggested solution to this problem is to limit energy crop production to
54 marginal lands.⁸ Various reasons, such as generating additional agricultural revenue and improving local
55 ecosystem services, support this solution.^{9,10-12} However, the definition of marginal land and the
56 methods used to identify marginal lands are diverse, making comparisons between studies and
57 standardization of estimates difficult.^{13,14,15}

58 This paper reviews and classifies published studies on marginal lands in the context of dedicated
59 energy crops (switchgrass, miscanthus, shrub willow, and hybrid poplars), based on a sustainability
60 framework. Its objective is to identify gaps in marginal land studies and suggest possible changes in
61 future study design and implementation for bioenergy crop sites identification. Section 2 introduces the
62 sustainability framework, Section 3 discusses the classification results, and the Section 4 makes
63 suggestions for future research.

64 **2. Methodology**

2.1 Sustainability framework

We propose a sustainability framework to assess marginal land studies (Figure 1). It places marginal lands at the intersection of biophysical, socioeconomic, qualitative, and quantitative considerations. We argue that marginal lands should be collectively assessed from these four perspectives.

It is important to emphasize the integration of biophysical and socioeconomic factors because these factors jointly influence marginal land identification and use. Biophysical factors, such as soil quality, influence marginal land identification¹⁶ while also having an impact on the marginal land use decision.^{17,18} Lichtenberg^{10,20,21} has reported that landowners tend to select row crops to plant on high-quality land first and specify other crops to plant according to land quality. Similarly, socioeconomic factors, such as land rent and production costs, influence marginal land use and can be used as an index to identify marginal lands.²² Lower land rent may characterize marginal lands due to poor soil quality or lower crop yields.²³ Therefore, biophysical and socioeconomic factors should be used jointly to assess marginal lands.

It is also important to combine qualitative and quantitative methods because they can provide cross-validation to capture uncovered attributes of marginal lands that might be neglected in one single method.²⁴ Qualitative methods typically use unstructured or semi-structured techniques to collect data, including focus group discussion, individual interviews, and participation/observations.²⁵ Quantitative methods apply numerical models and data to answer research questions. Qualitative methods can contribute to interpreting numeric results, clarifying puzzling findings, and validating results from quantitative methods. Quantitative methods can help systemize qualitative observations and generalize the qualitative results.²⁶ In the marginal land context, qualitative methods can be used to identify unique reasons explaining “marginality” from a landowner’s perspective and to assess whether the academic concept of marginal lands is consistent with that from landowners. At the same time, quantitative

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3 88 methods can be used to examine if the unique reason or academic definition of “marginal” can be
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5 89 generalized across different regions. Therefore, applying the combined methods is necessary for forming
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8 90 a consistent definition of marginal lands.
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11 91 In summary, the upper two components in the sustainability framework evaluate studies in terms of
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13 92 factors used to assess marginal lands. The lower two components emphasize the methods adopted in the
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15 93 selected studies.
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17 18 94 **2.2 Selected studies**

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21 95 The sustainability framework is proposed to correspond to two core research questions currently existing
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23 96 in marginal land literature: 1) what are marginal lands (marginal land identification), and 2) how should
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25 97 marginal lands be used (marginal land use).^{27,28} Various studies aim to answer these two questions in an
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28 98 energy crop context. We used Google Scholar Database and citation tracking to identify representative
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30 99 papers published over a 10-year period from 2006 to 2016. Any articles were removed if they did not
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32 100 meet one of the following criteria: 1) targeting one of these four energy crops: switchgrass, miscanthus,
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35 101 willow, or hybrid poplar; 2) focusing on marginal lands identification for planting energy crops; and 3)
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37 102 concentrating on marginal land use under the energy crop context. We selected 18 papers based on
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39 103 relevance (see Appendix 1). For each paper, we first examined the definition of marginal lands, then
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41 104 investigated how each working definition is framed. After that, we classified the selected studies into
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43
44 105 four groups based on the sustainability framework.
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46 47 106 **3. Results and Discussion**

48 49 50 107 **3.1 Working definitions**

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53 108 “Marginal lands” is the most commonly used term in the selected papers, appearing eight times (Table
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55 109 1). One reason explaining its popularity is because this term is more general compared to other terms.
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3 110 For example, Varvel et al.²⁹ compared corn and switchgrass ethanol yield on “marginal lands” vs.
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6 111 “productive lands.” Bryngelsson & Lindgren³⁰ assessed the likelihood of supplying energy crops on
7
8 112 “marginal lands” using the partial equilibrium model.
9

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11 113 The second most commonly used term is “marginal agricultural lands” or “agricultural marginal lands,”
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13 114 appearing three times. Marginal agricultural lands are usually defined as the agricultural lands not
14
15 115 suitable for food crop plantation. Energy crops may have competitive yield advantages over
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18 116 conventional crops on these marginal lands.³¹ Switchgrass and miscanthus yield can reach to 14 Mg ha⁻¹
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20 117 yr⁻¹ and shrub willow yield can reach to 9.5 Mg ha⁻¹ yr⁻¹.^{32,33} These yields are comparable to those on
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22 118 productive lands.³¹ In addition, the ability of energy crops to generate ecosystem benefits, such as
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24 119 increasing carbon sequestration and reducing nitrogen loading, is also assessed on agricultural land.³⁴ By
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26
27 120 ameliorating the soil’s physical and chemical properties, these crops have the potential to improve the
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29 121 productivity of marginal agricultural land over time. These reasons make the term “marginal agricultural
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31 122 lands” popular both in marginal land identification studies and marginal land use studies.
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34 123 Several other more specific terms also have been used to describe marginal lands, including marginal
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36 124 cropland, non-crop marginal lands, abandoned agricultural lands, degraded lands, and
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39 125 biophysically/physically marginal lands. “Marginal cropland” or “non-crop marginal lands” is a
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41 126 subgroup of marginal agricultural lands.⁷ These two terms indicate the unproductive parts within
42
43 127 cropland. The abandoned agricultural land consists of land that was previously used for agriculture or
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46 128 pasture but abandoned without being converted or reverted to forest or urban areas.¹⁴ Abandoned
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48 129 agricultural land usually implies a temporal change in land use, not a static characteristic of land cover
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50 130 or productivity.^{14,35} Degraded land is a term usually describing a long-term loss of ecosystem function
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52
53 131 and services, which cannot be recovered without aid. The variety of definitions of marginal lands
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3 132 derives from different factors and methods used in studies.³⁶ The next section discusses the studies in the
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6 133 context of classifying their factors and methods.

8 134 **3.2 Biophysical studies**

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11 135 Studies classified under the biophysical category (Figure 1) are those focused on applying biophysical
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13 136 information to answer the question of “what are marginal lands?” Based on study purposes, these
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16 137 studies can be further classified into two subgroups: 1) land-identification studies, and 2) crop
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18 138 performance and/or ecosystem services evaluation studies (Table 2).

21 139 **3.2.1 Land identification studies**

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24 140 Land identification studies apply spatially-explicit geographic information system (GIS) techniques to
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26 141 various biophysical factors, such as soil quality, land cover, terrain, and weather, to identify marginal
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29 142 lands. Gopalakrishnan et al.³⁷ is an example study where marginal lands are identified by soil health,
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31 143 land cover, and other factors such as land contamination source and water contamination source. They
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33 144 note that land is marginal if it is: (i) *eroded, (primarily moderately and severely eroded)*, (ii) *frequently*
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36 145 *flooded (>50% chance of flooding in a year)*, (iii) *poorly drained (soil drainage classes 6 and 7)*, (iv)
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38 146 *highly sloped (slope >15°)*, and (v) *of low productivity for the main grain crop*. Based on these criteria,
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40 147 they identified approximately 1.6 million ha of marginal lands in Nebraska. Similarly, Kang et al.³⁸
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43 148 created maps of four different types of marginal lands in Michigan using a variety of biophysical factors.
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45 149 They regard: 1) *lands, with slope greater than 30%, rock fragment greater than 35% and other*
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47 150 *biophysical factors influencing land productivity as physically marginal lands*; 2) *lands with sand*
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50 151 *content greater than 90% and water table less than 0.3m, as biologically marginal lands*; and 3) *lands*
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52 152 *with soil organic carbon decreasing trend and erosion number eight, as environ-ecologically marginal*
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54 153 *lands*.

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3 154 Although these studies present detailed information on biophysical features of marginal lands, they did
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6 155 not evaluate energy crop performance on these lands, implying a potential issue: these lands may be too
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8 156 marginal to grow crops economically.
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10 157 3.2.1 Crop production and ecosystem service analysis 11 12

13 158 Studies in this group focused on crop performance and/or ecosystem service provisions of planting
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15 159 energy crops on marginal lands. For example, Varvel et al.²⁹ compared corn and switchgrass ethanol
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18 160 yield on marginal lands. Schmer et al.³⁹ estimated switchgrass yield and greenhouse gas emission from
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20 161 ten farms with marginal soils in the Northern Great Plains with a field experiment and a life-cycle
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22 162 analysis model. These two studies provided specific information about the crop performance but did not
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25 163 apply detailed biophysical factors to define marginal lands, as the previous studies did. Varvel et al.²⁹
26
27 164 just describes marginal lands as “*one of the less fertile fields....*” The vague description of marginal
28
29 165 lands makes replicability of experiment difficult and casts doubt on the result’s robustness.
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32 166 Some studies emphasized both biophysical features and crop performance and/or ecosystem services
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34 167 provision of marginal lands. For example, Amichev et al.¹⁰ estimated the carbon stock and fluxes of
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37 168 afforesting “*marginal agricultural lands*” with shrub willow. In their study, they identified 2.2 million
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39 169 ha of marginal agricultural lands in Saskatchewan, considering land cover, soil classification, and land
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41 170 limitations information. At the same time, they applied a 3PG growth model and a Carbon Budget
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43
44 171 Model to quantify potential willow yield and carbon stock. Similarly, Niu & Duiker⁴⁰ examined carbon
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46 172 sequestration potential by afforestation of marginal agricultural lands in the Midwestern U.S. In this
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48 173 study, they quantified 6.5 million ha of marginal agricultural lands in the U.S., considering land cover,
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51 174 soil quality, and land erodibility. They also simulated the carbon changes for short-rotation woody crops.
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53 175 These studies presented a clear and detailed description of marginal lands, making the results of yield
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55 176 and ecosystem service provision reliable. Lands meeting the criteria in these studies can expect similar
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177 yields and ecosystem benefits if energy crops were planted, which is helpful in exploring the suitable
178 sites for these new crop plantations.

179 In summary, the basic assumption of biophysical studies is that marginal lands are not as productive as
180 other agricultural lands because of biophysical limitations. Across the studies, the thresholds or the
181 starting values used to classify limitations were different. For example, Gopalakrishnan et al.³⁷ and
182 Milbrandt and Overend¹¹ both looked at the land cover to identify marginal lands. However,
183 Gopalakrishnan et al.³⁷ included idle and fallow croplands, while Milbrandt and Overend¹¹ only
184 included bare and herbaceous areas. In addition, these two studies had different criteria on slope
185 limitations. Gopalakrishnan et al.³⁷ classified marginal lands with a slope over 15%, while Milbrandt
186 and Overend's classification ranged from 8% to 16%. One of the reasons explaining this discrepancy is
187 the different spatial datasets used in these studies. Gopalakrishnan et al.³⁷ used USDA-NACS databases,
188 while Milbrandt and Overend¹¹ used Food and Agriculture Organization of the United Nations (FAO)
189 and International Institute for Applied Systems Analysis (IIASA) databases. Therefore, it is not
190 surprising that slope thresholds vary from study to study. In addition, different study regions also
191 influenced the threshold choice. Gopalakrishnan et al.³⁷ targeted marginal land in Nebraska, while
192 Milbrandt's study targeted marginal lands in the Asia-Pacific Economic Cooperation (APEC) countries.
193 Marginal lands in different regions have various features. Therefore, studies need to apply different
194 thresholds, making comparisons across studies difficult.

195 Generally, these biophysical studies ignore the socioeconomic factors in identifying marginal lands.
196 Ignoring the socioeconomic factors means neglecting landowner thinking and cutting off the link
197 between land value and land-use decision. This could result in larger amounts of marginal lands
198 biophysically available but which landowners are not willing to use, or vice versa. The following section
199 considers socioeconomic aspects of quantifying marginal lands.

3.3 Socioeconomic studies

Socioeconomic studies aim to answer questions about how to use marginal lands. These studies concentrate on modeling the landowner land-use decision process either from a conceptual or an empirical perspective (Table 3).

3.3.1 Conceptual analysis

Conceptual studies set up a theory basis for analyzing landowner decisions on marginal land use. The basis for the farmer's or landowner's choice of whether to put marginal land into production for a specific crop depends on the land's productivity and location, the prices of crop inputs and products, and the landowner's earnings from other land uses as well as his or her appreciation of the land in non-crop uses.^{41,42} These factors influencing land use decisions are united in land rent theory.⁴³⁻⁴⁵ Landowners may want to use marginal lands when the land rent from the energy crop exceeds the rent of current crops, based on the basic economic assumption that landowners have rational preferences among outcomes that can be identified and associated with a value and always try to maximize utility either from consuming or from producing. Swinton et al.⁴⁶ is an example study. In this study, they found that farmers and landowners are reluctant to put their marginal lands into biomass production in the near-term because the land rent from planting energy crops will be lower than grain crop plantation due to the potential increase in world grain price.

The rent-driven land use decision also implies two features of marginal land use: "relative" and "dynamic."⁴⁶ The "relative" feature reveals that marginal land use should be discussed for at least two different land use scenarios because landowners will make their decisions based on land rent comparison. Clearly specifying the land is marginal for what crop type is the basis for assessing marginal land use. The "dynamic" feature implies that marginal land use is not a fixed status. Any factors influencing land rent, such as price, land location, input price, and landowner's income from other land uses, can alter the

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3 223 landowner's decision on marginal land use. Brynegelsson et al.³⁰ is an example study. They applied a
4
5 224 conceptual partial-equilibrium model to examine long-term food-price implications stemming from the
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8 225 increased land-use competition under large-scale introduction of energy crops. They found that large-
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10 226 scale introduction of energy crops would raise food prices. The potentially increased food prices will
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12 227 lower the likelihood of planting energy crops on marginal lands due to a high opportunity cost.

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15 228 The conceptual studies laid a solid theoretical foundation for empirical analysis but did not build any
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17 229 econometric relationships between land rent and decision making. Without having the quantitative
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20 230 model, it is hard to measure how changes in factors influencing land rent affect landowner decisions.

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24 25 232 3.3.2 Econometrically empirical analysis

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28 233 Studies in this group established an econometric model to assess socioeconomic factors influencing
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30 234 marginal land use.

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33 235 These studies first identify marginal lands based on the land cover information. For example, Skeva et
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35 236 al.⁴⁷ defined marginal lands as a combination of fallow cropland, shrubland, and grassland. Swinton et
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37 237 al.⁴⁸ defined marginal lands as the "*farmable noncropland*," and Mooney et al.²² defined marginal lands
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40 238 as the land "*having one or more limiting soil characteristics, including poor drainage, shallow*
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42 239 *bedrock/water table, seasonal flooding, and excessive stoniness.*" After identifying marginal lands,
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44 240 these studies adopted a spatial sampling method to locate landowners who own the identified marginal
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47 241 lands to collect socioeconomic information by sending surveys.

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50 242 The closely-related socioeconomic factors, i.e., marginal land area and land rental rate, were assessed in
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52 243 these studies. However, the effect of these two factors varies across different regions. Mooney et al.²²
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54 244 found that marginal land area has a positive effect on a landowner's initial decision on energy crop

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3 245 supply and, for landowners who are willing to supply energy crops, the marginal land area has a positive
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6 246 effect for landowners from southwestern Wisconsin. Skevas et al.⁴⁷ noticed that marginal land area did
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8 247 not influence a landowner's decision on bioenergy supply, but did significantly influence how many
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10 248 hectares a landowner wanted to devote to energy crop plantations for landowners from southern
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12 249 Michigan. The key factor affecting a landowner's initial decision was the land rental rate. However,
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14
15 250 Swinton et al.⁴⁸ noticed that land rental rate did not influence a landowner's initial decision, but current
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17 251 land uses did influence decisions of landowners from northern Michigan.

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20 252 Other socioeconomic factors appearing in these studies were landowner attitudes, knowledge, and
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22 253 concerns regarding bioenergy. Mooney et al.²² noted that landowners who hold a positive attitude
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24 254 towards renewable energy and a stronger preference for environmental quality are more likely to supply
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26
27 255 energy crops, and these variables have a positive effect on how many hectares landowners would like to
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29 256 dedicate to energy crop plantations. Skevas et al.²⁶ grouped landowners from southern Michigan based
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31 257 on their answers to the survey questions assessing their attitude, awareness, and willingness towards
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34 258 bioenergy crops into four classes: disamenity-sensitive, profit-oriented, bioenergy supporters, and
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36 259 bioenergy skeptics. They found that profit-oriented landowners, bioenergy supporters, and bioenergy
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38 260 skeptics were all willing to make non-crop marginal land available for biomass production, while
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41 261 disamenity-sensitive landowners were highly disinclined to rent out their land for bioenergy crops.

42
43 262 In summary, the econometrically empirical analysis builds the quantitative model to assess the effects of
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45
46 263 multiple socioeconomic factors on landowner decisions about whether they want to supply energy crops
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48 264 on marginal lands and how many hectares they would devote to energy crops. However, these studies
49
50 265 did not incorporate biophysical information of identified marginal lands such as soil, slope, land cover,
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53 266 or general land quality index in the econometric models. Without including this information, it is
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55 267 difficult to assess how biophysical factors influence landowner decisions. In addition, these studies

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3 268 seldom report whether academically identified marginal lands are consistent with the landowners'
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5 269 definition of marginal land. These studies avoid asking landowners the reasons why and how they
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8 270 designate marginal lands. Without this information, we cannot know if the previously-identified
9
10 271 marginal lands are consistent with landowner thinking, making it difficult to identify some unique
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12 272 reasons explaining "marginality."
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15 273 **3.2 Quantitative and qualitative studies**

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18 274 All studies reviewed here, including conceptual socioeconomic studies, applied a quantitative method to
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20 275 analyze marginal lands. Biophysical studies applied spatial data and crop modeling or ecosystem service
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22
23 276 data to identify marginal lands. Various spatial datasets containing information on soil, topography,
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25 277 current land use, historical land use, and climate appear in biophysical studies. For example, Cai et al.⁴⁹
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27 278 worked with the Harmonized World Soil database, the State Bureau of Surveying and Cartography
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29
30 279 topography database, and the land use dataset from Resources and Environmental Sciences to identify
31
32 280 marginal lands. Milbrandt et al.¹¹ worked with data from Global Agro-Ecological Zones (GAEZ) system
33
34 281 to identify marginal lands for APEC countries.
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36
37 282 Empirical socioeconomic studies applied an econometric model and survey data to analyze marginal
38
39 283 land use. Most studies applied a contingent valuation (CV) method and a two-step modeling procedure
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41
42 284 to simulate landowner land-use decisions. CV is a widely-used economic tool for valuing non-market
43
44 285 and pre-market goods using stated preference information.⁵⁰ Freeman⁵¹ defines CV as a survey-based
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46 286 study that elicits individual valuation of a specified commodity or environmental change by using
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49 287 landowner responses to questions about hypothetical scenarios. Given the immature market of energy
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51 288 crops, CV is an appropriate method to elicit landowners' decisions.⁵² The two-step model corresponds to
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53 289 the two-step land-use decision process. The first step is to apply a discrete choice model to evaluate the
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55 290 extensive margin which determines whether or not landowners want to supply energy on marginal lands.
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3 291 The second step identifies the intensive margin, which examines how many hectares landowners want to
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5 292 convert to energy crop plantations. Survey data collected were mainly information on land availability,
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7 attitudes towards bioenergy, willingness to supply bioenergy crops, and demographic information.^{22,47,48}
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11 294 In the review of studies, no qualitative studies emerged that elicited landowner opinions about marginal
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13 295 lands. Obtaining their opinions is helpful in validating academic definitions and in assessing landowner
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15 296 perspectives of the potential land base. Conducting qualitative structured or semi-structured research
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17 297 interviews is helpful to provide a deeper understanding of marginal lands that would be obtained from
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19 purely quantitative methods.⁵³
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23 299 **4. Conclusion and future work**

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26 300 We presented an integrated sustainability framework to classify studies addressing marginal lands for
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28 301 energy crop plantations. The framework will enhance how we view the interaction and complementary
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30 302 mix of biophysical vs. socioeconomic factors, as well as qualitative vs. quantitative methods. From a
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32 review of relevant studies, we found that they largely concentrate on biophysical perspectives of
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34 marginal lands, or on the ecosystem service provision of land use change by planting energy crops.^{37,54}
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37 305 Those that focused on socioeconomic factors recognized the “relative” and “dynamic” attributes of
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39 marginal lands⁴⁶, but lack interaction between biophysical and socioeconomic factors.
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43 307 Using this framework can address two critical gaps in current studies: 1) how to link biophysical factors
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45 308 and socioeconomic factors together to define marginal lands, and 2) how to apply both qualitative and
46
47 309 quantitative analyses to marginal lands analysis. Land rent can be used to integrate biophysical factors
48
49 and socioeconomic factors because marginal lands are lands with lower land rent either due to poor soil
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51 quality, physical location, or the landowner’s socioeconomic attributes. A workflow for achieving the
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53 sustainability-based analysis for marginal lands assessment is provided (Figure 2). For a study site, one
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3 313 can start with biophysically marginal lands identification by applying biophysical filters such as high-
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5 314 slope, low-land capability classification index with quantitative analysis. After identifying biophysically
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8 315 marginal lands, one can turn to socioeconomic marginal lands identification by calculating land rents for
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10 316 at least two different land uses (grain crops vs. energy crops). Socioeconomic marginal lands could be
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12 317 identified as the lands which are economically marginal for grain crops but not for energy crops (land
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15 318 rent for grain crops is lower than for energy crops). With the socioeconomic and biophysical marginal
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17 319 lands, it will be easy to identify landowners who own these identified lands. Performing a qualitative
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19 320 analysis, such as a survey or interview to elicit their opinions about their land, will examine whether the
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22 321 academic identified marginal land concept is consistent with landowner's opinions. With the empirical
23
24 322 opinions from landowners, validation of quantitatively-derived, academically-defined marginal lands
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26 323 can be done by comparing them with qualitative landowner perspectives on marginal lands.
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2014	Skevas, T., Swinton, S. M., & Hayden, N. J.	What type of landowner would supply marginal land for energy crops? <i>Biomass and Bioenergy</i> , 67, 252-259.
2015	Mooney, D. F., Barham, B. L., & Lian, C.	Inelastic and Fragmented Farm Supply Response for Second-generation Bioenergy Feedstocks: Ex Ante Survey Evidence from Wisconsin. <i>Applied Economic Perspectives and Policy</i> , 37(2), 287-310.
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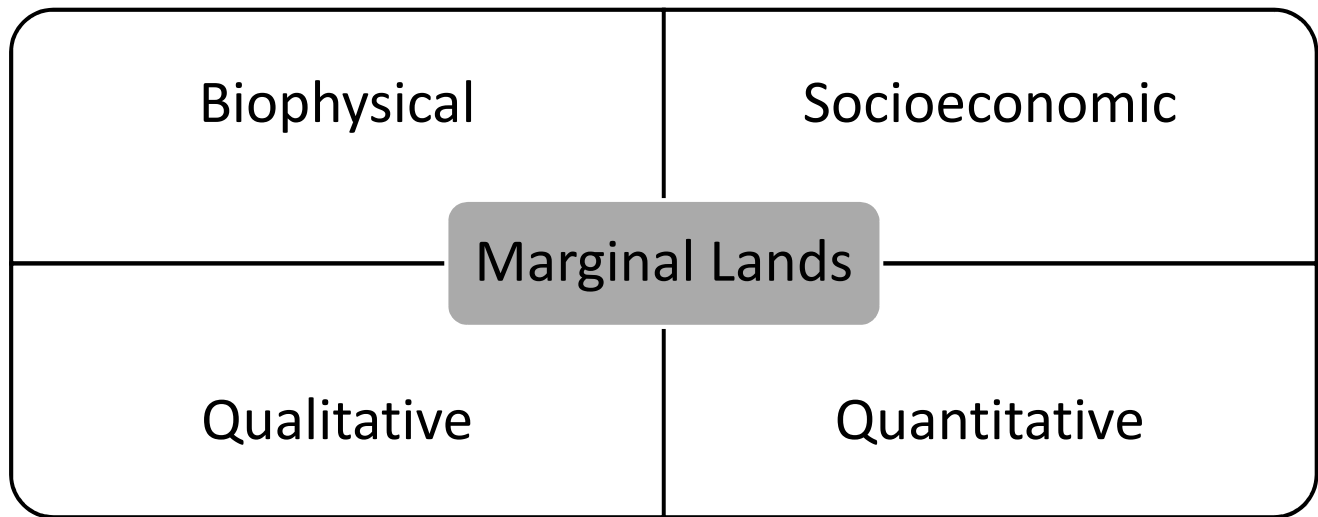


Figure 1. Sustainability framework for assessing marginal land for energy crop production

Peer Review

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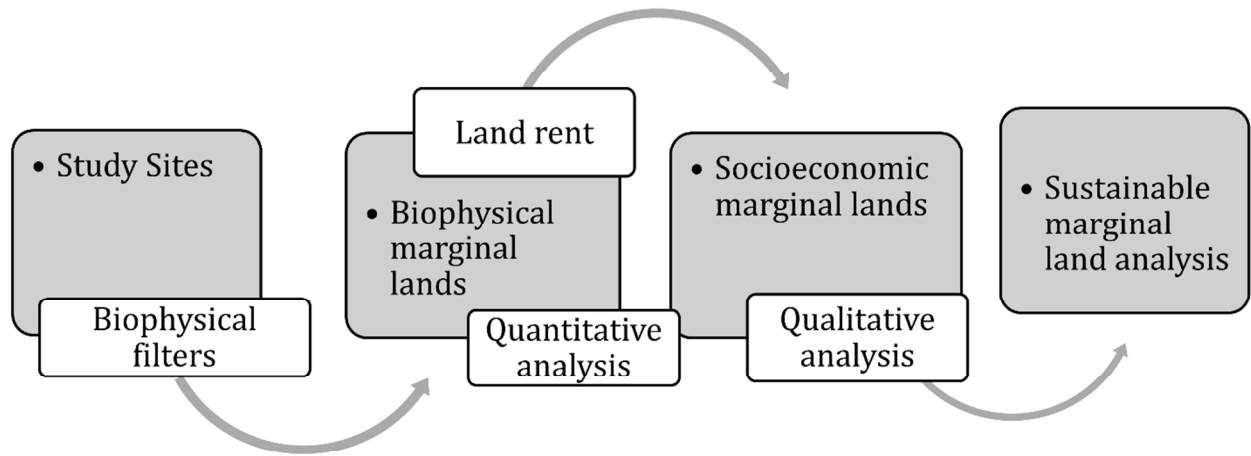


Figure 2. A workflow to assess marginal land based on the sustainability framework

Review

522 Table 1. Terminology used in studies

Paper	Term Used
2006 Xianzeng Niu & Duiker	Marginal agricultural land
2008 Campbell, Lobell, Genova, & Field	Abandoned agriculture lands
2008 Varvel, Vogel, Mitchell, Follett, & Kimble	Marginal soils
2008 Schmer, Vogel, Mitchell, & Perrin	Marginal croplands
2009 Milbrandt & Overend	Marginal lands
2011 Cai, Zhang, & Wang	Marginal agricultural lands
2011 Gopalakrishnan, Cristina Negri, Snyder, & Negri	Marginal lands
2011 Swinton, Babcock, James, & Bandaru	Non-crop marginal lands
2012 Amichev, B. Y., Kurz, W. A., Smyth, C., & Rees, K. C.	Agriculturally marginal lands
2012 Liu, Yan, Li, & Sang	Marginal lands
2013 Bryngelsson & Lindgren	Marginal lands
2013 Gelfand, I., Sahajpal, R., Zhang, X., Izaurrealde, R. C., Gross, K. L., & Robertson, G. P.	Marginal lands
2013 Kang, S., Post, W., Wang, D., Nichols, J., Bandaru, V., & West, T.	Physically marginal lands; Biologically marginal lands; Environ-ecologically marginal lands; Economically marginal lands
2014 Skevas, T., Swinton, S. M., & Hayden, N. J.	Non-Crop marginal lands
2014 Aust, C., Schweier, J., Brodbeck, F., Sauter, U. H., Becker, G., & Schnitzler, J. P.	Degraded lands, abandoned lands and marginal lands
2015 Mooney, D. F., Barham, B. L., & Lian, C.	Marginal croplands
2016 Skevas, T., Hayden, N. J., Swinton, S. M., & Lupi, F.	Non-Crop marginal lands
2016 Swinton, S. M., Tanner, S., Barham, B. L., Mooney, D. F., & Skevas, T.	Farmable noncropland

524 Table 2. Biophysical studies, research procedure, and used factors

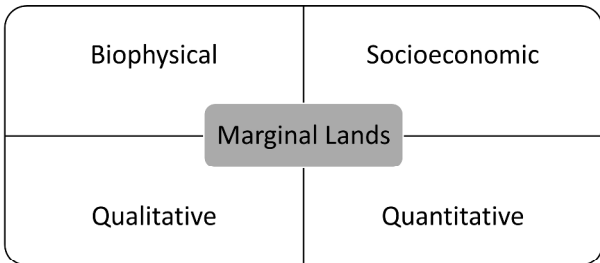
Research Goals	Biophysical Studies	Research Procedure	Used Factors
Land identification	Gopalakrishnan, G., Cristina Negri, M., & Snyder, S. W (2011)	Land identification	Soil: soil erosion, flooding, drainage Landscape: slope Land cover: idle and fallow cropland, buffer strips along rivers and roadways Environmental degradation: (i) brownfield sites consisting of land that has been contaminated with chemicals from prior industrial use, (ii) land where surface water resources (rivers and streams) or groundwater resources are contaminated, and (iii) land where irrigation is significant and could lead to depletion of water resources
	Kang, S., Post, W., Wang, D., Nichols, J., Bandaru, V., & West, T. (2013)	Land identification	Soil: temptation, erosion, flooding, rock content moisture, depth, physical attributes, chemical attributes Landscape: slope Landcover: wetland, buffer zone or corridors Economics: fixed break-even price or yield
Crop performance	Varvel, G. E., Vogel, K. P., Mitchell, R. B., Follett, R. F., & Kimble, J. M. (2008).	Land identification	General description: CRP land
		Crop yield assessment	Yield: field study Modeled crop: corn and switchgrass
	Liu, W., Yan, J., Li, J., & Sang, T. (2012).	Land identification	Soil: erosion, texture, drainage, chemical attributes, depth Landscape: slope
		Crop yield assessment	Yield: radiation model (Monteith, 1977) Modeled crop: Miscanthus
	Aust, C., Schweier, J., Brodbeck, F., Sauter, U. H., Becker, G., & Schnitzler, J. P. (2014).	Land identification	Soil: soil quality Landcover: cropland and grassland Landscape: gradient Climate: temperature, climatic water balance
		Crop yield assessment	Yield: various models Modeled crop: poplar and willow
	Campbell, J. E., Lobell, D. B., Genova, R. C., & Field, C. B. (2008)	Land identification	Land cover: crop and pasture land Time: 1700-2000
		Productivity assessment	Biomass model: Carnegie-Amers-Stanford Approach Ecosystem Model
	Cai, X., Zhang, X., & Wang, D (2011)	Land identification	Soil: soil productivity properties; soil temperature Landscape: land slope Climate: humidity index
		Productivity assessment	Energy model: Net Energy Gain
Milbrandt, A., & Overend, R. P (2009)	Land identification	Soil: Lands with soil problems (soil depth, soil drainage, soil physical attributes, soil chemical attributes) Landscape: Lands with moderate (8-16%) and steep (16-30%) slope	

			Land cover: Barren and herbaceous areas
		Productivity assessment	Biomass model: SUCROS
Ecosystem Service Assessment	Niu, X., & Duiker, S. W. (2006)	Land identification	Land cover: pastureland, cropland, barren land, Soil quality: marginal farmland, erosion
		Crop yield assessment	Yield: various modeling methods such as Marland and Marland (1992) Modeled crop: short-rotation trees and permanent forest
		Ecosystem service assessment	GHG: K.I. Paul et al. (2003) model
	Amichev, B. Y., Kurz, W. A., Smyth, C., & Rees, K. C (2012)	Land identification	Soil: land classification capability, land limitation Landcover: cropland, forage land and grassland Landscape: slope Climate: temperature, annual precipitation, growing degree days
		Crop yield assessment	Yield: 3PG model Modeled crop: shrub willow
		Ecosystem service assessment	GHG: Carbon Budget Model of the Canadian Forest Sector
	Gelfand, I., Sahajpal, R., Zhang, X., Izaurralde, R. C., Gross, K. L., & Robertson, G. P. (2013)	Land identification	Soil: land capability classification Landscape: slope and gradient Landcover: rural lands, non-forest land
		Crop yield assessment	Yield: EPIC model Modeled crop: poplar
		Ecosystem service assessment	GHG: carbon budget
	Schemer, M. R., Vogel, K. P., Mitchell, R. B., & Perrin, R. K. (2008).	Land identification	General description: CRP land
		Crop yield assessment	Yield: field study Modeled crop: switchgrass
		Ecosystem service assessment	GHG: Energy and Resources Group Biofuel Analysis Meta-Model

Table 3. Socioeconomic studies of marginal lands

	Socioeconomic studies	Social Factors	Used model	Crops
Conceptual analysis	Swinton, S. M., Babcock, B. A., James, L. K., & Bandaru, V. (2011)	Crop-specific land rent	Conceptual	General biomass crop
	Bryngelsson, D. K., & Lindgren, K. (2013)	Land rent	A conceptual partial equilibrium model	General biomass crop
Empirical analysis	Skevas, T., Swinton, S. M., & Hayden, N. J. (2014)	Bioenergy attitude Rental concerns	Factor analysis Cluster analysis Multinomial probit	Corn, switchgrass, poplar, and prairie
	Mooney, D. F., Barham, B. L., & Lian, C. (2015)	Farm type indicators (crop, dairy, other livestock farm), Land cover (Cultivable area, marginal cropland, unfarmed open space, CRP), Energy and environmental attitude Social-demographic variables	Probit and Tobit	Corn stover and switchgrass
	Skevas, T., Hayden, N. J., Swinton, S. M., & Lupi, F. (2016)	Land size Land rental situation Land rent Contract length Bioenergy attitude Rental concerns Social-demographic variables	Hurdle	Corn, switchgrass, poplar, and prairie
	Swinton, S. M., Tanner, S., Barham, B. L., Mooney, D. F., & Skevas, T. (2016)	Land size Land rental situation Land rent Bioenergy attitude Rental concerns Social-demographic variables	Hurdle	Corn, switchgrass, poplar, and slash

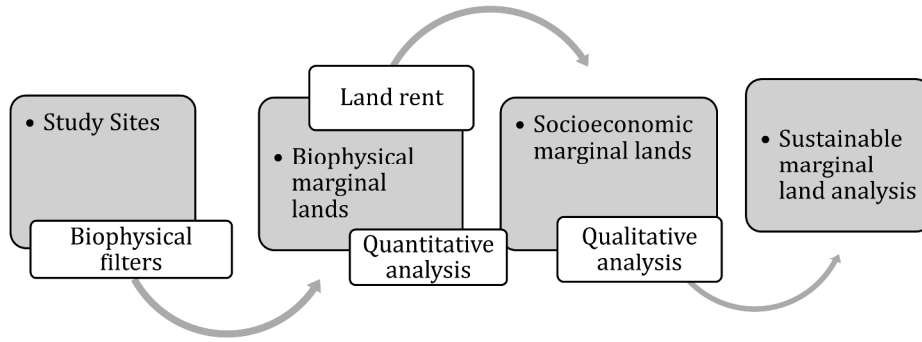
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