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Farmers' motivations to cultivate biomass for energy and implications

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ABSTRACT

Bioenergy derived from agricultural biomass can contribute to meeting the rising demand for renewable energy. To estimate the agricultural sector's potential to contribute to bioenergy, it is crucial to understand what motivates farmers to increase agricultural feedstock production sustainably. Through eight semi-structured interviews and online surveys with 174 farmers in southern Sweden, we explore the barriers and incentives farmers perceive in starting or increasing feedstock production for energy purposes sustainably using production methods with a low risk of causing indirect land use change (iLUC). Among the most prominent barriers are low profitability, high-risk investments, and potential negative environmental consequences such as soil depletion. Higher market prices for plant residuals and energy crops, combined with more long-term and reliable subsidies that support investments in new machinery, facilities, and production systems, are major driving factors to increase feedstock production for bioenergy. The study found that the farmers see little potential in using marginal lands due to their low soil productivity and spatial characteristics. Further, the potential for intensifying biomass production on currently cropped land is also found to be limited due to risks of soil depletion and environmental degradation. Our study highlights that the potential of bioenergy production from underutilized land and intensive production in Scania may be overestimated, and realizing this potential in practice may require suitable policy changes.

1. Introduction

1.1. Background

Bioenergy development has been recognized as an alternative to fossil fuels with climate change mitigation potential in the short to medium term (Blair et al., 2021; Mandley et al., 2022). Indeed, several major countries have introduced policy targets for bioenergy use (Das, 2021). This has significantly increased the global demand for biomass for energy purposes. However, it has also resulted in several negative unintended consequences. For example, using agricultural-based biomass feedstocks (i.e., cereal grains, oil seeds, etc.) for biofuel production has raised regional and global food security concerns. It has created globalized bioenergy value chains driving direct and indirect land use changes (iLUC) (Fritsche et al., 2010), and intensive farming practices. These have adverse effects on biodiversity (Donnison et al., 2021), soil, and water in the producing regions. Since bioenergy production and consumption are not entirely carbon-neutral and sustainable, the focus has shifted to local or regional bioenergy development.

Sweden has a long-term goal to be carbon-neutral by 2050. One of the milestone goals is to achieve a fossil-free vehicle fleet with 50% of passenger cars running on biofuels (Fossil Free Sweden, 2022). Its large forest industry is expected to supply a significant biomass demand for energy purposes (Börjesson, 2016). But, currently, a significant part of the biofuel demand is being met with imported resources. Historically, the policies in Sweden have focused on expanding the usage of biofuels rather than increasing production (Swedish Energy Agency, 2021a). For example, the Swedish reduction mandate rewarded the use of advanced biofuels with low carbon dioxide emissions (Lundberg et al., 2023). This created a huge demand for advanced biofuel consumption (25 TWh in the year 2022), but not domestic production (Sweden produced only 7.5 TWh of biofuels in 2022, mainly from Liquid biofuels (5.2 TWh) and biogas (2.3 TWh) (Energigas Sverige, 2022)). Thus, a huge part of the biofuel demand is being met through imports of biofuels or the feedstocks to produce them (Ericsson and Nilsson, 2004; Hedeler et al., 2023; Martin et al., 2020). This includes imports of biofuels from The Netherlands, wood chips from The Baltic countries, FAME from Lithuania, Germany, Norway, and Italy, and corn-based ethanol, tall oil,

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and pellets from North and South America (Hedeler et al., 2023; Lundberg et al., 2023; Martin et al., 2020). However, there is an interest in increasing the domestic production of biofuels from Swedish raw materials to reduce dependence on imports. This includes utilizing the potential of agricultural-based biomass for energy purposes (Börjesson, 2016). Indeed, recent studies (Ahlgren et al., 2017; Börjesson, 2021; Prade et al., 2017) have found that Sweden may sustainably meet its demand for bioenergy through low iLUC methods, such as utilization of additional biomass feedstock[1] from residues, productive arable land, underutilized marginal land, and sustainable intensive farming. Estimates show that 20 TWh of biofuels can be produced from low iLUC feedstocks from forest (8–11 TWh) and agricultural (4–10 TWh) sectors (Prade et al., 2017). However, despite this potential and existing institutional support, agricultural-based bioenergy production is limited in Sweden. There is a gap in knowledge about the farmers' motivational drivers (both as drivers and barriers) to adopt low-iLUC methods for agricultural-based bioenergy production. Understanding the farmers' motivational drivers is crucial to introducing suitable policy measures to accelerate the adoption of these methods.

1.2. The potential of low i-LUC inducing energy crops in Sweden

Based on large areas of available arable land set aside or fallow, the Swedish strategy for bioenergy recognizes no conflict between the production of bio-raw materials and food production (Fossil Free Sweden, 2022). The common agricultural energy crops that can be grown in Sweden for producing heat, electricity, and biogas are fast-growing broadleaf trees such as willow, poplar, and aspen, grass on arable land, and nitrogen-fixing crops (Börjesson, 2021).

The main low iLUC-risk methods for biomass production in Sweden are identified as agricultural residuals, additional feedstock from productive arable land, feedstock from underutilized marginal land, and intensified production. Agricultural residuals, such as straw, ensilage, and excess grass, may contribute to iLUC-free feedstock if these do not have other markets or uses, such as animal bedding or animal feed. Additional agricultural feedstock could be produced through cultivating or harvesting crops on arable land that is currently underutilized. This includes growing intermediate crops between main crops and harvesting biomass on land left for environmental values such as ecological focus areas EFA, corresponding to areas for enhanced conditionality and eco-schemes under the new Common Agricultural Policy, 2023. Biomass on EFAs is generally not allowed to be harvested to provide environmental services. However, Ahlgren et al. (2017) and Prade et al. (2017) suggest that harvesting biomass from EFAs and producing feedstock from underutilized lands can be supplied through extensive biomass production on farmland that is underutilized due to marginal profit, such as field edges, abandoned farmlands or inaccessible fields, as well as land fallowed for improving soil fertility. Intensified production of biomass, mainly extensively produced grass, may contribute to bioenergy production without competing with current production on the land or claiming more land. This research focuses on these four production methods.

1.3. Farmers' motivational factors

Globally, several studies have investigated farmers' attitudes toward adopting more sustainable agricultural energy crops, such as woody crops and switchgrass (Burli et al., 2019; Fürtner et al., 2022; Hand et al., 2019; Hannerz and Bohlin, 2012; Helis et al., 2021) and perennial crops (Yang et al., 2021), and straw (Wilson et al., 2014). Other issues directly related to farmers have been analyzed, e.g., their willingness to adopt new farming practices (Paulrud and Laitila, 2010; Ranacher et al., 2021), use of marginal lands for bioenergy crops (Helliwell, 2018; Markiewicz-Keszycka et al., 2023), and pro-environmental diversification of land use (Markiewicz-Keszycka et al., 2023). In context to support bioenergy development in Sweden, previous studies have focused on analyzing (1) the drivers and barriers (Jonsson et al., 2011; Ostwald et al., 2013); (2) incentives and potentials (Helby et al., 2006; Jonsson et al., 2011; Lantz et al., 2007; Ostwald et al., 2013; Parra-López et al., 2017); (3) infrastructure needed to support cultivation of these crops (e.g., irrigation systems (Campana et al., 2022) and expansion and distribution (Jonsson et al., 2011; Ostwald et al., 2013; Parra-López et al., 2017)); and (4) the role of governing mechanisms (e.g., compliance to sustainability criteria (Lazarevic and Martin, 2018)).

More generally, the drivers and barriers to pro-environmental behavior change do relate to agreements, knowledge, technological economic, social and political, and administration (cf. (Simmons and Trudgill, 1993)). Previous studies (Börjesson, 2021; Jonsson et al., 2011; Mola-Yudego and González-Olabarria, 2010; Ostwald et al., 2013) identify profitability, policy reliability, and relation to the land as necessary in Sweden. However, there is a lack of information on the social, cultural, institutional, and environmental factors from the perspective of individual farmers. Further, there is often a gap between an individual's motivation and their action. This study explores the farmers' motivations in the context of drivers and barriers to their actions toward adopting energy crops.

1.4. Aim and objectives

This research aims to understand farmers' motivations to increase biomass cultivation for bioenergy purposes using the low iLUC-risk biomass feedstock production methods, including agricultural residuals, additional feedstock from arable land, feedstock from underutilized land, and intensified production. The research questions (RQ) in focus are: RQ1: What drivers and barriers do farmers face in Scania to increase biomass feedstock production for energy purposes? RQ2: Which low iLUC-risk production methods do farmers in Scania see the most potential in utilizing for energy purposes? RQ3: How can policies enhance drivers and address barriers to initiating and/or increasing Scania's agricultural biomass production for energy purposes?

The study focuses on farmers with active crop cultivation in Scania, the most arable part of southern Sweden, where farmland makes up almost half of the region (Statistics Sweden, 2019). Scania is one of the regions with the most farmers in Sweden (Swedish Board of Agriculture, 2020), which makes it particularly interesting when exploring the potential of agricultural bioenergy and informing farming policies that allow a sustainable expansion of domestic bioenergy production.

The rest of the article is organized as follows: Section 2 provides an overview of the key concepts; Section 3 describes research materials and methods employed during the study; Section 4 presents the study's key results, followed by a discussion on policy implications in Section 5. The article ends with critical conclusions of the study (Section 5).

2. Materials and methods

This study utilizes the motivation-action model (Heckhausen and Heckhausen, 2018) to identify farmers' motivational factors to increase biomass cultivation for bioenergy purposes (Fig. 1). For this purpose, the research started with 8 in-depth semi-structured interviews with farmers to get an overview of these motivational factors. This information was used to develop an online survey of farmers to collect detailed empirical data on these factors. These factors were classified as drivers and barriers to understand and discuss their policy implications.

2.1. Motivation-action model

In the field of motivation psychology, which "*seeks to explain the*

[1] In this study, we use the term 'feedstock' for agriculture-based organic raw materials that can be used directly to produce energy or after an intermediate processing step.

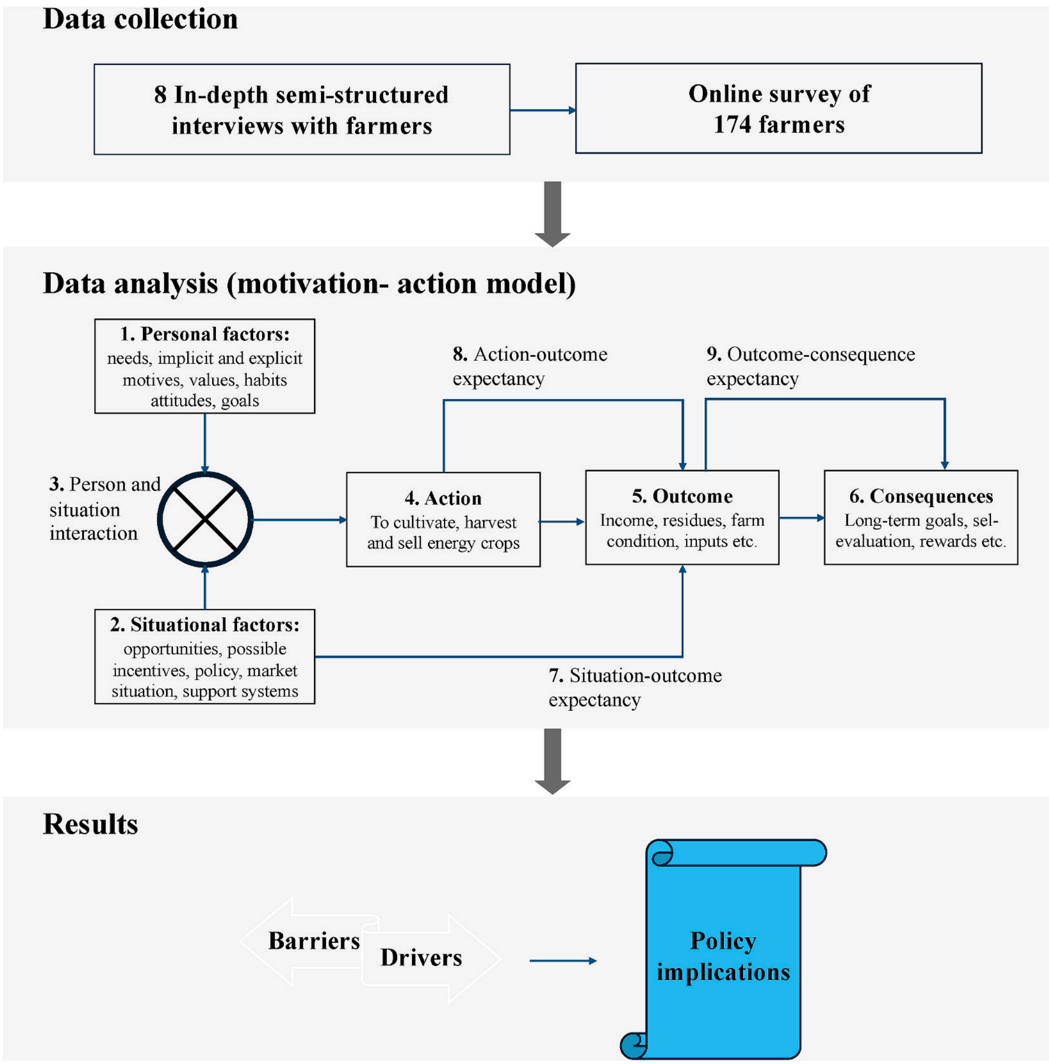

Fig. 1. Model of motivated action based on the interaction of personal and situation*al factors, and outcome- and consequence-related expectancies. The study identifies these factors as drivers and barriers to a motivated action, and their policy implications. Adapted from* Heckhausen and Heckhausen (2018).

direction, persistence, and intensity of goal-directed behavior", an individual's motivation to pursue a goal depends on their personal preferences and situational factors (Heckhausen and Heckhausen, 2018, p. 3). The personal factors include, e.g., needs, personalities, attitudes, values, and habits. In contrast, policy frameworks, support systems, market situations, and legal regulations are situational factors.

In the motivation and action model (Heckhausen and Heckhausen, 2018), the interaction of these factors leads to one's actions, and therefore, the expected desired outcomes and consequences (see Fig. 1). Each action has its specific intrinsic and extrinsic incentives. Intrinsic incentives are derived from the activity itself, and its outcomes, e.g., profitability, farm yield, etc. Extrinsic incentives are derived from the consequence of actions and their outcomes, e.g., in our case, the satisfaction of contributing to self-sufficiency, energy security, environmental sustainability, etc. When situation-outcome expectancy is high, meaning the situation factors are such that they ultimately lead to the desired outcome even without active intervention, the incentives to act are low. For example, if currently the farmers' desired income levels are achieved with conventional farming activities, they will not invest their resources to produce new crops (or energy crops). However, when situation-outcome expectancy is low and action-outcome expectancy is high, meaning the incentives are also dependent on the farmer's actions, the incentives to act are high, considering that the outcome-consequence expectancy is favorable. As an example, if higher economic outcomes depend on a farmer's actions rather than the situational factors alone, the incentives for the motivated action would be higher. A harmonized policy environment can create situational factors and outcome expectancies that are conducive to a desired motivated action.

This model was applied to identify and analyze the farmers' motivational factors as significant drivers and barriers to action toward cultivating agricultural energy crops using low iLUC production methods. The factors encouraging the farmers to start or increase biomass production were classified as drivers, and the factors discouraging the farmers were considered as barriers. These drivers and barriers impact the farmers' actions to start or increase agricultural biomass production for energy purposes.

Based on these drivers and barriers, significant policy implications were identified and discussed. We classify these implications as: (1) administrative, i.e., related to laws, regulations, etc.; (2) economic i.e., market-based incentives, environmental taxes, subsidies for products or investments, and payments, etc.; (3) information, i.e., related to technical know-how; and (4) transactional, i.e., the fuzzy costs of actually implementing a policy instrument, such as bureaucracy related costs.

2.2. Empirical data collection methods

2.2.1. Semi-structured in-depth interviews with farmers

Firstly, individual semi-structured interviews were conducted over the phone or via video call with eight farmers in Scania, seven of whom specialized in crop cultivation. The farmers were reached through farming websites and organizations and selected to represent diversity in cultivation type, farm size, and geographical spread. The interviews followed an interview guide focusing on exploring (1) the farmers' motivational factors to produce biomass using the low-iLUC risk production methods and (2) the incentives and barriers they perceive in starting or increasing biomass production for bioenergy purposes (see Appendix A1). The eight interviewed farmers were men between 30 and 70 years old, with varying crop cultivation systems and farm sizes geographically spread out in Scania (Table 1). We contacted a few female farmers; however, they referred us to contact their husbands for the information we requested from them. None of the farmers were selling biomass for bioenergy purposes. However, two farmers used biomass to generate heat and electricity on their farms.

The eight recorded interviews, which ranged from 30 to 60 min, were transcribed with the help of Microsoft Word ® online transcribing software. The transcriptions were further analyzed using a structured analysis of the content of the transcripts. All the transcripts were analyzed individually to identify the barriers and drivers related to the farmers' personal or situational factors described above. Therefore, the codes and themes in our analysis were primarily informed by the specific research questions of this study (i.e., deductively). However, we also included the themes that emerged while the data was being analyzed (i.e., inductively). These interviews were coded and analyzed using Nvivo® software (https://lumivero.com/).

2.2.2. Online farmer surveys

Based on the preliminary findings of the in-depth interview study, an online survey was developed consisting of closed and open-ended questions (see more details in Appendix A2). The survey was sent to 1672 farmers in Scania through their e-mail addresses provided by the Swedish Board of Agriculture. The survey was directed to the farmers who had active crop production. A total of 174 farmers answered the online survey. Table 2 summarizes the demographic characteristics of the respondents and their farming practices. The respondents were 25 to over 80 years old, with farms of various sizes. These farmers were located in 30 of the 33 Scanian municipalities, i.e., except Bromölla, Landskrona, and Malmö. Most survey respondents were men (87%) and conventional farming was the most common type of farm (77%) (see Table 2). This fits with the actual distribution of women and men in Sweden (91%) and the Scania region (87%) and conventional type of farming practice in the country (91%) (as per the Eurostat's data on the agricultural census in Sweden as of 2010).

Table 1
Characteristics of interviewed farmers (N = 8) and characteristics of their farms. All farmers except one were specialized in crop cultivation.

Farmer number	Gender	Age	Farmland for crop cultivation (ha)	Cultivation form
1	Man	60–70	30	Conventional
2	Man	50–60	45	Conventional
3	Man	60–70	78	Organic
4	Man	40–50	190	Conventional
5	Man	30–40	300	Conventional
6	Man	40–50	440	Conservation agriculture
7	Man	30–40	550	Conventional
8	Man	50–60	11000	Conventional

3. Results

This section presents the key results of this research. First, based on the interview study, an overview of the farmers' motivational factors as the drivers and barriers to producing agricultural biomass for energy purposes is provided (Section 3.1). Second, based on the farmers' surveys, these drivers and barriers are presented in context to the low iLUC production methods (Section 3.2).

3.1. Drivers and barriers to producing agricultural biomass for bioenergy (based on the interviews)

The drivers and barriers affecting the farmers' willingness to initiate or increase biomass production for bioenergy purposes are summarized in Table 3. These were identified in the farmers' interviews and classified into two factors: personal (e.g., attitudes, values, habits, and needs) and situational (e.g., market situations, infrastructure, environmental conditions, institutional frameworks, and legal settings).

3.1.1. Related to the attitudes and values

The drivers and barriers associated with the farmers' attitudes and values were closely related to energy security and geopolitical concerns. The study found that contributing to a more self-sufficient and domestic production $_{(1)}$[2] of renewable energy $_{(2)}$ was a key motivational factor for several farmers. Russia's ongoing invasion of Ukraine at the time of the interviews and geopolitical conflicts were seen as significant drivers contributing to energy security. Farmer 4, for example, said, "*I see it as we have the potential to produce both food and energy from the Swedish agricultural land. It would be a shame not to use that potential. A lot has happened in the world in the last month, and we see that there is a demand, and it also strengthens our country if we can produce the food and energy ourselves.*" Although many farmers considered bioenergy necessary to reduce society's dependency on fossil fuels, increasing bioenergy production was less prioritized than food and feed production $_{(3)}$. When the interviewed farmers were asked whether they would use the land and biomass for food, feed, or bioenergy production with the same profit, all of them prioritized biomass for food and feed over selling feedstock for bioenergy. Farmer 8 referred to it as one might think it is "*more correct to produce food right now*" and continued explaining that "*we can produce energy from other areas, but we only have agricultural land to produce food.*"

Furthermore, there were conflicting views on the agricultural sectors' potential to produce feedstock for energy purposes. Whereas some farmers acknowledged a great potential in using low iLUC-risk production methods to make more feedstock, others thought the agricultural sector's potential was insignificant compared to other bioenergy sources in Sweden, e.g., feedstock from forestry $_{(4)}$.

3.1.2. Related to habits

The drivers and barriers related to habitual factors originated from their lack of knowledge regarding profitability, environmental impacts, and their farming capabilities. The farmers were also interested in trying new crops and production techniques, in addition to producing biomass for bioenergy purposes that they already had in their production systems, such as grass, intermediate crops, and energy trees. There were, however, concerns regarding the profitability and adverse environmental impacts. Some of the farmers anticipated a potential conflict with their current cultivation system $_{(14)}$ when growing fast-growing trees such as poplar and willow for energy purposes on their agricultural lands.

3.1.3. Related to their needs

These drivers and barriers were associated with the farmers' need for better access to technical knowledge to enhance biomass production.

[2] Subscripted numbers indicate the factor(s) listed in Table 3.

Table 2
Description of respondents in the online survey (N = 174) and their characteristics.

Age	(%)	Gender	(%)	Size of areal land used for crop cultivation (ha)		Type of farm	(%)
<25	0%	Men	87%	<5	14.37%	Conventional	77%
25–30	0.57%	Women	11%	5–10	13.21%	Organic	6.3%
30–40	11.49%	Unknown	2%	10–20	14.94%	Conventional and organic	7.5%
40–50	16.09%			20–50	13.21%	Other	9.2%
50–60	28.16%			50–100	16.67%		
60–70	32.18%			100–300	17.82%		
70–80	8.62%			300–500	5.17%		
>80	0.57%			500–1000	3.45%		
Prefer not to answer	2.29%			>1000	1.15%		

Table 3
An overview of the farmers' motivations as drivers and barriers to initiating or producing more agricultural biomass for bioenergy purposes. These factors are numbered (in subscript) and are elaborated on in the text.

Motivational factors		Drivers	Barriers
Personal factors	**Attitudes and values**	- Contribution to domestic energy system $_{(1)}$ -Contributing to renewable energy production/ Consuming less fossil energy $_{(2)}$	-Potential competition with food and feed $_{(3)}$ -Expectancy of insignificant contribution to bioenergy production $_{(4)}$
	Habits	-Low maintenance crops $_{(12)}$	-Lack of knowledge and experience $_{(21)}$ -Limitations in cultivation systems $_{(14)}$
	Needs	-Better access to advisory services $_{(22)}$ -Better utilization of underutilized lands and agricultural by-products $_{(24)}$	-Lack of specific machinery $_{(7)}$
Situational factors	**Market situation**	-Profitable investments $_{(5)}$	-High expenses/Low profitability $_{(6)}$ -Lack of demand for biomass feedstock $_{(8)}$
	Institutional framework and legal setting	-Financial support $_{(11)}$ -More flexible policies $_{(23)}$	-Bureaucratic hurdles $_{(9)}$ -Uncertain framework and financial support $_{(10)}$
	Environment	-Positive ecological consequences from increased landscape heterogeneity to potential habitat for some species $_{(12)}$ -Increased yields and new production potentials from changing climatic conditions $_{(15)}$ -Return of organic fertilizer $_{(17)}$	-Negative ecological consequences from intensified production and potential competition with conservation actions $_{(13)}$ -Increased uncertainty and loss of harvests due to changing climate conditions and extreme weather events $_{(15)}$ -Negative physical impact on soil $_{(16)}$
	Infrastructure	-Decentralized infrastructure for bioenergy production $_{(19)}$ -Potential for technical advances and new knowledge $_{(20)}$	-Lack of flexible infrastructure $_{(18)}$ -Lack of technical advances $_{(20)}$

Several farmers raised concerns over the limitations in technical advances $_{(20)}$ and know-how $_{(21)}$. For instance, one farmer considered Germany and Denmark a step ahead of Swedish agriculture in utilizing residues for bioenergy. Issues such as more research, better access to consultants $_{(22)}$, and more flexible policies $_{(23)}$ were highlighted to motivate farmers to initiate new biomass feedstock production to utilize their underutilized lands and agricultural residuals $_{(24)}$. When asked where the farmers would look for information and guidance to start cultivating a new crop or using underutilized land, some responded that they would turn to existing advisory organizations for information about new crops and production systems. There was, however, also the perception that governmental agencies should act more on advising rather than monitoring.

3.1.4. *Related to the market situation*

These drivers and barriers were related to the economic viability of the investments needed to enhance biomass production. According to most farmers, potential profitability was the most important incentive to make new (i.e., bioenergy-related) investments $_{(5)}$. For example, utilizing residues for on-site heat and electricity production or harvesting intermediate crops was seen by several farmers as an opportunity for profitable investments. However, significant investments (i.e., high risk-taking) and low returns from bioenergy were consequently viewed as significant barriers $_{(6)}$. For instance, this included substantial investments in the machinery and facilities needed to change the production system $_{(7)}$ to utilize bioenergy.

Several farmers pointed out that they are flexible and can adjust to the market's increased demand for biomass for bioenergy if there were sufficient financial incentives for the biomass. The low profitability for the crops that can be produced with low iLUC-risk production methods, such as willow, grass, and intermediate crops, as compared to other (food or feed) crops, was ascribed to the relatively low demand (i.e., prices) for them. Investing in new machinery for producing crops for bioenergy was thus seen as very risky and with a low expected return on the investment.

3.1.5. *Related to insitutional framework and legal settings*

Most of the interviewed farmers prefer to depend on the market for their income, as the increased societal demand was seen as more secure than relying on government support. Subsidies were generally perceived as highly bureaucratic $_{(9)}$ and unreliable $_{(10)}$. For example, farmer 5 abstained from applying for the support he was entitled to, as he found the requirements for the subsidy too strict regarding what could and could not be harvested, without considering the unpredictable risks that may come with agriculture, such as poor weather conditions. Farmer 4 phrased it as: "*I am against all this* support*, really. Pay us for what we produce instead so that we can stop with this charity. It will be more sustainable if we get the right profit for our produce*". Subsidies were, however, seen as helpful in driving a change toward a more reliable market by contributing to financial support $_{(11)}$ as the demand from the market increases. The subsidies could support investments in the machinery and facilities needed to produce biomass feedstock for energy.

3.1.6. Related to environmental aspects

The interviewed farmers brought up positive and negative environmental consequences impacting their willingness to grow different crops for bioenergy. While Farmer 5 pointed out that the fast-growing trees, such as poplar and willow, could have positive environmental impacts $_{(12)}$, several farmers expressed concerns about harvesting additional biomass or growing crops more intensely. This could harm biodiversity and species richness $_{(13)}$. Farmer 4, for example, said that he depended on pollinators in his cultivation system and thus needed sown wildflower strips. Another farmer expressed that a changing climate $_{(15)}$ could allow new energy crop types and higher yields. This, however, was also seen as a potential barrier where more extreme and unpredictable weather would produce more uncertain and unevenly spread yields.

Another barrier to harvesting biomass from arable lands, such as EFAs and fallowed land, was the risk of soil depletion $_{(16)}$ due to the extraction of the soil nutrients and organic matter. In this context, biogas production was considered an ecologically more favorable bioenergy production method, as organic matter would be returned to the farm as organic fertilizer $_{(17)}$. Farmer 3, who had an organic farm, saw the return of organic fertilizer as the most significant driving factor for producing feedstock for bioenergy, as he needed organic fertilizers for organic farming.

3.1.7. Related to infrastructure

These drivers and barriers were mainly associated with viable access to the infrastructure for biomass processing (i.e., (economically and environmentally). The possibility of using agricultural residuals, intermediate crops, and harvests of EFAs and fallow land was limited by the access to biogas facilities, which were for some farmers too far away for the transportation to be profitable and sustainable from an overall energy gain perspective. Furthermore, one farmer pointed out that the facilities were likely to have requirements for the type and amount of crop, which only sometimes aligned with what the farmers had to offer $_{(18)}$. Several farmers, therefore, suggested a more decentralized and flexible biogas facility structure, such as cooperation among the farmers, to shorten the distance to the facilities and allow a more flexible production $_{(19)}$.

3.2. Drivers and barriers to adopting low iLUC-risk methods for producing biomass for bioenergy (based on the survey)

This section presents the results of farmers' surveys. It describes how the drivers and barriers above apply to the four production methods with low iLUC risks. Out of the 174 farmers who responded to the survey, 17 were currently producing biomass feedstock for bioenergy purposes, and many of them are utilizing straw residuals and energy wood. Of these 17 farmers, 10 sold the feedstock, and 8 used it on the farm (some doing both) for heating or electricity production (for more details, see Appendix A3).

More than half of the farmers (53%) stated that they could consider increasing their biomass production for bioenergy under current or changed circumstances (Fig. 2), i.e., 76 farmers out of the total 174 farmers surveyed. When these 76 farmers were asked what would motivate them to produce more feedstock, economic factors were dominating, such as increased market price (87% or 66 out of these 76 farmers), more long-term financial support, and subsidies (38% or 29 out of these 76 farmers). Some (17% or 13 out of these 76 farmers) would do it if it were easier to apply for existing financial support.

When asked to choose up to three out of ten benefits of producing feedstock for bioenergy, the most chosen factors by the respondents (N = 174) were 1) that it contributes with energy to society (43%, 75 farmers), 2) that they could produce heat and electricity on their farm (29%, 51 farmers), and 3) that the feedstock could be sold for a reasonable price (29%, 51 farmers) (Question 30 in Appendix A2).

The farmers who would not consider increasing their feedstock production (21%, i.e., 36 farmers) motivated this in comments categorized into four themes seen in Table A3.9 in Appendix: 1) competition with feed and food; 2) low profitability 3) limited space for additional production; and 4) negative environmental consequences, mainly for soil quality (Question 29 in Appendix A2).

As farmers were asked to choose up to three barriers to producing feedstock for bioenergy, almost half of the 174 farmers agreed that energy crop production would compete with other types of crop production (47% of 174 farmers, 81 farmers). In the comment section, one farmer wrote: *"Food production must be a priority, as hungry people in a small country without self-sufficiency become dangerous in the long run. Energy becomes secondary."* Almost as expected were the opinions that profitability is too low (42% of 174 farmers, 73 farmers) and that harvesting biomass (such as straw and haulm) for bioenergy would remove nutrition from the soil (30% of 174 farmers, 52 farmers). Of the 174 farmers answering the survey, 137 responded that they would consider growing more biomass for bioenergy or that they did not know, which were asked further on their preferences as presented below.

3.2.1. Related to utilizing agricultural residuals

Among the interviewed farmers (N = 8), utilizing crop residuals was seen as a viable option since it did not compete with current crop production and land use. Although the farmers, in general, were optimistic about utilizing the residuals, the access to plant residuals varied depending on farm size and type of production. Two of the interviewed farmers used plant residuals for their energy production and were motivated to lower their costs and lessen their dependency on fossil fuels. One of the farmers noted that when his neighbor retired from farming and no longer needed his straw residuals for feed, he would be open to using them for biofuels. Another farmer commented that he had flax straw but needed technologies to use these residuals.

The most common plant-derived residuals amongst the farmers (N = 137) were straw (55%, 76 farmers) and straw residuals (29%, 40 farmers). Most (two-thirds) of these farmers would consider using it for bioenergy with available straw (i.e., 50 out of 76 farmers with available straw and 26 out of 40 farmers with straw residuals). When asked to choose major barriers to using agricultural residuals for energy purposes (Question 24 in Appendix A2), these were: 1) the farmer could not afford to produce bioenergy on their farm (41%, 56 farmers), 2) it was not profitable enough (39%, 53 farmers), 3) a lack of demand for residuals (26%, 36 farmers), 4) lack of storage space (25%, 34 farmers) and 5) that residuals are already in use, e.g., for feed (22%, 30 farmers).

3.2.2. Related to growing additional feedstock from arable land

Several interviewed farmers (N = 8) were open to producing

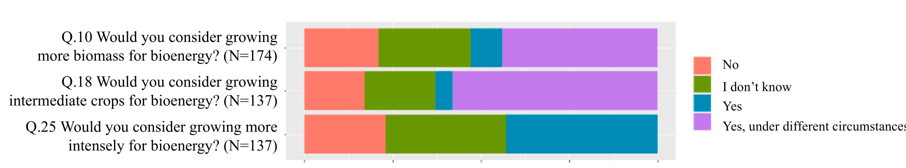

Fig. 2. Percentage of farmers willing to increase production of energy crops or residuals for bioenergy purposes, given that it does not compete with current production. 137 out of the total 174 surveyed were willing to more biomass for bioenergy purposes by growing intermediate crops or more intensely.

additional crops on arable land by cultivating intermediate crops and harvesting biomass on EFAs to provide profitable opportunities with low-maintenance cultivation and use of underutilized lands (17). Intermediate crops were of particular interest to many farmers with crop cultivation. However, some farmers growing intermediate crops reported that these crops were not harvested for biomass due to a lack of demand. There were also practical issues with growing and harvesting intermediate crops, such as hindering tillage in fall and negatively affecting the soil quality if the crops were harvested in the wrong weather conditions (19). Farmer 5, who currently leaves his intermediate crops in the field to improve soil quality, found flexibility to be critical when sowing intermediate crops, where using the biomass for feedstock was one out of three options: *"Either you can have animals graze it down if there is a lack of feed, or you harvest it for animals. The alternative is biogas if it is suitable, but if it is a wet autumn and you don't want to drive in the fields, you can let it be and rot in the field to improve the soil and build up mulch. With the right choice, there is no downside really to any alternative. But finding a recipient who is just as flexible is important."*

Given that crops on EFAs would still have positive ecological impacts, several farmers were open to harvesting biomass from these areas. Several farmers commented that they would rather have EFAs and fallow lands as a part of the crop rotation, where soil-improving crops could be grown and biomass harvested for bioenergy purposes. EFAs integrated into the crop rotation were argued to refrain from competing with food production if the soil-improving measures would increase the yields of food crops in the coming years.

About two-thirds (63%) of the 137 farmers in the survey who would consider producing biomass for bioenergy were optimistic about harvesting intermediate crops for bioenergy. However, more than half (58%) would only do so under other circumstances (Fig. 2). When these 80 farmers were asked to choose up to three factors that would motivate them to grow intermediate crops, the most common factors were: 1) that they wanted to get better paid for intermediate crops (75%, i.e., 60 out of these 80 farmers), 2) increased demand for the crops (41%, 33 farmers), and 3) more financial support (25%, 20 farmers). Other circumstances mentioned in the optional comments were if the yield could be increased by using fertilizer.

Farmers were strongly willing to harvest bioenergy from EFAs if permitted (Fig. 2). Of these 137 farmers, 57% had ecological focus areas (i.e., 78 farmers). Most farmers said they would use these areas for intermediate crops, harvest grass that could be sown into the main crop, or sow plants on unused field edges. Only a few farmers (12%, i.e., only 9 farmers) were not interested in it (see Fig. 3 and Appendix A4). One of the significant barriers brought up was that cultivating these lands would be too costly. One farmer wrote that these lands were: "*Too small and often poor area to spend time sowing and harvesting something there, the fallowed lands are often in fallow for that reason. The field edges are too cumbersome and expensive to sow and cultivate*". A few farmers also mentioned using their ecological focus areas to cultivate flowering crops instead.

3.2.3. Related to producing feedstock on underutilized land

Both interviews and surveys indicated that the farmers are open to using unproductive or underutilized land for growing energy crops. However, several barriers to using unproductive or underutilized land for bioenergy production are identified. Firstly, both interviewed and surveyed farmers brought up the limited potential of using marginal lands such as field edges and small and irregular lands, as these were costly to harvest and often served a purpose for ecological benefits. This was reflected in the survey responses, which found a greater interest in growing energy crops for biofuels than that can be produced on underutilized land. Out of the 137 farmers who would consider growing energy crops, most were willing to produce crops that can be used for type 1 biofuels (74%), which in this study was not considered a sustainable bioenergy production method. The interest in bioenergy production on underutilized land was slightly lower, such as biomass that can be sold for heat or electricity generation (67%) or used on the farm for heat and electricity production (59%). One-third of the farmers (33%) would consider producing biogas to use on their farms (see Question 13 in Appendix A2).

One of the significant barriers to cultivating energy crops on underutilized land was that the land was often unproductive and was suited for crops other than those currently grown, such as energy trees and other perennials needing different machinery. Indeed, the surveyed farmers with access to underutilized land, that could be used for bioenergy production with current regulations, showed the least interest in growing energy trees due to their long rotation time and impact on the soil (see Question 22 in Appendix A2).

Another barrier to producing energy crops on underutilized land is that most farmers include their underutilized land in fallow lands, such as ecological focus areas where harvesting is generally prohibited. Out of the 137 surveyed farmers who would consider cultivating crops for energy production, 77% stated that they did not have access to unproductive land outside of the fallowed land used for ecological focus areas (see Question 20 Appendix A2). Therefore, the possibility of utilizing unproductive land relies on changing policy regulations allowing biomass harvesting on unproductive fallowed land.

Of the 137 farmers, 22 declared they had additional underutilized land, of which 17 would consider using it for bioenergy purposes. Nearly all of them would consider using uncultivated, low-productive land, and almost as common as using uncultivated fertile land and fallowed land (Fig. 4). When asked which crops they would consider growing on the unutilized land, the most chosen crops were grass from ley, cereals, or energy grass.

3.2.4. Related to intensifying biomass production

When asked whether they would consider intensifying their current production, most of the interviewed farmers (N = 8) expressed that they already produce the maximum capacity within their economic and ecological limits. The farmers highlighted that intensification of production would either negatively impact the soil or crop or have adverse

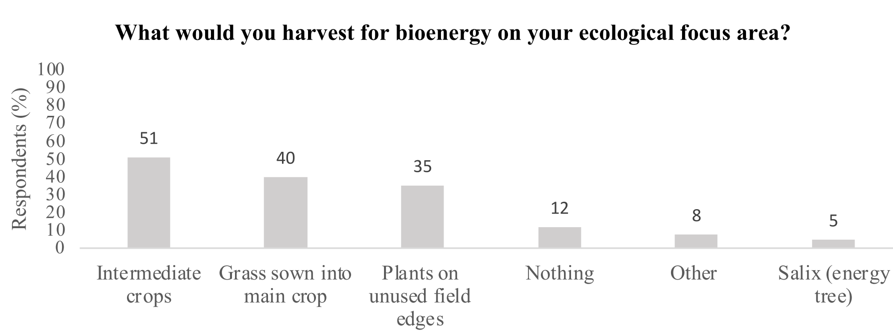

Fig. 3. Ecological Focus Areas. Biomass, which farmers with EFAs (N = 78) would be willing to grow for bioenergy purposes in their ecological focus area. The farmers were asked to choose all the options that applied.

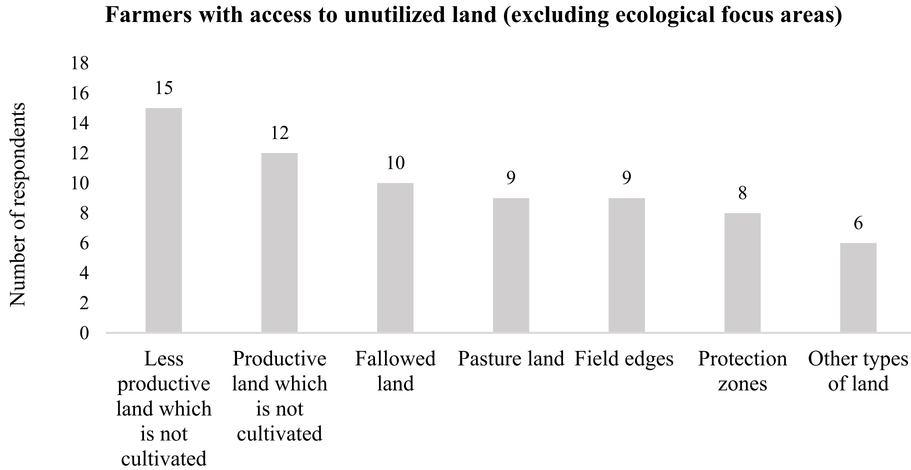

Fig. 4. Types of underutilized lands (excluding ecological focus areas) that farmers (N = 17) would consider using for bioenergy production. Arranged from most common land type to least common land type.

effects on the environment and ecosystems. Further, it would be too costly due to more fertilizer usage. Two farmers brought up rapeseed as an example of a crop they would preferably produce more, as it was profitable. Still, they had reached their area limits for avoiding diseases amongst the crops.

When asked in the survey if the farmers (N = 137) would consider agricultural intensification to increase biomass production, 43% (59 out of 137 farmers) said they would think so. In comparison, 23% would not (Fig. 2) (see Question 25 in Appendix A2). Out of the 59 farmers who would consider more intense feedstock production, a majority would increase their production of cereals (70%, 41 farmers), grass (51%, 30 farmers), and oil crops (44%, 26 farmers). The 32 farmers who would not consider intensifying production motivated this by one of the following reasons: 1) increased costs due to fertilizers and fuels, 2) ecological consequences, or 3) limitations in soil conditions. One farmer summarizes the three themes in a comment: "*More intensive production would require machine investments and possibly affect the environment more. The areas I have are well suited for extensive grazing and forage.*"

4. Conclusion and policy implications

Understanding the drivers and barriers to biomass cultivation for bioenergy is crucial for estimating the production potential of the agricultural sector to contribute to renewable energy. This study identified substantial drivers and barriers influencing farmers' willingness to use low iLUC-risk production methods for biomass production for energy purposes. The study provides a spectrum of motivational factors amongst farmers rather than an attempt to generalize these factors or weigh them against one another. Furthermore, the results are based on the farmers' experience of the drivers and barriers in their routine farming operations. Thus, the identified drivers and barriers do not automatically translate to what is socioeconomically motivated. Further, the limited number of interviews conducted was an indicative sample and may not represent all farmers in Scania. Thus, a larger sample size can avoid any potential inherent bias and further improve the quality of the findings. Finally, the study has focused on a region in Sweden with a high density of farmers and fertile farmland. For comparative studies, additional regions must be included to put these results in a broader context and draw conclusions for Sweden.

This section provides an overview of policy needs and recommendations to address the significant drivers and barriers to producing low iLUC-risk feedstock for bioenergy purposes (Table 4).

4.1. Policy needs to address the drivers and barriers

4.1.1. Related to administrative instruments

Interviews and surveys revealed that many farmers prefer to rely on an increased demand from the market for increasing biomass production for energy purposes (see Sections 3.1.5 and 3.2). The study also pointed out that subsidies can play an essential role in creating this demand and supporting farmers during a transition towards a market where these crops are used, as well as supporting investments in facilities and machinery. These subsidies can also influence attitudes and motivation to adopt a specific crop or measure. For example, sowing wildflower strips has been established within agri-environmental schemes and management advice across Europe in the past decade (Haaland et al., 2011), which several farmers mentioned as an essential conservation practice and contribution to biodiversity. Increased awareness and production could be expected if similar subsidies and management advice were given to biomass cultivation for bioenergy.

The study found that while farmers are interested in increasing their production, this is limited by economic, ecological, regulatory, and policy constraints. For instance, removing organic matter could have undesirable effects on the soil organic matter (Björnsson and Prade, 2021). Despite this, there was a particular interest amongst many farmers in using agricultural residuals and additional feedstock from arable land, mainly through cultivating intermediate crops. Using the low iLUC-risk methods (e.g., intensified production of grassland with the highest potential for sustainability) calls for increased flexibility in feedstock management, which can result in an uneven supply. For instance, harvesting intermediate crops for bioenergy purposes should be one of several options depending on what is more suitable at the time of harvest, as harvesting in a wet season might result in damaged fields. With a changing climate, flexibility will become even more critical, as more extreme weather and other crises may cause changed needs.

Flexibility should also apply when forming policies. Despite acknowledging that fallow land is often made up of less productive and accessible lands, most farmers were open to using this land if it could provide them with additional profit. The same results were seen in a study by Ranacher et al. (2021), focusing on Slovakian farmers' willingness to grow short-rotation coppice, where the production of an energy crop was generally prioritized over having fallowed land. However, harvesting biomass on underutilized lands such as EFAs (P2) and fallow lands (P3) would call for changing the policies that currently prohibit harvests on these lands (i.e., lands used for EFAs).

For instance, based on a regional assessment in southern Sweden, Björnsson and Prade (2021) argue that a general restriction on straw removal in European studies is insufficient for soil organic matter

Table 4
From a policy perspective, an overview of the drivers and barriers to producing low iLUC-risk feedstock for bioenergy purposes.

Drivers	Barriers	Policy needs	
Ability to better utilize available land (that are not part of EFA) Additional financial support for transition	Cannot utilize all available land (i.e., currently uncropped) for feedstock production due to e.g., EFA Unreliable to depend on public subsidies and support (uncertain framework and financial support) Potential negative impacts on the environment with increasing demand for biomass	Financial support for initial investments to produce more feedstock for bioenergy. Support an expanded infrastructure for bioenergy derived from feedstock (e.g., initial investment in infrastructure for biogas production and consumption, and support initial demand of biogas on the market).	**Administrative instruments**
Opportunity for additional income from residuals Farmers rather invest in products that are requested on the market (with possibility for profit) rather than relying on subsidies. The market can signal demand by increasing investment into expanding feedstock production	Large investments with high risks (lack of machinery) Low profitability due to low demand Not a clear demand from market of feedstock in comparison to raw material for type 1 biofuels (based on crops). Competition between biomass for bioenergy and feedstock for cattle Lack of technical advances Lack of flexible infrastructure	Market-based instruments to increase demand of biomass derived from marginal land (e.g., biogas) over biomass competing with food (e.g. ethanol). Decentralized infrastructure supporting biofuels derived from feedstock - such as decentralized biogas facilities. Demand of feedstock for competing profitability with alternative biofuels	**Economic instruments**
Biomass contribution to domestic renewable energy production can serve as a motivational driver to produce more feedstock Positive impact on environment (e.g., additional habitats, less reliance on fossil fuels, return of fertilizer from biogas facilities)	Not enough support from governmental authorities and other actors for R&D of practices and knowledge sharing and counselling Lack of knowhow for the local/regional context Negative impacts on the environment (e.g., impact on soil, less land for conservation and regeneration	Information on the added value of growing feedstock on marginal land in comparison with other types of feedstock production methods. Information on sustainable methods for utilizing feedstock (e.g., low iLUC production method including, intermediate crops, and in what condition they can be used) Researching and sharing information on potential ecological benefits and implications with expanding biomass from marginal land (e.g., how the biomass competes with feed for livestock and soil improving measures of leaving biomass). Need for development of informative policy instruments for knowledge sharing and counselling and R&D.	**Informational instruments**
More flexible policies	Bureaucratic hurdles	Need for "flexible" policies allowing harvesting of feedstock such as intermediate crops when weather conditions allow. E.g., more flexible usage of EFA-zones.	**Transactional**

preservation in this region. However, a combination of unrestricted straw removal and cultivation of intermediate crops could increase the availability of removable straw 2.5 times at little extra cost (Björnsson and Prade, 2021). Thus, more regional studies are needed to support policymaking in this area. If not carefully designed, increased production on or removal of EFAs and fallow land for bioenergy production will imply trade-offs with other environmental objectives. Several farmers also argued that catch crops (intermediate crops) should be taken into the crop rotation on arable land, as they would improve soil structure while hindering leakage of nitrogen and phosphorus (Liu et al., 2015; Valkama et al., 2015). This practice could contribute to biomass for bioenergy without competing with food production if adequately managed, as the soil improvement allows for a larger yield of crops that are sown afterward. However, further research is needed on the environmental effects of harvesting catch crops for energy purposes and using EFAs and fallow land for energy crop production.

4.1.2. Related to economic instruments

Policies in Sweden have generally focused more on increasing the demand for biofuels rather than creating incentives to increase agricultural bioenergy production sustainably (Swedish Energy Agency, 2021b). A majority of the biofuel used in Sweden is imported (Lundberg et al., 2022), and many farmers need more demand for crops that can be grown with low iLUC-risk production methods. While the demand is predicted to increase, the feedstock that is most efficient to produce does not necessarily align with the type of biofuel that society has the highest demand for (Swedish Energy Agency, 2021b). While biofuels such as ethanol and biodiesel, made from starch and oil-rich crops, will play an essential role in meeting this demand, most of the energy crops generated from low iLUC-free production methods that farmers are willing to produce are suitable for heating and biogas production. Although producing rapeseed would be more profitable for farmers and meet the demand for fuel in the transportation sector, it is considered a high iLUC-risk production as it competes with food crops. Furthermore, farmers growing rapeseed commented that they could not increase their production as that would risk spreading diseases in the crops.

On the other hand, intermediate crops and agricultural residuals can be used for biogas production without competing for additional land while contributing to by-products that can be used as organic fertilizer to improve soil quality. However, whether this will be profitable depends on society's demand for biogas. Further, several farmers pointed out that decentralization of biogas facilities would make it more profitable for farmers to contribute with feedstock to biogas plants, as they would be closer and possibly more flexible in their demand. With uncertainties regarding long-term demand for biogas, the farmers' willingness to invest will be low due to a lack of security for their investments. Therefore, stable, long-term incentives need to be created to reduce farmers' risks in producing biomass for biogas (or bioenergy).

Furthermore, the availability of agricultural residuals largely depends on how alternative markets for residuals develop, such as feed for cattle. Over the last two decades, the number of animal farms has declined heavily in Sweden (Swedish Board of Agriculture, 2020), which may, if not decrease, then possibly centralize the need for feed to areas where larger farms are located, which may cause an excess of biomass production potential in other parts. Strategic development of biogas infrastructure in areas where animal numbers have declined could increase the production of low iLUC-risk bioenergy while mitigating farmland abandonment or afforestation.

A changing climate with a higher risk of extreme weather and droughts (Kronnäs et al., 2023) could alter the demand for straw and haulm for feed, which calls for a system where the usage of residuals is flexible concerning other markets. This requires creating multiple markets or demands for agricultural residuals to make them economically viable.

The farmers' motivation to grow biomass is affected by both personal and situational factors. In contrast, situational factors such as market demand, technical advances, and infrastructure development, are influenced by other economic sectors and stakeholders in society. Thus, a holistic approach to policymaking is needed that includes multiple stakeholders and cross-sectoral interactions.

4.1.3. Related to information

Our findings indicate a discrepancy between the estimated theoretical bioenergy potential from low iLUC-risk land seen by policy and research and the practical potential experienced by farmers. Under current policies, the farmer responses suggest that if a farmer achieves an increased production potential from intensification or cultivation of underutilized land, a prioritization for food and feed crop cultivation or environmental conservation actions is likely to occur rather than cultivation for bioenergy. More information and advice about iLUC-free bioenergy options, combined with examples of successful practices, could lessen the barrier from the experienced competition with food production and create synergies with environmental conservation.

Like Hannerz and Bohlin's (2012) findings, this study found that an uncertain demand for energy crops for low iLUC-risk methods negatively affected farmers' willingness to cultivate energy crops, as the low demand paired with uncertain yields was perceived as too risky and unprofitable (relative to the expected profitability). The significant investments and long-term planning needed for new crop production make it particularly important for farmers to know their investments will be worthwhile without excessive risk. Thus, an increased demand was found to be amongst the most prominent incentives to increase feedstock production. Growing energy crops was, however, also seen as a potentially profitable investment, primarily when it could be managed with current machinery without competing with ongoing production. This can likely act as a barrier to cultivating dedicated energy crops, such as short-rotation coppice, that require specific machinery and management and could instead favor producing crops with a higher iLUC risk, such as food and feed crops. The perception of whether feedstock production is profitable or not thus likely depends on what type of crops the farmer already cultivates, what machinery is available, and what risks the farmer associates with adopting low iLUC-risk production methods. The centrality of economic aspects is also seen in previous studies on farmers' willingness to cultivate short-rotation coppice in Slovakia (Ranacher et al., 2021) and to adopt new agricultural systems in Wales (Morris et al., 2017). These critical barriers need to be addressed by creating long-term market demand for domestic bioenergy and supporting farmers with initial investments in technologies for biomass harvesting and processing.

The knowledge obtained from interviews and surveys with farmers in Scania confirms that many of the driving factors identified in studies looking at specific energy crops, such as short rotation coppice (Hannerz and Bohlin, 2012; Ranacher et al., 2021) also apply to energy crops in a more general context. When investigating Swedish farmers' attitudes towards producing short-rotation crops or forestry, such as poplar and willow, Hannerz and Bohlin (2012) found that many farmers were motivated to contribute to a more self-sufficient energy production, which was also a prominent incentive amongst farmers in this study.

However, this study adds to the existing literature by highlighting how an ongoing political conflict in Europe affects the food and energy supply (Benton et al., 2022) and may increase farmers' willingness to contribute to energy security. Crisis and conflicts, such as the COVID-19 pandemic and the Russian invasion of Ukraine, have exposed the need for a quicker transition to renewable energy systems (Hosseini, 2022). These conflicts were brought up as a motivation amongst farmers to contribute to domestic renewable energy production, indicating that ideologies and the framing of energy production play a crucial role in adopting bioenergy production. However, crises also increase the demand for domestic food production, which could heighten the conflict regarding whether agricultural land should be used for energy production. Interestingly, although the four bioenergy production scenarios relevant to this study did not compete with food production, many farmers argued that agricultural land should be prioritized for food rather than energy. These results align with previous results (such as by Convery et al., (2012)), where farmland is thought to give the most value when used for food and feed production.

4.1.4. Related to transactional costs

Our study found the bureaucracy of applying for subsidies is seen as cumbersome, and the associated support instruments too unreliable in the long run to be relied on when making investment decisions. As mentioned earlier, the farmers prefer to rely on market-based incentives rather than subsidies. Further, uncertainties regarding the policy framework and financial support systems add to these transactional costs negatively affecting the farmers' motivations. This calls for addressing such transactional costs by devising more long-term and flexible policies.

4.2. Key policy implications

Overall, the study points a few clear policy implications of low motivation among farmers. First, the farmers saw little potential in using marginal lands due to their spatial characteristics (e.g., field edges, small, isolated, and irregular lands) and low soil productivity. Due to these characteristics, they were relatively costly to harvest and often served a purpose for ecological benefits, such as biodiversity conservation. The underutilized land is the least productive due to poor soil quality (i.e., underutilized for this reason) which can be seen as a substantial barrier for bioenergy production. Using such land for production would likely be unprofitable due to high costs of cultivation and harvesting, and the farmers might not risk their investments. This is a major policy implication. The potential of biomass production for bioenergy from marginal (i.e., underutilized) lands is likely overestimated. The marginal or underutilized lands, therefore, may be better suited for meeting other objectives such as biodiversity conservation.

Second, the study found that the farmers feel that they already produce to their maximum capacity, i.e., within their economic and ecological limits. Thus, the potential for intensifying biomass production on currently cropped land seems limited due to risks associated with negative environmental impacts and soil-productivity depletion. These policy implications are in addition to already known factors for the low interest among farmers, i.e., low profitability and risky investments. This raises an important policy question often not adequately addressed in bioenergy discussions – are we overestimating the sustainable potential to intensify? The policymakers, researchers, engineers, or energy companies may have been driving their efforts toward sustainable bioenergy production by their respective socioeconomic, political, or ecological agendas without addressing the constraints of the farmers or other intermediate actors in the supply chain. For a sustainable value chain, more collaboration among the critical societal actors throughout the bioenergy production and consumption chain is needed.

Third, given these constraints, policies may prioritize utilizing currently available agricultural residues for energy purposes. Utilizing additional agricultural residues for energy purposes (e.g., biogas production) requires more flexible and decentralized bioenergy facilities to overcome financial costs due to the transportation of biomass feedstock over long distances. Strategic development of biogas infrastructure in these areas could increase utilization of such low iLUC-risk biomass feedstock while mitigating farmland abandonment or afforestation.

Nevertheless, farmers perceive the potential to overcome the barriers they face through policy interventions. These include long-term guarantees for investments in bioenergy production through, e.g., investment support and production subsidies, investments in flexible and decentralized bioenergy facilities, and better access to consultancy services financed by the state.

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CRediT authorship contribution statement

Hedda Thomson Ek: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jagdeep Singh:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Josefin Winberg:** Writing – review & editing, Validation, Supervision, Methodology. **Mark V. Brady:** Writing – review & editing, Validation, Supervision, Methodology. **Yann Clough:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2024.114295.

Appendices.

A1. Semi-structured Interview guide

Research topic	Research questions (RQs)	Interview questions
How informed are farmers on bioenergy production?		
Demographic information about the farmer:	What information about the farmer and the farm	What is your age? Where in Scania is your farmland? How many acres agricultural land do you cultivate? What type of crops do you cultivate? What is your main direction?
Experience with agricultural energy production:	What experiences does the farmer have with agricultural bioenergy production?	How familiar are you with how agricultural feedstock can be used for bioenergy? Do you currently produce feedstock for energy purposes? If yes: What type of energy crops/residuals do you produce for bioenergy use purposes? For how long have you produced crops/residuals used for bioenergy purposes? What motivated you to start growing energy crops?
What is the potential for producing biomass for bioenergy?		
Willingness to start or increase feedstock production for bioenergy purposes	Would the farmer consider starting new or increasing current low iLUC-risk production of feedstock?	Would you be willing to increase/start the production in ways that does not compete with food production? Yes, as it is today. Yes, under other circumstances. No, not even with increased profitability
Willingness to increase production through low iLUC-risk production methods	Could the farmer increase feedstock production though using residuals?	Would you consider starting/increasing feedstock production using residuals? Yes, as it is today.

(*continued on next page*)

(*continued*)

Research topic	Research questions (RQs)	Interview questions
		Yes, under other circumstances. No, not even with increased profitability.
	Would the farmer increase feedstock production using additional feedstock derived from arable land?	Would you consider producing feedstock for bioenergy purposes using productive lands which are not used for food production? I.e., intermediate crops and ecological focus areas? Yes, as it is today. Yes, under other circumstances. No, not even with increased profitability
	Would the farmer increase feedstock production using feedstock from underutilized land?	Would you consider using underutilized land which could potentially be used for energy crop production? I.e., Abandoned farmland, field edges, turning zones, small and irregular lands, fallow land) Yes, as it is today. Yes, under other circumstances. No, not even with increased profitability
	Would the farmer increase feedstock production by intensifying current production?	Would you consider increasing current production through intensifying current production? I.e. Grass production Yes, as it is today. Yes, under other circumstances. No, not even with increased profitability
Follow up questions for options: **Yes, as it is today.** **Yes, under other circumstances.** **No, not even with increased profitability**	What would the farmer grow if increased/new production?	What crop would you produce?
	Under which circumstances would the farmer start/ increase low iLUC-risk production methods?	Under which circumstances would you start increase feedstock production? Does it matter if profitability comes from the market prices or subsidies and financial support? What crop would you produce?
	How would farmers increase production indirectly?	Why would you not consider starting or increasing feedstock production?
What motivates/demotivates farmers for biomass production for bioenergy?		
What motivates/demotivates an increased production?	What factors would motivate farmers to increase feedstock production for energy purposes?	What benefits do you see with producing biomass? What would motivate you to produce more feedstock for bioenergy (using low iLUC-risk production methods)?
	What obstacles do farmers experience in increasing/ new energy crop production?	What obstacles do you see with starting/increasing production for energy purposes (in low iLUC-risk production methods)
Agricultural sector's role in energy production	What is the farmers overall attitude to growing bioenergy deriving from agricultural land?	What role do you think the agricultural sector should play in producing bioenergy?
Round up.	Additional thoughts/questions?	Do you have any additional thoughts/questions on the topic? Do you have any other questions about the study?

A3. Tables summarizing key information

Table A3.1
Incentives (all farmers).
Factors that farmers (N = 174) experience are incentives with growing biomass for bioenergy purposes when asked to choose up to three of ten factors. (Q28)

Incentives with factors to produce biomass for bioenergy	Numbers of persons answering yes	Percentage (%)
It contributes to society's energy supply	75	21
I can be more self-sufficient in energy	51	14
I think it will be more profitable in the future	51	14
It benefits ecosystem services (e.g., game habitats and pollinators)	46	13
I see no benefits	42	12
I get back important residual products (e.g., for fertilization)	38	11
I can spread the risk in the crop rotation on what I grow	33	9
I can apply for support and subsidies	10	3
Other factors	6	2
It provides a secure return	5	1

Table A3.2
Incentives (farmers with ongoing production).
Factors that farmers who produce bioenergy on their farms (N = 17) experience are incentives with growing biomass for bioenergy purposes when asked to choose up to three of eight factors. It is calculated based on the number of responses (not on the number of respondents) because the respondents could choose up to three options (Q8).

Incentives with producing biomass for bioenergy purposes	Number of persons answering yes	Percentage (%)
It contributes with energy to the society	8	23
I can produce heat or electricity on my farm	7	20
It can be sold for a good price	6	18
I can use my land more efficiently	5	15
I will be able to sell it for a good price in the future	4	11
It fits in the crop rotation	2	6
I can apply for subsidies	1	3
Other	1	3

Table A3.3
Barriers to using residuals. Barriers for producing residuals, which farmers (N = 137) agreed with when asked to choose up to three barriers for using residuals for bioenergy production. (Q24)

Barriers for using residuals for bioenergy	Number of persons answering yes	Percentage (%)
I cannot finance a facility to produce bioenergy on my farm	56	23
It is not profitable enough	53	22
There is not big enough of an interest to buy residuals	36	15
I don’t have enough storage space to store residuals	34	14
I am already using the residuals for other purposes (e.g., feed)	30	12
Other	18	7
I don’t see any barriers	16	7

Table A3.4
Barriers (all farmers).
Farmers (N = 174) experience barriers to growing biomass for bioenergy purposes when asked to choose up to three of ten factors. (Q29)

Barriers and negatives for producing biomass for bioenergy	Number of persons answering yes	Percentage (%)
It competes with other types of crop production	81	21
I do not get paid enough for energy crops/bioenergy residues.	73	19
Nutrition is removed from the soil.	52	13
I do not have the tools or the machines to grow for bioenergy.	40	10
I need more knowledge	38	10
There are difficulties with logistics around e.g., harvesting/storage/transport.	34	9
There is not enough financial support to grow bioenergy.	32	8
It does not fit in my crop rotation	19	5
Other	12	3
I don’t see any negatives.	9	2

Table A3.5
Motivational factors.
Factors that farmers (N = 174) experience as motivational factors to start or increase biomass production for bioenergy purposes when asked to choose up to the three factors. It is calculated based on the number of responses (not on the number of respondents) because the respondents could choose up to three options (Q30).

Motivational factors for producing biomass for bioenergy	Number of persons answering yes	Percentage (%)
Increased market prices for energy crops and residuals	102	28
More long-term financial support	42	11
Higher demand for bioenergy in society.	42	11
Better/closer infrastructure for taking care of and converting energy crops and residues into bioenergy.	39	11
Less regulations regarding cultivation for bioenergy.	35	10
Nothing can motivate me.	33	9
Better access to tools/machines needed for handling energy crops (e.g., sowing/harvesting)	22	6
More guidance for energy crop production.	29	8
Another factor.	10	3
Easier access to financial support	10	3

Table A3.6
Residuals for bioenergy.
Percentage of farmers who get agricultural residuals (N = 137) when asked if they would consider using it for bioenergy purposes. (Q23)

	Straw	Haulm	Manure	Other
I get the residual product and *would consider* using it for bioenergy purposes.	36	19	31	11
I get the residual product but *would not consider* using it for bioenergy purposes.	19	10	12	2
No, I don't get this type of residuals	37	65	54	69
I don't know	7	6	3	19

Table A3.7
Intermediate crops. Motivational factors for farmers to grow intermediate crops for biomass production when asked to choose up to three factors. (Q19)

Motivations to grow intermediate crops for bioenergy purposes	Number of persons answering yes	Percentage (%)
If I got better paid for the intermediate crops	60	33
If there was more interest in purchasing intermediate crops	33	18
If I received support or grants to sow and harvest the intermediate crops	20	11
If it was less costly to sow and harvest	17	9
If I could get better advice on how to grow and harvest intermediate crops	16	9
If I can sow or harvest them in a way that affects the soil less.	13	7
If the facilities purchasing the intermediate crops were closer	10	6
Other	6	3
If the facilities that buy in the intermediate crops were more flexible in how often and how much they want.	4	2
I don't know	2	1

Table A3.8
Intensified production. Comments written by farmers (N = 23) when asked why they would not consider intensifying their production. (Q27)

Barriers	Comments (C21–C26)
Increased costs (1)	"The input costs today are too high, i.e., fertilizer and diesel"
	"It is difficult to grow more intensively than is already being done. Especially with the prevailing external situation and shortage/costly inputs"
Environmental consequences (2)	"Catastrophe for the environment and poorer quality of straw hay sustainability"
	"Intensive cultivation rhymes poorly with organic farming, and can lead to increased energy consumption/ha, which takes advantage of more"
Limitations in soil conditions (3)	"The fields are too small and in poor condition"
	"I grow as intensively as I can (now) already. Of course, I try to improve my cultivation continuously, but it is mostly increased fertility that can give a higher harvest now"

Table A3.9
Barriers to bioenergy production- A selection of comments from farmers who would not consider producing feedstock for bioenergy when asked why they would not consider this (Q12).

Barriers	Comments (C3–C10)
Competition with feed and food (1)	"I need all my farm for cultivating animal feed and grazing for my meat animals"
	"We must provide Sweden with food"
Low profitability (2)	"It is almost impossible to get it harvested today. No one can or thinks it is profitable anymore. Very sad!"
	"The energy forest I have has been a very bad business"
Limited space for additional production (3)	"The small area is needed for producing only fruit to achieve profitability."
	"Have too small area, cultivate food for the pigs"
Environmental consequences (4)	"The added value is too low for the energy you get; animal products provide more for food and for sustainability such as biodiversity and carbon storage".
	"It is madness to take energy away from land, when energy can be extracted more efficiently with nuclear power plants."

A4. Figures summarizing key information

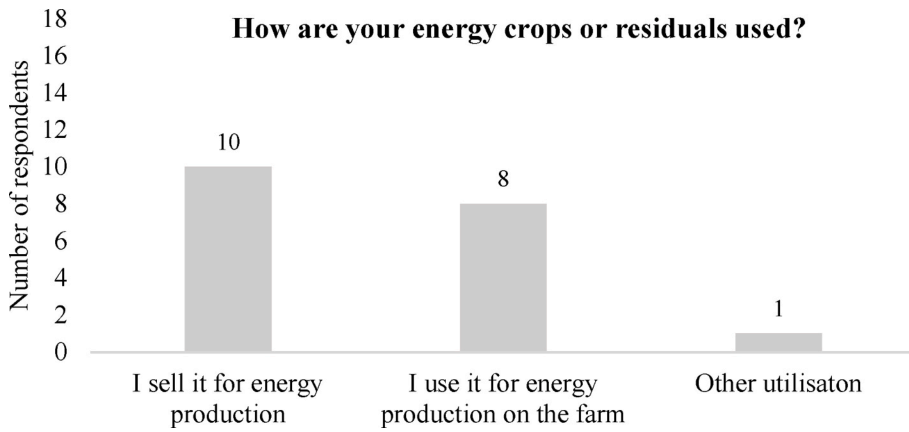

Fig. A4.1. Usage of bioenergy. How farmers are using energy crops and residuals for bioenergy (N = 17) and are using their feedstock for external or on-site energy production (Q7).

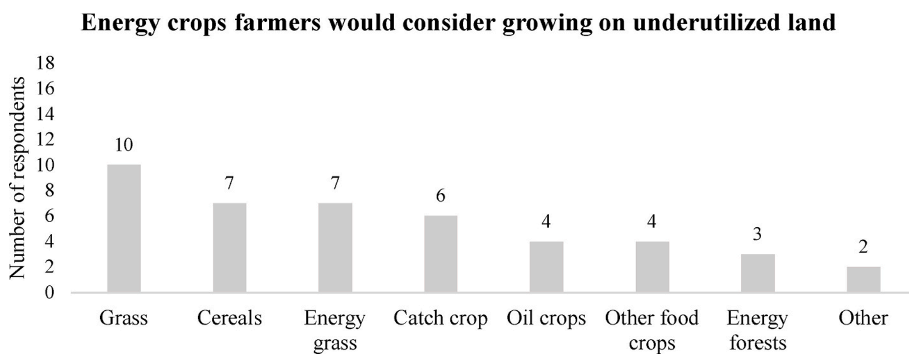

Fig. A4.2. Underutilized lands. Energy crops that farmers (N = 17) would consider growing on their underutilized lands. (Q22).

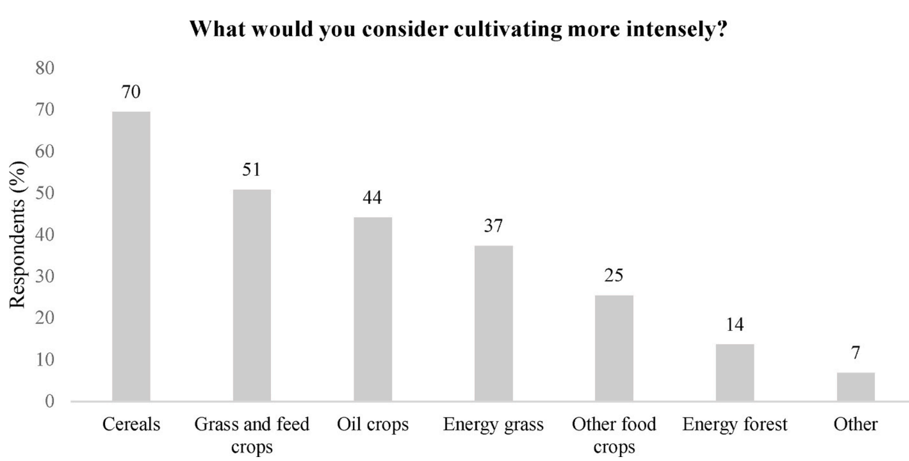

Fig. A4.3. Crops for intensified production. Crops that farmers (N = 59) who would consider growing more intensely for bioenergy purposes would consider cultivating. (Q26).

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