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Farmers' willingness to introduce short-rotation tree plantations on agricultural land: A case study in southern Sweden

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ABSTRACT

To meet climate targets, expanding *Populus* spp. tree cultivation is proposed as a potential biomass feedstock, especially on agricultural land that does not come into conflict with food production. However, biomass potential assessments typically overlook landowners' perspectives, risking a gap between theoretical potentials and realisation. Here, we test empirical consequences of two hypotheses based on a survey targeting southern Swedish farmers: 1) Relying exclusively on agricultural land cover data to identify abandoned agricultural land leads to an overestimation of the total agricultural land that can be utilised for future biomass production from *Populus* spp. feedstocks. 2) The absence of data on farmers' intentions to cultivate fast-growing tree species on agricultural land leads to overestimation of the potential biomass supply from *Populus* spp. in biomass assessments. Findings suggest that less than 50 % of farmers with unsubsidised arable land, which is often assumed to be abandoned, would consider cultivating these tree species on this type of land (26 % [7–48]). Furthermore, only 11 % [6–17] would consider cultivating *Populus* spp. on agricultural land overall during 2021–2030, indicating a generally low level of interest among farmers. However, higher rates were observed in forested areas. The projected near-future cultivation potential of 2.0 kha [1.1–3.0] suggests an at least threefold overestimation in previous theoretical assessments. This study highlights a disparity between biophysical land data and producer perspectives, showing that neglecting farmers' perspectives risks overestimating the biomass supply, potentially leading to misguided expectations and inefficient policies. Our findings support targeted policy recommendations.

1. Introduction

In line with the European Green Deal, the transition to make the European Union (EU) climate-neutral by 2050 requires an increased share of renewable energy (RE) in the energy sector. Given the need to speed up the EU clean energy transition, the Renewable Energy Directive (RED) [1] was revised in 2023 with a binding target of at least 42.5 % RE in the EU's gross final energy consumption by 2030 [2].

Biomass is a versatile renewable energy source that can be transformed into a spectrum of energy carriers and bio-products, including heat, electricity, transportation fuels and chemicals. This flexibility not only aids in broadening the bioenergy supply and supports the EU in meeting its RE targets, but also plays a vital role in reducing the EU's reliance on imported fossil fuels [2].

However, biomass must be produced, harvested and converted without causing undesirable impacts or greenhouse gas (GHG) emissions elsewhere. The potential drawbacks connected to indirect land-use change (iLUC) are frequently highlighted in the debate regarding the sustainability context of using land dedicated to energy [3,4]. Loss of biodiversity, competition with food, feed and fibre, and uncertainties surrounding GHG emission reduction abilities are all examples of negative consequences (often referred to as trade-offs) mentioned within this debate [5,6]. Consequently, attention is frequently directed towards the utilisation of 'surplus', marginal and abandoned areas [7–10]. Using this type of land to produce biomass for energy and other bio-based products is usually assumed to avoid direct conflicts with food production and negative iLUC effects. Moreover, it has been suggested to curb land abandonment, provide job opportunities and bolster economic viability within rural regions [11].

Strategically integrating woody energy crops into the more fertile

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regions of the agricultural landscape can unlock synergistic benefits. For example, these cultivations can play a dual role in reducing fossil GHG emissions while simultaneously having a positive impact on other critical aspects, including mitigating soil erosion, promoting biodiversity, enhancing water and soil quality, and increasing soil carbon sequestration [12–15]. A conversion of intensively managed agricultural land to perennial cultivations can thereby effectively contribute to mitigating adverse impacts stemming from agriculture while supporting the growing use of bioenergy and other bio-based products [14–16].

Several studies have proposed expanding the cultivation of fast-growing tree species, such as *Populus* spp., on agricultural land to enhance biomass potential in the EU [10,17,18]. *Populus* spp. are among the fastest-growing deciduous tree species in the EU, and due to their high productivity, early growth culmination and ability to regenerate via stump and root shoots, they are well suited for short rotation plantation (SRP) systems [19,20]. These systems offer flexibility, with options ranging from highly intensive cycles harvested every three to five years [21] to longer rotations spanning approximately 20 years [9].

However, the area of SRP devoted to biomass production in the EU remains limited, with the total area of perennial biomass crops stagnating, despite significant investments in research and development and public-private initiatives, such as those led by the EU's Biomass-Based Industries Consortium [22,23].

This stagnation has been attributed to uncertainties faced by potential growers and supply chain managers, including technical crop management challenges [24] and insufficiently coordinated policy support from governments to establish a sustainable market for the biomass produced [25,26]. Other barriers have also been identified, such as reduced land use flexibility [27], trade-offs between food and fuel production [11] as well as heritage aspects of land [28,29].

Regional differences in adoption rates and factors influencing these outcomes have been reported [22]. Sweden is often recognised for its pioneering role in developing SRPs [13,30,31]. The primary focus pertains to the expansion of *Salix* spp. on agricultural land in the early 1990s. Driven by favourable support systems and optimistic market expectations [32], the area cultivated with *Salix* spp., peaked around 2000, with approximately 14,000 ha under cultivation, equivalent to roughly 0.5 % of the total arable land [33]. However, this peak was followed by a gradual decline, and by 2023, only 3900 ha cultivated with *Salix* spp. were officially registered [34]. This decline has been attributed to various factors, including increased cereal prices, reduced subsidies, poor plantation performance, management issues and increased incineration of waste in district heating plants [22,33,35,36]. The area cultivated with *Populus* spp. on former agricultural land in Sweden currently accounts for almost 3 kha (equivalent to 0.1 % of the agricultural land), of which slightly more than a quarter consists of hybrid aspen and the rest is poplar [37].

According to a recent review by Clifton-Brown et al. [23], the adoption of *Populus* spp. and other perennial biomass crops has been limited in Germany, with significant barriers including technical uncertainties, insufficient policy support, and concerns about land-use change and environmental impacts, while in the UK, where larger areas of perennial biomass crops have been established, only small trials of *Populus* spp. have been established and adoption has been similarly limited due to market uncertainties, policy misalignments and the ongoing "food versus fuel" debate.

Despite the fact that a significant portion of agricultural land in the EU is privately owned [38], much of the research on biomass potential overlooks the perspectives of landowners and intended producers [6, 39–41]. As Clifton-Brown et al. [23] highlight, land managers will ultimately decide the extent to which land is allocated to biomass production, with policies needing to account for local conditions. Understanding these local perspectives is crucial, as they directly influence the feasibility of expanding biomass cultivation on agricultural land. The present study addresses farmers' perspectives on cultivating *Populus* spp. in a Swedish context.

1.1. Overview of the potential of Populus spp. cultivation on agricultural land in Sweden

1.1.1. Cultivation of Populus spp

Compared to *Salix* spp., which is grown under more intensive management practices [42], *Populus* spp. usually grows to larger dimensions in Sweden, with lower stem density and longer rotations [9]. Depending on management goals, a final felling is typically scheduled within ten to 30 years [43]. Several studies report on various aspects of *Populus* spp. cultivation, such as their establishment and management (e.g., Refs. [44,45]), production (e.g., Refs. [42,46–49]), their role as carbon sinks (e.g., Refs. [50,51]), bioenergy applications (e.g., Refs. [9,52]) and their impact on biodiversity (e.g., Ref. [53]).

1.1.2. Strategies to identify agricultural land suitable for short-rotation plantations

Like other European nations, Sweden has seen a decades-long decline in arable land [54]. Between 1980 and 2022, the amount of arable land decreased from about 3 to 2.5 Mha [55], and this area is projected to continue to decrease by a further 0.5 Mha by 2050 [56]. Various studies have focused on the ongoing reduction of arable land, highlighting the potential for using abandoned areas for the cultivation of *Populus* spp. (e.g., Refs. [47,57,58]). However, assessing the area that is potentially available for new cultivation has been challenging, since the land boundaries are not clearly defined between the official agricultural and forest land statistics [58]. Moreover, it is difficult to identify the current status of this area due to the lack of management data [59].

Data concerning land management activities in Sweden are chiefly sourced from the Swedish Board of Agriculture's administrative register for area-based support, known as the block database [58]. The block database encompasses data on geographic regions classified as agricultural land according to EU delineations [59], serving as the primary guide for agricultural financial support [57]. However, the relevant management information will be lacking if a landowner fails to apply for agricultural support [57]. Although a landowner is supposed to give notice if agricultural land is taken out of use, this is rarely done in practice [58]. Consequently, there are large areas of agricultural land where information about further management is missing. This unsubsidised land is commonly referred to as abandoned (e.g., Refs. [9,59]). In the subsequent sections, arable land lacking financial support will be designated as "unsubsidised arable land".

To broaden the scope of potentially available agricultural land for woody biomass production while avoiding food and feed land-use conflicts, other areas – such as fallow land, unspecified arable land and land referred to as extensive lay production – have been accounted for [9]. In some cases, all agricultural land has been considered [17].

1.1.3. Examples of biomass potential assessments targeting agricultural land

A 2009 government-initiated investigation identified a maximum of 400 kha of arable land that, in the long run, could provide approximately 6 Mm^3/year of woody biomass when planted with a mix of spruce (30 %) and hybrid aspen [58]. Considering a density of 0.35 Mg m^{-3} for the wood [60], this would correspond to about 39 PJ/year (higher heating value, HHV). This assessment included 140 kha of arable land that has become unsubsidised during the past 20 years, as well as an additional 260 kha of arable land that may become available over the next 40 years.

In a Geographic Information System (GIS) analysis using a variety of official maps, including the block database, Olofsson and Börjesson [59] identified a total of 88 kha of unsubsidised arable land which, if cultivated with poplar or hybrid aspen, could result in an annual energy output of around 10 PJ (HHV).

Böhlenius et al. [9] identified a total of 479 kha, consisting of a combination of unsubsidised arable land and arable land that does not come into conflict with food or feed production, and that could potentially be utilised for large-scale cultivation of poplar or other fast-growing tree species. Under the assumption of 25 % utilisation, this land was considered to yield 0.9 million Mg of dry weight (DW) per year, equating to approximately 17 PJ/year (HHV).

In the assessments mentioned above [9,58,59], all unsubsidised arable land was assumed to be abandoned. However, information about whether or how the owner uses this unsubsidised land is limited. This motivated an explorative study in the form of nine semi-structured interviews with landowners identified as having unsubsidised arable land (see Appendix A, Text A.1). The explorative study's primary outcome was that most of this unsubsidised arable land should fulfil a function for the individual landowner. Only three interviewees reported that their unsubsidised arable land had no specific function (see Appendix A, Table A.1).

Well-defined and transparently documented biomass potential assessments, including limitations such as technical, ecological and economic considerations [61], serve as tools for, e.g., evaluating feedstock options and gaining insights into suitable geographical locations. However, there is a deficiency in subsequent studies when it comes to examining the landowner's willingness to realise these potentials. This oversight is particularly pronounced regarding Swedish farmers' perspectives on hybrid aspen and poplar, a concern highlighted by Ostwald et al. [62] as early as 2012. While individual landowners will play a vital role in the future biomass feedstock supply chain, this perspective remains significantly under-researched more than ten years later.

1.2. Aim and objectives

The present study assesses the alignment between farmers' willingness to expand the area used for SRP's in the county of Scania, southern Sweden, and previous biomass potential assessments. Building upon a literature review and an explorative pilot study, we formulated and tested the following hypotheses using data from a survey conducted among farmers:

1) Relying exclusively on agricultural land cover data to identify abandoned agricultural land leads to an overestimation of the total agricultural land that can be utilised for future biomass production from *Populus* spp. feedstocks (cf. explorative study, see Appendix A, Table A.1), and
2) The absence of data on farmers' intentions to cultivate fast-growing tree species on agricultural land leads to overestimation of the potential biomass supply from *Populus* spp. in biomass assessments (cf. [63]).

More precisely, we tested the following empirical consequences of the two hypotheses:

1a) Less than 50 % of farmers with unsubsidised arable land in Scania, Sweden, would consider cultivating hybrid aspen or poplar on their unsubsidised arable land, and
2a) Less than 50 % of farmers in Scania, Sweden, would consider cultivating hybrid aspen or poplar on their agricultural land during 2021–2030.

The results were used to estimate the current realisable potential of *Populus* spp. on agricultural land during the period 2021–2030 in Scania, Sweden. This outcome was compared to previous biomass potential assessments that do not account for farmers' willingness to introduce short-rotation species on their agricultural land, and potential policy implications were suggested.

2. Material and methods

2.1. Study area

Scania County, situated in southern Sweden (see Fig. 1), is distinguished by its substantial agricultural land coverage (45 %) [64] and a high number of agricultural enterprises (n = 7.6k) [65]. The arable land in Scania is the most fertile in the country [66], and agricultural production is dominated by annual crops, mainly cereals [67]. However, there are large differences in land use within the county. Lowland coastal areas are predominantly covered by agricultural land (60–81 %), whereas northern central areas are primarily forested (5–19 %), with intermediate areas falling in between [67] (Fig. 1). In 2020, the registered area cultivated with hybrid aspen and poplar on agricultural land in Scania amounted to 798 ha [37]. This area is equivalent to 0.16 % of Scania's total agricultural land (490 kha) [65], or 0.18 % of total arable land (435 kha), excluding pasture land [55].

2.1.1. Survey

Building on the insights obtained from the explorative pilot study (see Appendix A, Text A.1) and the literature overview, an unstratified broad internet-based survey was conducted to reach a wide-ranging sample of farmers. A random sample of 2567 farmers, corresponding to 50 % of all main members of the Federation of Swedish Farmers (LRF) in Scania, were selected and invited via e-mail by LRF to participate in a web-based survey. In relative terms, this parent member group encompasses approximately 85 % of all agricultural holdings recorded in the farm register in Scania [65,68].

The questions were formulated in Swedish, and the questionnaire was constructed and made accessible using the survey tool Netigate [69]. The questionnaire included a cover letter (see Appendix B, Text B.1) informing the participants of the study's objectives, that participation in the survey was voluntary and that none of the questions were compulsory to answer. The survey comprised 30 questions (see Appendix B, Table B.1). Responses to nine of the 30 questions were used for data analysis in this study (Table 1), with four questions exclusively tailored for respondents with unsubsidised arable land (Table 1).

The survey was deployed on February 17, 2021 and remained open until April 23, 2021. A reminder about participation was issued once to all of the farmers in the sample. A total of 179 respondents submitted responses to the questionnaire, yielding a response rate of 7 %. Of these, 48 responses were excluded due to incomplete information. A refined

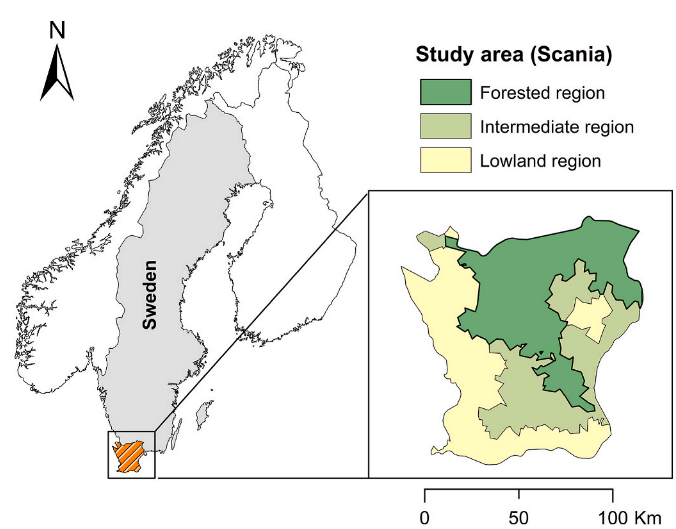

Fig. 1. The study area, Scania, is located in southern Sweden. The colour coding indicates three dominant types of land use. Made with Natural Earth. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Questions with response options analysed in the present study. See Appendix B, Table B.1 for the complete questionnaire.

Number	Question	Response option
Q1a	On the farm you operate, do you have any agricultural land that was not included in any subsidy application to the Swedish Board of Agriculture during 2020?	Yes No Don't know
Q1b	How has the agricultural land not included in your application for any agricultural financial support been used in the past, and how many ha does it comprise?[a]	Arable land:____ha Pasture land: ha Don't know:___ha
Q1c	What function does the agricultural land not included in any agricultural subsidy application currently serve?[a] (Multiple response options allowed)	Pasture Cultivation of agricultural crops Other cultivation Biodiversity Game management Personal value It does not fulfil any function Don't know Other function (specify)_____
Q1d	Would you consider cultivating hybrid aspen or poplar on the agricultural land that was not included in your agricultural subsidy application?[a]	Yes, definitely Yes, probably Don't know Probably not Definitely not
Q2	In the coming decade (2021–2030), would you consider cultivating or increasing the cultivation of the following options on your agricultural land: a) Hybrid aspen? b) Poplar?	Yes, definitely Yes, probably Don't know Probably not Definitely not
Q3	In which harvest zone is the land you cultivate located?[b]	Forested region Intermediate region Lowland region Don't know
Q4a	How many ha of arable land does the farm you manage encompass? (Include both owned and leased arable land, but exclude arable land you lease out.)[c]	It does not have any arable land It has ha of arable land
Q4b	How many ha of pasture land does the farm you manage encompass? (Include both owned and leased pasture land, but exclude pasture land you lease out.)[c]	It does not have any pasture land It has ha of pasture land
Q5	Do you have any other comments?	Free text option

[a] This question was contingent on a "Yes" response to Q1a.
[b] The response options have been aggregated into production regions in accordance with Appendix C, Table C.1.
[c] Leased out agricultural land was excluded to avoid double counting of land.

sample of 131 responded to the questions used in this study (5 % response rate), representing 2 % of the farming community in Scania.

2.2. Statistical analysis

A Bayesian binomial test was employed to test whether the relative frequency of a group is less than 50 %. The estimated relative frequency was deemed significantly less than 50 % when the probability of the estimated relative frequency being lower was 95 % or more. Additionally, this test was applied to determine the 95 % credible interval (CI) associated with the parameter(s) of interest, signifying that, based on the evidence from the observed data, there is a 95 % probability that the true (unknown) estimate falls within the interval.

A Bayesian proportion test was conducted to assess disparities between the relative frequencies of two groups. Significance in group differences was inferred by determining the posterior probability that the relative frequency of success in one group differed from zero, with a threshold of 95 % or more, indicating statistical significance.

In our analysis, a non-informative uniform prior distribution (Beta 1,1) was specified in all tests to reflect a lack of previous information regarding the relative frequencies. All observations were assumed to be independent.

The open-source software R Project for Statistical Computing v. 4.2.3 [70] was used for all statistical analyses using the Bayesian First Aid package [71].

2.3. Biomass potential estimation for poplar and hybrid aspen in southern Sweden, accounting for farmers' willingness to cultivate

The realisable biomass potential of hybrid aspen and poplar in Scania was estimated using a three-step process. Firstly, the number of prospective producers was derived by multiplying the proportion (average and estimated CI) of farmers who would definitely or probably consider cultivating hybrid aspen or poplar on any of their agricultural lands during the period 2021–2030 (Q2 in Table 1) by the number of agricultural holdings possessing arable and/or pasture land according to the farm register in Scania as of 2021 [65].

Secondly, each prospective producer was assumed to cultivate a stand with the size of recently established hybrid aspen and poplar stands in Sweden, thereby generating a projected area of hybrid aspen and poplar cultivations within 2021–2030 in Scania. The size of recently established poplar plantations in Sweden is approximately 2 ha, and the corresponding figure for hybrid aspen is approximately 3 ha [33]. In Scania, this would amount to 3–5% of the county's average size of agricultural holdings [65].

Thirdly, an estimated biomass production capacity was calculated for all stands based on the projected cultivation of hybrid aspen and poplar, and this estimate was then converted into an estimated energy capacity. The conversion factors utilised are presented in Table 2.

2.3.1. Previous biomass potential assessments used for comparison with this study estimate

The biomass potential estimated in this study was compared with findings from two earlier resource assessments, which identified Scania as a suitable region for expanding hybrid aspen and poplar cultivations.

Olofsson and Börjesson [59] identified that 6.76 kha (equivalent to around 1.5 %) of Scania's arable land did not receive any subsidies and was not affected by any significant land cover changes. This area was inferred to be abandoned and potentially available for *Populus* spp. cultivation.

Meanwhile, Böhlenius et al. ([9]) identified 22 kha of arable land inferred to be abandoned by cross-referencing statistics from the Swedish Board of Agriculture with the total agricultural area documented in the Land Survey's property database. Additionally, they pinpointed 31 kha of fallow land, extensive ley, and unspecified arable land that was presumed to be free from conflicts with food or feed production. Their assessments assumed a potential utilisation of 25 % of

Table 2
Conversion factors used to estimate the production (dry weight) and corresponding energy capacity for each ha of poplar or hybrid aspen stands.

Conversion	Parameter	Unit	Factor
Area to biomass	Yield (dry)	$Mg\ DW\ ha^{-1}\ yr^{-1}$ [a]	8.0
Biomass to energy	Energy capacity	$GJ\ Mg^{-1}\ DW$ [b]	18.7

[a] The biomass potential assessment is based on Böhlenius et al. (2023), which exclusively included poplar plantations of the genotype OP42, the most planted clone in Sweden [9]. While this study did not include hybrid aspen, other research suggests a comparable production potential for hybrid aspen on agricultural land in southern Sweden [9,46,49,60].
[b] Calculated with a high heating value (HHV), following Olofsson & Börjesson (2016) [59].

this combined area, amounting to 13.3 kha.

3. Results

3.1. H1: Relying exclusively on agricultural land cover data to identify abandoned agricultural land leads to an overestimation of the total agricultural land that can be utilised for future biomass production from Populus spp. feedstocks

Of the 131 responses from farmers, approximately 10 % reported ownership of unsubsidised arable land, constituting roughly 0.3 % of the respondents' total arable land. Most of the respondents who owned unsubsidised arable land were active in the intermediate region (50 %), followed by the forested region (33 %) (see Figs. 1), and 78 % of all the respondents managed a holding with less than 50 ha of agricultural land (Appendix C, Table C.2).

An empirical consequence of H1 was tested: 1a) Less than 50 % of farmers with unsubsidised arable land in Scania, Sweden, would consider cultivating hybrid aspen or poplar on their unsubsidised arable land. The results showed that approximately one in four respondents would probably cultivate *Populus* spp. on their unsubsidised arable land (Test 1, Table 3) (Fig. 2) (Appendix C, Table C.2). Meanwhile, approximately one in six respondents responded with *Don't know*, while the majority exhibited a determinant negative attitude.

Approximately three quarters of respondents with unsubsidised arable land reported that all or some of their unsubsidised arable land remained under cultivation (response options *other cultivation*, *agricultural crops* and *other functions*) or was used as pasture land. Only two out of 13 respondents selected the *No specific function* response option (Fig. 3) (Appendix C, Table C.2).

3.2. H2: The absence of data on farmers' intentions to cultivate fast-growing tree species on agricultural land leads to overestimation of the potential biomass supply from Populus spp. in biomass assessments

An empirical consequence of H2 was tested: 2a) Less than 50 % of farmers in Scania, Sweden, would consider cultivating hybrid aspen or poplar on their agricultural land during 2021–2030. The results showed that eleven per cent of the respondents would definitely ("Yes, definitely") or probably ("Yes, probably") consider cultivating hybrid aspen or poplar on their agricultural land during 2021–2030 (Test 2, Table 3) (Fig. 4) (Appendix C, Table C.3). Approximately three in five respondents would definitely not or probably not consider cultivating hybrid aspen or poplar on their agricultural land during 2021–2030, and approximately one in four answered *Don't know*.

Table 3
Statistical analysis of the respondents' answers to the questions: "Would you consider cultivating hybrid aspen or poplar on the agricultural land that was not included in your agricultural subsidy application?" (for respondents with unsubsidised arable land) and "In the coming decade (2021–2030), would you consider cultivating or increasing the cultivation of the following options on your agricultural land: hybrid aspen and poplar?" (for all respondents), based on the type of agricultural land. The relative frequency of respondents who would definitely ("Yes, definitely") or probably ("Yes, probably") consider cultivating *Populus* spp., 95 % CI and the predicted probability that the relative frequency of respondents expressing interest is below 50 % (See Q1a, Q1d and Q2 in Table 1.).

Type of land	Survey question	Number of *Yes, definitely* and *Yes, probably* responses (total number of responses)	Estimated relative frequency (%) [95 % CI]	Probability that the relative frequency of interested respondents is less than 50 %
Unsubsidised arable land	Q1d	3 (13)	26 [7–48]	0.971
Any agricultural land	Q2	14 (131)	11 [6–16]	>0.999

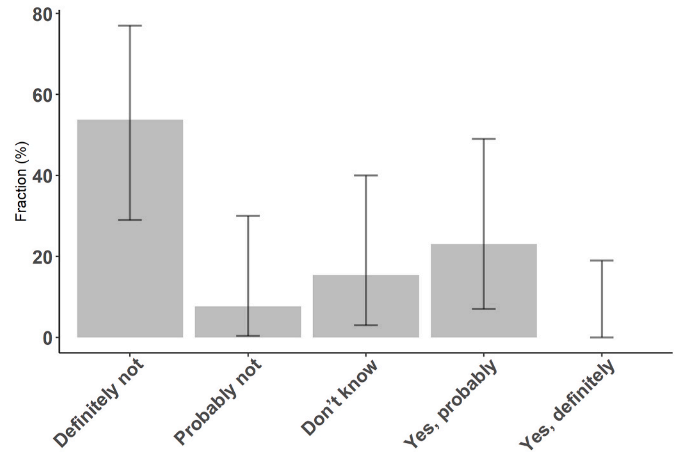

Fig. 2. Responses to the question "Would you consider cultivating hybrid aspen or poplar on the agricultural land that was not included in your agricultural subsidy application?" from respondents with unsubsidised arable land. Percentages of respondents by response option (n = 13) with 95 % CI. (See Q1d.)

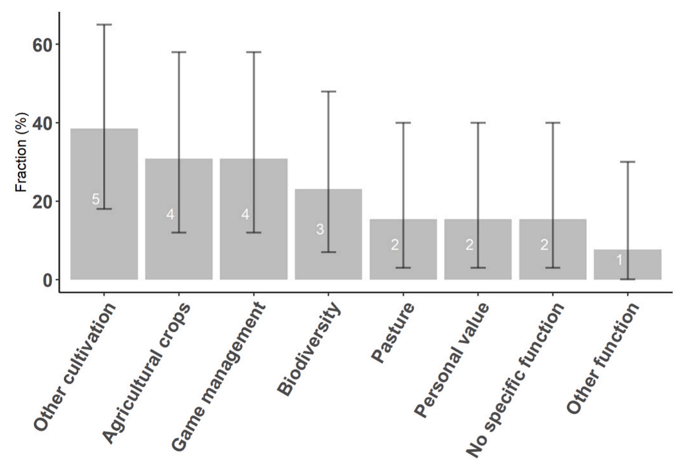

Fig. 3. Responses to the question "What function does the agricultural land not included in any agricultural subsidy application currently serve?" from respondents with unsubsidised arable land. Percentages of respondents reporting each function (n = 13), with 95 % CI. Multiple response options were allowed, resulting in total percentages exceeding 100 %. The option "Don't know" was excluded as no respondents selected it. (See Q1a and Q1c in Table 1.).

However, regional differences in the likelihood of respondents considering cultivation were identified. The fraction of respondents who would definitely or probably consider cultivating hybrid aspen or poplar on their agricultural land during 2021–2030 was significantly higher if the farm was located in the forested region compared to those in the intermediate and lowland regions (Fig. 5) (Appendix C, Table C.4).

A total of 25 farmers provided feedback in the survey's free text section (Q5 in Table 1), with some highlighting concerns about cultivating *Populus* spp. (Appendix C, Table C.5). One theme was the perceived shift from agricultural to forested land, as many view *Populus* spp. cultivation as incompatible with traditional arable land use. One farmer noted: "It may be an alternative to other types of trees after felling, but it doesn't belong on arable land." Another stated: "If the goal is to replace fossil raw materials, agricultural crops on productive land are preferable to planting forests."

Additional comments underscored the multifunctional value of agricultural land, emphasising food production and biodiversity. One

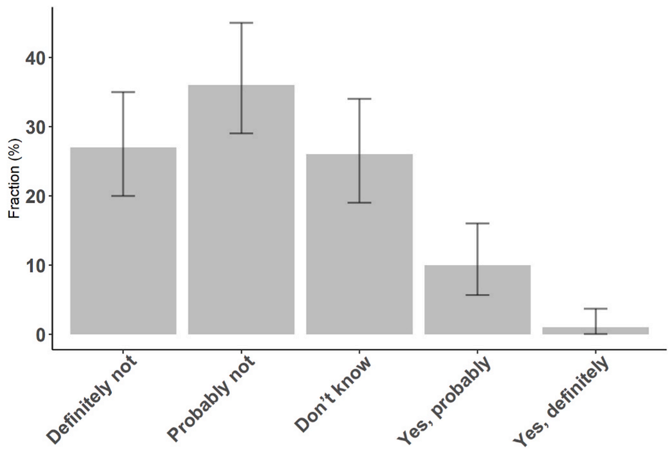

Fig. 4. Responses to the question "In the coming decade (2021–2030), would you consider cultivating or increasing the cultivation of the following options on your agricultural land: hybrid aspen and poplar?". Percentages of respondents by response option (n = 131) with 95 % CI (See Q2 in Table 1).

respondent argued: "… Financially, it may be profitable, but money isn't everything. We must prioritize food production." Another pointed out: "The problem in Sweden is not deforestation but the overgrowth of pastures, which threatens biodiversity." Concerns were also raised about the difficulty and costs of restoring land after *Populus* spp. cultivation due to resprouting and challenges in removing roots and stumps, with one farmer commenting: "Drains are blocked, and it becomes costly to restore the land to arable use if you need to remove the stumps and restore drainage systems."

3.3. Projected area of agricultural land available for hybrid aspen or poplar in Scania, associated biomass potential and comparison with previous potential assessments

With 11 % [CI 6–16] of respondents considering cultivating hybrid aspen or poplar during 2021–2030 (Table 3), and given the total of 7582 agricultural holdings [65], the estimated number of prospective producers in Scania is 810 [450–1200].

Only 8 % of the respondents indicated a marginal preference for either hybrid aspen or poplar (Q2 in Table 1). Therefore, no differentiation between the options was incorporated into the subsequent analyses. Each prospective producer was assumed to cultivate 2.5 ha of *Populus* spp., corresponding to the mean area of the currently cultivated hybrid aspen and poplar stands [33]. In this way, the projected area and corresponding energy potential of hybrid aspen and poplar cultivations during 2021–2030 were estimated (Table 4). The projected area amounted to approximately 0.4 % [0.2–0.6] of Scania's agricultural land in 2021 [65]. A comparison with previous biomass potential assessments that do not consider farmers' willingness to cultivate these species is provided in Table 4.

4. Discussion

The integration of *Populus* spp. as a dedicated biomass crop on agricultural land remains limited in the EU, with varying regional factors influencing these outcomes [22,23]. From a theoretical biomass potential perspective, Scania County has been suggested as a promising location for expanding the establishment of SRPs, primarily due to its favourable soil characteristics, its strategic location and the assumed land availability [9,17,59]. However, these assessments often overlook local practical realities on the ground, such as farmers' willingness to introduce these species, potentially leading to an inaccurate reflection of the current realisable potential. Therefore, this study aimed to assess farmers' current levels of interest in expanding hybrid aspen and poplar cultivation in Scania, and to use this assessment to estimate the biomass potential from these species while considering farmers' perspectives, targeting two spatial levels of agricultural land: unsubsidised arable land, commonly referred to as 'abandoned', and agricultural land in a

Table 4
Estimated energy potentials from hybrid aspen and poplar cultivations in Scania, taking farmers' inclination to consider cultivating these tree species during 2021–2030 into account (Q1 in Table 1). Includes energy potential estimates applied to county data (Scania) given by Ref. [59] (p. 49) and [9] (p. 3). All estimates were made using conversion factors presented in Table 2.

Biomass potential assessment	Type of land considered in the assessment	Estimated area of *Populus* spp. (kha)	Yield, DW (Gg DW yr^{-1})	Energy capacity (PJ yr^{-1})
The present study	All agricultural land	2.0 [1.1–3.0]	16 [9.1–24]	0.30 [0.17–0.45]
Olofsson & Börjesson [59]	Unsubsidised arable land	6.76	54.0	1.0
Böhlenius et al. [9]	Unsubsidised arable land + non-food/feed competing arable land	13.3[a]	106	2.0

[a] This area was split into 5.55 kha of unsubsidised arable land and 7.75 kha of fallow, extensive ley and unspecified arable land.

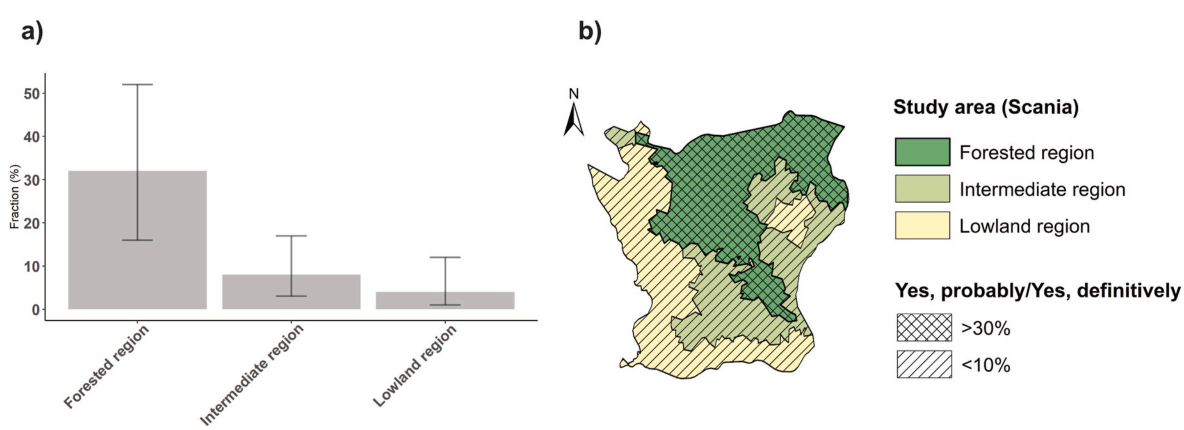

Fig. 5. Percentage of respondents answering "Yes, definitely" or "Yes, probably" to the question "In the coming decade (2021–2030), would you consider cultivating or increasing the cultivation of the following options on your agricultural land: hybrid aspen and poplar?" (Q2 in Table 1) split by production region (see Fig. 1) Error bars signify 95 % CI and total n = 125 (a). Statistically significant differences between production regions (b).

broader context.

4.1. Unsubsidised arable land

Considerable effort has been invested in evaluating the scope of abandoned arable land and its potential for fast-growing tree species like hybrid aspen or poplars in Sweden [9,58,59]. Issues arising from unclear definitions, overlapping statistics and inadequate data have been identified as problematic [58,59], leading to diverse outcomes. In these assessments, the predominant focus has been on hectare counts rather than on farmers' willingness to cultivate, and areas not associated with official statistics have been deemed abandoned and assumed to be available for cultivation.

4.1.1. Scanian farmers' willingness to cultivate unsubsidised arable land

Approximately one in four farmers with unsubsidised arable land would consider cultivating this land with hybrid aspen or poplar, exclusively selecting the *Yes, probably* response option, with no respondents choosing *Yes, definitely* (Table 3). Hence, despite a small sample size, the empirical consequence 1a), stating that less than 50 % of farmers with unsubsidised arable land in Scania would consider cultivating hybrid aspen or poplar on their unsubsidised arable land, was corroborated.

The proportion of unsubsidised arable land identified in this study (0.3 % of the arable land managed by survey respondents) is lower than the percentage reported by Olofsson and Börjesson [59] (1.6 % of the arable land in Scania [55]). This prompts questions regarding the representativeness of the sample of farms used in this study. In comparison with agricultural statistics [65,72], our sample exhibits a relatively even proportion of respondents across all acreage classes and production regions, albeit with a slight underrepresentation of farmers with smaller holdings (<20ha) and those active in forest districts (Appendix C, Table C.3). A potential drawback lies in the survey outreach, given its exclusive focus on farmers affiliated with LRF. Although the LRF member group proportionally encompasses approximately 85 % of all registered agricultural landholders in Scania [65], this choice may potentially have overlooked a group of landowners included in the study by Olofsson and Börjesson [59] but excluded in this study due to their disconnection with LRF.

However, as revealed in both interviews and the survey, few farmers were willing to cultivate hybrid aspen or poplar on their unsubsidised arable land, with their responses lacking decisiveness. Therefore, this study lends support to hypothesis H1, stating that relying exclusively on agricultural land cover data to identify abandoned agricultural land leads to an overestimation of the total agricultural land that can be utilised for future biomass production from *Populus* spp. feedstocks. It is important to note the relatively small sample size, which could impact the generalisability of these findings.

The data suggests that the assessment conducted by Olofsson and Börjesson in 2016 overestimates the current realisable biomass potential for this type of land unless the willingness to cultivate is substantially larger among the group of farmers (15 %) not affiliated with LRF.

4.1.2. Unsubsidised arable land from a bottom-up perspective

In addition to the assessment of farmers' willingness to cultivate *Populus* spp. on unsubsidised arable land, this study also sheds light on assumptions regarding land abandonment. In contrast to previous potential estimates in Sweden, which often conflate unsubsidised land with abandonment, the findings of this study indicate that such an assumption does not consistently hold true. Unsubsidised arable land may maintain its significance for individual farmers and should not, therefore, be categorically labelled as abandoned.

Efforts to map abandoned land are constrained to variables that can be quantified on a large scale, and may thereby overlook the intricate nature of landholder decision-making and how landholder choices affect the cessation of agricultural use [73]. Our understanding of land abandonment within a more extended temporal context is limited, primarily due to the challenges associated with collecting comprehensive data on the duration and long-term trajectories of its existence [74,75]. This potential disparity in delineation underscores a gap between narratives built on categorisations of land based on momentary snapshots that are not integrated with landowner data and ground realities on a more local level.

4.2. Agricultural land, overall

4.2.1. Scanian farmers' willingness to cultivate any of their agricultural lands

The data presented in this study suggests a generally low level of interest among Scanian farmers in cultivating poplar and hybrid aspen on agricultural land under current conditions, with only approximately one in ten farmers indicating that they would consider cultivating these species within the next decade. Consequently, the empirical consequence 2a – which states that less than 50 % of farmers in Scania, Sweden, would consider cultivating hybrid aspen or poplar on their agricultural land during 2021–2030 – is corroborated. These findings also support H2, which states that the absence of data on farmers' intentions to cultivate fast-growing tree species on agricultural land leads to overestimation of the potential biomass supply from *Populus* spp. in biomass assessments.

Limited enthusiasm for cultivating woody energy crops among landowners has been noted in other parts of the northern hemisphere (e.g., Refs. [28,29,76–78]). However, this study found an increased interest among farmers active in the forested areas (Fig. 5). Previous research on poplar and hybrid aspen cultivation in Sweden also shows that most new plantations are located in regions with a high proportion of forest land [79]. This has been interpreted as farmers without connections to forest land possibly being less inclined to cultivate woody crops due to unfamiliarity and limited understanding of these species. This finding aligns with other studies highlighting the importance of familiarity and knowledge in shaping attitudes towards woody bioenergy crops [27,80–82] and reforestation of agricultural land [83]. In agreement with studies in Germany and the UK [23], free text comments were given reflecting the trade-off between arable land for food or fibre production (Appendix C, Table C.5).

The data from the present study on farmers' willingness to cultivate *Populus* spp. on their agricultural land suggest that the assessment conducted by Böhlenius et al. [9], which considered unsubsidised arable land as well as fallow land and land associated with extensive ley production, may overestimate Scanian farmers' willingness to consider these species. This conclusion is particularly relevant, as farmers were only asked about their cultivation intentions without being prompting to consider contributing to fulfilling any potential biomass supply.

4.3. Estimated area of agricultural land available for hybrid aspen or poplar in Scania, associated biomass potential and comparison with previous potential assessments

The area for expanding the cultivation of hybrid aspen and poplar in Scania was estimated optimistically in this study, with an average expansion of 2 kha between 2021 and 2030 (Table 4), equivalent to 0.4 % of current agricultural land [65]. Each prospective producer was assumed to cultivate only one field of the mean area of hybrid aspen and poplar fields in Sweden (see Ref. [33]). This size corresponds to the mean area of recently cultivated stands, with over 50 % of poplar stands found to be smaller than 1 ha on an aggregate level [33].

Although prospective producers could cultivate areas smaller or larger than this average size, the estimate is optimistic because it extrapolates the proportion of potential producers based on all agricultural holdings in Scania. Notably, no farmer with a farm of 10 ha or less expressed an interest in cultivating hybrid aspen or hybrid aspen (results not shown). Considering that this group constitutes 20 % of the surveyed farmers and that more than one-third of Scania's holdings fall within this size bracket [65], the estimated area available for cultivation may be smaller than anticipated. Nonetheless, the relatively high prevalence of *Don't know* responses is noteworthy and could have an impact on the realised cultivated area (Fig. 4).

With a wood-based heat and electricity production capacity of at least 10 PJ per year already installed in Scania [84], an expansion in line with this study's estimate (Table 4) would contribute around 3 % (0.30 PJ) of the current biomass feedstock demand. Compared to the utilisation of unprocessed wood fuel in Sweden at the national level in 2022 (198 PJ) [85], this contribution corresponds to approximately 0.2 %. It is crucial to note that the biomass supply will experience delays due to the extended period required, particularly under Swedish conditions, to reach full harvestability.

Compared to previous biomass potential assessments using narrower land criteria, the potential presented by Olofsson and Börjesson [59] exceeds this study's estimate by more than three times, while the assessment by Böhlenius et al. [9] surpasses our estimate by more than six times (Table 4). This comparison should not be regarded as an absolute measure, due to the slightly higher willingness among landowners with unsubsidised land (Fig. 2). However, it highlights how biomass potential assessments may diverge substantially from actual feasibility under current conditions.

While this study's estimate of the biomass potential of hybrid aspen and poplar in Scania reflects the current willingness among agricultural landowners to introduce these species, it is important to investigate further how this willingness may change over time. For example, significant increases in biomass feedstock prices could potentially enhance this willingness, driven by the prospect of higher profitability for landowners.

4.4. Potential policy implications

Our results highlight the critical importance of incorporating local farmers' perspectives when assessing the biomass potential of *Populus* spp. on agricultural land. Assessments that overlook these views risk producing misleading results and ineffective policies. In Scania, Sweden, where attitudes towards the cultivation of *Populus* spp. vary between production regions, our results suggest that policies would be more effective if they targeted landscapes with forests, rather than those consisting to a larger extent of arable land (Fig. 5). The Swedish Board of Agriculture notes that introduction of SRP on arable land can significantly affect the landscape and the natural environment. Under the Swedish Environmental Code (SFS 1998:808) consultation with the county administrative board is required in such cases [86]. Furthermore, the Swedish Board of Agriculture highlights that cultivation adjacent to a forest can provide landscape benefits, as it is less disruptive to the existing environment [87].

Therefore, aligning policy interventions with these guidelines by focusing on forested landscapes would not only be consistent with environmental regulations but also enhance the effectiveness of such policies.

5. Conclusions

The study highlights the importance of integrating local farmers' perspectives into assessments of biomass potentials for hybrid aspen and poplar plantations in order to better distinguish between theoretical and realisable biomass potentials. It also challenges assumptions about land abandonment, emphasising the ongoing importance of unsubsidised arable land for individual farmers. The study updates the estimated area available for cultivation of hybrid aspen and poplar, and demonstrates that specific local conditions can have an impact on attitudes towards cultivation. Therefore, understanding farmers' perspectives on cultivating these species is essential for designing effective policies that facilitate changes in agricultural practices.

CRediT authorship contribution statement

Elin Anander: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Pål Börjesson:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Lovisa Björnsson:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Kristina Blennow:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

Statement: During the preparation of this work, the authors used Grammarly (https://www.app.grammarly.com) and ChatGPT (https://chat.openai.com) in order to edit the English language. After using the tool/service, the authors reviewed and edited the content as needed. Finally, the manuscript was edited by a professional editing service. The authors take full responsibility for the contents of the publication.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biombioe.2024.107424.

Data availability

Once uploaded to the Swedish National Data Service, the data will be assigned the following doi:https://doi.org/10.5878/g2jv-2929.

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